INTRODUCTION TO COMPUTABLE GENERAL EQUILIBRIUM MODELS

THIRD EDITION

MARY E. BURFISHER

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For my family

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About This Book

Objectives

This book will introduce you to computable general equilibrium (CGE) models. A CGE model is a powerful analytical tool that can help you gain a better understanding of real-world economic issues. Computable general equilibrium models are a class of economic model that over the past three decades has gained widespread use in the economics profession, particularly in government. Economists today are using these models to systematically analyze some of the most important policy challenges and economic "shocks" of the twenty-first century, including global climate change, trade agreements, the spread of human diseases, and international labor migration.

Since the early 1990s, prominent CGE models have been built and maintained at the US International Trade Commission, the Organisation for Economic Cooperation and Development, the International Food Policy Research Institute (IFPRI), the World Bank, and many other national agencies and international organizations to provide ongoing economic analytical capability. These models have come to play an important part in government policy decisions worldwide. For example, the models' predictions about prices, wages, and incomes have factored heavily in debates about the terms-of-trade agreements such as the first and second North American free-trade agreements and the Trans-Pacific Partnership, and the models are contributing to a clearer understanding of the costs of mitigating and adapting to global climate change. Computable general equilibrium-based analyses have also helped governments anticipate and design responses to substantial changes in the availability of key resources, ranging from petroleum to people.

Computable general equilibrium models are comprehensive because – whether they are detailed or very simplified – they describe all parts of an economy simultaneously and how these parts interact with each other. The models describe the efficiency-maximizing behavior of firms and the utility-maximizing behavior of consumers. Their decisions add up to the macroeconomic behavior of an economy, such as changes in gross domestic product (GDP), government tax revenue and spending, aggregate savings and investment, and the balance of trade. As might be expected, such models can require large databases and contain sophisticated model code. Yet despite their complexity, continuing advances in modeling software and database development are making CGE models increasingly accessible and intuitive. Minimizing the technical entry barriers to CGE modeling has freed economists to focus on the models' economic behavior and the economic insights that can be derived from their results. These innovations have also made CGE models an ideal laboratory in which economics students can learn to manipulate, observe, and deepen their knowledge of economic behavior.

The primary goal of this book is to provide a hands-on introduction to CGE models. You will draw on theory from microeconomics, macroeconomics, international trade and finance, public finance, and other areas of economics, as you observe how producers and consumers in the CGE model respond to various changes in market conditions that we refer to as "model experiments." The guided model exercises show you how to use demonstration CGE models to assess the economywide effects of such economic shocks as the elimination of agricultural subsidies and trade barriers, labor immigration, and changes in a tax system. By the end of this book, you will have begun to develop your skills as both a producer and a consumer of professional CGE-based economic analysis.

The book introduces the CGE models and databases that are used by professional economists. We will study the key features of "standard" CGE models, which are static (single period), single- and multi-country models, with fixed national endowments of factors of production. Most textbook examples and model exercises use RunGTAP, a user-friendly, menu-driven interface (Horridge, 2001) of the Global Trade Analysis Project (GTAP) CGE model. The GTAP model was developed by Hertel and Tsigas (1997) and has been substantially updated by Corong and others (2017). It may be downloaded at no charge from the GTAP website. The GTAP model is written in the GEMPACK software language.

The GTAP project maintains a global database that CGE modelers rely on as a data source for many types of CGE models. The database is built from data contributions by CGE modelers around the world, which GTAP then organizes and balances into a consistent, global database. The 8.1 version of the database, used for demonstration in this book, describes 134 countries or regions and 57 industries in 2007. Modelers may use GTAPAgg, a freeware program developed by Horridge (2015a) and available from the GTAP project, to aggregate the global database into smaller sets of regions and industries that are relevant for their research. All but the latest release of the

P.1 *Modeling and data resources used in this book*

Resource	Source
RunGTAP CGE model	Download from GTAP.org
NUS333 model version	Included in the RunGTAP software
Small pedagogical CGE models used in the chapters and exercises	Download from www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5941

GTAP database can be downloaded and aggregated free of charge. In this book and in most model exercises, we use a small-dimension, two-region aggregation of the database, named NUS333, which describes the United States and an aggregate rest-of-world region. The NUS333 model version is included in the RunGTAP software or you can download it from the GTAP website.

What's New in the Third Edition

The main change in the third edition is the update of the text, toy models, and modeling exercises to be compatible with the new version of the GTAP model, called GTAPv7. The update of the GTAP model brings it closer in theory and notation to other widely used CGE models, so the revisions in this book edition will be of benefit not only to modelers who wish to work in the GTAP framework, but also to modelers planning to use other standard CGE models.

These are the key changes made in the third edition:

- The new model used for demonstration throughout the book and in most model exercises is named NUS333. The NUS333 model version contains the same data as the 2007 US3x3v8 model version used in the second edition. The N prefix is added to denote that the US3x3v8 data are reorganized and renamed to be compatible with the GTAPv7 CGE model. The model is renamed "333" because the new GTAP model now allows a "non-diagonal make matrix," in which each production activity can make multiple commodities, and multiple activities can make the same commodity. In the NUS333 model version, there are three production activities and three commodities, with each activity making a single commodity, and there are three factors of production.
- Variable and set names throughout the book are updated to conform to the new notation in the GTAPv7 model.
- Chapter 2 – The discussion of price relationships is revised to reflect changes in their treatment in the GTAPv7 model. Additional elasticities are introduced that describe CGE models with non-diagonal make matrices. New taxes are

introduced, and a discussion is added to describe the calculation of tax rates and the power of tax rates.

- Chapter 3 – New material describes three extensions to the standard Social Accounting Matrix – non-diagonal make matrices, domestic trade margins, and multi-region input-output (MRIO) tables.
- Chapter 4 – A new section describes the import demand behavior depicted in MRIO-supply chain CGE models.
- Chapter 5 – A new section describes the production structure and behavior in a CGE model with a non-diagonal make matrix, in which a production activity can produce multiple commodities, and multiple production activities can produce the same commodity.
- Modeling Exercises – These are revised to be compatible with the new GTAPv7 model and their subject matter is updated to reflect current public policy topics, with a greater emphasis on climate change applications and the costs of trade barriers.
- Other updates and additions appear throughout the book, including the addition of new text boxes with examples of recent, influential CGE-based analyses.

Organization

This book covers nine topics, beginning with an introduction to CGE models (Chapter 1), their elements and structure (Chapter 2), and the data that underlie them (Chapter 3). Chapters 4–6 focus on the microeconomic underpinnings of CGE models. Chapter 4 describes final demand by households, government, and investors; the demand for imports and exports; and welfare measurement. Chapter 5 describes supply, focusing on the technology tree and the producer's cost-minimizing demand for intermediate and factor inputs. Chapter 6 covers additional aspects of factor markets, including factor mobility, factor endowment and productivity growth, factor substitutability, and factor employment assumptions. Trade topics, including theorems on the effects of changes in factor endowments and world prices, are covered in Chapter 7. Chapter 8 explores public finance topics related to trade and domestic taxes, including preferential tariffs. Chapter 9 presents the economic theory of two types of regulations, nontariff trade measures and the correction of production externalities, and explains how these regulations are analyzed in a standard CGE model.

Chapters 1–9 adhere to a common template, consisting of:

- Chapter text (e.g., "Introduction to Computable General Equilibrium Models")
- Text boxes
- Chapter summary
- Key terms (e.g., "stock" and "flow")
- Practice and review exercises
- Model exercise

Text boxes introduce examples of classic, innovative, and influential CGE-based economic analyses that relate to chapter topics. These summarized articles offer practical examples of how the concepts that you are learning about in the chapter are operationalized in CGE models. Practice and review exercises review and reinforce the central concepts in each chapter.

Model exercises linked to each chapter provide step-by-step direction and guidance to help you develop your modeling skills (P.2). The modeling problems are general enough to be suitable for use with almost any standard CGE model, but their detailed instructions are compatible with RunGTAP. The first three model exercises guide you in setting up the NUS333 model, used for demonstration, and learning core modeling skills. You may use the NUS333 demonstration model to replicate almost all results reported in the tables in Chapters 1–9 of this book. Exercises 4–11 are case studies that begin with a discussion of a timely topic or influential CGE analysis such as labor immigration and US tax policies. They demonstrate how to design model experiments and how to use economic theory to select and interpret model results. Three are "challenge exercises" that introduce advanced students to baseline scenarios, updates of tax data, and uncertainty about elasticity parameters and economic shocks.

P.2 *Chapters and related model exercises*

Chapter	Model exercise
1. Introduction to CGE models	ME 1 – Setup the GTAP model
2. Elements of a CGE model	ME 2 – Explore the GTAP model and database
3. The CGE model database	ME 3 – Skill-building in Using the Model
4. Final demand in a CGE model	(1) ME 4 – Climate shocks and food price spikes (2) ME 10 – Successful quitters: "MPOWER" changing consumer attitudes toward tobacco use *(Challenge exercise)*
5. Supply in a CGE model	ME 5 – Food fight: agricultural production subsidies
6. Factors of production in a CGE model	(1) ME 6 – How immigration can raise wages (2) ME 9 – Climate change – the world in 2050 *(Challenge exercise)*
7. Trade in a CGE model	ME 7 – Anatomy of a trade war
8. Taxes in a CGE model	ME 8 – The marginal welfare burden of the US tax system
9. Regulations in a CGE model	ME 11 – Deep integration in a Japan–US Preferential Trade Agreement *(Challenge exercise)*

Resources for New CGE Modelers

We recommend that beginning modelers start by reading articles and monographs, both current and classic, which provide general introductions to, or critiques of, CGE models. Particularly recommended as introductory treatments are Piermartini and Teh (2005), McDaniel et al. (2008), Shoven and Whalley (1984), Bandara (1991), Francois and Reinert (1997), Robinson et al. (1999), Devarajan et al. (1990, 1997), and Borges (1986). Breisinger, Thomas, and Thurlow (2009), Reinert and Roland-Holst (1992), and King (1985) provide introductions to social accounting matrices, which are the databases that underlie CGE models.

As your skills progress, we recommend that you read intermediate-level treatments of CGE models. Perhaps the most important of these is the collection of articles by distinguished CGE modelers in the *Handbook of Computable General Equilibrium Modeling*, edited by Dixon and Jorgenson (2013). Kehoe and Kehoe (1994) provide a primer on CGE models and Dervis, deMelo, and Robinson (1982) offer an introduction to open economy CGE models. Hosoe, Gasawa, and Hashimoto (2010) introduce students at an intermediate level to CGE models, focusing on models coded in General Algebraic Modeling Software (GAMS). Some books and articles that describe specific CGE models are also useful for new modelers, who will recognize many of the same features in those models as in the standard CGE model that we study in this book. Corong and others (2017) and Hertel and Tsigas (1997) provide an overview of the GTAP model. Lofgren, Harris, and Robinson (2002) describe the IFPRI standard single-country CGE model and database. DeMelo and Tarr (1992) describe the structure and behavior of their CGE model of the United States. Thierfelder and McDonald (2011) describe the multi-country GLOBE CGE model. For more advanced students, Shoven and Whalley (1992) provide a practical introduction to CGE models, and Scarf and Shoven (2008) present a collected volume of case studies that describe different aspects of CGE models.

CGE modeling is a dynamic field of research. A premier source on frontier developments in CGE modeling is the *Journal of Global Economic Analysis*, an open-access journal published by the GTAP Center. Other ways to keep abreast of developments in CGE modeling and in the applications of CGE models is to review working papers and conference papers. The GTAP website (www.gtap.org), particularly the annual conference programs, is a useful source for up-to-date information on CGE-based research papers, CGE model databases, and research tools and utilities related to the GTAP model and data. All papers presented at annual GTAP conferences are posted online, providing students with access to unpublished papers and work in progress by many leading CGE modelers using many types of

CGE models. Perusing recent conference papers can give you ideas for timely research topics and experiment designs for your own research projects.

The International Food Policy Research Institute, which developed the "IFPRI standard" CGE model, has published many studies based on variations of that model as well as papers about model databases and database construction. These publications are available from their website at www.ifpri.org.

Many international organizations, such as the World Bank, and national government agencies, such as the US International Trade Commission, also produce and post CGE-based working papers and research products. In addition, the GAMS website (www.gams.org) maintains a library of simple CGE models that can be downloaded and run using the free demonstration version of GAMS. Also, the United States Naval Academy hosts the Tools for Undergraduates "TUG-CGE" model (Thierfelder, 2009), a GAMS-based, single-country CGE model designed for undergraduate pedagogical use.

For the Instructor

This book is designed for use in a one-semester class that is spent primarily doing hands-on model exercises and independent research, with the book used as background reading. The exercises are all fully portable. They are designed to use free materials downloaded from the Internet so they are suitable for students to carry out in computer labs or on their personal computers. The ideal classroom setting is one that promotes student teamwork and ongoing discussion among students and teachers while students carry out model exercises.

P.3 *Recommended sequences for courses of different lengths*

Chapter	One-semester course	Six-week course	One-week course
1. Introduction to CGE models	0.5 week	0.5 week	Omit
2. Elements of a CGE model	1 week	0.5 week	0.25 day
3. CGE model database	1 week	1 week	0.5 day
4. Demand in a CGE model	1.5 weeks	0.5 week	0.5 day
5. Supply in a CGE model	1 week	0.5 week	0.5 day
6. Factors of production in a CGE model	1 week	Optional	Omit
7. Trade in a CGE model	1 week	0.5 week	0.5 day
8. Taxes in a CGE model	1 week	0.5 week	0.5 day
9. Regulations in a CGE model	1 week	Optional	0.25 day
independent research	6 weeks	2 weeks	2 days

This book can also be used in condensed courses, with our recommendations for selecting and paring materials described in P.3. For courses of all lengths, we recommend a generous allotment of time for model exercises and independent research, because students will then learn by doing. If the book is used as a supplementary hands-on resource for economic theory courses, such as macroeconomics or international trade, we suggest that the teacher cover Chapters 1–3 and their related model exercises and then assign only the chapter and exercise that is relevant to the course. Most teachers are likely to find that some or all of Chapter 8 on taxes are relevant because taxes are a policy lever that governments use to address many economic problems.

1

Introduction to Computable General Equilibrium Models

This chapter introduces students to computable general equilibrium (CGE) models, a class of economic model that describes an economy as a whole and the interactions among its parts. The basic structure of a CGE model and its database are described. We introduce a "standard" CGE model and provide a survey of CGE model applications.

Economic Models, Economists' Toys

When an economist wants to study the economic behavior observed in the complex world around us, the first step is often to build an economic model. A model can focus an analysis by stripping down and simplifying real-world events into a representation of the motivations of the key players in any economic story. Some amount of context and interesting detail must be left out as the economist distills a model rich enough to explain events credibly and realistically but simple enough to put the spotlight on the essential actions in the story. When an economist succeeds in building a model, he or she now has a tool that can be manipulated. By playing with this "toy" representation of economic activity, the economist can learn more about the fundamentals behind an event and can study likely outcomes or possible solutions.

There are many kinds of economic models. The type that we will be studying is a computable general equilibrium (CGE) model. It is an "economy-wide" model because it describes the motivations and behavior of all producers and consumers in an economy and the linkages among them. It depicts firms that respond to demand by purchasing inputs, hiring workers, and using capital equipment. The income generated from sales of firms' output ultimately accrues to households, who spend it on goods and services, taxes, and savings. Tax revenue funds government spending and savings lead to investor spending. The combined demand by private households, government, and investors is met by firms that, to complete the *circular flow of income and spending*, buy inputs and hire workers and capital used in their production processes. Such a comprehensive model may seem to be very complex, but we hope that its deconstruction in the following chapters will reveal it to be a relatively simple, "toy" representation of our complex world.

As a point of departure for our study, we begin by examining a toy partial equilibrium model. Suppose we are asked to build an economic model to analyze the supply and demand for bicycles. We can draw on our microeconomic theory to introduce a supply equation to describe bicycle production. First, we use general functional notation to express that the quantity of bicycles that producers supply, QO, is related to their unit cost of production, PO, which includes the prices of commodities used as bicycle inputs, such as rubber tires, plus the costs of labor and capital equipment. The output quantity also depends on the market price of bicycles, P. With this general notation, we know only that there are causal relationships between output and price variables but not their sizes, nor whether they are positive or negative. We can also draw on microeconomic theory to introduce a demand equation. Again using general notation, we express that the quantity of bicycles that consumers demand, QDS, is a function of their income, Y, and the price of bicycles. Finally, we know from economic theory that a market economy will tend toward market clearing; that is, the price of bicycles will adjust until the quantity that producers supply equals the quantity that consumers demand. To describe this equilibrium in the model, we introduce the *market-clearing constraint*, $Q^* = QO = QDS$; the equilibrium quantity of bicycles supplied and demanded must be equal.

The three equations describing the bicycle industry model, expressed in general notation, are listed in Table 1.1. The model has two *exogenous* variables: input price, PO, and consumer income, Y. Their values are

Table 1.1 *Bicycle industry model*

Model element	General notation	Numerical function
Supply equation:	$QO = G(PO, P)$	$QO = -4PO + 2P$
Demand equation:	$QDS = F(P, Y)$	$QDS = 2Y - 2P$
Market-clearing constraint:	$Q^* = QO = QDS$	
Endogenous variables		
Q^* = equilibrium quantity of bikes		
P = market price of bikes		
Exogenous variables		
PO = input cost (e.g., tires, labor)		
Y = income		

determined by forces outside the model, and we take them as given. The model has two *endogenous* variables: the equilibrium quantity, Q*, and the market price, P, of bicycles. Their values will be determined as solutions to our model's equations.

Using our bicycle industry model with general notation, we can draw these qualitative conclusions about the effects of changes in our exogenous variables on the endogenous variables: A change in income, Y, will affect the quantity of bicycles that consumers demand, while a change in input prices, PO, will affect the quantity of bicycles that producers supply. Given our market-clearing constraint, a change in either exogenous variable will lead to a change in the price of bikes until the quantities of bikes that are supplied and demanded are again in equilibrium.

Our model becomes more useful if we have sufficient data on the supply and demand for bicycles to estimate the sign and size of the relationships among the variables. We can then express our model equations in specific and numerical functional form, such as $QDS = 2Y - 2P$, which is a linear demand function. With this information, we can now say that the quantity of bicycles demanded can be calculated as two times income minus two times the market price of bicycles. Perhaps we also estimate this linear supply function for bicycle supply: $QO = -4PO + 2P$. We now have a quantitative model that describes both demand and supply and is capable of yielding numerical solutions.

If we are now given values for our exogenous variables, Y and PO, we can solve our model to find the initial, market-clearing values for the two endogenous variables, P and Q*. If, for example, we know that the value of Y is 10 and PO is 4, then we can substitute these values into our equations and solve. The market-clearing quantity should be two bicycles at a price of $9 each.

We can learn a great deal about the bicycle industry by using the model to conduct a model experiment. We carry out an experiment by changing an exogenous variable in the model, Y or PO. When we change one exogenous variable at a time, we are using our model of the bicycle industry to conduct a controlled experiment. This "what-if" scenario helps us isolate and understand the role of a single factor, such as income, in explaining the changes in the bicycle quantities and prices that we observe in our model. We can also now offer quantitative conclusions, such as: "If we double income, bicycle production will increase to twelve and the price of bicycles will rise to $14."

What Is a Computable General Equilibrium Model?

A CGE model is a system of equations that describes an economy as a whole and the interactions among its parts. Despite its comprehensiveness, it is much like the bicycle model. It is based on equations derived directly from economic theory, which will look familiar to students from their courses in microeconomics and macroeconomics. The equations may describe producers' supply or consumer demand, or be familiar macroeconomic identities such as GDP = C + I + G + E – M. Like the bicycle model, a CGE model includes exogenous and endogenous variables and market-clearing constraints. All of the equations in the model are solved simultaneously to find an economy-wide equilibrium in which, at some set of prices, the quantities of supply and demand are equal in every market.

To conduct experiments with a CGE model, the economist changes one or more exogenous variables and resolves the CGE model to find new values for the endogenous variables. The economist observes how the exogenous change, or "economic shock," affects the market equilibrium, and draws conclusions about the economic concern under study – be it a rise in the price of bicycle tires, or fuel, or labor immigration.

A CGE model differs from our model of the bicycle industry because it represents the whole economy, even if at times in a very stylized and simplified way. A CGE model describes production decisions in two or more industries – not just one, as in the bicycle model. A CGE model also includes demand for all goods and services in the economy, not just for bicycles. While the *partial equilibrium* model assumes income and prices in the rest of the economy are fixed, a CGE model describes how changes in the demand and supply for a good such as bicycles can lead to changes in employment and wages, and therefore in households' income. It also describes changes in prices for other goods and services in the economy, such as bicycle inputs and the products that compete with bicycles in consumer demand. A CGE model also includes all sources of demand, not only from producers and private households but also from other economic agents – the government, investors, and foreign markets. Because a CGE model depicts all of the microeconomic activity in an economy, the summation of these activities describes the macroeconomic behavior of an economy, including its gross domestic product (GDP), aggregate savings and investment, the balance of trade, and, in some CGE models, the government fiscal deficit or surplus.

We can learn more about the basic features of a CGE model by considering the meaning of each component of its name: "computable," "general," and "equilibrium."

Computable

The term *computable* in CGE models describes the capability of this type of model to quantify the effects of a shock on an economy. As an economist, you can generally rely on economic theory to help you anticipate a directional change. For example, if you are asked to describe the expected effect of a reduction in a US tariff, you are likely to argue that it will lower the domestic price of the import, leading to an increase in the quantity of demand for imports and a decrease in the quantity of demand for the domestic, import-competing variety. However, policymakers or industry advocates may want to know if this effect will be large or small.

The equations of a CGE model utilize data for an actual economy in some base year, such as the US economy in 2020. In this case, the utility functions incorporate data on US consumer preferences in 2016. The production function for each industry is based on US firms' technology – inputs and production levels – in 2020. Because the equations in a CGE model incorporate real data about an actual economy, the model's new equilibrium values following an experiment enable you to quantify in a realistic way the anticipated value of the impact on the economy, such as a $25 million or $2.5 billion change in an industry's output.

The ability to quantify the values associated with the outcomes of various "what-if" scenarios allows the economist to make a powerful contribution to debates about economic policy. CGE modelers have provided influential analyses of the costs and benefits of government policies, such as trade agreements like the Trans-Pacific Partnership, the Paris climate accord, and the costs of pandemic containment measures to the global economy. CGE models have also been used to quantify the effects of market shocks including oil price hikes and labor migration.

General

In a CGE model, the term *general* means that the model encompasses *all* economic activity in an economy simultaneously – including production, consumption, employment, taxes and savings, and trade – and the linkages among them. For example, if higher fuel prices raise the cost of producing manufactured goods such as bicycles, books, cars, and TVs, then the prices of these goods will rise. The demand response of consumers will lead to changes throughout the economy. For example, consumers may buy fewer bicycles, cars, and TVs but may buy more Kindles and e-books. The changes in consumer demand and industry output will then affect employment, incomes, taxes, and savings. In an open economy, the fuel price hike also may lead to changes in trade flows and in the exchange rate; the latter is a macroeconomic shock that will in turn affect the whole economy.

One way to depict the interrelationships in a CGE model is to describe them as a circular flow of income and spending in a national economy, as shown in Figure 1.1. You may recall this circular flow diagram from your macroeconomics class. To meet demand for their products, producers

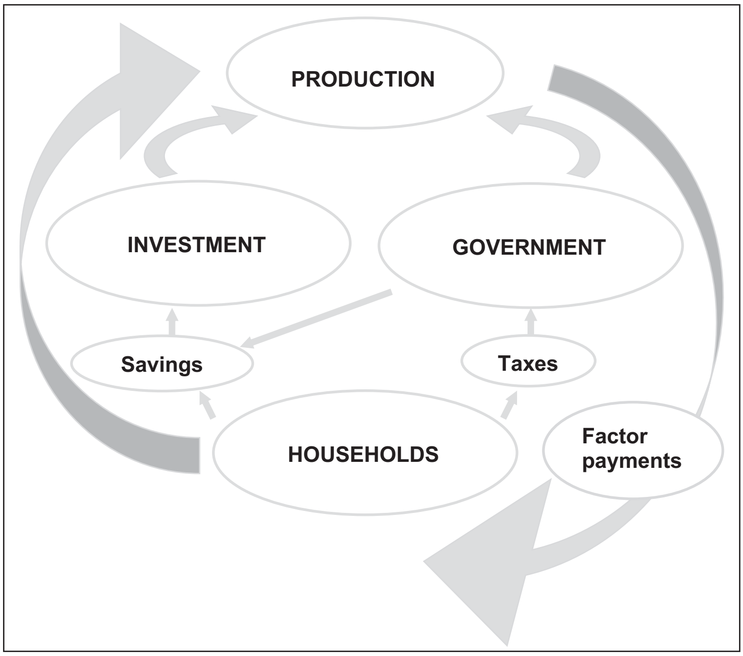


Figure 1.1 The circular flow of income and spending in a national economy

purchase inputs such as rubber tires and bicycle seats. They also hire factors of production (labor and capital) and pay them wages and rents. The factor payments ultimately accrue to private households as wage and capital rental income. Households spend their income on goods and services, pay taxes to the government, and put aside savings. The government uses its tax revenue to buy goods and services and may run a budget surplus (adding to national savings) or a budget deficit (reducing national savings). Investors use savings from households and the government to buy capital investment goods for use in future production activities. The combined demand for goods and services from households, government, and investment constitutes final demand in the economy. Firms produce goods and services in response to this demand, which in turn determines input demand, factor employment levels, households' wage and rental income, and so forth, in a circular flow. If we introduce trade into this circular flow, we would account for the role of imports in meeting some of the domestic demand, and we would add export demand as an additional source of demand for domestic goods. Finally, we can think of policies such as taxes and subsidies as "price wedges" that increase or lower the prices of goods between buyers and sellers, or as transfers that directly affect households' level of income and therefore their levels of consumption, savings, and taxes.

A general equilibrium model describes all of these interrelationships in an economy at once: "Everything depends on everything else." An important caveat to "everything" is that CGE models are "real" models. A real model does not include money, describe financial markets or changes in overall price levels (like inflation or deflation), or reflect the effects of monetary policy such as an increase in the money supply. Instead, a real model measures all variables in terms of physical quantities and the relative prices at which goods are exchanged for each other, such as three books per DVD.

It is likely that most of your economics coursework so far has presented partial equilibrium models. A partial equilibrium model describes economic motives and behavior in one industry, such as the bicycle industry, or of one type of economic agent, such as household consumers, and holds prices and quantities in the rest of the economy constant. A partial equilibrium analysis is similar to placing a magnifying glass over one part of the economy and assuming that the action in the rest of the economy is either not important or not changing at the moment. This focus on a specific part of the economy allows economists to develop richly detailed analyses of a particular industry or economic activity, but the trade-off is that important, interdependent links with the rest of the economy are not taken into account. These linkages are particularly important if the industry or other aspect of economic activity under study is large relative to the rest of the economy.

Equilibrium

An economy is in *equilibrium* when supply and demand are in balance at some set of prices, and there are no pressures for the values of these variables to change further. In a CGE model, equilibrium occurs at that set of prices at which all producers, consumers, workers, and investors are satisfied with the quantities of goods they produce and consume, the industry in which they work, the amount of capital they save and invest, and so forth. Producers have chosen input and output levels that have *maximized their efficiency* given the costs of inputs such as fuel and equipment, their sales prices, and the technological constraints of their production processes. Consumers have *maximized their utility*, or satisfaction, by purchasing the most satisfying bundle of products – such as books, bicycles, cars, and TVs – given their budgets and the prices of consumer goods. The CGE model's equilibrium must also satisfy some important macroeconomic, market-clearing constraints; generally, these require that the aggregate supply of goods and services equals aggregate demand, all workers and the capital stock are employed, and national or global savings equals investment spending.

The CGE modeler conducts an experiment by creating "disequilibrium" – that is, by changing an exogenous variable in the model. For example, the modeler may specify an increase in an import tariff. This shock will change the economy – consumers are likely to buy fewer imports and more of the domestic product, and domestic firms are likely to expand their production to meet growth in demand. When running a model experiment, the CGE modeler is like a billiard player who hits one ball, causing reactions and interactions among all of the balls on the table, and who must wait to see where all the balls come to rest. All of the CGE model equations must be re-solved to find new solution values for all of the endogenous variables in the model. The new values represent a new equilibrium in which the quantities of supply and demand are again equal at some set of prices. The CGE model that we will study does not show the adjustment process; we do not watch as the billiard balls knock against each other as they traverse the table. We simply observe and compare the balls' stationary positions before and after they are shocked into movement. This is an important point to keep in mind as you use a standard CGE model to conduct policy analysis.

A Standard CGE Model

CGE models come in all shapes and sizes. Despite this diversity, most models share the same core approaches to depicting supply and demand, factor markets, savings and investment, trade, and taxation. In this book, we concentrate on these shared, core elements as we introduce you to a "standard" CGE model, which is a static (single-period), single or multi-country CGE model with a fixed endowment of factors of production, such as labor and capital.

A *static* CGE model provides a before- and after-comparison of an economy when a shock, such as a tax, causes it to reallocate its productive resources in more or less efficient ways. Static models can tell a powerful story about the ultimate winners and losers from economic shocks. However, a noteworthy drawback is that they do not describe the adjustment path. The adjustment process may include periods of unemployment and dislocation that could exact a high societal price, regardless of the size of expected benefits in the new equilibrium.

A standard CGE model assumes that an economy's factors of production are in fixed supply, unless they are changed as a model experiment. For example, the size of the labor force is assumed to be fixed, and the available quantity of capital equipment does not change. Often, models depict a medium-run adjustment period following a model shock. This period is long enough to allow the fixed supplies of factors to change employment in response to changes in wages and capital rents across industries, but it is too short for long-run changes in factor productivity, growth in the size of the labor force, or capital stock accumulation to take place.

We consider both single-country and multi-country CGE models in the following chapters. *Single-country* models describe one country in detail, with a simple treatment of its export and import markets. *Multi-country* CGE models contain two or more countries (or regions) and describe their economies in full, including each country's production, consumption, trade, taxes, tariffs, and so on. The economies in multi-country models are linked to each other through trade and sometimes through capital or labor flows.

No single CGE model has all of the features that we describe in the following chapters. Rather, our intent is to provide you with a solid foundation in CGE modeling basics that will equip you to understand or to work with almost any standard CGE model. Later, you can build on this foundation to learn about and appreciate the ramifications of differences among CGE models and the capabilities of more sophisticated or special-purpose models. We describe some of these more sophisticated models and the frontiers of CGE modeling in text boxes throughout the book, and in our concluding chapter.

CGE Model Structure

A CGE model consists, essentially, of a set of commands. Some of the commands simply provide the model preliminaries. They define sets, parameters, and exogenous and endogenous variables. We discuss these elements of a CGE model in detail in Chapter 2. Other commands present the economic equations of the model. These are typically organized into blocks related to as follows:

- consumption
- production
- factor markets (e.g., capital and labor)
- international trade
- taxation

We explore each of these economic components of a CGE model separately and in-depth in Chapters 4 through 9.

CGE Model Database

A CGE model's database has two components. The first is called a Social Accounting Matrix or SAM. A SAM describes the circular flow of income and spending in a national economy during a specific time period, usually a year, such as 2007. It reports the values of all goods and services that are produced and the income generated from their sale. It describes households' income and their spending, government tax revenue and outlays, savings and investment spending, and international trade. CGE model databases typically use data from official national accounts. The second component of the CGE model database presents elasticity parameters. Elasticities describe producer and consumer responses to changes in prices and income.

To be tractable, a CGE model database must be aggregated to provide a summary description of all of this economic activity. Industries are therefore aggregated into representative groups of industries, such as agriculture, manufacturing, and services. Households' transactions are often summed into those of a single, representative household, or into a small number of household types, perhaps categorized by income class, geographical location, or demographic characteristics. The goods and services consumed in the economy are also aggregated into broad categories of commodities, such as agriculture, manufacturing, and services.

Every researcher must decide how to aggregate economic activity in their database, balancing the need for detail, for example on specific industries that are relevant to the research question, with the benefits that a small, highly aggregated database offers in terms of experimenting with the model, and understanding and communicating model results. Many CGE modelers use the global CGE model database developed by the Global Trade Analysis Project (GTAP) (see Text Box 1.1). Modelers typically aggregate this database in ways that are relevant to their research question. For example, we use the GTAP database to develop a small, 3×3×3 database for 2007 for the United States and an aggregated rest-of-world region. Its three production activities are agriculture, manufacturing, and services; its three commodities are agriculture, manufacturing, and services; and its three factors of

Text Box 1.1 The GTAP global database

"The GTAP Data Base: Version 10" (Aguiar et al., 2019).

The Global Trade Analysis Project (GTAP) database, developed and maintained by researchers at Purdue University, is a publicly available resource (www.gtap.org) that provides the core data sets required by CGE models. The GTAP global database is regularly updated every three to four years and relies on broad participation by a network of database users who donate data. The database describes the world economy and distinguishes 65 sectors in each of the 141 countries and regions. The 121 countries in the database account for 98% of world GDP and 92% of world population. For each country/region, the database reports production, intermediate and final uses, international trade and transport margins, and taxes/subsidies. The GTAP database underlies most, if not all, global computable general equilibrium models.

production are land, labor, and capital. We use this small model version, named NUS333, for demonstration throughout this book.

A CGE model database provides the values of all exogenous variables and parameters, and the initial equilibrium values of all endogenous variables. The database is typically maintained in a computer file separate from the CGE model, whose equations are written in general terms. This approach makes it easier for the researcher to use the same general CGE model but swap databases when the country, sectors, or factors under study change. When the database is read into the general model, the researcher now has a quantitative CGE model that can yield numerical solutions.

CGE Model Applications

CGE models have been applied to the study of a wide and growing range of economic problems. A comprehensive guide to their applications is well beyond the scope of this book, or indeed of any one survey article. Nevertheless, there are several noteworthy books, articles, and surveys that can provide you with a solid introduction to this growing body of literature. The early CGE model applications were mainly to tax policies in developed countries and to development policy in developing countries. Recommended surveys of this early literature are Shoven and Whalley (1984) and Pereira and Shoven (1988), who survey CGE-based analyses of taxation in developed countries. deMelo (1988) and Bandara (1991) review CGE analyses of trade and development policy in developing countries, and Decaluwe and Martens (1988) provide a survey of CGE-based country studies. These classic surveys remain of interest for new modelers because they served as introductions of CGE models to the economics profession and thus include overviews of the core structure and behavior of CGE models.

By the early 1990s, many CGE modelers began to focus on trade liberalization within regional free-trade areas and at the global level. Informative surveys of this literature include Robinson and Thierfelder (2002) and Bouet (2008). A new generation of trade-focused CGE models is now examining nontariff, regulatory barriers that affect trade in both goods and services. Fugazza and Maur (2008) and Tarr (2013) offer introductions to this innovative area in trade policy modeling. Another frontier area in trade policy applications is the incorporation of modern trade theory into CGE models, following the ideas of Paul Krugman and Marc Melitz on firm-level product differentiation. Dixon, Jerie, and Rimmer (2016) provide an overview of heterogeneous firm models and the implications for model results. Melitz-type CGE models are discussed in more detail in this book's final chapter.

CGE models also have been applied to the study of subnational regions. Partridge and Rickman (1998) survey approaches to developing regional

CGE models that describe economic activity at subnational levels; Giesecke and Madden (2013) provide a more recent review of this class of models. Notable examples of regionalized CGE models are the TERM model of Australia (Horridge, 2012) and the USAGE-ITC model (Dixon, Rimmer, and Tsigas, 2007). Also, see Taylor et al. (1999), who developed an interesting CGE model of a village in Mexico.

More recently, CGE models are making important contributions to the analysis of climate change impacts, the costs and benefits of mitigating policies, and the potential for adaptive behaviors. Bergman (1988, 2005) and Bhattacharyya (1996) survey the early CGE-based climate change literature, and Burniaux and Truong (2002) detail and compare the approaches to modeling climate change mitigation in several prominent CGE models. Hertel and others (2019) provide a review of the recent literature on climate change and CGE modeling, focusing on the models' increasingly refined treatment of land use and land cover change and the integration of CGE models, which are defined at the national level, with models defined at different geographic scales. Other influential contributions to climate analysis are based on the EPPA model developed at the Massachusetts Institute of Technology (Paltsev et al., 2005); CIM-EARTH, a CGE model developed at the University of Chicago and Argonne National Laboratory (Elliott et al., 2010a); and the SAGE model developed at the US Environmental Protection Agency (Marten and Garbaccio, 2018).

The growing diversity of CGE model applications means that many innovative studies are not readily categorized into the broad areas described in surveys. Some examples that may help you appreciate the breadth of CGE model applications include analyses of the economic effects of AIDS/HIV (Arndt, 2002) and of the Ebola Virus (World Bank, 2014), tourism and climate change (Berrittella et al., 2004), growing antibiotic resistance (Keogh et al., 2009), nutrition and caloric intake (Britz, 2020), employment alternatives to illegal gold mining in Peru (Pineiro et al., 2016), and investments in regional transportation grids (Sakamoto, 2012). As you undertake a literature review for your own research project, you will discover many innovative and creative ways that CGE models are being applied today.

Summary

A CGE model is a system of equations that describes an economy as a whole and the interactions among its parts. Its equations describe producer and consumer behavior and impose market-clearing constraints, and are solved for the set of prices at which the quantities of supply and demand are in equilibrium in all markets. A model experiment perturbs this equilibrium, and the model is re-solved for new market-clearing prices and quantities. In this book, we study a "standard" CGE model, which is a static (single-period), single- or multi-country model with fixed national supplies of the factors of production (e.g., labor and capital). CGE models have been applied to the study of a wide and growing range of economic problems including taxation, economic development, trade policy, climate change, tourism, transportation, and disease.

Key Terms

Circular flow of income and spending
Computable general equilibrium model
Endogenous variable
Equilibrium
Exogenous variable
Multi-country model
Partial equilibrium model
Single-country model
Static model

PRACTICE AND REVIEW

1 **Solve the Bicycle Model**

A CGE model is solved to find the set of prices at which quantities supplied are equal to the quantities demanded. In this exercise, you are asked to solve a partial equilibrium model of the bicycle industry for the market-clearing price and quantities.

Model equations:

$$QDS = 2Y - 2P$$

$$QO = -4PO + 2P$$

$$QO = QDS$$

Exogenous parameters:

$$Y = 6$$

$$PO = 1$$

Solve for the base values of the two endogenous variables:

P______________

QO = QDS = _________

2 **Carry Out a Model Experiment**

Model experiments change the value of an exogenous variable(s) or parameter(s), and the model solves for new values for the model's endogenous variables.

Assume that the exogenous variable in the bicycle model, income, Y, has increased from 6 to 8. Solve for the new equilibrium values of the endogenous variables:

P______________

QO = QDS = ___________

3 Partial Versus General Equilibrium Analysis of the Bicycle Industry

How important is a general equilibrium perspective in economic analysis? Is it possible that conclusions based on a partial equilibrium analysis could be wrong in either magnitude or the direction of change? In this exercise, you are asked to use your economic theory to make predictions about changes in the output price and output level of the bicycle industry following a price shock to one of its inputs – rubber tires. First, you will consider only the effects on supply and demand for bicycles – this is a partial equilibrium analysis that could be drawn from the simple bicycle model we developed in this chapter. Then you will be asked to consider some general equilibrium dimensions of the problem, and to compare these results with the partial equilibrium analysis. You are simply asked to reach *qualitative* conclusions about the general equilibrium impacts of an increase in the price of rubber tires.

Assume that the market is perfectly competitive, so that bicycle producers are price-takers in both input and product markets. This is shown in Figure 1.2, where D^1 is the demand for bicycles and S^1 is the initial supply of bicycles. In the initial equilibrium, at point A, 20 bicycles are supplied and demanded at a price of \$1.00 per bike.

Consider the effects of the increase in price of rubber tires on bicycle production and sales price. An increase in input costs shifts the supply upward to S^2, because producers must now charge a higher price for any given quantity of bicycles. (We could also say that the supply curve shifts left, because a smaller quantity can be

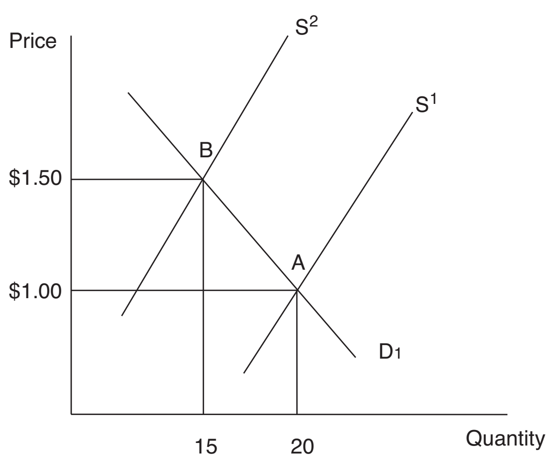


Figure 1.2 Effects of higher rubber tire prices on the domestic bicycle industry

Table 1.2 *Practice and review – partial versus general equilibrium analysis*

	Bicycle equilibrium price Is higher/lower than $1.50	Bicycle supply/ demand equilibrium is greater/less than 15	Which curve shifts and in which direction?
Increase in price of rubber tires	$1.50	15	Supply (S^1)– upward/left
Bicycle workers accept lower wages	higher/lower	greater/less than	
Consumer demand shifts to imported bicycles	higher/lower	greater/less than	
Decline in exports causes depreciation and higher imported input costs	higher/lower	greater/less than	
Bicycle seat price falls due to fall in demand from bicycle producers	higher/lower	greater/less than	

produced for any given price.) The increase in price causes the quantity demanded to fall, shown as a movement along the demand curve, D^1. At the new equilibrium, at point B, the bicycle price has increased by 50%, to $1.50, and the quantity demanded has fallen by 25%, to 15.

This is a partial equilibrium analysis of the bicycle industry. The results are reported in the first row of Table 1.2. You will use these base results for comparison with your general equilibrium results.

Next, consider the interactions between the bicycle industry and the rest of the economy – a general equilibrium analysis. Analyze each of the following circumstances, *each independent of the rest.* Show how each of these factors individually can lead to an outcome that modifies the result of your partial equilibrium analysis.

Start by describing how each of the following factors causes a shift in either the supply curve, S^2, or the demand curve, D^1, and results in a new equilibrium price and quantity of bicycles. In Table 1.2, compare the new equilibrium with the results reported in the first row of the table, which describe point B. When you are done, look at the entries in the table and consider how your general equilibrium analysis compares with the partial equilibrium results.

In this thought exercise, you consider each of the factors individually. In a CGE model, all of these forces influence model results simultaneously. As you progress through this book and learn how to interpret your CGE model results, you may want to return to this exercise to remind yourself of some of the most important factors that may explain your new equilibrium.

1. Bicycle workers are highly specialized and unable to find work easily in other industries. Because of their limited job mobility, they choose to accept a drastic reduction in their wage to retain their jobs. The wage cut lowers the cost of bicycle production.
2. Imported bicycles are now cheaper than those made in the domestic industry. Because customers find imported bicycles to be almost indistinguishable from domestic ones, the domestic price increase causes the market share of imports to increase relative to domestically produced bicycles. Assume that the demand curve reports only demand for domestically produced bikes.
3. Assume that the higher price of rubber has increased the cost of production of autos, Tupperware, and many other products, causing exports of these goods to fall and the domestic currency to depreciate. Most of the steel used to produce bicycles is imported. How will depreciation influence your input costs and the supply curve for bicycles?
4. Any decline in your bicycle production reduces your demand for all of your inputs. Because you are the only industry that uses bicycle seats, your reduced production causes their price to drop. How will the falling price of your input from this "upstream" industry affect your supply curve, sales price, and output level?

2

Elements of a Computable General Equilibrium Model

In this chapter, we deconstruct the computable general equilibrium model and describe its core elements. These include sets, endogenous and exogenous variables, exogenous parameters, behavioral and identity equations, and model closure. We describe composite commodities and prices, price linkages, price normalization, price transmission, and the numeraire. We also describe the structure of a CGE model and explain how it runs and how to carry out an experiment.

A computable general equilibrium (CGE) model is a system of mathematical equations that describes an economy as a whole and the interactions among its parts. A model this comprehensive is more complex than the bicycle industry model we built in Chapter 1, but it need not be a "black box." In this chapter, our objective is to introduce, at a general level, the model's elements and mechanics. Even so, for many students, it may suffice to skim this chapter and return to it as needed as your modeling skills progress. For now, we also set aside any consideration of the economic theory that governs behavior in the model. Here, we do not consider how the model describes the motivations behind producers' decisions about how much to produce or consumers' decisions about how much to buy, or a nation's choice between consumption of its domestic production and imported goods. Of course, the economic properties of a CGE model are its real heart and soul, but they also present a much broader area of study; most of the other chapters in this book address this study.

In this chapter, we deconstruct the CGE model to describe its core elements. We show that a CGE model and the simple bicycle model share many features, such as exogenous and endogenous variables, market-clearing constraints, and identity and behavioral equations. We explain and compare linearized and nonlinear expressions of the behavioral equations in a CGE model. We explain how goods and factors are combined into composite bundles and show how their composite prices are calculated.. We describe how the price of a single commodity changes as it moves along the supply chain from producers to consumers and the implications for price transmission. We explain the practice of normalizing prices and the role of the price numeraire. We introduce model closure, which is the decision about which variables are exogenous and which are endogenous. We also describe how the CGE model runs by explaining the sequence of model calibration or consistency check, baseline model solution, and model experiment.

Sets

A CGE model starts by introducing sets. A *set* is the domain over which parameters, variables, and equations are subsequently defined. For example, we can define set *c* as the commodities in the model, which in the NUS333 database consists of agriculture, manufacturing, and services. If "Q" is the aggregate consumption quantity, then we can define a variable Q_c, which is the quantity consumed defined over the set *c*. That is, Q_c is a vector with three elements. It includes the quantity consumed of agriculture, manufacturing, and services. To refer to only one element in set *c*, for example, the quantity of agricultural commodities that are consumed, we express the variable as $Q_{\text{"agriculture"}}$, where one element of set *c*, in this case agriculture, is identified in quotes.

Similarly, we might define a different variable, PPD, over the same set *c*, where PPD is the household consumer's price of the domestic variety of *c*. If our equation refers to PPD_c, then we are referring to the consumer price of domestically produced agriculture, manufacturing, and services commodities. To refer to the consumer price of domestic services alone, we would identify the set element in quotes, as $PPD_{\text{"services"}}$.

Different variables in the CGE model can have different set domains. For example, our model might include a set *e* that contains two factors of production – labor and capital. In that case, we could define variable QE_e as the national endowment quantity of factor *e*. The variable is a vector with two elements – labor and capital. Variables may also have more than one domain. For example, variable $QFE_{e,a}$ is the quantity of factor *e* employed in production activity *a*, which is the set of industries in the model. The variable is a matrix, with *e* rows and *a* columns.

In multi-country models, including the one used for demonstration in this book, many variables have a set dimension *r* that identifies the region. In the NUS333 database, the set of regions has two elements – the United States and rest-of-world – and variable QFE is defined over sets *e, a*, and *r*. Variable $QFE_{e,a,r}$ therefore has three dimensions that describe the demand for each factor *e* by each production activity *a* in each region *r*. To simplify our discussions throughout much of this book, we drop the *r* subscript from variable names unless it is relevant to our subject.

Table 2.1 *Sets in the NUS333 database*

Set notation	Set name	Set elements
a	Production activities	Agriculture, manufacturing, services
c	Commodities	Agriculture, manufacturing, services
e	Factor endowments	Land, labor, capital
r (*s*,*d*)	Regions	United States, rest of world (ROW)

Note: Set names *s* and *d* are used to describe source and destination regions in bilateral trade variables.

Multi-country CGE models describe bilateral trade flows among each of the countries in the model. To describe the quantity of bilateral exports by source and destination countries, we can define a variable QXS, which is defined over *c*, the commodity that is traded, and two elements of set *r* that specify the exporting country and the importing country. To avoid ambiguity, with two elements of set *r* in the same variable name, we can use set names *s* and *d* to denote source and destination regions. It is the convention that the first country name in a trade variable is the source country and the second country name is the destination country. For example, variable $QXS_{c,s,d}$ describes the quantity of commodity *c* exported by source region *s* to destination region *d*. So, if variable $QXS_{\text{“agriculture,” “USA,” “ROW”}}$ refers to exports of agriculture from the United States to the rest-of-world region, it is also equal to the quantity of agricultural goods imported from the United States by the rest-of-world region.

Sets are a flexible tool for a CGE model because they allow data to be changed without “hardwiring” the model to a particular database or set elements. For example, the set elements defined in the NUS333 database, shown in Table 2.1, could be swapped with a database with the same set names, such as *c*, *e*, and *r*, but that instead defines 6 commodity set elements, 4 factor set elements, and 12 regions, without having to change the equations in the CGE model itself. The same model equations will be applied in the same way to whatever number of commodities, factors, and regions are the elements of the identically named sets of the new database.

Endogenous Variables

Endogenous variables have values that are determined as solutions to the equations in the model, similar to the equilibrium price and quantity of bicycles in our simple partial equilibrium model of Chapter 1. Examples of endogenous variables in CGE models are prices and quantities of commodities that are produced and consumed, prices and quantities of imports and exports, tax revenue, and aggregate savings.

Text Box 2.1 Math refresher – working with percent changes

Computable general equilibrium model results are usually reported as the percent change from initial, or base, values. The following are three useful mathematical formulae for working with percent change data:

1. **Percent change in a variable** is the new value minus the base value, divided by the base value, multiplied by 100.

   Example: If the labor supply, L, increases from a base value of 4 million to 4.2 million, then:

   $$\text{Percent increase in L} = (4.2 - 4)/4 = 0.05 * 100 = 5$$

2. **Percent change in the product of two variables** is approximately the sum of their percent changes, when the changes are small.

   Example: GDP = P * Q, where P is the price and Q is the quantity of all goods in the economy. If P increases 4% but Q decreases 0.05%, then:

   $$\text{Percent change in GDP} = 4 + (-0.05) = 3.95$$

3. **Percent change in the quotient of two variables** is approximately the dividend (numerator) minus the divisor (denominator), when the changes are small.

   Example: Per capita GDP is GDP/N, where N is population. If GDP grows 1% and N grows 0.2%, then:

   $$\text{Percent change in per capita GDP} = 1 - 0.2 = 0.8$$

When describing CGE model results, our notational convention in this book is to describe the level of a variable (e.g., the quantity of a good produced or its price) in uppercase letters and to denote the percent change in a variable in lower-case italics. (See Text Box 2.1.) For example:

Variable $QO_{\text{“mfg”}}$ = quantity of output supplied by the manufacturing production activity.

Variable $qo_{\text{“mfg”}}$ = percent change in quantity of output supplied by the manufacturing activity.

A CGE model usually has the same number of endogenous variables as independent equations. This is a necessary (although not a sufficient) condition to ensure that the model has a unique equilibrium solution.

Exogenous Variables

Exogenous variables have values that are fixed at their initial levels and do not change when the model is solved. For example, if a region's aggregate labor supply is assumed to be an exogenous variable, then its labor supply will remain at its initial quantity, both before and after a model experiment.

Model Closure

Modelers decide which variables are exogenous and which are endogenous. These decisions are called *model closure*. An example of a closure decision is the modeler's choice between (1) assuming that the economy's aggregate labor supply is exogenous, and an endogenous wage adjusts until national labor supply and demand are equal, or (2) assuming that the economywide wage is exogenous, and an endogenous labor supply adjusts until national labor supply and demand are equal.

To illustrate the important concept of model closure, assume that we are studying the effects of a decline in the demand for computers, which causes the computer industry's demand for workers to fall. If we assume the nation's total labor supply is exogenous (i.e., fixed at its initial level), then economywide wages will fall until all laid-off computer workers are reemployed in other industries. However, if the closure instead defines the economywide wage as exogenous (and fixed at its initial level), then the loss of jobs in the computer industry may cause national unemployment but will have no effect on wages. Because a change in the size of a country's labor force changes the productive capacity of its economy, its real gross domestic product (GDP) will decline more in a CGE model that allows unemployment than in a model whose closure fixes the national labor supply.

Because the choice of closure can affect model results in significant ways, modelers try to choose closures that best describe the economy they are studying. Computable general equilibrium models usually have a section of model code that lists model closure decisions. In the Global Trade Analysis Project (GTAP) model, for example, one of the tabbed windows on the model's front page is titled "Closure." The closure page lists all of the exogenous variables, and the remainder is endogenous. On this page, the modeler could choose to change the closure by redefining one or more endogenous variables as exogenous and redefining an equal number of endogenous variables as exogenous.

Exogenous Parameters

Computable general equilibrium models include *exogenous parameters* that, like exogenous variables, have constant values. These models contain three types of exogenous parameters: tax and tariff rates, elasticities of supply and demand, and the shift and share coefficients used in supply-and-demand equations.

Tax and Tariff Rates

Taxes influence economic behavior because they change relative prices. For example, if a consumer must pay a tax on imports, called an import tariff, they are likely to purchase fewer imports. Because tax and tariff rates are exogenous, modelers can change a rate as a model experiment. For instance, the modeler may want to know what would happen in the economy if the government reduces the import tariff rate on autos. As an experiment, the modeler lowers the auto tariff and re-solves the CGE model to find the new marking-clearing price and quantity of auto imports.

We usually describe a tax rate in percentage terms, such as "25%," and we can express it in decimal format as 0.25. An approach taken in some CGE models is to express a tax rate as the "power of a tax." The power of a 25% tax rate is expressed as:

$$\text{Power of the tax}: \ 1 + \ (\text{tax rate}/100)$$

$$\text{Example}: \ 1 \ + \ 25/100 = 1.25.$$

The advantage of this approach is that it allows us to define the effect of the tax on a price, such as $1, in this way:

$$\text{Pre-tax price} * \text{power of the tax} = \text{post-tax price}$$

$$\text{Example}: \ \$1 * 1.25 = \$1.25.$$

When we express the tax rate as 25%, its new value after a tax cut of 50% can be calculated in a straightforward way as 0.5 * 25% = 12.5%. But, when we express the tax in terms of a power, it would not be correct to multiply the 1.25 power by 0.5. Instead, we calculate the new power of the tax after a 50% tax cut in this way:

$$((1 - \text{power of the tax}) * \text{tax rate cut}) + 1 = \text{new power of the tax}$$

$$((1 - 1.25) * 0.5) + 1 = 1.125$$

When setting up a CGE model experiment, you may want to define the shock as the percent change in the power of the tax. For example, let's assume that you want to describe a 50% cut in the tax rate, from 25% to 12.5%. The percentage change in the power of the tax is calculated as:

$$(\text{New power of tax} - \text{initial power of tax})/\text{initial power of tax} * 100$$

$$= \ \% \text{ change in power of tax}$$

$$(1.125 - 1.25)/1.25 * 100 = -10\%.$$

As you can see, the percentage change in the power of the tax (–10%) is very different than the percentage change in the tax rate (–50%). But, both yield the same new tax rate of 12.5%.

Consider an example in which an existing tax is being changed to a subsidy. In the NUS333 model, there is an output tax of 1.057% on the production of manufactured goods by the manufacturing activity. Assume that the government replaces the tax with a 10% output subsidy. Tax rates are positive for taxes and negative for subsidies. The percentage change in the power of the output tax to replace it with a subsidy is calculated in the same way as earlier:

$$\text{Power of the initial tax rate} = 1 + 1.057/100 = 1.01057$$

$$\text{Power of the new tax rate} = 1 + (-10.0/100) = 0.9$$

$$\text{Percent change in the power of the tax}: -10.9414.$$

Elasticity Parameters

Elasticities are exogenous parameters in a CGE model that describe the responsiveness of producers and consumers to changes in prices and income. The magnitudes of model results stem directly from the size of the elasticities assumed in the model. For example, suppose that the National Chefs' Association has asked you to study the possible effects of economic growth on the demand for restaurant meals. If consumer demand for restaurant meals is assumed to be very responsive to income changes (so the income elasticity of demand parameter is high), then even a small increase in income will lead to a relatively large increase in the demand for restaurant services. However, if the income elasticity is assumed to be low, then even large economic growth will have only a small effect on the quantity of demand for restaurant services. Because the income elasticity of demand determines how much the demand for restaurant meals will increase for any given change in income, the assumed value for this parameter is a critical component of your analysis.

In the following two sections, we describe the supply-and-demand elasticity parameters used in many CGE models and show how each influences the slope or shift in supply or demand curves. Table 2.2 provides a list of these elasticities. The types of elasticities used in CGE models vary because they depend on the types of production and utility functions assumed in the model. A standard CGE model generally utilizes some, but not all, of these parameters.

Table 2.2 *Elasticity parameters in standard CGE models*

Symbol	Definition
Supply elasticity parameters	
σ_a^{VA}	Factor substitution
σ_a^{INT}	Intermediate input substitution
σ_a^{AGG}	Aggregate input substitution
σ_e^{F}	Factor transformation (mobility)
σ_a^{Q}	Commodity output transformation
σ_c^{S}	Commodity sourcing substitution
$\sigma_{c,a}^{X}$	Export transformation
Demand elasticity parameters	
η_c	Income
ε_c	Own-price
$\sigma_{c,n}^{P}$	Commodity substitution
σ_c^{D}	Import-domestic (Armington) substitution
σ_c^{M}	Import–import (Armington) substitution
θ_c	Export demand

Supply Elasticity Parameters

Factor Substitution Elasticity. This parameter, σ^{VA}, relates to a production activity's demand for factors of production, such as labor and capital. A producer combines labor, capital, and any other factors into a bundle, called "value added," that is used in the production process. This elasticity describes the flexibility of a production technology to allow changes in the quantity ratios of factors used in a given bundle of value added as relative factor prices change. For example, the parameter describes the ease with which producers in an industry can hire more labor and use less capital when the wage falls relative to the price of machinery and equipment.

The elasticity – one for each production activity *a* in the model – describes the percent change in the quantity ratio of factor inputs given a percent change in their inverse price ratio and holding the total bundle of factor inputs constant:

$$\sigma_a^{VA} = \frac{\%\text{ change } \frac{QFE_{L,a}}{QFE_{K,a}}}{\%\text{ change } \frac{PFE_{K,a}}{PFE_{L,a}}}$$

where $QFE_{L,a}$ and $QFE_{K,a}$ are quantities of labor and capital employed in production activity *a*, and $PFE_{L,a}$ and $PFE_{K,a}$ are the wage and capital rent in that activity. The parameter's value ranges from zero to infinity. For example, a 0.5% factor substitution elasticity means that a 2% increase in capital rents relative to wages will lead to a 1% increase in the ratio of labor to capital quantities in the production process. As the parameter value approaches infinity, labor and capital become perfect substitutes. One worker can always be substituted for the same amount of capital with no reduction in the total quantity of factor inputs. When the parameter is zero, the factors are complements, and producers must use a fixed ratio of capital and labor, regardless of changes in wages compared to rents.

Producers who can more readily substitute among factors have a more elastic industry supply curve, such as curve S^1 in Figure 2.1, where the axes represent output quantity and output price. When this production activity increases its output, producers can keep the costs of production low by switching to lower cost factor inputs. For example, a production activity with a flexible technology (a high factor substitution elasticity) can become more mechanized if its expansion causes wages to increase by more than capital rents. A production activity with a more rigid technology and a low factor substitution elasticity is described in Figure 2.1 by the less elastic, and steeper, supply curve, S^2.

Intermediate Input Substitution Elasticity. This parameter, σ^{INT}, is analogous to the factor substitution elasticity except that it describes the demand by a production activity for quantities of intermediate inputs, such as tires and steering wheels used in the production of a car. The producer assembles these inputs into a bundle of intermediate inputs, which is later combined with the bundle of factor inputs to produce a final product.

The elasticity – one for each production activity *a* in the model – describes the percent change in the quantity ratio of *a*'s intermediate inputs – we'll call

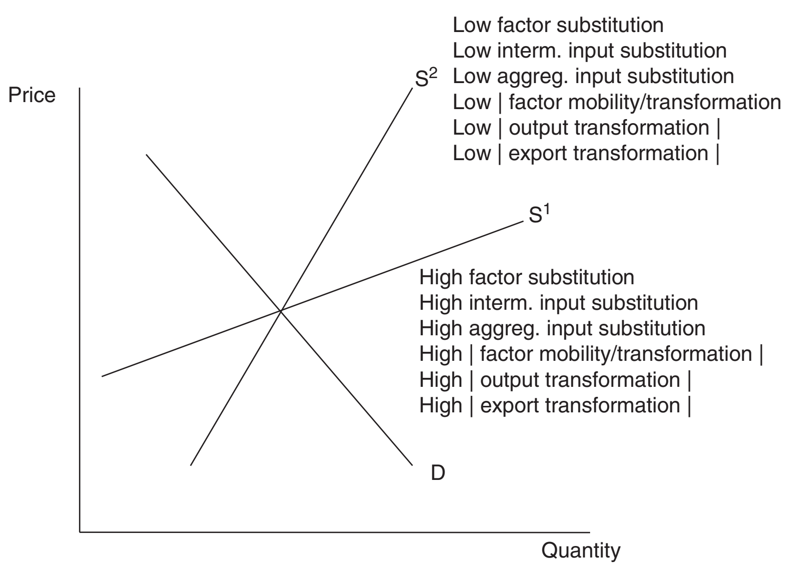


Figure 2.1 Effects of supply elasticity parameters on the slope of the supply curve

them input x and input y – given a percent change in the inverse ratio of their prices, where $QFA_{x,a}$ and $QFA_{y,a}$ are the quantities of the two inputs and $PFA_{x,a}$ and $PFA_{y,,a}$ are their prices. The elasticity describes the percent change in the quantity ratio of inputs given a percent change in their inverse price ratio, holding the total bundle of intermediate inputs constant:

$$\sigma_a^{INT} = \frac{\%\text{ change}\,\frac{QFA_{x,a}}{QFA_{y,a}}}{\%\text{ change}\,\frac{PFA_{y,a}}{PFA_{x,a}}}$$

The parameter's value can range from zero to infinity. In most standard CGE models, the default parameter value is assumed to be zero. Intermediate inputs are described as "Leontief" complements that must be used in fixed proportions to produce the final good. For example, production of every car requires four tires and one steering wheel. No substitution between these inputs is possible regardless of any changes in their relative prices. When the parameter value is low, the production activity has a relatively inelastic industry supply curve, such as curve S^2 in Figure 2.1, where the axes represent output quantity and output price. A production activity with a more flexible technology and a high substitution elasticity between intermediate inputs is described in Figure 2.1 by the more elastic supply curve, S^1.

Aggregate Input Substitution Elasticity. Once the bundle of value added, QVA, and the bundle of intermediate inputs, QINT, in production activity *a* are assembled, this parameter, σ^{AGG}, describes the flexibility allowed by the production technology to vary the quantity ratios of the two bundles in the production of the final good. The elasticity – one for each activity *a* in the model – describes the percent change in the quantity ratio of the value-added and intermediate bundles given a percent change in their inverse price ratio and holding the total output quantity of the final good constant:

$$\sigma_a^{AGG} = \frac{\%\text{ change }\frac{QVA_a}{QINT_a}}{\%\text{ change }\frac{PINT_a}{PVA_a}}$$

where $PINT_a$ is the activity's price of the intermediate input bundle and PVA_a is the price of its value-added bundle. The parameter's value can range from zero to infinity. In most standard CGE models, the parameter value is assumed to be zero. The two bundles are "Leontief" complements that must be used in fixed proportions to produce the final output, regardless of any change in their relative prices.

Factor Transformation Elasticity. This elasticity parameter, σ^F, describes the ease with which factor endowments move across production activities, "transforming" themselves for new employment in response to changing industry wages or rents, for a given national endowment of a factor *e*. For example, it describes the willingness of a worker to move to another industry if it offers a higher after-tax wage than their current job.

One elasticity is defined for each factor *e* in the CGE model. It governs the percent change in the share of the national factor supply employed in production activity *a* given a percent change in the after-tax wage or rent received from employment in *a* relative to the economy-wide average wage or rent. For example, the labor mobility elasticity describes the change in the number of workers employed in activity *a* ($QES_{L,a}$) relative to the total labor force (QE_L), as a function of its wage earned in *a* ($PES_{L,a}$) relative to the average, economywide labor wage (PE_L):

$$\sigma_L^F = \frac{\%\text{ change } \frac{QES_{L,a}}{QE_L}}{\%\text{ change } \frac{PE_L}{PES_{L,a}}}$$

The parameter value can range between zero (factors cannot move between sectors) and negative one (factors move proportionately to a change in relative factor prices). The lower range restriction of negative one reflects that the factor supply function, in those CGE models that explicitly include one, is used to describe relatively inflexible factor movements. As an example, an elasticity of –0.5% means that a 2% increase in the wage in the computer industry relative to the average wage results in a 1% increase in the share of the labor force employed in computer production.

When an industry employs factors that move sluggishly (with low absolute values of the mobility elasticity), its supply curve becomes relatively steep, like S^2 in Figure 2.1, where the axes represent output quantity and output price. This is because its wage and rental costs must rise sharply to attract the additional factors needed to increase production. The more mobile factors are and the larger the parameter's absolute value, the more elastic is the industry's supply curve, such as S^1 in Figure 2.1.

Commodity Output Transformation Elasticity. This parameter, σ^Q, is used in CGE models in which a production activity produces more than one commodity. It describes the technological ability of a producer to transform a given quantity of the activity's output between different commodities. For example, farmers may be able to produce both food crops and feed crops. The parameter describes how easily farmers can reallocate their production mix toward food and away from feed given an increase in the sales price they receive for food relative to feed.

For each production activity *a*, the elasticity measures the percent change in the ratio of its output quantity of commodity *c* ($QCA_{c,a}$), to its output quantity of commodity *z* ($QCA_{z,a}$) given a percent change in the inverse ratio of their supply prices ($PS_{z,a}/PS_{c,a}$):

$$\sigma_a^Q = \frac{\%\ \text{change}\ \frac{QCA_{c,a}}{QCA_{z,a}}}{\%\ \text{change}\ \frac{PS_{z,a}}{PS_{c,a}}}$$

The value of the output transformation elasticity can range from zero to negative infinity. For example, a –0.5% parameter value means that a 1% increase in the price received for commodity *c* relative to commodity *z* will lead to a 0.5% increase in the quantity ratio of commodity *c* to *z* in producers' total output.

If the parameter has a low absolute value, then the resources used in the production of one commodity are relatively difficult to transform into the production of the other commodity. For example, to increase the production of food grains, farmers must shift toward greater use of land that is better suited to feed crops. This raises the cost of increasing food grain production and limits farmers' supply response. In Figure 2.1, assuming that the axes represent quantity of food grains and the food grain price, the lower the absolute value of the commodity output transformation elasticity, the less elastic (and steeper) the production activity's supply curve, such as S^2 in Figure 2.1. When the output transformation parameter is high in absolute value, then producers can readily expand their output of a commodity with less upward push on their costs of production. Their supply curve is therefore more elastic, such as shown by S^1.

Commodity Sourcing Substitution Elasticity. This parameter, σ^S, describes the ease with which the sourcing of the national supply of a commodity can be switched among competing domestic suppliers. The elasticity is used in models in which there is more than one production activity producing the same commodity. For example, solar and wind farms and nuclear plants all can produce the same commodity – electricity. Their electricity products may be indistinguishable or there may be costs to switching among the alternative suppliers of electrical energy. The parameter is calculated as the percent change in the quantity ratio of the same commodity *c* produced by both activity *a* ($QCA_{c,a}$) and activity *b* ($QCA_{c,b}$) given a percent change in the inverse ratio of each activity's supply price for the same commodity ($PCA_{c,a}$ and $PCA_{c,b}$), holding total output of the commodity constant:

$$\sigma_c^S = \frac{\%\ \text{change}\ \frac{QCA_{c,a}}{QCA_{c,b}}}{\%\ \text{change}\ \frac{PCA_{c,b}}{PCA_{c,a}}}$$

One parameter value is defined for each commodity, with a range between zero and infinity. If the substitution elasticity is 2, for example, then a 1% increase in the price of activity *a*'s commodity relative to that of *b* will lead to a 2% increase in the quantity ratio of *b*'s product relative to *a*'s product. As the parameter value increases, market shares become more sensitive to changes in relative supply prices. Assume that the axes in Figure 2.2 describe quantities of activity *a*'s output and its supply price, and that demand curves D^1 and D^2 represent low and high switching costs, respectively. When costs are high, the substitution parameter has a low value, so even a large shift in *a*'s supply curve results in small changes in its market share and output. As the parameter value increases, changes in market share and output are larger as relative supply prices change.

Export Transformation Elasticity. This parameter, σ^X, describes the technological ability of a producer to transform a given level of commodity output between the varieties sold in the domestic and export markets. For example, it describes how easily automakers could shift production between models for the home market and models that are more popular in foreign markets.

For each production activity *a* and each commodity *c*, the elasticity measures the percent change in the ratio of the export quantity, $QXW_{c,a}$, to the quantity sold domestically, $QDS_{c,a}$, given a percent change in the ratio of the producer's domestic sales price, $PDS_{c,a}$ to its world export price, $PXW_{c,a}$:

$$\sigma^X_{c,a} = \frac{\%\text{change } \frac{QXW_{c,a}}{QDS_{c,a}}}{\%\text{change } \frac{PDS_{c,a}}{PXW_{c,a}}}$$

with a value that ranges from zero to negative infinity. For example, a –0.8% parameter value means that a 2% increase in the domestic price relative to the export price will lead to a 1.6% decline in the quantity ratio of exports to domestic sales in producers' total output.

If the parameter has a low absolute value, then the resources used in the production of one variety are relatively difficult to transform into the production of the other variety. To increase their production of exports, producers must shift toward greater use of relatively unsuitable inputs taken from the production of the domestic variety. This raises the cost of expanding export sales and therefore limits the export supply response. In Figure 2.1, assuming that the axes represent export quantity and export price, the lower the absolute value of the export transformation elasticity, the less elastic (and steeper) the industry's export supply curve such as S^2 in Figure 2.1. When the export transformation parameter is high in absolute value, then producers can readily expand their export output with less upward push on their costs of production. The export supply curve is therefore more elastic, such as S^1.

Demand Elasticity Parameters

Income Elasticity of Demand. This elasticity parameter (η) describes the effect of a change in income on demand for a commodity. One parameter is defined for each household consumption commodity *c* in the model. It measures the percent change in the quantity that households demand, QPA_c, given a percent change in income, Y:

$$\eta_c = \frac{\%\ \text{change}\ QPA_c}{\%\ \text{change Y}}$$

Income elasticity parameter values between zero and less than one indicate *necessity goods*, such as food, for which demand grows by proportionately less than growth in income. Parameter values greater than one describe *luxury goods*, for which demand grows by proportionately more than growth in income. An income elasticity of one describes consumers whose quantity demanded changes by the same proportion as their income. In CGE models, goods are usually "*normal*"; that is, income elasticities are positive so that an increase in income leads to an increase in demand for a good.

In Figure 2.2, a change in income could be shown as a shift in the demand curve, where the axes represent the quantity of the commodity and its consumer price. The higher the income elasticity, the larger the rightward (leftward) shift in the demand curve for any given increase (decrease) in income.

Not all CGE models allow the modeler to specify an income elasticity of demand. Often, the models assume utility functions in which the income elasticity of demand is "hardwired" to have a value of one. See Chapter 4 for a more complete discussion of homothetic (unitary income elasticity) and nonhomothetic (nonunitary income elasticity) utility functions.

Own-Price Elasticity. This parameter measures the responsiveness of consumer demand to a change in the price of a commodity. The own-price elasticity (ε) measures the percent change in quantity of household demand for commodity *c* (QPA_c) given a percent change in its consumer price, PPA*c*:

$$\varepsilon_c = \frac{\%\ \text{change}\ QPA_c}{\%\ \text{change}\ PPA_c}$$

CGE models generally assume that the *Law of Demand* holds; that is, an increase in the price of a good causes the quantity demanded to fall, so the own-price elasticity of demand is negative. When consumer demand is price-sensitive, the own-price parameter is large in absolute terms. In this case, the demand curve for the good is relatively elastic, such as curve D^1 in Figure 2.2, where the axes describe the quantity demanded of good *c* and its consumer

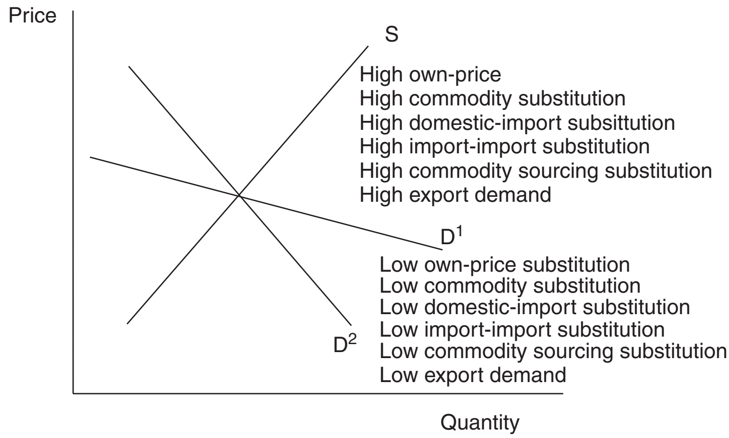


Figure 2.2 Effects of demand elasticity parameters on the slope of the demand curve

price. When the own-price elasticity parameter is low, then the demand curve becomes less elastic, such as D^2.

Commodity Substitution in Consumer Demand Elasticity. This parameter, $\sigma^P_{c,n}$ describes the willingness of household consumers to substitute among the commodities in their consumption basket, at a given level of utility, when the relative retail prices of the goods in that basket change. In a two-good example, the parameter measures the percent change in the household's quantity ratio of commodity *c*, QPA_c, relative to commodity *n*, QPA_n, given a percent change in the inverse ratio of their prices (PPA_n and PPA_c):

$$\sigma^P_{c,n} = \frac{\%\ \text{change}\,\frac{QPA_c}{QPA_n}}{\%\ \text{change}\,\frac{PPA_n}{PPA_c}}$$

An increase in the consumer price of commodity *n*, relative to the price of commodity *c*, will cause the quantity demanded of good *n* to decrease, and the quantity demanded of *c* to increase, and vice versa. A parameter value that is near infinity describes two goods that are strong *substitutes* (like brown sugar and dark brown sugar). A value that approaches zero describes two goods that are *complements* (like left shoes and right shoes). In Figure 2.2, a high value for the parameter is represented by a more elastic demand curve, such as D^1, for commodity *c*. As the parameter value becomes smaller, the demand curve becomes more inelastic, as described by demand curve D^2.

Import-Domestic Substitution (Armington) Elasticity. This parameter, σ^D, relates to the demand for imports. It describes the willingness of consumers to shift between imports (QPM_c) and the domestically produced variety (QPD_c) in their consumption of a given quantity of commodity c as the relative consumer price of the domestic good (PPD_c) to the composite import price (PPM_c) variety changes. For example, it describes the willingness to shift from an imported car to the domestic model when the relative price of the import rises.

The parameter is calculated as the percent change in the quantity ratio of the import to the domestic variety given a percent change in their inverse price ratio:

$$\sigma_c^D = \frac{\%\ \text{change}\ \frac{QPM_c}{QPD_c}}{\%\ \text{change}\ \frac{PPD_c}{PPM_c}}$$

One parameter is defined for each commodity with a value that ranges between zero and infinity. For example, if the substitution elasticity is 2, then a 1% increase in the price of the domestic commodity relative to the price of the import will lead to a 2% increase in the ratio of the import relative to the domestic quantity for a given total consumption quantity. Assume that the axes in Figure 2.2 describe quantities of imports and the import price. When the import-domestic substitution parameter has a low value, import demand is inelastic, shown as D^2 in Figure 2.2. As the parameter value increases, the import demand curve becomes more elastic, such as D^1.

Import-Import Substitution (Armington) Elasticity. Multi-country CGE models usually have a second import demand elasticity, σ^M, that describes consumers' willingness to shift among foreign sources in their imports of a commodity. The parameter is analogous to the import-domestic elasticity of substitution. It defines the willingness of consumers in destination country d to shift the sourcing of their import quantity from source country s ($QXS_{c,s,d}$) to country z ($QXS_{c,z,d}$) for a given level of total imports from all sources, as the domestic price of the import from country s ($PMDS_{c,s,d}$) changes relative to that of country z ($PMDS_{c,z,d}$).

For each commodity c, the parameter is calculated as the percent change in the quantity ratio given a percent change in their inverse price ratio:

$$\sigma_c^M = \frac{\%\ \text{change}\ \frac{QXS_{c,s,d}}{QXS_{c,s,z}}}{\%\ \text{change}\ \frac{PMDS_{c,z,d}}{PMDS_{c,s,d}}}$$

One parameter is defined for each commodity with a value that ranges between zero and infinity. Assume that the axes in Figure 2.2 represent the quantity of imports from country *s* and the price of imports from country *s*. When the import-import substitution parameter has a low value, the demand for imports from country *s* is inelastic, shown as D^2 in Figure 2.2. As the parameter value increases, the import demand curve becomes more elastic, such as D^1.

Export Demand Elasticity. Single-country CGE models describe the rest of the world's demand for a country's exports as a function of its export price. Usually, when its export price rises relative to the world price, the country's foreign sales will fall. An export demand elasticity parameter, θ, describes the percent change in the share of a country's exports of commodity *c* (QXW_c), in world trade ($QXWCOM_c$), given a percent change in the ratio between the average world price ($PXWCOM_c$) and the exporter's price (PXW_c):

$$\theta_c = \frac{\%\ \text{change}\ \frac{QXW_c}{QXWCOM_c}}{\%\ \text{change}\ \frac{PXWCOM_c}{PXW_c}}$$

One elasticity parameter is defined for each exported commodity *c* in the CGE model with a value that ranges from zero to infinity. An increase in the exporter's price relative to the world price causes its export quantity and world market share to decline. The larger the elasticity parameter value, the larger the decline in its exports as the country's relative export price increases. A parameter value that approaches infinity describes a small country in world markets, so even a small deviation in its export price relative to the world price will result in a large change in its market share. A parameter value near zero describes a very large country in world markets. In Figure 2.2, if we assume that the axes represent the quantity of a country's export good and its export price, then a high value of the export-demand elasticity parameter is shown as the very elastic export demand curve, D^1, for a small country's exports. A low parameter value is described by the relatively inelastic export demand curve of a large country, D^2.

Shift and Share Parameters

Shift parameters and *share parameters* are exogenous values used in the supply-and-demand equations in a CGE model. As an example, consider the shift and share parameters in a Cobb-Douglas production function. This function is used in some CGE models to describe the production technology of an industry:

$$QO = A(K^{\alpha}L^{1-\alpha})$$

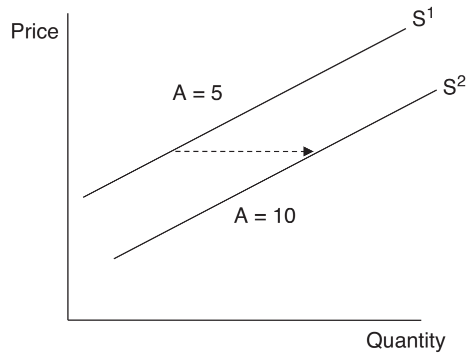


Figure 2.3 Effect of an increase in the shift parameter value on the supply curve

where QO is the output quantity. Parameter A is a shift parameter whose value is greater than zero and that describes the productivity of capital, K, and labor, L, in the production process. Parameter α is a share parameter, ranging between zero and one. It measures the share of K in the total income received by labor and capital from their employment in the industry. Labor's income share parameter is $1 - \alpha$.

Parameter A is called a shift parameter because a change in its value causes the industry supply curve to shift to the right or the left. For example, if the shift parameter increases in value, perhaps from A = 5 to A = 10, then factors are more productive, and the same quantity of K and L can produce a larger quantity of output. This change in the shift parameter is described by the rightward shift in the supply curve from S^1 to S^2 in Figure 2.3. Computable general equilibrium modelers can change the value of the shift parameter in the production function as a model experiment to describe changes in factor productivity.

Share parameters used in production and consumption equations in a CGE model describe percentage shares that are calculated from the base data. Some examples are shares of each commodity in consumers' total consumption, shares of imported and domestic varieties in the demand for commodities, and shares of domestic and export sales in total industry output.

Equations

Computable general equilibrium models have behavioral and identity equations. *Behavioral equations* describe the economic behavior of producers, consumers, and other agents in the model based on microeconomic theory. You may recognize some of the behavioral supply-and-demand equations in the model from your economics coursework. For example, CGE models include a behavioral equation that describes how firms minimize the costs of inputs to produce a specific level of output, given input and output prices and subject to the technological constraints of their production process.

Computable general equilibrium models also include a utility function that describes the combinations of goods that consumers prefer. The choice of utility function – for example, Cobb-Douglas or Stone-Geary – depends on which best describes consumer preferences in the country under study. Given consumers' preferences, a behavioral equation describes how they choose quantities of goods that maximize their utility subject to the prices of goods and their budget. Additional behavioral equations in the CGE model explain the demand for imports and the supply of exports.

Identity equations define a variable as a mathematical function (sum, product, etc.) of other variables. Identity equations therefore hold true by definition. If the value of any one of the variables in the identity equation changes, then one or more of the other variables must also change in order to maintain the equivalence.

Some identities in a CGE model are accounting equations. For example, an accounting equation can be used to define the consumer retail price as the sum of the wholesale price plus the retail sales tax. Other identity equations act as market-clearing constraints in a CGE model to ensure that the model solves for a set of prices at which quantities supplied and demanded are equal. These equations are similar to the market-clearing constraint in our bicycle model of Chapter 1, that QO = QDS. Model closure is the choice made by the modeler as to which variable adjusts to maintain a market-clearing identity.

An example of a market-clearing identity equation in a CGE model is this expression as follows:

$$\mathrm{QE}_e = \Sigma_a \mathrm{QFE}_{e,a}$$

The equation states that the total supply of factor endowment *e* (QE_e) is equal to the sum of production activities' demands for quantities of factor *e* ($\mathrm{QFE}_{e,a}$). If the modeler chooses a closure in which the total factor supply is exogenous (fixed at its base value), then this identity imposes a full-employment constraint in which a fixed, total supply must equal aggregate demand for each factor *e*.

Macroclosure

Computable general equilibrium models include an identity equation that imposes the constraint that total savings is equal to total investment. Some multi-country models impose this constraint at the global level. Other single- and multi-country models impose it at the national level. *Macroclosure* describes the modeler's decision about which of the two macroeconomic variables – savings or investment – will adjust to maintain the identity that savings equals investment.

Standard, static CGE models rely on an identity equation to model savings and investment because these behaviors are determined largely by macroeconomic forces, such as monetary policy and expectations about future economic conditions, which are outside the scope of a real CGE model.[1] Nevertheless, the models account for them because savings and investment are part of the circular flow of income and spending, with effects on the real economy. Savings affect the demand side of the economy because households and the government allocate some share of their disposable income to savings, which reduces the income they have available for purchases of goods and services. Investment affects the production side of the economy because it funds investment spending on capital equipment that is produced by industries.

Computable general equilibrium models differ in their default assumptions as to whether savings or investment adjusts to maintain the savings-investment identity. In some models, such as the default closure in the GTAP model, the savings rate (the percentage of income that is saved) is assumed to be exogenous and constant, so the quantity of savings changes whenever income changes. Investment spending then changes to accommodate the change in supply of savings. A model with this closure is called savings-driven, because changes in savings drive changes in investment. An advantage of this closure is that a nation's savings rate remains the same as the rate observed in the base year. This is appealing if we think that base year savings rates reveal the subjective preferences of a country's households and government.

In other CGE models, aggregate investment is fixed at its initial level, and savings rates are assumed to adjust until savings are equal to investment spending. A model with this closure is called investment-driven. This closure is well suited for the study of countries in which governments use policies that influence savings rates to achieve targeted investment levels.

To demonstrate how this macroclosure decision can matter, assume that a country's income increases. In a savings-driven model, households save a fixed share of their income, so income growth will cause savings to increase and therefore investment spending to rise. In an investment-driven model, investment is fixed, so the supply of savings is also fixed. In this case,

[1] For a more detailed discussion of macroclosure and savings and investment, see Lofgren et al. (2002), Hertel and Tsigas (1997), Robinson (1991), and Dewatripont and Michel (1987). Shoven and Whalley (1984) discuss the effect of the choice of closure in predetermining model results.

households will spend, rather than save, their additional income and their savings rate will fall. Because households and investors are likely to prefer different types of goods, the two alternative closures will lead to a different commodity composition of demand. The savings-driven model is likely to result in an increase in demand for and production of machinery and equipment, which is what investors prefer to buy. An investment-driven model is likely to result in an increased demand for and production of consumer goods, like groceries, apparel, and consumer electronics.

Some CGE models, such as those in the Dervis, deMelo, and Robinson (1982) tradition, specify additional macroclosure rules to describe the current account balance and the government fiscal balance. These macroclosure decisions address components of national savings. The current account closure describes whether foreign savings inflows (the current account) are exogenous and the exchange rate is endogenous, or vice versa. An exogenous current account closure fixes the supply of foreign savings (the current account deficit or surplus) at its initial level and the exchange rate adjusts to maintain it, whereas a fixed exchange rate makes foreign savings endogenous. The government budget closure describes whether government savings (the federal deficit) is endogenous and government spending is fixed or vice versa.

Modelers choose macro-closure rules that best describe the economy under study. The rules also offer researchers the flexibility to explore macroeconomic policy shocks in a CGE model, such as currency devaluation or pay-go federal budget rules. See, for example, Cattaneo, Hinojosa-Ojeda, and Robinson's (1999) methodical study of the effects of alternative macroeconomic policies in Costa Rica, which are simulated by running the same policy shock with different macroeconomic closures (Text Box 2.2).

Nonlinear and Linearized CGE Models

Computable general equilibrium models generally include a mix of linear and nonlinear equations. Identity equations are typically linear equations. Many behavioral equations are nonlinear. An example is this nonlinear behavioral equation describing the quantities of household demand for the domestically produced (QPD) variety and the import (QPM) of a commodity:

$$\frac{\text{QPM}}{\text{QPD}} = \alpha \left(\frac{\text{PPD}}{\text{PPM}} \right)^{\sigma}$$

where α is a constant, PPD is the price of the domestic product, PPM is the price of the import and σ is the import-domestic substitution elasticity that

Text Box 2.2 Macroclosure and structural adjustment in Costa Rica

"***Costa Rica Trade Liberalization, Fiscal Imbalances, and Macroeconomic Policy: A Computable General Equilibrium Model***" (Cattaneo, Hinojosa-Ojeda, and Robinson, 1999).

What is the research question? In the 1980s, Costa Rica signed structural adjustment agreements with the World Bank that included trade liberalization, elimination of producer and consumer subsidies, and other policy reforms. How might the broader reform program that Costa Rica must carry out temper the gains from the trade liberalization component?
What is the CGE model innovation? The authors develop a multi-household SAM for Costa Rica for 1991. Using the IFPRI standard CGE model, they vary macro-closure rules to describe alternative ways to implement structural adjustment commitments.
What is the experiment? A single trade liberalization experiment that removes all import tariffs and export taxes is carried out under two alternative foreign savings closures: fixed foreign savings and an endogenous exchange rate versus a fixed exchange rate and endogenous foreign savings. Both scenarios are also conducted with three alternative closures for government savings: loss of trade tax revenue causes the government to run a deficit; and the government budget balance is fixed with trade tax revenue replaced by a corporate income tax or by a retail sales tax.
What are the key findings? Trade liberalization generates efficiency gains for the economy as a whole, and changes in the distribution of income across households are small. However, there are trade-offs that the government must face to maximize these potential gains. The scenarios offer a blueprint for government policy, recommending reduced government expenditures and higher retail sales taxes to offset the significant loss of trade tax revenues.

describes the willingness of household consumers to substitute toward the import as its price falls relative to that of the domestic variety. The variables in this nonlinear equation are expressed in levels. That is, QPM is the number of imported items that consumers demand, QPD is the number of domestic items, and PPD and PPM are the prices per unit of the domestic and imported varieties, respectively.

Some CGE models are written as systems of linearized equations. In this approach, the nonlinear behavioral equations of the model are expressed in percentage change terms. For example, the nonlinear consumer import demand equation given earlier can be expressed in its linearized form as:

$$qpm - qpd = \sigma(ppd - ppm)$$

where *qpm* is the percentage change in the quantity of imports demanded, *qpd* is the percentage change in the quantity demanded for the domestic variety, and *ppd* and *ppm* are the percentage changes in prices of the domestic and imported varieties. Recall our convention that uppercase letters denote the level of a variable and lowercase letters denote its percentage change.

The two different ways to express CGE model equations are a result of the different solution algorithms used by two of the main CGE modeling softwares. GAMS, a software package used for many CGE models, finds solution values for nonlinear equations whose variables are expressed in levels. GEMPACK, the software package used by GTAP and other models, solves linearized equations. It traces a nonlinear solution by breaking up the model shock into several smaller shocks and solving sequentially for many small, straight-line segments. After each shock, the levels data are updated and the next small shock is applied until the full shock is implemented. The most important thing to know is that nonlinear and linearized expressions are equally valid ways to describe the same consumer and producer behavior and both solution methods lead to similarly accurate results.[2]

For most modelers, the decision on how to express the nonlinear equations in their model is today mainly a question of convenience. Foremost, they follow the convention used by the CGE model and software that they adopt for their research. Some researchers prefer models in which equations can be expressed in nonlinear form because they can be drawn directly from economic theory and may be easier to add or modify in a model.

Other researchers prefer models with linearized equations. An advantage of this approach is that it avoids the need for model calibration, described in the following section. Also, model results are more intuitive to interpret. Consider, for example, the linearized equation provided earlier that describes import demand. Assume that the substitution elasticity is 1.5 and that the model solution is as follows:

$$5 - 2 = 1.5\,(3 - 1)$$

You can see straightaway that the larger impact on the quantity ratio of imported to domestic varieties is the 3% change in the domestic price, compared to the smaller change in price of the import variety. You can also view the role of the import substitution elasticity in determining this result.

[2] The equivalent accuracy of results was an important question for the CGE modeling community in the early 1990s. Horridge and Pearson (2011) and Horridge et al. (2013) provide an overview and comparison of the history and evolution of CGE modeling software and a comparison of their solution methods. Hertel et al. (1991a) demonstrate that the two expressions of behavioral equations in a CGE model are equally valid starting points for a model solution of the same accuracy. Harrison et al. (1993) also address the equivalent accuracy of results.

Model Calibration

The model *calibration* procedure, required for a CGE model that is expressed in levels, calculates prices and quantities, and the shift and share parameters used in its production and utility functions so that solutions to the equations replicate the initial equilibrium database. The calibrated model solution is then used as the benchmark equilibrium, against which the results of model experiments are compared. The inputs to the calibration process are the SAM, the model's behavioral equations (such as a Cobb-Douglas production function), and the elasticity parameters.

As an example of the calibration procedure, let's again consider a CGE model that assumes this Cobb-Douglas production function:[3]

$$QO = A(K^{\alpha}L^{1-\alpha})$$

Suppose the SAM reports that the industry employs $30 worth of capital, K, and $70 worth of labor, L, with a value of output of $109. The model calibration process defines these values as quantities by "normalizing" wages, rents, and output prices as $1, so that the quantities of K and L per dollar are 30 and 70, respectively, and the base year quantity of output, QO, is 109 units. The calibration then calculates the share parameters α and $1 - \alpha$. The share of capital, α, in total factor payments of $100 is 0.3, and the income share of labor, $1 - \alpha$, is 0.7. With these share parameters, and the values of QO, K, and L, the calibration process then solves for A as follows:

$$109 = A(30^{.3}\ 70^{.7})$$

whose value is 2. You can also verify for yourself that the production function, with these calibrated shift and share parameters, reproduces the base year output of 109.

The calibrated shift and share parameters used in the model's production and utility functions always remain at their initial values, even though actual shares may later change as the result of model experiments. Modelers sometimes change the calibrated shift parameters used in production functions as an experiment to analyze the effects of productivity shocks. Sometimes, too, modelers change calibrated share parameters as an experiment. An interesting examples of this share-parameter approach is a study by Kuiper and van Tongeren (2006), summarized in Text Box 2.3, who change the import share parameters.

A linearized model such as GTAP need not be calibrated because its equations are expressed in percentage change terms. It does not require

[3] Note that the modeler does not need to specify any elasticities in the case of a Cobb-Douglas production function because these are implied by the properties of the function: the own-price elasticity of demand for each factor is –1, and the factor substitution elasticities are 1.

Text Box 2.3 The small share problem and the Armington import aggregation function

"*An Empirical Approach to the Small Initial Trade Share Problem in General Equilibrium Models*" (Kuiper and van Tongeren, 2006).

What is the research question? CGE-based analyses of trade liberalization describe the effects of eliminating trade barriers on import quantities. The majority of these analyses assume an Armington import aggregation function. The "small share problem" is due to the scaling effect of the share parameter in the Armington import demand equation as follows:

$$\frac{M}{Q} = \alpha \frac{P_M^{-\rho}}{P_Q}$$

where M is the import, Q is the composite commodity (the sum of imported and domestically produced varieties), P_M and P_Q are the prices of the import and of the composite commodity, respectively, and parameter ρ is related to the import substitution elasticity parameter. Parameter α is the initial quantity share of imports in the consumption of commodity Q. Its value is calculated during model calibration and does not change following a model experiment. Notice that if the initial import share is small, then even a large change in the relative price of the import, or a large increase in the size of the import substitution parameter, can result only in small changes in the import share of consumption. This scaling effect may lead to unrealistically small import quantity results in trade liberalization simulations that cause the import price to fall. Could a gravity model provide an empirical basis for changing the share parameters as part of a trade liberalization experiment?

What is the model innovation? The researchers develop a gravity model to identify the role of trade barriers in bilateral trade flows. They use the gravity model to simulate trade liberalization and estimate changes in bilateral trade shares. Then, they modify their GTAP model to adjust the calibrated trade shares to those of the gravity model results as part of a trade liberalization experiment.

What is the model experiment? The authors eliminate global import tariffs and export subsidies (1) with and (2) without changes in import share parameters.

What are the key findings? The adjustments shift bilateral trade flows, causing some regions to gain larger shares of the world market following trade reform and other regions to lose market share, compared with a standard CGE model analysis. Adjusting the import share parameters does not change the size of global welfare effects by very much.

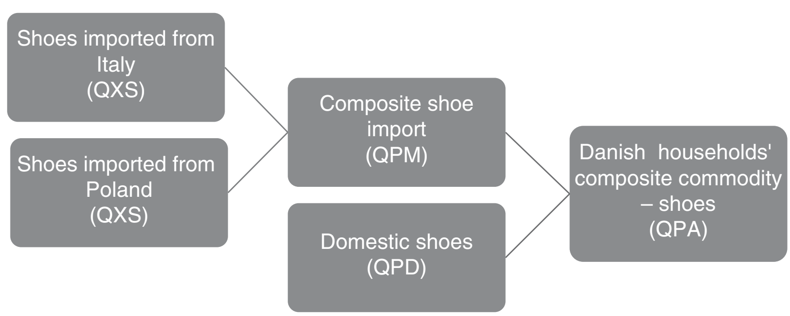
initial levels such as K, L, QO, or A. Instead, a linearized model undergoes a consistency check to ensure that solutions to its equations produce a balanced database. This approach saves computing time, once an important consideration when computers were less powerful than they are today.

Composite Commodities, Factors, and Prices

In a CGE model, commodities are gradually combined with different varieties of like products into bigger bundles until they are ultimately sold to household consumers, investors, or the government to satisfy their demand for final goods or used by firms as intermediate inputs. A bundle of like goods is called a *composite*. As an example, let's consider shoes that are purchased by Danish households. Shoes imported by Denmark may come from many countries, such as Italy and Poland. A multi-country CGE model keeps track of all of Denmark's shoe imports by source (QXS), and bundles the quantity of shoes from all foreign sources into a *composite import* (QPM) purchased by households. The composite shoe import is then combined with domestically produced shoes (QPD) into the *composite commodity* (QPA), called shoes, that is purchased by Danish household consumers, as shown in Figure 2.4.

Similar to household consumers, the government and investors also consume composite imports and composite commodities in their final demand. Firms demand composite imports and composite commodities for use as intermediate inputs in their production activities. On the export side, producers who ship their output to many countries produce a *composite export* (QXW) that is an aggregation of their bilateral exports to all destinations. In addition to composite commodities, CGE models describe a *composite value-added* (QVA) bundle. It comprises the mix of factors of production (land, labor, and capital) that are required by firms to produce their goods.

The price of a composite is the weighted sum of all of the unit prices in the bundle, where the weights are the shares of each component in the total cost or value of the composite. For example, the *composite import price* (PMS) of the composite shoe import in Denmark is a *trade-weighted* aggregation of the



Total Danish demand for imports is met by combining shoes from multiple sources into a composite shoe import. Households then combine quantities of the composite shoe import with domestically produced shoes into the composite commodity – "shoes."

Figure 2.4 An example of shoes as a composite commodity consumed by households in Denmark

Table 2.3 *Calculating composite prices of shoes in Denmark*

Composite import price of composite shoe imports	
Imports from Italy (PMDS)	0.60 * $2 = $1.20
Imports from Poland (PMDS)	0.40 * $4 = $1.60
Composite import price of shoes (PMS)	$1.60 + $1.20 = $2.80
Consumer market price of shoes	
Composite import price (PPM)	0.60 * $2.80 = $1.68
Denmark domestic shoe price (PPD)	0.40 * $1.00 = $0.40
Consumer market price (PPA)	$1.68 + $.40 = $2.08

price from each import supplier, where the trade weights are the cost shares of shoe imports from Italy and Poland in the total value of Denmark's shoe imports. Households' *consumer market price* (PPA) of shoes in Denmark is the weighted sum of the composite import price (PPM) and the price of domestical shoes (PPD), both include retail taxes, where the weights are the cost shares of the composite import and the domestic shoes in total consumer expenditure on shoes.

Table 2.3 presents an example of how Denmark's household consumer price for shoes is calculated. To simplify, let's assume that there are no retail taxes (so PMS = PPM). Suppose Italy accounts for 60% of the value of Denmark's imported shoes, at a price of $2 per pair, and Poland accounts for 40% of Danish shoe imports at $4 per pair. These import cost shares are the trade weights used for each of Denmark's partners. Multiplying each supplier's shoe price by its trade weight, and then summing the weighted prices, results in a composite price of shoe imports in Denmark of $2.80 per pair. Now we can calculate the market price of the composite shoe commodity. Assume that imports account for 60% of the value of household shoe consumption, and domestically produced Danish shoes account for the remaining 40%. Multiplying the composite price of the shoe imports and the price of domestic shoes by their respective cost shares results in a composite market price of the composite shoe commodity of $2.08. There are other types of composite prices in a standard CGE model and all are calculated using the same principles as in the example of Danish shoes.

Normalizing Prices

The value of output of good X is the product of its price times its quantity. For example, the value of production of apples is the product of their price (say, $1.50 each) and the quantity of apples (10), which is $15. The database of most CGE models comprises only value flows. It reports the value of output of each good in the model, but not their quantities or prices. It reports

Table 2.4 *Normalizing the price and quantity of apples in a CGE model*

	Base values for apples			50% increase in apple quantity		
	Price	Quantity	Value	Price	Quantity	Value
Actual market data	5	6	3	5	9	4.5
Normalized data	1	3	3	1	4.5	4.5

the value of factor inputs, such as total labor costs, but not the number of workers who are employed or their wage rates. However, you will see that a CGE model reports the results of model experiments for both quantities and prices. For example, a new production subsidy may increase the quantity produced of X by 5% and cause its sales price to fall by 2%. How does a CGE model develop price and quantity data if its database contains only value data?

CGE models translate value data into price and quantity data by *normalizing* prices. This procedure converts most of the initial, or base, prices in the model into $1 or one unit of the currency used in the model.[4] Quantities of goods and of factors of production (e.g., labor and capital) are then interpreted as the quantity per $1 or unit of currency.

Let's use a simple example of apples to show how prices are normalized. According to the actual market data reported in Table 2.4, apples cost 50 cents each and the initial quantity demanded is six, so the value of apples sold in the market is $3. In a CGE model database, we know only the value of apples sales, which is $3. By normalizing prices, we describe the apple price as $1 and the quantity as the unit quantity per dollar, which is three. That is, each quantity unit of apples in the model is two actual apples.

Normalizing prices does not affect our results. To illustrate this point, consider what happens if the sales quantity of apples increases by 50%. If we use actual market data, then the value of sales increases to $4.50 (9 apples × 50 cents). When we use the normalized data, we get the same answer. The apple quantity rises 50%, from 3 to 4.5 units of apples, and 4.5 apples × $1 = $4.50.

The practice of normalizing data considerably reduces the information needed to build a CGE model database without losing the capability of the CGE model to generate results for prices, quantities, and values. This approach also means that most, but not all, prices in a CGE model have an initial level value of one. Some prices in the CGE model are adjusted to include taxes or subsidies, and these initial prices do not equal one. An example is the domestic price of an import. If its normalized *cif* price at the

[4] This practice is attributed to Arnold Harberger (1964), who normalized the prices and quantities of factors in a general equilibrium analysis of the US income tax.

entry port is $1 and the import tariff is 10%, then the initial domestic price of the import in the CGE model is $1.10.

Price Linkages

If you purchase a shirt in China for $14 that is imported from Brazil, you probably realize that the Brazilian company that manufactured the shirt does not receive $14 for it. The difference between the price that you pay in China and the cost of producing the shirt in Brazil includes any production taxes or subsidies received by the Brazilian producer, any export taxes that the Brazilian company paid to its government, the costs of transporting the shirt between Brazil and China, and any import tariffs and retail sales taxes that you paid to your own (Chinese) government. We omit discussion of the costs of wholesale and retail trade services incurred in bringing the shirt from the port to your department store.

A CGE model reports several prices for a single commodity, such as this Brazilian shirt, because it tracks goods and prices all along the supply chain from producers to consumers. Some of these prices are the composite prices that we studied earlier in this chapter. Table 2.5 describes these price linkages as the shirt moves from Brazil's factory to China, and is then combined with Chinese-made shirts into the composite shirt (imports plus the domestic variety) purchased by the Chinese consumer.[5] The table includes the general expressions for each price. In our example, commodity *c* is a shirt, production activity *a* is the shirt manufacturer, Brazil is the import source country, *s*, China is the destination country, *d*, that imports Brazilian shirts, and set *r* includes both Brazil and China.

At the beginning of the chain, at the top of Table 2.5, is the Brazilian firm's *supply price* (*PS*). In a perfectly competitive market, in which there are zero economic profits, the supply price of a production activity is equal to the unit cost of producing a commodity, excluding any taxes or subsidies entailed in the production process. The Brazilian shirt, for example, may require $5 worth of inputs like cloth and thread, plus $2 for the services of tailors and sewing machines, so the supply price of shirts in Brazil is $7. The *producer sales price* (PDS) of the domestic commodity includes any output taxes or subsidies, and it is the sales price received by producers. If Brazil imposes a $1 output tax per shirt, then the sales price of Brazil's shirts increases to $8.

So far, all of the shirts produced in Brazil's shirt factory have the same price. Brazilian shirt prices will now diverge depending on whether the shirts are destined for Brazil's domestic market or for export. In our example, we track only Brazil's shirt exports. The shirt that Brazil exports to China is

[5] See Appendix B Table for a detailed reference on price and quantity definitions in a standard CGE model.

Table 2.5 *Price linkages – tracking the household consumer price of a shirt in China from producers to consumers*

		Shirt price in Brazil-China trade	Price definition
China'shirt imported from Brazil		\$7	$PS_{c,a,r}$ Brazil's producer supply price of shirt = the unit cost of production
		\$8 = \$7 + \$1	$PDS_{c,r} = PS_{c,a,r} + TO_{c,a,r}$ Brazil's producer sales price of shirt = supply price plus output tax/subsidy (TO) for shirt commodity made by shirt production activity
		\$9 = \$8 + \$1	$PFOB_{c,s,d} = PDS_{c,s} + TXS_{c,s,d}$ Brazil's bilateral FOB shirt export price = producer price plus bilateral export tax (TXS) on shirt exported by Brazil to China
		\$12 = \$9 + \$3	$PCIF_{c,s,d} = PFOB_{c,s,d} + PTRANS_{c,s,d}$ China's bilateral CIF shirt import price = Brazil's bilateral FOB export price plus price of shirt transport (PTRANS) from Brazil to China
		\$13 = \$12 + \$1	$PMDS_{c,s,d} = PCIF_{c,s,d} + TM_{c,s,d}$ China's bilateral domestic price of shirt import = China's bilateral CIF import price plus China's bilateral import tariff (TM) on shirts from Brazil
		\$13 = 100%*\$13	$PMS_{c,r} = SHRWT_{c,s,d} * PMDS_{c,s,d}$ China's domestic price of composite shirt imports = share-weighted (SHRWT) sum of bilateral basic prices of shirt imports from all sources (in this case, Brazil is the only supplier, so its SHRWT = 100%)
		\$14 = \$13 + \$1	$PPM_{c,r} = PMS_{c,r} + TPM_{c,r}$ China's composite consumer import price = Composite import price + China's retail sales tax (TPM) on shirt imports
China's consumer market price		\$14.50 = 50% * \$14+50% * \$15	$PPA_{c,r} = MSHR_{c,r} * PPM_{c,r} + (1\text{-}MSHR_{c,r}) * PPD_{c,r}$ China's private consumer market price of shirt = share-weighted sum of consumer price of composite import of shirt plus consumer domestic price of shirt

(*continued*)

Table 2.5 *(cont.)*

	Shirt price in Brazil-China trade	Price definition
China's domestically produced shirt	\$15 = \$12 + \$3	$PPD_{c,r} = PDS_{c,r} + TPD_{c,r}$ China's private consumer domestic price of shirt = producer sales price plus retail sales tax (TPD) on private household consumption of domestic shirt
	\$12 = \$10 + \$2	$PDS_{c,r} = PS_{c,r} + TO_{c,a,r}$ China's producer sales price of shirt = producer supply price plus price plus output tax/subsidy (TO) for shirt commodity in shirt production activity
	\$10	$PS_{c,a,r}$ China's producer supply price of shirt = the unit cost of production

valued at its *bilateral fob export price* (PFOB), or "free on board" price. It is the price of the good at the exporter's port, and is equal to the producer sales price plus any export taxes or subsidies. It is described as bilateral because export taxes may vary by destination. In our example, Brazil levies an export tax of \$1 per shirt on export sales to China, but it may levy a different export tax on Brazil's sales to Uruguay or France. In Table 2.5, the Brazilian producer pays \$1 per shirt in export taxes on sales to China, so its bilateral *fob* export price is \$9 per shirt.

Transporting the shirt from Brazil's port to China's port incurs insurance and freight charges, called *trade margin costs*. After adding the trade margin costs to Brazil's *fob* export price, the price of China's shirt imports from Brazil becomes the *bilateral cif import price* (PCIF). It is called a bilateral price because freight and insurance charges are likely to differ across trade partners, depending on the distance that goods must be shipped, the mode of shipment, and other factors. If trade margin costs total \$3 per shirt, then China's *cif* import price for a shirt imported from Brazil is \$12.

Once the shirt reaches China, the Chinese government might impose an import tariff on the shirt. The *bilateral domestic price of imports* (PMDS) is the *cif* price plus the import tariff. It is still a bilateral price because tariffs can differ by trade partner. For example, China may have higher tariffs on shirts imported from Vietnam than on shirts imported from Brazil. Let's assume that China has a \$1 tariff on Brazilian shirts, so that its bilateral domestic import price on shirts from Brazil is \$13.

Chinese consumers likely want to wear shirts imported from many other countries, in addition to Brazil. That is, China's imported shirts are a composite of shirts imported from many suppliers. In this case, the bilateral prices of imported shirts from Brazil and all other sources are combined into the trade-share weighted *composite domestic price of composite imports* (PMS). To keep our example simple, let's assume that Brazil is the only source of China's shirt imports. In that case, Brazil's trade weight is 100% and the composite import price is the same as the bilateral price of imports, at $13.

Many countries impose retail sales taxes on the sale of imported goods. These tax rates may differ by type of consumer, such as households or investors. After adding a retail tax to the composite domestic price of imports, the price paid by Chinese household consumers is the *composite consumer import price* (PPM). If households pay a sales tax of $1, then the composite consumer price of the imported shirt from Brazil is $14.

Some shirts sold in China are produced domestically. Table 2.5 describes the price linkages between China's domestic shirt producers and Chinese household consumers. Assume that the supply price for shirts in China is higher than in Brazil, at $10 per shirt. As in Brazil, China imposes output taxes on its shirt producers. If that tax is $2 per shirt, then the producer sales price of domestically produced shirts in China rises to $12. If Chinese consumers pay a retail sales tax of $3 per domestic shirt, the *consumer domestic price* (PD) of Chinese shirts increases to $15.

Finally, Chinese consumers buy a composite commodity – a "shirt" – that is an aggregation of shirts from domestic and all imported sources. The households' price in China for the composite shirt is a composite price, the *consumer market price* (PPA). It is a share-weighted average of the composite consumer price of imported shirts and the consumer price of domestic shirts. If imported and domestic shirts each account for 50% of the total value of Chinese shirt consumption, then the weights on each price are 50%, and the composite consumer price of the composite shirt commodity is $14.50.

For simplicity, we assumed that Brazil was the only supplier of Chinese shirt imports. However, there are typically many suppliers of the same imported product. Multi-country CGE models with bilateral trade flows report bilateral *fob* export and *cif* import prices for every commodity traded between every pair of trading partners in the model. Tracking bilateral export and import prices allows the modeler to take into account that export taxes, import tariffs, and trade margin costs may differ among trade partners.

Notice, too, that the price of the imported Brazilian shirt is lower in China than the price of a shirt made in China, yet Chinese consumers buy both shirt varieties. The price difference reveals something important about consumer preferences in a CGE model. A shirt from one country is not necessarily indistinguishable from a shirt from another country – consumers have preferences that cause them to differentiate shirts based on their country of origin. For example, Chinese consumers may think that shirts from Brazil are different than shirts from China – not necessarily better, but perhaps one is more suited for evening wear, and the other is more comfortable during hot weather. As a result, China may buy shirts from both Brazil and domestic producers even when Chinese shirts are more expensive than Brazilian shirts. There also can be two-way trade in the same product. For example, China may export shirts to Brazil at the same time that it is importing shirts from Brazil. We examine the important "Armington" assumption of product differentiation by country in more depth in our study of import demand in Chapter 4.

An important implication of the price structure and the supply-and-demand behavior in a CGE model is that *price transmission* is limited. That is, a $2 increase from $7 to $9 in the supply price of Brazilian shirts may translate into an increase of less than $2 in the consumer market price of shirts in China.

For example, let's assume that imports account for 50% of China's shirt consumption. Brazilian shirts account for a 50% of the imports, at a bilateral domestic price of imports of $5 and the United States accounts for the remaining 50% of China's import market, also at a price of $5. The domestic variety, which accounts for a 50% of China's consumption, is supplied at the consumer domestic price of $5. To simplify, we assume there are no trade margin costs, taxes, or tariffs.

The example in Table 2.6 illustrates the effect of a $2 price hike in Brazil's supply price on China's consumer market price, which increases by $1.06. Notice that in the new equilibrium, both the market shares and the prices from competing suppliers also change in response to the supply price increase in Brazil. Brazil's market share in China falls because Chinese consumers substitute toward the cheaper, competing domestic and US varieties. This shift in demand toward Chinese and US shirts causes their prices to increase.

One way to describe our result is that "about 50 percent of Brazil's producer price hike is transmitted to Chinese consumers." Another way is to calculate the *elasticity of price transmission*. This is defined as the percent change in one price for a given percent change in another price. In our example, the elasticity of price transmission is the percentage change in China's consumer market price of shirts from $5 to $6.06 (21%) relative to the percentage change in Brazil's producer price of shirts from $5 to $7 (40%): 21/40 = 0.53.

Table 2.6 *Calculating price transmission in a CGE model*

	Base values for market shares and prices	Updated values for market shares and prices
Bilateral domestic price of import – Brazil shirt (PMDS)	$5.00	$7.00
Bilateral domestic price of import – US shirt (PMDS)	$5.00	$6.00
Composite consumer import price (PPM)	.5 * $5 + .5 * $5 = $5.00	.3 * $7 + .7 * $6 = $6.30
Consumer domestic price (PPD)	$5.00	$6.00
Consumer market price (PPA)	.5 * $5 + .5 * $5 = $5.00	.2 * $6.30 + .8 * $6 = $6.06

The elasticity of price transmission is different from the other elasticities that we have studied in this chapter. Whereas those elasticities are fixed in value and govern the supply-and-demand behavior in the CGE model, this elasticity is a descriptive statistic that describes the results of a price shock in a CGE model. Such price transmission impacts are an important subject of CGE-based analyses, particularly for small countries that must adjust to external price shocks. In general, the transmission of a price shock in country A to country B is higher, the lower the values of the CGE model's elasticity parameters, the higher the share of country A in the imports of country B, and the lower are taxes and trade margin costs.[6]

Numeraire

A CGE model describes only relative prices. To express all prices in relative terms, the modeler chooses one price variable in the CGE model to remain fixed at its initial level. This price serves as the model's *numeraire*, a benchmark of value against which the changes in all other prices can be measured (see Text Box 2.4).

As an example, consider a model with three goods: agriculture, services, and manufacturing. The producer prices of manufactured goods and services could be measured in terms of – or relative to – the price of the agricultural good, which we have selected to be the numeraire. Initially, the producer prices of all three goods are $1 because they have been normalized. Let's assume that after a model shock, the producer price of the numeraire (agriculture) remains at $1 (it must because it is the numeraire), but the

[6] See Siddig and Grethe (2014) for a clear and systematic exposition of how elasticity parameters and trade shares in a CGE model are related to the size of international price transmission.

Text Box 2.4 The numeraire and Walras's law

Computable general equilibrium modelers can be more confident that their model has a feasible and unique solution if it is "square" – that is, if the number of variables and equations in the model are equal. When we fix one price to serve as the numeraire, we are dropping one variable from our model. Are we therefore causing the number of variables to be one fewer than the number of equations? The answer is no, and it rests on Walras's Law.

Leon Walras was a nineteenth-century economist who studied the interconnectedness among all markets in an economy. He focused in particular on the problem of whether a set of prices exists at which the quantity supplied is equal to the quantity demanded in every market simultaneously. His theoretical, general equilibrium model was much like the standard, "Walrasian" CGE model that we are studying. They share the features that: (1) producers are profit maximizers who sell their goods in perfectly competitive markets at zero economic profit; (2) consumers are utility maximizers who spend all of the income they receive from their production and sale of goods; and (3) prices adjust until demand for each commodity is equal to its supply. Based on these assumptions and market-clearing constraints, Walras's Law states that, for the economy as a whole, the aggregate value of excess supply in the economy must be matched by the aggregate value of excess demand. This is essentially because producers plan to sell that value of goods that will enable them to afford their desired purchases. A shortfall in their actual sales (excess supply) therefore results in an equal shortfall between their actual and desired consumption (excess demand).

An implication of Walras's law is that equilibrium in the last market follows from the supply-demand balance in all other markets. As a result, the equations in his model were not all independent. One equation was redundant and had to be dropped – but this meant his model had one more variable than the number of equations. Walras's solution was to fix one price in the model to serve as numeraire, making his model "square" once again. He could now solve for the market-clearing set of relative prices.

To make their models square, CGE modelers, too, usually drop one equation and fix one price variable to serve as numeraire. Any equation can be dropped without influencing results if the model is homogenous of degree zero in prices (as they usually are). In practice, modelers usually omit the macroeconomic market-clearing equation that defines aggregate savings (S) to be equal to aggregate investment (I). As an alternative, some modelers fix a numeraire but keep the redundant equation and add an additional variable called "Walras," that is, S = I + Walras. If all markets in the CGE model are in equilibrium, then the Walras variable's value will equal zero. Such a variable can be useful to the modeler as a way to check that all markets are in equilibrium in the base data and model solutions.

producer price of the manufactured good has doubled; the relative producer price of manufactures is now \$2/1 = 2.

Because the exchange ratios of all goods are specified relative to the numeraire, you can also compare the prices of nonnumeraire goods – in this case, the price of manufactured goods relative to services. Assume that the price of services increased only 20%; then its relative price in terms of agriculture is 1.20/1 = 1.20. The price of services (1.20) has fallen relative to manufacturing (2).

You can choose any price in the CGE model to be the numeraire. Your choice of numeraire has no impact on real, or quantity, variables that result from an experiment. Some modelers define the numeraire to be the consumer price index (CPI), which is calculated as the weighted sum of initial consumer prices, where the weights are each good's base budget share in the consumption basket. Other modelers select a producer price index or an index of the prices of domestically produced, nontraded goods. In the GTAP model, the default numeraire is an index of global wages and rents for labor, capital, and other factors.

Structure of a CGE Model

The programming code of a CGE model can be lengthy, so it is a common practice to organize it into a small number of blocks that accomplish different tasks.[7] Although this organization can vary among models, the structure of most CGE models and the steps required to run the model and an experiment are similar to those described in Figure 2.5.

A CGE model often opens with one or more blocks of code whose task is to introduce and define each of the sets, exogenous and endogenous variables, and exogenous parameters used in the model. The modeler must define each of these elements in the model code before the model can recognize and use them.

For example, model code may define an endogenous variable, the total export quantity of commodity *c*, as:

$$\text{QXW}_c = \text{total export quantity of commodity } c$$

Once the model code defines the variable QXW_c, all subsequent model code, such as equations, can recognize it. If an equation or other types of model

7 Models get more complex as their analytical capabilities are enhanced. Two examples of relatively simple CGE models are the Cameroon model developed by Condon et al. (1987), and the ERS/USDA model developed by Robinson et al. (1990). Both can be downloaded from the GAMS model library at www.gams.com. Students can run the models by downloading a demonstration version of GAMS software.

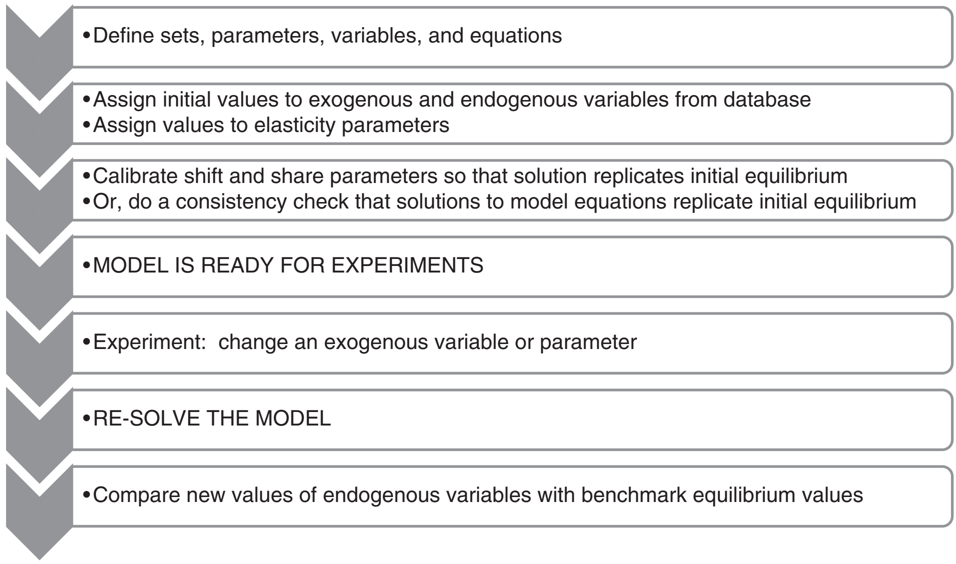


Figure 2.5 Structure of a CGE model and experiment

commands refer to a set, parameter, or variable that has not yet been defined, the model will fail to solve.

Next, a CGE model has programming code whose task is to assign initial values to variables from the model database and to define elasticity parameter values. For instance, now that QXW_c has been defined, values from the database can be assigned to its set elements, such as:

$$QXW_{\text{“Agriculture”}} = 552$$

Once sets, parameters, and variables have been defined, and values have been assigned, the model can be calibrated or a consistency check can be carried out. Results of the calibration or consistency check are the benchmark solution to the model that should exactly replicate the equilibrium described in the initial database. The CGE model equations are now numerical equations, similar to our bicycle model.

At this point, the modeler is ready to carry out an experiment. An experiment involves changing the value of at least one of the exogenous parameters or variables, such as the tax on agricultural exports. This change – a “shock” – is a controlled experiment in which the only change in the economy is the value of the exogenous parameter or variable, as specified in the experiment. The modeler resolves the model, which recalculates new equilibrium values for all endogenous variables. The new solution values for the endogenous variables are compared with the benchmark solution values. The resulting changes in variables’ values, such as a 5% decline in the quantity of exports compared to the base value, describe the effects of the economic shock on the economy.

Summary

In this chapter, we described the elements of standard CGE models, focusing only on their mechanics and leaving the study of their economic behavior for Chapters 4–9. For many students, this chapter can serve as a practical reference guide that you can return to as your modeling skills progress and questions arise.

CGE models of all types share many common features. They include behavioral equations that describe the behavior of producers and consumers, identity equations that describe accounting relationships and impose market-clearing constraints, and macroclosure rules that govern the savings and investment balance. Computable general equilibrium models follow the convention of normalizing prices so that the value data in the model database can be used to describe changes in both prices and quantities. Computable general equilibrium models report several prices for a single good because the models track prices at all points in the supply chain that links producers and consumers. All prices in the model are relative and expressed in terms of the numeraire. Computable general equilibrium models contain both linear and nonlinear equations; for small changes, nonlinear equations can be expressed in linearized form without loss of accuracy. In most CGE models, the program code first defines the names of the sets, endogenous and exogenous variables, and exogenous parameters used in its equations. Next, the model assigns numerical values from the database to all variables and defines elasticity parameter values. Blocks of equations then describe the model's economic behavior. The model is first calibrated or a consistency check is carried out. These procedures utilize model equations and the initial database to yield a model solution that replicates the initial base data. This solution becomes the benchmark equilibrium against which the results of experiments are compared.

Key Terms

Accounting equation
Behavioral equation
Calibration
Closure
Complement
Composite quantity
Composite price
Cost, insurance, freight (*cif*)
Elasticity, aggregate input substitution
Elasticity, commodity output transformation
Elasticity, commodity sourcing substitution

Elasticity, commodity substitution in consumer demand
Elasticity, export demand
Elasticity, export transformation
Elasticity, factor transformation (mobility)
Elasticity, factor substitution
Elasticity, import-domestic (Armington) substitution
Elasticity, import-import (Armington) substitution
Elasticity, income
Elasticity, intermediate input substitution
Elasticity, own price
Elasticity, price transmission
Endogenous variables
Exogenous parameters
Exogenous variables
Free on board (*fob*)
Identity equation
Law of demand
Linearized equation
Luxury good
Macroclosure
Market-clearing constraint
Necessity good
Nonlinear equation
Normal good
Normalized price
Numeraire
Price transmission
Set
Share parameter
Shift parameter
Tariff rate
Tax rate
Trade margin
Trade weight
Walras's Law

PRACTICE AND REVIEW

1. Assume a set of consumer goods *c* with three elements: agriculture, manufacturing, and services. If P is the consumer market price, use set notation to express these variables:

   Consumer market price for set *c*__________
   Consumer market price of manufactures________________

2. If QMS is the bilateral import quantity, define QMS (“AGR,” “USA,” “Brazil”): ______________________________
3. Review the role of supply elasticities in a demand shock.
   a. Draw a graph of the supply and demand for one good. Label the supply curve S^1 and the demand curve D^1. Label the axes and the initial equilibrium.
   b. Draw a second supply curve that shows the industry with a more elastic supply that has the same equilibrium as S^1 and D^1. Label the second supply curve S^2.
   c. Assume that an income tax cut increases disposable income and consumer demand. Draw a new demand curve, labeled D^2, and label the two new equilibria along S^1 and S^2.
   d. In no more than a paragraph, (1) explain the difference between the two market equilibria and (2) identify the elasticity parameters in a CGE model that can cause S^2 to be more elastic than S^1.

4. Review the role of demand elasticities in a supply shock.
   a. Draw a graph of supply and demand for one good. Label the supply curve S^1 and the demand curve D^1. Label the axes and the initial equilibrium.
   b. Draw a second demand curve that shows the consumer with a more elastic demand curve that has the same equilibrium as S^1 and D^1. Label it D^2.
   c. Assume a supply shock, such as favorable weather, that increases the supply of a good. Draw the new supply curve, labeled S^2, and label the two new equilibria along D^1 and D^2.
   d. In no more than a paragraph, (1) explain the difference between the two market equilibria and (2) identify the elasticity parameters in a CGE model that can cause D^2 to be more elastic than D^1.

5. Normalize prices.

   Assume that the apple sales quantity has increased by 50%. Calculate the percent change in the value of apple sales in the first row of Table 2.7. Next, normalize apple prices and quantities and calculate the percent change in value of sales. Demonstrate that this result is the same for both actual and normalized data.

Table 2.7 *Practice and review – normalizing prices and quantities of apples*

	Base values			50% Change in quantity			
	Price	Quantity	Value	Price	Quantity	Value	% Change in value
Actual	2	12		2	18		
Normalized	1			1			

Table 2.8 *Practice and review – calculating the US consumer composite import price (PPM) of corn*

	France	Germany	South Africa
Exporter's market share of US corn imports	50%	25%	25%
Exporter bilateral *fob* export price (PFOB)	$1.25	$0.85	$1.90
Trade margin	$0.25	$0.15	$0.10
US bilateral *cif* import price (PCIF)			
Tariff	$.50	$0.40	$0.10
Bilateral domestic price of import (PMDS)			
Trade-weighted domestic price of import (import share * PMDS)			
Domestic price of composite import (PMS) (sum of weighted PMDS's)			
Import sales tax for households	$0.12		
US composite import price (PPM)			

6. Calculate a consumer import price.
   Use the data in Table 2.8 to calculate the US consumer import price (PPM) for corn.
7. Calculate a price transmission elasticity.

   Assume that France's bilateral *fob* export price to the United States increases by 50% and causes a 10% increase in the US consumer import price of corn. What is the price transmission elasticity between the French and US prices?

3

The CGE Model Database

In this chapter, we describe the two components of the database of a computable general equilibrium (CGE) model. The first is the Social Accounting Matrix (SAM). The SAM database reports the value of all transactions in an economy during a period of time. The data are organized in a logical framework that provides a visual display of the transactions as a circular flow of national income and spending. The SAM's microeconomic data describe transactions made by each agent in a region's economy. When aggregated, the SAM's microdata describe the region's macroeconomy. The SAM's microdata can be used to calculate descriptive statistics on an economy's structure. We describe three extensions to a standard SAM: non-diagonal make matrices, domestic trade margins, and multi-region input-output tables. A CGE model database also includes elasticity parameters that describe the responsiveness of producers and consumers to changes in income and relative prices. The role of these parameters in driving model results can be evaluated in a sensitivity analysis.

The database of a computable general equilibrium model has two components. One is the *Social Accounting Matrix* (SAM). The SAM database reports the value of all transactions in an economy over a specified period of time, usually a year. The SAM data are organized in a logical framework of rows and columns that provides a visual display of the transactions as a circular flow of national income and spending in an economy. The SAM that we use throughout this book, for demonstration, describes the economy of the United States in 2007. The second component of a CGE model database provides the elasticity parameters that describe producer and consumer responsiveness to changes in prices and income.

Until relatively recently, development of a database for a CGE model represented a time-intensive first step in a CGE-based analysis. Today, most CGE-based research draws at least in part on a global database of country SAMs and elasticity parameters that was developed and is regularly updated by the Center for Global Trade Analysis (GTAP) at Purdue University. The GTAP Center relies on individual researchers to contribute country data. The data are drawn from multiple sources, including national income and product accounts, international trade databases such as the United Nation's

Comtrade, and other data sources that describe taxes, tariffs, and other government interventions. The GTAP Center integrates and balances the country data contributions into a unified and internally consistent global database. A researcher then aggregates the large global database into a smaller database that focuses more narrowly on the countries and commodities that are the subject of their research.

In this book, we have aggregated the GTAP database into the NUS333 version that we use for demonstration and model exercises. The NUS333 SAM that we study in this book has three production activities – agriculture, manufacturing, and services; three commodities – agriculture, manufacturing, and services; and three factors – land, labor, and capital. That is why we call it the NUS333 SAM.[1]

Introduction to the Social Accounting Matrix

The SAM is a logical arrangement of income and spending data that provides an easy-to-read, visual display of the linkages among *agents* in the economy. Agents typically include production activities (industries), factors of production (e.g., labor and capital), household consumers, the government, investors, and the rest-of-world (ROW) region, which supplies imports and demand exports.

A SAM is a square matrix of data (see Text Box 3.1). It is square because every economic agent in the economy has both a column account and a row account. The SAM's column accounts record each agent's spending. Row accounts record each agent's sources of income. Therefore, every cell in the

Text Box 3.1 Key features of a SAM

- A SAM is a square matrix because each agent has both a column and a row account.
- Column accounts record spending.
- Row accounts record income.
- Each cell in the SAM is simultaneously an expenditure by an agent and a source of income to an agent.
- For each agent, total expenditure (column account total) must equal total income (row account total).

[1] The N prefix denotes that the database is structured to be compatible with the GTAPv7 CGE model, GTAP's newly updated CGE model introduced in 2017.

Table 3.1 *A two-agent SAM*

	Farmer spending	Baker spending	Total income
Farmer income		Baker buys $1 wheat from farmer	Farmer income = $1
Baker income	Farmer buys $1 bread from baker		Baker income = $1
Total spending	Farmer spending = $1	Baker spending = $1	

SAM matrix describes a single transaction as being simultaneously an expenditure by an agent's column account and the receipt of income by an agent's row account. This procedure for recording transactions visually records how any single transaction links two agents in the economy.

Table 3.1 shows a simple example of the SAM accounting framework. There are two agents: a farmer and a baker. Each agent has both a row account and a column account. The farmer's expenditure of $1 on bread is reported in his column (expenditure) account, "Farmer spending," and his income of $1 from the sale of wheat to the baker is reported in his row (income) account, "Farmer income." The baker's expenditure of $1 on wheat is reported in the column account "Baker spending," and her income of $1 from the sale of bread to the farmer is reported in the row account, "Baker income." Note that the $1 the farmer spends on bread is simultaneously the $1 earned by the baker on the sale of bread. This single cell therefore reports both sides of the same transaction. Finally, the incomes of the farmer and the baker of $1 are equal to their expenditures of $1.

The SAM format enables the modeler to verify visually that its data are balanced. A SAM is balanced when every agent meets this constraint: Total spending (its column sum) equals total income (its row sum). For example, by comparing the baker's column sum with her row sum, you may easily verify that her income of $1 is equal to her expenditure of $1. When income is equal to spending in every account, then the economy's aggregate spending is equal to its aggregate income, and the database describes an economy in an initial equilibrium. A CGE model requires a balanced database as an initial starting point. As we will see in later chapters, model shocks will disturb this equilibrium. Prices, supply, and demand will then readjust until the economy is in a new equilibrium in which income again is equal to expenditure for all agents in the economy.

Accounts in a SAM

The SAMs used in CGE models usually contain more accounts than in our simple example of the transactions between the farmer and the baker. SAMs contain accounts that describe the supply and demand for all products and the incomes and spending of all agents in the model. Additional accounts describe income transfers among agents such as payments from governments directly to households. SAMs also include a financial account to describe the sources of national savings and composition of investment spending.

Throughout this book, we will study a SAM for the United States in 2007 (Appendix A Table). In this SAM, the circular flow begins with columns and rows that describe transactions related to US imports. It does not matter in which order accounts are presented in a SAM, although it is the convention that the ordering of row accounts is the same as that of columns. The accounts included in SAMs often differ across CGE models. They may differ in dimensions – that is, in their number of production activities, factors of production, or household types. For example, some SAMs may have accounts that divide an economy into two production activities, such as mining and nonmining industries, while other SAMs may have accounts for 400 or more industries. SAMs' accounts can differ, too, because the structure and theory of the CGE models in which they are used differ. A SAM and its CGE model must be consistent with each other. For example, one CGE model may include a regional household while another model does not. Their SAMs will differ in that case – one SAM will include row and column accounts for a regional household while the other will not. Note, too, that even when the accounts of two SAMs are identical, the location of data in their cells can differ. This point is particularly important for tax data. Taxes' cell locations describe the transactions in the CGE model on which each tax is assumed to be levied. For example, in some SAMs (and their related CGE model) an income tax may appear as an expenditure in the private household's spending column that is paid to the government row account. Other SAMs (and their CGE models) may describe income tax as a payment from the labor and capital column accounts.

Studying the accounts and the cell locations of data in your SAM is a good first step in learning about your CGE model. This study can help you identify both visually and intuitively the industries and agents in your model, their economic interrelationships, and the activities on which taxes are levied.

Table 3.2 presents a summary of the accounts typically found in SAMs. This summary, and the US SAM that we will study, are compatible with the GTAP CGE model, which we use for demonstration throughout this book. You can use the NUS333 SAM to follow along as we discuss each of the accounts in a SAM in detail.[2]

[2] In a few instances in this chapter, you will encounter "rounding errors." The GTAP database is expressed in millions of US dollars, with six decimal places, and SAMs' row sums exactly match their related column sums. To simplify our discussion in this chapter, we convert the US SAM to billions of US dollars, with zero decimal places. This inevitably introduces some rounding errors.

Table 3.2 *Accounts in a social accounting matrix with a regional household*

	Commodities						Final demand					
	Import	Domestic	Production activities	Factors	Taxes	Regional household	Private hhs	Govt.	Investment	Trade margins	Rest-of-world	Total
Imports			Demand for imported intermediates				Demand for imports	Demand for imports	Demand for imports			Aggregate demand
Domestic			Demand for domestic intermediates				Demand for domestic	Demand for domestic	Demand for domestic	Export of trade margins	Exports	
Production activities		Domestic production										Domestic sales
Factors of production			Factor payments									Factor income
Taxes	Import tariff	Export tax	Taxes on output, factor use, inputs	Income tax			Sales tax	Sales tax	Sales tax			Tax revenue
Regional household				Net factor income	Tax revenues							Aggregate income
Private household						Household income						Private household income
Government						Government income						Government income
Savings				Depreciation		Domestic savings				Foreign savings	Foreign savings	Savings
Trade margins	Trade margins on imports											Foreign exchange outflow
Rest-of-world	Imports											
Total	Aggregate supply		Gross domestic production	Factor expenditure	Tax expenditure	Aggregate expenditure	Private consumption expenditure	Govt consumption expenditure	Gross investment expenditure	Foreign exchange inflow		

Commodities

Many SAMs begin with commodity accounts. The commodity accounts describe the sources of supply from domestic production and imports.[3] For example, in the NUS333 SAM, the US supply of the commodity "agriculture" is the sum, or composite, of the imported agricultural variety plus the domestically produced variety of agricultural goods (see Appendix A Table). In 2007, the US imported $34 billion worth of agricultural goods and produced $326 billion worth of agricultural products (shown as the column totals of the imports and domestic commodity columns). The total supply of the agricultural commodity was worth $360 billion.

The commodity row accounts describe the demand side of the model. Production activities, households, government, and investors all demand commodities, and some share of domestic production is used to satisfy export demand. In the US SAM, for example, imported agricultural products are used as intermediate inputs into all three production activities. The US agricultural producers purchase $1 billion worth of imported agricultural goods. Manufacturers ($15 billion) and service producers ($5 billion) purchase additional agricultural imports for use in their production processes. About $13 billion worth of agricultural imports are sold to private households. Notice that the row total of the agricultural import account ($34 billion) is equal to the account's column total. In other words, import supply is equal to import demand in the agricultural import account.

Likewise, the commodity row account for domestic agriculture describes the economy's demand for this good. In total, $221 billion worth of domestically produced agricultural products are used as intermediate inputs into the agricultural, manufacturing, and services production activities ($35 + $165 + $21 = $221 billion). In addition, the domestically produced agricultural product is sold to private households ($53 billion) and some is exported ($52 billion). In this account, too, the column sum of $326 billion (total supply) equals the row sum of $326 billion (total demand) (except for rounding errors).

Each of the domestic customers may demand different proportions of the imported and domestic varieties in their commodity bundle. In the US SAM, for example, $15 billion of the imported variety and $165 billion of the domestically produced variety of the agricultural commodity (including sales taxes) are purchased by the manufacturing production activity. The import share in its use of agricultural inputs (including sales taxes) is $15 / 180 * 100 = 8.3\%$. Private households purchase $14 billion of the imported variety of agriculture and $55 billion of the domestically produced variety (including sales taxes). In this case, households import about 20% of their total agricultural consumption.

3 Lofgren et al. (2002) and Breisinger, Thomas, and Thurlow (2009) provide illustrations of SAMs that combine domestic and imported varieties into a single column and row for each product.

Production Activities

A *production activity* is a domestic industry engaged in the production of a good or service. The activity accounts in the SAM describe the supply side of the model. An activity's column account describes all of its expenditures on intermediate inputs, payments to factors (labor, capital, and other factors) and taxes paid in its production process. For example, the column account for the US agricultural activity records its purchases of imported and domestically produced intermediate inputs. Intermediate inputs might include agricultural goods such as seeds, manufactured inputs such as fertilizer, and services such as bookkeeping. The remaining inputs – the sum of factor payments and all tax expenditures – are called an industry's *value-added*. The column sum for an activity is the value of its *gross output*. Gross output is value added plus the costs of all intermediate inputs. In the US SAM for 2007, for example, the value of gross output by the agriculture production activity is $326 billion.

An activity's row account records where the industry sells its output. Production activities sell their output to the domestic commodity column accounts. You might think of the activity row accounts as the producers and the commodity column accounts as the wholesale packagers who purchase goods and services from domestic producers and combine them with imported varieties to create the composite commodities sold to consumers.

In many SAMs, including the NUS333, each good or service has both an activity account and a matching domestic commodity account. That is, if there is an agricultural production activity account, there is also a domestic agricultural commodity account to which the activity's output is sold in its entirety. Notice how this results in a diagonal matrix of the activity rows and the domestic commodity columns. This section of the SAM is called the "make" matrix. Its diagonal reports that the entire output of each activity is sold to its matching domestic commodity account, with zeros in the off-diagonals. The agriculture activity, for example, sells all of its output, worth $326 billion, to the domestic agricultural commodity account. This one-to-one correspondence, though common, is not necessary. Sometimes, the same commodity is produced by more than one activity, or one activity produces two or more different commodities. We discuss these two possibilities in more detail in this chapter's section on non-diagonal make matrices.

Factors of Production

Factors of production are the resource endowments of land, labor, and capital that are combined with intermediate inputs such as steel, rubber gaskets, and electronic components to produce goods and services. The factors in the NUS333 SAM are land, labor, and capital. Some modelers further subdivide these factor types. For example, labor may be divided into skilled and unskilled workers, or land divided into cropland and forest, or irrigated and nonirrigated land. You can visualize the disaggregation of factors in a SAM by imagining that there is a new factor column and a new, matching row account for each additional factor in the model.

The row account for each factor reports the income it receives from the production activities in which it is employed. Production activities pay wages to labor and rents to capital and land. In the US SAM, for example, the manufacturing production activity pays $1,361 billion in wages to its labor force and $649 billion in rents for capital equipment.

The factor column accounts report factor expenditure. In the US SAM, for example, the land column account reports that $3 billion of its income is spent on income taxes and $33 billion in after-tax land factor income flows to the regional household. The capital income account also reports payments to the income tax and regional household accounts, but, in addition, it records capital depreciation of $1,260 billion as an expenditure in the savings-investment row account. Depreciation is counted as a capital expense because it is the cost to firms of replacing the capital equipment that has worn out or become obsolete.

Taxes

The tax row accounts in a SAM describe the economic activities on which taxes are levied and the amount of tax revenue that is generated. For example, in the US SAM, production activities pay production taxes (from their column accounts) to the production tax row account. The agricultural production activity spends $1 billion on this tax. Some taxes are reported as negative values, which denote a subsidy. For example, US agricultural producers received a subsidy (i.e., a negative sales tax) of $1 billion on their purchase of domestic agricultural inputs in 2007. Tax row sums report the value of total revenue from each tax, which is paid in its entirety by the column account for each tax to the regional household account. In the US SAM, for example, production taxes generated a total of $581 billion in revenue and income taxes generated $2,039 billion in revenue in 2007.

Regional Household

The *regional household* is a macroeconomic account found in some SAMs and CGE models.[4] It is very similar to the concept of GDP from the income

[4] IMPLAN (2020), Breisinger, Thomas, and Thurlow (2009), Reinert and Roland-Holst (1997), and Pyatt and Round (1985) offer introductions to SAMs without a regional household account.

side and from the expenditure side.[5] Its row account describes the sources of aggregate national income from factor incomes and taxes, and its column account describes aggregate domestic spending by private households and government, and national savings. In the US SAM, for example, the regional household accrues net factor incomes (after deducting factor income taxes and capital depreciation) along its row account: $33 + $6,463 + $1,994 = $8,490 billion. It also earns tax income from import and export taxes, sales taxes, and factor use, production, and income taxes, for a total regional household income of $12,802 billion. The regional household column account shows how national income is allocated to spending by private households ($9,949 billion) and government ($2,258 billion) and to domestic savings ($594 billion, combining private and public savings).

Private Households

The *private household* row and column accounts describe the income and spending of all of the individuals in an economy, aggregated into a single, "representative" household. The private household row account receives a share of the national income from the regional household's column account. Households spend this income in its entirety on goods and services and related sales taxes, as described in the household's column account. Private household consumption is usually a large component of an economy's final demand for goods and services. In the US SAM, for example, households spend $9.9 billion, which far exceeds spending by government and investors.

Sometimes, SAMs (and their related CGE models) disaggregate the single household into several representative household types. They may be disaggregated according to criteria such as sources of income (perhaps one household type earns low-skilled wages and the other type earns high-skilled wages), or location (e.g., rural or urban), or expenditure patterns (e.g., high or low share of spending on food). Disaggregating households allows the modeler to analyze the distributional effects of an economic shock across different household types. For example, a new tax may benefit rural households but impose a burden on urban households.

You can visualize a SAM with many households by imagining that the single private household row and column accounts in the US SAM are disaggregated into *n* household row accounts and *n* household column

5 The regional household concept differs from GDP because it excludes depreciation, which is the cost in the current year of replacing capital that has been used up or worn out. Regional household income thus measures "net domestic product," which includes only new investment, net of depreciation, rather than gross domestic product, which includes gross investment spending on both replacement and new capital goods. For example, in the US SAM, GDP is $14,062 billion but regional household income is $12,802 billion because it excludes depreciation of $1,260 billion. Why is depreciation excluded? Investment spending to replace worn-out equipment does not add any new productive capacity to the economy.

Text Box 3.2 Disaggregated households and production regions in a SAM for Morocco

"Policy Options and Their Potential Effects on Moroccan Small Farmers and the Poor Facing Increased World Food Prices: A General Equilibrium Model Analysis" (Diao, Doukkali, and Yu, 2008).

What is the research question? World food prices have increased sharply over recent years and do not appear likely to return to the 2000–2003 levels. How will higher food prices affect different household types and production regions in Morocco, which is dependent on food imports for a large share of its domestic consumption?

What is the CGE model innovation? The authors modify the IFPRI standard CGE model to account for disaggregated households and production regions in the SAM. They construct a SAM for Morocco that divides the household account in the SAM into ten representative groups consistent with the income deciles of rural and urban households. They also disaggregate each agricultural production activity account into six agroecological regions, each using a different production technology to produce the same good.

What is the model experiment? World import and export prices of food are increased, based on price projections from the US Department of Agriculture. Three mitigating policy options are modeled: (1) import tariff reforms, (2) import subsidies to the poor, and (3) compensatory direct transfer payments (negative income taxes) to poor households.

What are the key findings? Direct transfers to poor consumers, combined with increased public investment in agriculture to improve productivity, is a win-win strategy for Morocco's agricultural producers and consumers.

accounts, each describing the different income sources and expenditure patterns of *n* household types. Text Box 3.2 describes a research project in which the CGE modelers take this approach, subdividing households by levels of income in a disaggregated SAM for Morocco.

Government

The government row and column accounts report government income and its expenditure on goods and services. In the US SAM, the government account receives $2,258 billion from the regional household and spends it almost exclusively on domestically produced services.

Savings-Investment

The savings and investment row and column accounts describe an economy's loanable funds market, showing the supply of savings that is available for investment and how these investable funds are spent. The row account reports the sources of a nation's savings. In the US SAM, the savings row account shows the accumulation of saving from domestic sources ($594 billion from private and public savings combined) and from foreign sources. Foreign savings ($773 + $58 = $831 billion) equals the trade balance in goods and services and in trade margin services. The row account also reports the *depreciation* of the existing capital stock ($1,260 billion), which is the investment spending by firms to replace the capital stock that is used up or worn out in the production process.

The investment column account records *gross national investment*, which is the combined spending on replacement of depreciated capital plus investment in new equipment and machinery that will be used in future production activities. The SAM reports the goods and services that the investors purchase, but not the destination of those investment goods. For example, the US SAM reports that investors purchased $294 billion of imported manufactured products, but we do not know whether this new equipment will be installed in agriculture, manufacturing, or the services sector. In the US SAM, gross investment spending totals $2,686 billion. Some of the new capital goods replace the depreciated capital, and the remainder ($2,686 – $1,260 = $1,426) is *net investment*, or the net increase in the US capital stock.

Trade Margins

The *trade margin* accounts describe the insurance and freight charges that are incurred when goods are shipped by air, sea, or overland from an exporting country to the importing country. These costs raise the price of imports relative to the price received by the exporters. The exporter's margin-exclusive price is called the free on board, or *fob price*. The importer's margin-inclusive price is called the *cif price* (cost, insurance, freight). The difference between the *cif* and *fob* values of imports is the trade margin.

In the SAM, there are trade margin accounts for both imports and exports. For imports, the trade margin row account records the freight and insurance costs incurred for each imported good. For example, the United States spends $5 billion on margin services to import $28 billion worth of agricultural products. It spends a total of $86 billion on trade margin costs on its imports. The exports trade margin column account reports the value of trade margin services produced by the United States and exported for use in global trade.[6] The United States exports $28 billion in margin services. Because trade margins are essentially the export and import of a type of service,

[6] Export margin data are not tracked bilaterally in the GTAP database from which our SAM is derived.

a country has a balance of trade in trade margin services. It is the value of trade margin exports minus trade margin imports and reported as a foreign capital inflow or outflow in the savings-investment row. The United States has a trade deficit in margin services, resulting in a foreign savings inflow of $58 billion ($86 – $28).

Rest-of-World

This account describes trade and investment flows between a country and the ROW. The ROW's row account in the SAM shows the home country's (in this case, the United States) foreign exchange outflow, which is its spending on each import valued in ROW's *fob* world export prices. The ROW column account reports the home country's foreign exchange inflow, or export sales of each commodity, valued in the home country's *fob* world export prices. The column account also records the balance of trade as a payment by, or inflow from, the ROW to the savings-investment account. This component of the balance of trade is the difference between the *fob* values of the home country's exports and imports. When the country runs a trade deficit (its imports exceed its exports), its foreign savings inflow is positive. In this case, the country is borrowing from abroad and the foreign savings inflow increases its supply of savings. When a country runs a trade surplus (the value of its exports exceeds the value of its imports), its foreign savings inflow is negative. In the US SAM, imports of goods and services worth $2,139 billion and exports of $1,367 billion result in a foreign savings inflow to the United States (a trade deficit) of $773 billion. The total US trade deficit is its combined deficits in trade margins and in goods and other services ($58 + $773 = $831 billion). When combined, it is the *fob* value of its exports minus the *cif* value of its imports.

Microeconomic Data in a SAM

A SAM database presents microeconomic data. Microeconomic data describe a nation's economic activity in detail. For example, the SAM's microeconomic data on production describe the amount spent by each industry on each type of intermediate and factor input, and each type of tax. Its data on household demand describe expenditure on each type of commodity by that agent in the economy. Microeconomic data on trade describe the commodity composition of imports and exports. Even when the modeler chooses to summarize an economy into a relatively small number of highly aggregated industries or factors, we still consider the SAM to be a presentation of microeconomic data.

Macroeconomic Data in a SAM

Macroeconomic data provide a summary description of a nation's economic activity. Some of the row sums and column sums of the SAM are macroeconomic indicators. For example, the column sum of the private household account reports an economy's total private consumption expenditure, and the row sum of the ROW account reports total imports of goods and services. We can also aggregate other microeconomic data in the SAM to calculate descriptive macroeconomic statistics, such as the gross domestic product (GDP). Developing macroeconomic indicators from the data in a SAM is a useful exercise because it illustrates how the macroeconomic behavior of an economy rests on the microeconomic behavior of firms and households. Text Box 3.3 provides an interesting example of a group of modelers who work in the opposite direction. In their research, they impose long-run growth projections for macroeconomic variables, such as the labor force, as an experiment, and then solve for the resulting microeconomic structure of the economy.

In the following examples, we use microeconomic data from the US SAM to calculate three important macroeconomic indicators: GDP from the income and expenditure sides and the savings-investment balance.

GDP from the Income Side

GDP from the income side reports the sources of total national income from (1) the wages and rents that production activities pay to the factors (e.g., labor and capital) that they employ (reported on a net, or after-income tax, basis), and (2) total tax revenues in the economy:

$$\text{GDP} = \text{net factor income} + \text{tax revenue}$$

We calculate this macroeconomic indicator using data from the US SAM's row accounts, which report income flows as follows:

Factor payments = 9,749 =
- Land factor payments: 36
- Labor factor payments: 47 + 1,361 + 6,797 = 8,205
- Capital factor payments: 53 + 649 + 2,846 = 3,548
- Minus income taxes: 3 + 1,742 + 294 = 2,039

Plus indirect taxes = 4,312 =
- Import tariffs: 1 + 23 = 24
- Export taxes: 3
- Sales taxes on imported variety: 1 + 59 + 0 = 60 (from sales tax row totals)
- Sales taxes on domestic variety: 1 + 204 + 58 = 263 (from sales tax row totals)
- Factor use taxes: – 1 + 1,232 + 112 = 1,343 (from factor use tax row totals)
- Production taxes: 1 + 70 + 511 = 581
- Income taxes: 3 + 1,742 + 294 = 2,039

Thus, US GDP from the income side is:

GDP = 9,749 + 4,312 = 14,062 billion (adjusted for rounding)

Text Box 3.3 Macroeconomic projections in a CGE model of China

"***China in 2005: Implications for the Rest of the World***" (Arndt et al., 1997).

What is the research question? In 1992, the Chinese economy was projected to triple in size over the next thirteen years. How will China's rapid growth affect its competing exporters in world trade and its import suppliers?

What is the CGE model innovation? The authors simulate the projected growth rates in macroeconomic variables (population, capital stock, and productivity) and analyze the resulting effects on the microeconomic composition of industry supply, demand, and trade in fifteen regions, including China, in the GTAP CGE model. The authors also carry out a systematic analysis of the sensitivity of their results to alternative values of import substitution elasticities, and they decompose welfare effects using the GTAP welfare decomposition utility.

What is the experiment? The experiment imposes cumulative projected growth rates of macroeconomic variables. The results describe the level and microeconomic structure of the fifteen economies in 2005. An alternative experiment assumes a lower growth rate of Chinese factor endowments that eliminates growth in its per capita GDP. The results of this alternative scenario for 2005 are deducted from those of the first scenario to identify the effects of China's rapid economic growth.

What are the key findings? Based on net-trade positions and likely changes in world prices, China's growth has an adverse impact on other developing countries. However, from a broader perspective that considers terms-of-trade benefits, efficiency gains, and factor endowment effects, China's growth benefits 12 of the other 14 regions in the model, a result that is robust to a wide distribution of assumed trade elasticity values.

GDP from the Expenditure Side

GDP from the expenditure side is a macroeconomic indicator that reports the allocation of national income across four aggregate categories of final demand: private household consumption expenditure, C, gross investment expenditure, I, government consumption expenditure, G, and net exports, E–M. You may recall this important equation, called the national income identity equation, from your macroeconomics studies:

$$GDP = C + I + G + (E - M)$$

We calculate GDP from the expenditure side using data from the US SAM's column accounts, which report expenditure flows:

$$C = \text{demand for commodities} + \text{sales taxes}$$
$$= \text{total private consumption expenditure}$$
$$C = (13 + 501 + 51 + 53 + 1,355 + 7,742) + (1 + 43 + 2 + 137 + 51)$$
$$= 9,949$$
$$G = \text{demand for commodities} = \text{total government consumption expenditure}$$
$$\text{(governments usually don't pay tax)}$$
$$G = 2,258$$
$$I = \text{demand for commodities} + \text{sales taxes} = \text{total investment expenditure}$$
$$I = (294 + 4 + 764 + 1,604) + (5 + 12 + 1) = 2,686$$
$$\text{(adjusted for rounding)}$$

The trade margin costs incurred in shipping goods to an importing country raises the costs of its imports. These margins are therefore included when calculating expenditures on imports. On the export side, a country's sale of the trade margin services used in global shipping is an export of a type of service, so, just like the export of any product, these sales are included in the value of its total exports. The GDP calculation excludes import tariffs and export taxes, however, because these are already embedded in the values of exports and imports reported in the final demand columns of the SAM.

$$E = \text{exports} + \text{exports of trade margins}$$
$$E = (52 + 970 + 345) + 28 = 1,395$$
$$M = \text{imports} + \text{trade margins on imports}$$
$$M = (28 + 1,797 + 315) + (5 + 81) = 2,226$$

Thus, US GDP from the expenditure side is:

$$GDP = 9,949 + 2,686 + 2,258 + (1,395 - 2,226) = 14,062 \text{ billion.}$$

Savings-Investment and the Balance of Trade

Recall from your macroeconomic coursework that by rearranging the expression for GDP from the expenditure side, we can derive this macroeconomic identity equation to describe the relationship between a nation's *domestic* savings, S_D, its investment spending net of depreciation, I_N, and its trade balance, E – M:

$$S_D - I_N = E - M$$

We can use data from the SAM to calculate the balance of trade and the savings-investment balance, and check that this relationship holds true in the US SAM, where:

$$S_D = \text{domestic savings} = 594, \text{ and}$$

$$I_N = \text{investment spending minus depreciation} = 2,686 - 1,260 = 1,426$$

and (E – M) is already known from our calculation of GDP from the expenditure side. Thus, we can verify that in our database, the gap between domestic savings and net investment equals the trade deficit:

$$(594 - 1,426) = (1,395 - 2,226) = -\$831 \text{ billion (adjusted for rounding).}$$

Structure Table

As a SAM's dimensions become larger, with an increased number of industries, factors, household types, or taxes, it becomes more challenging to fully understand or describe the complex economy that it depicts. (See Text Box 3.4.) One way to develop an overview of an economy without losing the detailed information available in the SAM is to construct a *structure table*. The table uses the microeconomic data in the SAM to describe the economy in terms of shares. For example, it reports the shares of each commodity in households' total consumption and the shares of each commodity in a country's total exports. Share data will enable you to make quick comparisons and to identify the most important features of the economy that you are studying. You are likely to find yourself often referring to your structure table as you define experiments and interpret your model results.

Table 3.3 presents an illustrative structure table constructed from the data in the US SAM. We can use the structure table to make observations like these about the US economy:

- The United States now has a service economy. Services account for 81% of GDP, 83% of labor employment, and 79% of household spending.
- US services is a relatively labor-intensive industry; labor accounts for a larger share (43%) of its production costs than in any other US industry.

Table 3.3 *Structure table for the United States in 2007*

	Industry GDP $US billion	Industry shares in GDP	Factor shares in industry costs			Industry shares in factor employment		
			Land	Labor	Capital	Land	Labor	Capital
Agriculture	136	1	11	16	16	100	1	1
Manufacturing	2,547	18	0	24	10	0	16	18
Services	11,379	81	0	43	16	0	83	80
Total	14,062	100	Na	na	na	100	100	100

	Commodity shares in:							
	Domestic demand				Trade		Import share of domestic consumption	Export share of domestic production
	Intermediate demand	Private household consumption	Government consumption	Investment demand	Imports	Exports		
Agriculture	19	1	0	0	2	4	11	16
Manufacturing	38	20	0	40	84	70	25	15
Services	44	79	100	60	14	27	2	2
Total	100	100	100	100	100	100	Na	na

Source: GTAP v8.1 database.

Text Box 3.4 Distributing national effects to the state level in a CGE model of the United States

"***Disaggregation of Results from a Detailed General Equilibrium Model of the US to the State Level***" (Dixon, Rimmer, and Tsigas, 2007).

What is the research question? The USAGE-ITC, developed at the US International Trade Commission, is a recursive dynamic CGE model descended from the Monash and ORANI models of Australia. It has more than 500 US industries and multiple US trade partners. However, US policymakers are often concerned with the impacts of national policies at the state level. Can an already large, national-level model be solved to also yield results for state-level variables?

What is the CGE model innovation? The authors develop a "top-down" approach to disaggregating national results to the state level. First, a static version of the CGE model is used to solve for variables at the national level, including employment, private and government consumption, trade, real GDP, and industry output and employment. Then, state-level results are computed using an "add-in" program. The program describes the impacts for each state as the change in the national-level variable plus a state-specific deviation term. This approach ensures that state-level impacts sum to the national level; however, the results at the state level do not feed back to affect national-level variables.

What is the model experiment? The authors test their approach using an illustrative experiment in which the United States removes all import tariffs and quotas.

What are the key findings? The authors focus on employment effects, concluding that differential employment impacts across states reflect not only the shares of industries in employment in each state but also states' proximities to ports and to other high- or low-growth states.

- The United States imports only 11% of its food supply and US households spend only 1% of their budget on food.
- Trade is relatively important to US manufacturing – imports account for 25% of total US consumption of manufactured goods, and exports account for 15% of manufacturing output.

You can follow the steps described in the following sections to construct a structure table for the country that you are studying. We demonstrate how each type of indicator is constructed, using data from the US SAM as an example, and we explain how each indicator can be useful as you begin to run model experiments and interpret your results.

Industry GDP

The GDP for production activity *a* is calculated from the SAM's activity and tax column accounts as follows:

Factor payments by *a* + taxes on factor use, output, sales, and trade of *a*

Using agriculture as an example, we can calculate the GDP for US agriculture from data in the US SAM as follows:

Agricultural factor payments = 36 + 47 + 53 = 136
Sales taxes paid by agricultural activity on imported inputs = 0
Sales taxes paid by agricultural activity on domestic inputs = –1 – 4 = –5
Factor use taxes in agriculture = –1 + 4 –2 = 1
Production tax on agricultural activity = 1
Import tariffs on agriculture = 1
Export taxes on agriculture = 0
Sales tax on final demand for imported and domestic agriculture = 1 + 2 = 3
Total agricultural GDP = 136 – 5 + 1 + 1 + 1 + 3 = 136 (adjusted for rounding).

Industry Share in GDP

The share of production activity *a* in total GDP is calculated as:

$$\text{industry } a\text{'s GDP/GDP} \ * \ 100.$$

The share of US agriculture in GDP is:

$$136/14,062 \ * 100 = 1.$$

Thus, agriculture accounts for only 1% of US GDP. The relative size of an industry in total GDP is among its most important economic characteristics. The larger its size relative to other industries, the greater is the impact of a shock in that industry on the rest of the economy. Given the small size of agriculture in the US economy, do you think that a policy shock, such as the removal of agricultural production subsidies, would have significant effects on the US economy as a whole? Probably not, although it may be a difficult shock to absorb for those engaged in agriculture.

Factor Shares in Industry Cost

Factor cost shares describe which factors are most important in an industry's total production costs. For example, capital equipment such as drills and pumps typically account for a far larger share of the input costs of the petroleum extraction industry than does labor. Factor cost shares are calculated for each factor *e* for each production activity *a* from data in the production activity column accounts. A factor's costs include the wages and rents that the producer pays directly to each factor plus factor use taxes such as Social Security, and total input costs are equal to the gross value of output:

$$(\text{factor payment plus factor use tax for factor } e \text{ in industry } a) / \text{ total input costs in industry } a * 100$$

As an example, we calculate the factor cost share for labor employed in the US manufacturing activity as follows:

$$\text{Labor cost share in mfg.}$$

$$= \text{labor payment plus labor use tax in mfg./total input costs in mfg.} * 100$$

$$(1,361 + 205) / 6,657 * 100 = 24$$

Thus, labor accounts for 24% of production costs in US manufacturing.

Factor cost shares in an industry matter when there are shocks that change the relative price or the productivity of a factor. For example, consider a production activity such as wearing apparel, which spends far more on wages than it does on capital equipment. If there is an increase in the labor supply that causes wages to fall, then the apparel industry's factor costs will fall by proportionately more than in the capital-intensive petroleum extraction industry, from our previous example. The apparel industry's proportionately larger factor cost savings are likely to lead to an increase in its output and in its size relative to the petroleum industry, depending on consumer demand.

Industry Shares in Factor Employment

Industry shares in factor employment describe where an economy's land, labor, and capital endowments are employed. The shares are calculated for factor *e* and industry *a* from the income data in the factor rows of the SAM:[7]

$$\text{Factor payment to factor } f \text{ in industry } a/\text{sum of factor payments to } e \text{ by all industries} * 100$$

Using data from the US SAM, we calculate industry employment shares for labor as:

Labor payment in agriculture / sum of activity payments to labor

$$47/(47 + 1,361 + 6,797) * 100 = 1$$

[7] Most CGE models include data on the value of factor payments or earnings, but not factor quantities, such as number of workers or acres of land. We can only infer industry shares in employment from income data if we assume that all farm acreage, workers, and capital equipment receive the same wages and rents across all industries. In this case, each dollar that any production activity pays to a factor buys the same factor quantity. This is the simplifying assumption made in many CGE models. However, wages and rents are often observed to differ across industries. Many doctors, for instance, earn more per hour than do programmers. In this case, two production activities may pay the same amount of wages and rents but employ different quantities of workers and equipment. Some CGE models account for wage or rent differentials across industries, but their databases must also include factor quantity data.

Labor payment in manufacturing / sum of activity payments to labor

$$1,361/(47 + 1,361 + 6,797) * 100 = 16 \text{ (with rounding)}$$

Labor payment in services / sum of activity payments to labor

$$6,797/(47 + 1,361 + 6,797) * 100 = 83$$

Most US labor is employed in services (83%) and just 1% is employed in agriculture.

Industry shares in factor employment are useful to know because the larger an industry's employment share, the larger the impact on the economy-wide wage and rent when there is a change in its production and factor demand. For example, with 83% of US labor employed in the service sector, a decline in the production of services would likely have a larger effect on national employment and wages than would a decline of similar proportion in agricultural output. Less employment in services could cause the average US wage to fall because the loss of even a small proportion of service jobs means that a relatively large share of the US workforce must look for new employment.

Commodity Shares in Domestic Demand

Firms, private households, government, and investors usually demand different types of goods and services. For instance, all households purchase food, whereas investors rarely buy food and instead purchase a lot of heavy machinery and equipment for use in factories and other businesses. The shares of each composite commodity c (which includes domestic and imported varieties) in total spending by each agent describe an economy's consumption patterns. Because sales taxes are part of the purchase price, the calculation of commodity shares also includes that tax.

Commodity shares for each agent and commodity are calculated from the spending data reported in the agents' columns in the SAM:

$$\text{Expenditure by agent } d \text{ on commodity } c \text{ plus sales taxes/total consumption expenditure by agent } d * 100$$

Using private household spending on the manufactured commodity and data from the US SAM as an example, the share of the manufactured commodity in total private household spending is calculated as follows:

$$(501 + 1,355 + 43 + 137)/9,949 * 100 = 20$$

When consumption patterns differ among agents, the same shock can affect each of them in different ways. For example, if the same sales tax is levied on all private-sector purchases of services, the impact on households will be proportionately greater than on investors, because households consume more services than do investors, as a share of their spending. Alternatively, taxes may be levied in a targeted way based on consumption shares. For example, a tax code may be designed to impose higher sales taxes on the types of goods that are purchased mainly by businesses, or by high-income households.

Commodity Shares in Exports and Imports

Commodity shares in the value of total exports and total imports describe the commodity composition of trade. The shares of each commodity *c* in total exports are calculated from data in the SAM's column accounts for export margins and the ROW. The export margins are included because margins are a type of service export. Export taxes are excluded because they are already embedded in the export value reported in the commodity row of the SAM:

$$\text{export of } c \;/\; \text{total commodity exports plus total margin exports} \; * \; 100$$

Using manufacturing as an example, and data from the US SAM, the share of manufacturing in total exports is as follows:

$$970 \;/\; (52 + 970 + 345 + 28) * 100 = 70$$

Thus, manufactured products account for 70% of total US exports of goods and services.

The share of each commodity *c* in the value of total imports is calculated using data from the column accounts of the imported variety of each commodity. The calculation uses the *cif* value of imports, which is the import value plus trade margins but excluding import tariffs:

$$\text{Import value plus trade margin on import of commodity } c \;/\; \text{total commodity imports plus total trade margins on imports} \; * \; 100$$

Using manufacturing in the United States as an example, its share in total US imports is:

$$(81 + 1{,}797) \;/\; (5 + 81 + 28 + 1{,}797 + 315) * 100 = 84$$

Import Share of Domestic Consumption

The share of imports in the total value of consumption of commodity *c* by firms, private households, government, and investors combined determines the strength of the linkage between events in world markets and domestic consumers. Consider the effect of an increase in world oil prices. Countries that depend on imports for a large share of their domestic petroleum consumption would experience a greater shock to their economy than would countries that import very little oil. Calculating import shares of consumption must take into account the sales taxes paid on both the imported and domestic varieties of commodity *c*.

The import share of consumption of commodity *c* is calculated as follows:

$$\text{Total domestic demand plus sales tax for the imported variety of } c \; / \; \text{total domestic demand plus sales taxes for imported plus domestic varieties of commodity } c * 100.$$

Using US manufacturing from the US SAM as an example, the import share in domestic consumption of the manufactured commodity is calculated from data in the commodity rows and sales tax rows:

$$\text{Total domestic demand for imports of mfgs.} = 1,117 + 544 + 299 = 1,960$$

where

Intermediate demand for mfg. import = (9 + 797 + 300) + (4 + 7) = 1,117
Private household demand for mfg. import = 501 + 43 = 544
Government demand for mfg. import = 0
Investment demand for mfg. import = 294 + 5 = 299

We leave it as an exercise for you to verify that the value of total domestic consumption of the manufactured commodity (imported plus domestic varieties) = 7,854. The import share of domestic consumption of manufactured goods is therefore:

$$1,960/7,854 * 100 = 25$$

Given a 25% share of imports in US consumption of manufacturing, what do you think would happen if a foreign export tax causes the price of manufactured imports by the United States to rise sharply? The effect will probably be significant (and negative), because imports constitute a large part of aggregate US demand for manufactures.

Export Share of Production

Similar to the case of imports, the share of exports in the total value of production of commodity good *c* determines the strength of the linkage between world markets and domestic producers. Because the revenue that producers get from export sales includes export taxes (or subsidies), the calculation of the export share of production also includes that payment. In our SAM, export taxes and subsidies are already embedded in the value of exports. Export margins are not included as a cost to exporters, since these freight and insurance charges are assumed to be paid by importers. The export share of production of each good or service is calculated from data in the domestic commodity row, and the ROW column in the SAM:

$$\text{Exports of good } c \text{ /activity output of } c * 100.$$

Using US agriculture as an example, we calculate the export share of production as:

$$52 / 326 * 100 = 16$$

Because US farmers export 16% of their output, how do you think they are likely to be affected by a real appreciation of the US dollar? Because exports represent a somewhat large share of US production, the impact is likely to be negative and rather important.

Extending the SAM: Non-diagonal Make Matrix

In most SAMs and their related CGE models, each production activity produces a single commodity. In our US SAM, for example, only the agricultural production activity supplies the domestic agricultural commodity; manufactured products are produced only by the manufacturing activity; and the services activity is the only supplier of services. But in real life, industries often produce more than one kind of commodity, or many production activities produce the same commodity. For example, beef ranchers can produce both meat and cowhides. And both farmers and the petroleum sector can produce the same commodity, energy, as biofuels and gasoline. To better represent these industry characteristics, modelers extend the standard one-to-one activity-commodity relationship and achieve a more realistic depiction of the structure of production using a *non-diagonal make matrix* in their SAM and their CGE model.

We first examine both the make and use matrices in our US SAM and then adapt our US SAM to illustrate the two cases of multi-activities and multi-products. Table 3.4 shows the parts of the US SAM that are of interest to us. On the left, the shaded area of the SAM is the "make" matrix. It shows the domestic commodities (in the column accounts) that are produced by production activities (in the row accounts). In our US SAM, with a one-to-one activity-commodity relationship, the total domestic output of each activity is reported along the diagonal of the make matrix, with zero values in the off-diagonal cells. Modelers describe SAMs and CGE models that have this one-to-one activity-commodity relationship as having a *diagonal make matrix*.

On the right side of the SAM, the shaded area is the "use" matrix. It shows the commodities (in the row accounts) that are consumed by the activities (in the column accounts) in their production process. (To simplify the table, we

Table 3.4 *Make and use matrices – with diagonal make matrix ($US millions)*

		Commodity – Domestic variety – "make" matrix			Production activity – "use" matrix		
		AGR	MFG	SER	AGR	MFG	SER
Commodity	Import AGR	-	-	-	**1**	**15**	**5**
	Import MFG	-	-	-	**9**	**797**	**300**
	Import SER	-	-	-	**1**	**22**	**236**
	Dom. AGR	-	-	-	**35**	**165**	**21**
	Dom. MFG	-	-	-	**62**	**2,007**	**1,502**
	Dom. SER	-	-	-	**86**	**1,329**	**4,821**
Activity	Activity-AGR	**326**	0	0	-	-	-
	Activity-MFG	0	**6,657**	0	-	-	-
	Activity-SER	0	0	**18,212**	-	-	-
Factor inputs/taxes		-	-	-	131	2,323	11,328
Total		326	6,657	18,212	326	6,657	18,212

Source: GTAP v8.1 database.

aggregate producers' expenditures on factor inputs and taxes into a single row.)

Table 3.5 illustrates how the make and use matrices appear when more than one production activity makes the same commodity. In this example, US agriculture is divided into organic and non-organic producers. The use matrix reports that organic farmers use a different mix of inputs than the non-organic farmers but both produce the same commodity, AGR. There are now four production activity column and row accounts, but only three commodity column and row accounts. The make matrix is therefore no longer diagonal. There are now two entries in the domestic AGR column account because more than one production activity produces the same commodity.

Table 3.6 illustrates how make and use matrices appear when one production activity makes more than one commodity. In this example, the AGR activity row now has two entries, in the Food and Feed commodity column accounts, because the AGR activity produces both commodities. There are still three production activity accounts but there are now four domestic commodity accounts so, once again, the make matrix is no longer diagonal.

SAMs with non-diagonal make matrices can only be used in CGE models that allow for this flexibility in the relationship between production activities and commodities. In this discussion, we describe only the data used in these models. In Chapter 5, we discuss how CGE models

Table 3.5 *Make and use matrices – more activities than commodities ($US millions)*

		Commodity – Domestic variety – "make" matrix			Production activity – "use" matrix			
		AGR	MFG	SER	Organic AGR	Non-org. AGR	MFG	SER
Commodity	Import AGR	-	-	-	**0**	**1**	**15**	**5**
	Import MFG	-	-	-	**3**	**6**	**797**	**300**
	Import SER	-	-	-	**0**	**1**	**22**	**236**
	Dom. AGR	-	-	-	**14**	**21**	**165**	**21**
	Dom. MFG	-	-	-	**19**	**43**	**2,007**	**1,502**
	Dom. SER	-	-	-	**36**	**40**	**1,329**	**4,821**
Activity.	Org. AGR	**100**	0	0	-	-	-	-
	Non-org. AGR	**226**	0	0	-	-	-	-
	MFG	0	**6,657**	0	-	-	-	-
	SER	0	0	**18,212**	-	-	-	-
Other inputs/taxes		-	-	-	29	102	2,323	11,328
Total		326	6,657	18,212	100	226	6,657	18,212

Source: Adapted from GTAP v8.1 database.

Table 3.6 *Make and use matrices – more commodities than activities ($US millions)*

		Commodity – Domestic variety – "make" matrix				Production activity – "use" matrix		
		AGR-Food	AGR-Feed	MFG	SER	AGR	MFG	SER
Commodity	Import Food	-	-	-		**0**	**5**	**1**
	Import Feed					**1**	**10**	**4**
	Import MFG	-	-	-		**9**	**797**	**300**
	Import SER	-	-	-		**1**	**22**	**236**
	Dom. Food					**25**	**165**	**21**
	Dom. Feed	-	-	-		**10**	**0**	**0**
	Dom. MFG	-	-	-		**62**	**2,007**	**1,502**
	Dom. SER	-	-	-		**86**	**1,329**	**4,821**
Activity	AGR	**300**	**26**	0	0	-	-	-
	MFG		0	**6,657**	0	-	-	-
	SER	0	0	0	**18,212**	-	-	-
Other inputs/taxes		-	-	-	0	131	2,323	11,328
Total		300	26	6,657	18,212	326	6,657	18,212

Source: Adapted from GTAP v8.1 database.

depict the economic behavior of producers in the case of a non-diagonal make matrix.

Extending the SAM: Domestic Trade Margins

The sale of domestically produced goods to the domestic market requires transportation to move the goods from the factory or farm to warehouses and retail shops and middlemen who provide the necessary wholesale and retail marketing services. Similarly, companies that export their products must transport their goods to the border and need middlemen to provide marketing services. The transfer of imported goods from the border to consumers also requires transport and marketing services. These transport, wholesale, and retail services are called domestic trade margins because they describe the costs of moving and selling goods within a country.

Many CGE models and their related SAMs treat domestic trade margins as a single good that is purchased in a bundle by consumers for final demand and by firms who purchase intermediate inputs. For example, retail consumers are assumed to buy items such as shoes, chairs, and oranges, valued at the producer price at the factory or farm, plus a single bundle of domestic margin services. The services are not identified with the purchase of any individual item, such as the domestic trade margin for shoes. Instead, the domestic margin bundle describes the consumer's total expenditure on these services for all of the commodities that they have purchased. Similarly, producers buy intermediate inputs valued in the SAM at producer prices, plus a single margin bundle that pays for the delivery of all inputs to the factory.

There are two main drawbacks to this bundling approach. First, if the price of a good in the consumer basket, such as shoes, increases, then consumers may buy more of the domestic margin bundle, even though the quantity demanded of shoes (and their associated requirements for margin services) falls. This occurs because goods in the consumer's basket are generally described in the model as substitutes for each other. As the price of one item increases, consumers substitute among the goods in their basket and buy less of the good whose relative price rose (shoes) and more of the good whose relative price fell (the margin services bundle).

The second drawback is that price transmission may not be described accurately. For example, let's assume that the cobbler charges $10 for a pair of shoes and the domestic margin cost is $2, so the retail consumer pays $12 in total. If the producer price rises by $1, then a model that does not account for the domestic trade margin on shoes will describe a 10% increase, from $10 to $11, in the consumer price. But, a model that accounts for the marketing margin on shoes will describe an 8.3% increase, from $12 to $13, in the consumer price. The different sizes of the price shocks will lead to different sizes of consumer response in the model.

A separate accounting of the margin services required for each product also allows modelers to explore the effects of a change in margin costs. For example, the advent of large retailers like Walmart has lowered trade margin costs and the retail prices paid by consumers. Efficiency gains that lower the cost of margin services can therefore lead to increased demand by consumers for the commodities.

We illustrate how domestic trade margins are incorporated into a SAM in Table 3.7, which presents a SAM in which the margins are identified by commodity. In the table, the three production activities and commodities differ from those in the US SAM because, to simplify, we combine the agriculture and manufacturing sectors into a single production activity and commodity, AGR/MFG, and we break a transportation activity and commodity out of the services sector. The transportation sector provides transport services that are used in domestic trade margins and by activities as an intermediate input and by consumers for transport needs such as air travel.

As in the NUS333 SAM, the production activities' column accounts describe the commodities used as inputs in their production processes, and their rows describe the sale of their output to the domestic commodity accounts. Let's assume that there is no trade, so there are no imported commodity accounts. The activities' column sums report gross output, valued in producer prices at the factory or farm gate, and their row sums report sales to the commodity accounts exclusive of trade margin costs.

Notice that we add new row and column accounts to the SAM, called "domestic trade margins." The domestic margin column account reports that the assembly of $15 worth of domestic margins requires $10 worth of transportation services and $5 worth of wholesale and retail services (which are produced by the "other services" sector) as inputs. The domestic margin row account reports the use of margin services by each commodity. For example, the sale of $30 worth of AGR/MFG requires $5 worth of trade margins to enable the product to reach buyers. Firms and final demand purchase $35 worth of AGR/MFG that is now valued in retail prices, and includes both the wholesale cost plus the cost of the domestic trade margins.

Our example describes only the domestic margins used to move goods from the domestic producer to the domestic consumer. The addition of domestic trade margins that are required to take exports from the producer to the border or to bring imports from the border to domestic consumers can

Table 3.7 *A SAM with domestic trade margin*

		Commodities			Production activities						
		AGR/ MFG.	Transport- ation	Other services	AGR/ MFG.	Transport- ation	Other services	Domestic trade margin	Factors	Final demand	Total
Commodities	AGR/MFG				20					15	35
	Transportation				5	25		10		5	45
	Other services					5	10	5			20
Activities	AGR/MFG	30									30
	Transportation		35								35
	Other services			20							20
Domestic trade margin		5	10								15
Factors					5	5	10				20
Final demand									20		20
Total		35	45	20	30	35	20	15	20	20	

be added by expanding the SAM's trade margin column and row into three columns and three rows – one each for margins on domestic sales, exports, and imports.

A SAM with domestic trade margins supports CGE models that account for domestic trade margins. In the SAM and the CGE model, producers receive payment for their output valued in producer prices. Consumers and firms purchase commodities valued in retail prices, with the explicit addition of the costs of trade margin services required for each commodity.

Extending the SAM: Multi-region Input-Output (MRIO)

In a standard CGE model, and its SAM, a country's imports are described as a bundle of bilateral imports that reaches its shore. The composite import (combined from all sources) is then allocated among production activities and categories of final demand (private, government, and investment consumption). Therefore, all agents in the importing country have the same import suppliers and face the same composite (trade-weighted) import tariffs.

As the world economy becomes increasingly integrated, more goods are being produced along global value chains (GVCs), in which successive stages of production are located across different countries. Firms engaging in GVCs import intermediate inputs and combine them with domestic inputs and factor services to produce final goods for domestic or export sale or to produce other intermediates for further processing along the chain. The growing importance of GVCs has led to an extension of the standard CGE model into a "supply chain" CGE model, in which production activities and each component of final demand directly import goods from bilateral trade partners, instead of dividing up the country's composite import bundle. Supply chain CGE models require extending the SAM to include a multi-region input-output (MRIO) table that reports bilateral exports by their end-use in the importing country – as an intermediate input used by a production activity, or in consumption by a category of final demand.

Several organizations now build and share MRIOs, which are used by both CGE modelers and in other types of analyses.[8] Some MRIOs are constructed by supplementing the data in a standard SAM with statistical concordances that map exported products to their end uses in the importing country. For example, the mapping may report that imported rice used as an intermediate input by food processors in Japan is mostly sourced from the United States, with a small share from Thailand, whereas most rice used for Japan's final demand is

[8] These organizations include the GTAP Center (Carrico et al., 2020), the World Input-Output Database (WIOD, 2020) and ImpactECON (Walmsley and Minor, 2016). The WIOD website provides a list of other organizations that have constructed MRIO databases.

sourced from Thailand, with a small share from the United States. Alternatively, some MRIOs are constructed using a proportionality assumption, in which firms and each type of final demand are simply assumed to have identical sourcing of imports, although they may have different ratios of imported to domestic goods in their input or consumption mix. For example, Canada may account for 75% of Brazil's total imports of wheat, with Mexico providing the remaining 25%. With a proportionality assumption, Brazil's firms, household consumers, government, and investors are all assumed to have the same 75/25 split in their sourcing of wheat imports. Therefore, they face the same initial trade-weighted composite import tariff from Canada and Mexico.

One implication of differences in import sourcing among domestic agents is that each of them may face a different composite import tariff if there are differences in bilateral import tariff rates. If Japan's tariffs differ on rice imported from the United States and Thailand, for example, then food processors and households will face a different composite (trade-weighted) tariff on imported rice. Furthermore, Japan may charge different import tariff rates on the same product from the same source, such as rice imported from the United States, depending on whether it is used by Japan's firms, households, or investors. Tariff rates may differ by end-user, too, if they buy different products within an aggregated category in the model. For example, consumers may buy more cheese and crackers that are aggregated within the NUS333 model's AGR commodity than do firms, which mostly buy coarse grains. If import sourcing, bilateral tariffs, products, and import demand behavior differ among end-users, then policies such as bilateral trade wars may affect each class of user differently.

Another reason for the growing interest in MRIO tables is to properly attribute the incidence of a shock's impacts if a change in demand for a final good in one country leads to changes in emissions, land use, or other outcomes in the regions from which it imports intermediate inputs. For example, assume that Belarus uses coal-based energy to produce intermediate inputs that are exported to France for their use in producing consumer products like toasters. It may appear that France has relatively low carbon emissions but, in fact, its consumer demand for a final good like toasters is linked to emissions in Belarus and in any other countries that emit pollution as they produce France's imported intermediates. To account for this, emissions from producing intermediate goods along a GVC could instead be attributed to the country that consumes the final product, and supply chain CGE models, which are capable of this accounting, can be used to analyze possible policy options. Text Box 3.5 describes an example of this type of analysis, using a supply-chain CGE model to track consumption-based emissions

Text Box 3.5 Tracing consumption-based carbon emissions in a supply-chain CGE model

"***National Policies for Global Emission Reductions: Effectiveness of Carbon Emission Reductions in International Supply Chains***" (Nabernegg, Bednar-Friedl, Muñoz, Titz, and Vogel, 2018).

What is the research question? National climate policies might be ineffective in reducing CO_2 emissions if the emissions are embodied in production along the international supply chains that serve domestic final demand. Could a CGE model that tracks CO_2 emissions embodied in domestic consumption help in the design of national climate policies that can be effective in reducing global emissions?

What is the CGE model innovation? The authors combine a CGE model with a MRIO model. The CGE model assesses the changes induced by national climate policies in terms of global supply, demand, prices, substitution effects, and carbon intensities across economic sectors. The MRIO model uses the results of the CGE model to calculate the consumption-based emission responsibilities along international supply chains and the change in global CO_2 emissions.

What is the model experiment? The authors analyze a set of policies in three industries with particularly high consumption-based emissions in Austria: building construction, public health, and transport. They simulate and compare the effects on emissions of a carbon tax, penalty fines, information requirements, mandated energy efficiency improvements, and incentives.

What are the key findings? The authors find that reducing global CO_2 emissions along the supply chain of domestic final demand is possible with domestic policy measures, but the relative effectiveness of different policies in reducing global emissions varies by industry.

that are embodied in Austria's final demand for imported and domestic products.

Table 3.8 illustrates a MRIO table in a simple example in which we assume that there are two countries (A, B) and two commodities (C1 and C2). We make the further simplifying assumptions that there are no taxes or transport costs in this small world. And, for convenience, there is a single final demand agent for each country that is the sum of the combined demand by households, government, and investors for final goods.

First, let's examine the similarities between the NUS333 SAM and the MRIO table. In the SAM, there is a column for each production activity that describes how the industry combines the composite import, and the domestic variety of each intermediate input with labor and capital to create its output. Likewise, in the MRIO table, there are columns that report the same information for country A's production of commodities C1 and C2. But, the MRIO table has additional

Table 3.8 *Example of a MRIO for two countries (A, B) and two commodities (C1, C2)*

	Production activities				Value added		Final demand			
	A	A	B	B	A	B	A	B	Total	Exports
	C1	C2	C1	C2						
A – C1	A's intermediate use of A's C1	A's intermediate use of A's C1	B's intermediate use of A's C1	B's intermediate use of A's C1	–	–	A's final demand for A's C1	B's final demand for A's C1	Total sales of A's C1	A's exports = Cols B-C1+ B-C2+B-FD
A – C2	A's intermediate use of A's C2	A's intermediate use of A's C2	B's intermediate use of A's C2	B's intermediate use of A's C2	–	–	A's final demand for A's C2	B's final demand for A's C2	Total sales of A's C2	A's exports = Cols. B-C1+ B-C2+B-FD
B – C1	A's intermediate use of B's C1	A's intermediate use of B's C1	B's intermediate use of B's C1	B's intermediate use of B's C1	–	–	A's final demand for B's C1	B's final demand for B's C1	Total sales of B's C1	B's exports = Cols. A-C1+ A-C2+A-FD
B – C2	A's intermediate use of B's C2	A's intermediate use of B's C2	B's intermediate use of B's C2	B's intermediate use of B's C2	–	–	A's final demand for B's C1	B's final demand for B's C2	Total sales of B's C2	B's exports = Cols. A-C1+ A-C2+A-FD
A – Value added	A's value added in C1	A's value added in C2	–	–	–	–	–	–	A's factor income	
B – Value added	–	–	B's value added in C1	B's value added in C2	–	–	–	–	B's factor income	

(*continued*)

A – Final demand	–	–	–	–	Factor income in A	–	–	–	A’s agent income
B – Final demand	–	–	–	–	–	Factor income in B	–	–	B’s agent income
Total	Gross output of A’s C1	Gross output of A’s C2	Gross output of B’s C1	Gross output of B’s C1	A’s factor payments	B’s factor payments	A’s final demand expenditure	B’s Final demand expenditure	
Imports	A’s interm. use = rows B-C1+B-C2	A’s interm. use = rows B-C1+B-C2	B’s interm. use = rows A-C1+A-C2	B’s interm. use = rows A-C1+A-C2			A’s FD use = rows B-C1+B-C2	B’s FD use = rows A-C1+A-C2	

Source: Adapted from Aslam et al., 2017.

production activity columns that report the inputs needed for B's production of C1 and C2. Notice that A's and B's input requirements in the activity columns specify the country from which the imported inputs were sourced, in their partner's activity rows. If we extended our MRIO to include a third country, X, then X would also have production activity columns and rows, and all three countries would report the import sourcing of their intermediate inputs.

As in the US SAM, A's value-added row reports factor payments by each production activity. In the MRIO table, a similar row reports B's factor payments by activity. For both A and B, the value-added columns report the combined income earned by all factor endowments, which is transferred to final demand (the regional household in the GTAP SAM). The final demand column of the SAM reports the expenditures on the final consumption bundle by households, government, and investors. In the MRIO table, two final demand columns report the same information for both A and B, but specify the sourcing of imported final products.

As in the SAM, trade flows remain balanced in the MRIO table, so that commodity exports by one region are equal to its partner's imports from that region. To illustrate this point, an import row and an export column are appended to the MRIO table. For example, A's export of C1 for use as an intermediate input in B's production of C1 is reported in row A-C1 and column B-C1. B's import of C1 from A for production of C1 is reported in the same cell. The total exports of A to B is calculated as the sum of the A-C1 and A-C2 rows in 3 B columns (intermediates and final demand), as shown in the export column. It is equal to the sum of B's imports of C1 and C2 from A for intermediate and final demand, as calculated in those 3 B columns in the import row of the MRIO table.

Updating the SAM

You may have noticed that the US SAM we use for demonstration describes the United States in 2007, and perhaps you consider it somewhat dated. A SAM database is often older than the data used in other kinds of economic analysis because of the lagged availability of data and the complex process of creating a balanced global database from multiple national and international sources of data. However, the age of a SAM is not necessarily important, because CGE models are primarily structural models. Their strength lies in describing the shares of activities in an economy, as we do in the US structure table, and in quantifying how an economy's structure changes in response to a shock.

However, there are at least two reasons why updating a SAM is warranted. One is to add better information on tax and subsidy policies to the database while minimizing any changes to the initial structure of the economy as it is described in the SAM. Tax and subsidy policies can be updated using approaches such as the GTAP model's Altertax utility (Malcolm, 1998). This utility "recalibrates" the model to the new tax rates by redefining the model closure and elasticity parameters so that changes in rates, introduced as an experiment, have minimal effects on the economy's initial economic structure or trade flows. The solution values become the new benchmark equilibrium that is used to run experiments.

The second reason to update the model is to describe structural changes that have occurred since the SAM was created, or that are expected to occur in the future, that will result in a changed economic environment for the shock that is under study. To describe changes in an economy's structure since the database was constructed, a modeler defines an experiment to introduce the source of the change, such as a productivity shock that reduces agricultural production. The results of the experiment describe a new, updated economic structure in which agriculture may have smaller shares in output, employment, and exports. This updated structure becomes the new benchmark equilibrium. The researcher can now run model experiments and compare results to the updated benchmark.

Modelers often use the second technique to project a SAM into the future. They define a *baseline scenario* as a model experiment that imposes macroeconomic projections of growth in a region's factor endowments, population, and real GDP or productivity. Growth in these variables then causes changes in economic structure. For example, consumers may have a high income elasticity of demand for services but a low income elasticity for food items. As their economy grows, the results of the baseline scenario describe how its structure will change. Services may account for a larger share of national output while the role of agriculture diminishes. Other baseline scenarios may also include future policy changes. For example, a researcher may want to study the effects of a country's entry into a free-trade agreement while taking into account other scheduled changes in tax policies that will influence its trade relations. In this case, the baseline scenario experiment introduces the scheduled tax changes.

After building a baseline scenario, a modeler defines a counterfactual experiment. For example, the baseline scenario may impose macro projections to describe an economy in 2025. A counterfactual experiment imposes the same macro projections with the addition of a shock, such as a new tax. A comparison of the results of the baseline and counterfactual experiments describes the effects of the new tax on a 2025 economy.

Text Box 3.6 presents an interesting example of the design of the baseline scenario for the World Bank Envisage CGE model. The scenario results describe a stylized pattern of exchange rate appreciation and structural change in developing countries. Model Exercises 9 and 10 demonstrate how to create a baseline scenario experiment.

Elasticities Database

A CGE model database includes elasticity parameters. Whereas a SAM presents a static picture of an economy's equilibrium at a point in time, the elasticity parameters help describe an economy's movement from one equilibrium to a new equilibrium following a shock. In Chapter 2, we studied 13 elasticity parameters. Not all CGE models include all of those elasticities. Your database will contain only those used in your model.

Some CGE modelers estimate their own elasticities specifically for their model and their policy question. More often, modelers choose the most appropriate parameter values for their model based on a careful review of relevant econometric studies that estimate supply-and-demand elasticities. What are important considerations when choosing elasticities for your model? Most of the CGE-based literature on elasticities has focused on the selection of import substitution elasticities. Our discussion, too, will focus on that elasticity, but keep in mind that many of these observations are also applicable to your selection of other elasticities.

Good rules of thumb for selecting your trade elasticities take into account recent innovations in their econometric estimation.[9] Early estimates of trade parameters were largely based on time series studies of the willingness of consumers to substitute imports for domestic goods. These import-domestic substitution (also called Armington) elasticity estimates were generally quite low – often about one. This means that a 1% increase in the ratio of the import price relative to the domestic price increases the quantity ratio of domestic to imported goods by 1%, for a given level of imports. Usually, the elasticities assumed for substitutability among suppliers of imports were roughly gauged to be twice the value of the estimated parameters, or about two.

There are a number of reasons why the estimated values for trade substitution elasticities are so unrealistically low. Many studies describe highly aggregated categories of commodities, such as "transport products," rather than studying individually the demand for planes, cars, trucks, and other transport modes. Recent empirical work has demonstrated that the more detailed the commodities, the higher the estimated

[9] This discussion draws on Hillberry and Hummels (2013), who provide a critical review of the evolution in parameter estimation and derive guidelines for CGE practitioners, and Hertel et al. (2004a).

Text Box 3.6 Baseline scenario in a stylized update of a CGE model database

"***Modeling the Global Economy – Forward-Looking Scenarios for Agriculture***" (van der Mensbrugghe, 2013).

What is the research question? The World Bank supports the Envisage model, a recursive dynamic CGE model used to analyze forward-looking questions about the economics of natural resources, commodities, and climate change. Its baseline scenario describes the future global economy over the 2005–2050 period in the absence of policy and other interventions that address climate change. What macroeconomic projections should be used to describe the baseline scenario?
What is the CGE model innovation? Using the neo-classical growth model as a framework, the author defines projected growth in factor supplies and productivity that replicate the "Samuelson-Belassa effect" in which the real exchange rate appreciates in developing countries experiencing high growth. The causal chain stems from a high productivity growth in manufacturing that raises wages and increases demand for nontraded services, such as restaurant meals. If productivity growth in services is assumed to be slower than in manufacturing, then the price of nontraded services increases relative to manufactured products, which is, in effect, a real exchange rate appreciation.
What is the model experiment? The baseline scenario experiment draws annual labor and population projections from the United Nations over the 2005–2050 period, and the CGE model solves for annual capital stock growth as a result of savings and depreciation. Services productivity growth is calibrated to reproduce projected per capita GDP growth rates by 2050, manufacturing productivity growth is 2% points higher than in services, and agricultural productivity growth is an average of 1% annually.
What are the key findings? A comparison of the baseline with a scenario that includes baseline projections plus climate change shocks describes the impact of climate change on the global economy in 2050. A key result is that world real GDP will be 0.7% lower in 2050 because of climate change.

import substitution elasticities. Estimates also typically exclude the role of quality. Because higher quality often leads to both higher prices and higher demand, importers may appear to be relatively price-insensitive. In addition, estimates may measure the short-term rigidities in markets that characterize consumer responses to transitory price variations rather than the larger market changes that occur over the long term when policies are adopted permanently.

Much of the new generation of trade elasticity estimates is based on cross-section or panel data, using econometric techniques and models that help correct some of the downward biases of conventional time series estimates.

These approaches generally estimate import-import substitutability among the foreign suppliers of an import rather than the import-domestic substitution parameter and have typically generated substantially higher estimates for these parameter values than the doubled values of the time series results. Hillberry and Russel find the median value of these import-import elasticities to be about five.

Rules of thumb, then, are to prefer elasticities from studies that employ cross-section or panel estimation techniques, whose commodity and country composition are relatively detailed and as closely related to your CGE analysis as possible, and whose parameter values tend to be longer term (and larger) rather than shorter term (and smaller).

Given the importance of the choice of parameter values in a CGE-based analysis and the inevitable uncertainty about their validity, many modelers carry out a *sensitivity analysis* of their model results to alternative sizes of elasticities. First, they run their model experiment with their assumed elasticity parameter. Next, they repeatedly change the values of one or more elasticities and rerun the experiment. They then compare the new experiment results with the results of the first experiment to determine whether their findings hold true across a reasonable range of elasticity values.

Summary

In this chapter, we described the SAM, a logical format used to organize and display CGE models' databases as a circular flow of income and spending in an economy. The SAM is a square matrix because each of its accounts is described by both a row, which records income, and a column, which describes spending. Each cell of the SAM describes a transaction simultaneously as an expenditure by a column account and as an income source to a row account. A SAM is balanced when the total income for each account (its row total) is equal to its total spending (its column total). A balanced SAM describes an economy in equilibrium. The accounts and the location of data in the cells of the matrix vary among SAMs because a SAM corresponds to the structure and theory of the CGE model in which it is used. Using a three-industry, three-factor SAM for the United States in 2007 as an example, we calculated macroeconomic indicators and developed a structure table. The structure table is a useful way to summarize the microeconomic data in the SAM and informs experiment design and the analysis of model results. We considered the reasons for updating the SAM and discussed the elasticities database and how to select elasticities.

Key Terms

Agent
Baseline scenario
cif (cost, insurance and freight) import price
Commodity
Depreciation
Diagonal make matrix
Domestic margin
Factors of production
Final demand
fob (free on board) export price
GDP from the expenditure side
GDP from the income side
Gross investment
Gross output
Intermediate input
Multi-region input-output (MRIO)
Net domestic product
Net investment
Non-diagonal make matrix
Private household
Production activity
Regional household
Savings
Sensitivity analysis
Social Accounting Matrix (SAM)
Structural model
Structure table
Trade margin
Value added

PRACTICE AND REVIEW

1. Using data from the US SAM (Appendix A table):
   a. What is the value of gross output of the manufacturing activity?
   b. What is the value added of the manufacturing activity?
   c. What is the GDP of the manufacturing activity?
   d. What is the total value of the intermediate inputs used in the production of manufacturing, excluding sales taxes?
   e. Verify that valued-added and intermediate costs sum to the gross output of manufacturing.

   f. What is the total labor cost in the services industry?
   g. What is the labor share of industry costs in services?
2. Using data from the commodity columns and rows for agriculture:
   a. What is the value of the imported supply of the agricultural variety (including import tariff and import margin)?
   b. What is the value of the supply from the domestic agricultural variety (including export taxes)?
   c. What is the total, or aggregate, supply of the agricultural commodity in the United States?
   d. What is the value of US agricultural exports (including export taxes)?
   e. What is the import share of private household agricultural consumption?
   f. What is the export share of agricultural production?
3. What are good rules of thumb for selecting the elasticities for your CGE model database?
4. Define a baseline scenario and explain how it can be used in a forward-looking analysis. Describe a study that you might carry out using a baseline scenario and a counterfactual experiment.
5. Table 3.9 presents a MRIO table. Using the data in the table, complete Table 3.10

Table 3.9 *Practice and review – a sample MRIO table*

	A C1	A C2	B C1	B C2	A Value added	B Value added	A Final demand	B Final demand	Total	Exports
A – C1	10	5	15	10			10	5	55	30
A – C2	15	5	15	5			5	5	50	25
B – C1	5	10	5	15			10	10	55	25
B – C2	5	10	5	10			15	15	60	30
A – Value added	20	20	–	–					40	
B – Value added	–		15	20					35	
A – Final demand	–		–		40				40	
B – Final demand	–		–			35			35	
Total	55	50	55	60	40	35	40	35	370	
Imports	10	20	30	15			25	10		

Table 3.10 *Practice and review – exercise in interpreting a MRIO table*

	Importer end-user			
	Intermediate use	Final demand	Total exports	Share of exports used as intermediate inputs by partner
A exports of C1				
A exports of C2				
B exports of C1				
B exports of C2				

4

Final Demand in a CGE Model

In this chapter, we describe final demand by domestic agents – private households, government, and investors – and by the export market. Data in the Social Accounting Matrix (SAM) describe agents' incomes and the commodity composition of their spending. The computable general equilibrium (CGE) model depicts demand by domestic agents as a three-stage decision. First, consumers decide on the quantities of each commodity in their consumption basket. Second, an "Armington" import aggregation function describes their choice between domestic and imported varieties of each commodity. In some CGE models, a third stage describes the sourcing of imports. We survey functional forms commonly used in CGE models to describe private household preferences. We also introduce the concept of "national welfare," which is the monetary value of changes in a nation's well-being following an economic shock.

The $1 trillion US government infrastructure stimulus plan, proposed during the Covid crisis, was designed to increase government spending in order to compensate for sharp declines in spending by private households and investors, and in export sales. These four categories of demand – private households, investment, government, and exports – constitute the demand side of an economy. They are called components of *final demand*, since the goods and services that are consumed are in their end use; they are not further combined or processed into other goods and services. An economy's structure can change when the categories of aggregate final demand change in relative size, because each type of final demand usually purchases different goods and services. For example, households purchase items like groceries and entertainment, whereas investors purchase mainly machinery and equipment, and governments mostly purchase services. The increased share of the government in US final demand as a result of the stimulus program will likely change the types of goods demanded in the US economy, at least in the short term.

In this chapter, we learn how the SAM's data describe each component of final demand. We then study how each final demand agent is assumed to behave in the CGE model. Our discussion in this chapter mostly focuses on commonalities among CGE models, including the concept of "commodities," the three-stage budgeting decision, and the measurement of national welfare. Computable general equilibrium models differ widely in their descriptions of private households' consumption behavior, making it difficult to characterize a "standard" CGE model in this respect. Thus, we survey four functional forms commonly used in CGE models to describe private households' preferences, and we explain the differences among these functions that are of practical importance to the modeler.

Final Demand Data in a SAM

Table 4.1 presents data on final demand from the US SAM. The table reproduces the column accounts (omitting the rows with zeros) that record expenditures by domestic consumers – which include private households, government, and investors – and by the rest of world.

Consumers demand commodities, such as "agriculture," which are composites of the domestic and imported varieties of goods. In the US SAM,

Table 4.1 *Final demand data in the US SAM ($US billions)*

	Private household	Government	Savings-investment	Trade margin export	Rest-of-world
Imports					
Agriculture	13	0	0	0	0
Manufacturing	501	0	294	0	0
Services	51	0	4	0	0
Domestic					
Agriculture	53	0	0	0	52
Manufacturing	1,355	0	764	0	970
Services	7,742	2,258	1,604	28	345
Sales taxes–imports					
Agriculture	1	0	0	0	0
Manufacturing	43	0	5	0	0
Services	0	0	0	0	0
Sales tax–domestic					
Agriculture	2	0	0	0	0
Manufacturing	137	0	12	0	0
Services	51	0	1	0	0
Savings–investment	0	0	0	58	773
Total	9,949	2,258	2,686	86	2,139

Source: GTAP v8.1 database.

consumers' column accounts separately record their spending on the imported and domestic variety of each of the three commodities (agriculture, manufacturing, and services). For example, US private households spend a total of $66 billion on the agricultural commodity, composed of $13 billion worth of imported agricultural goods and $53 billion of the domestic variety. Private households also spend $1 billion on retail sales taxes on the imported variety and $2 billion on retail sales taxes on the domestic variety. The total value of private household expenditure on all commodities, including sales taxes, is $9,949 billion. The column accounts for the US government and investors similarly report their total spending on commodities plus sales taxes.

The export trade margin's column account reports US exports of insurance and freight services used in global trade, worth $28 billion. Expenditures reported in the rest-of-world's column account report foreign purchases of US goods, worth $1,367 billion, which are valued in US *fob* export prices (i.e., excluding freight and insurance charges). Both of these column accounts include, in addition, payments to the savings-investment row account. The payments report the balance of trade in margin services and in other goods and services. A positive value indicates a foreign exchange inflow (a balance-of trade-deficit), and a negative value indicates a foreign exchange outflow (a balance-of-trade surplus). In the US SAM, the positive numbers signal that the United States has trade deficits in both trade margin services and in goods and services, which sum to $831 billion.

We can use the final demand data in the SAM to calculate *budget shares*. A budget share is the value share of a good in the consumer's total spending. For example, private households' spending on imported manufactured goods (including the sales tax) accounts for 5.5% of their total spending.

Income Data in a SAM

Computable general equilibrium models impose the constraint that spending on goods and services, taxes, and savings must equal income. You may recognize this model constraint from your microeconomic theory, in which spending is subject to a *budget constraint*. Indeed, you may recognize this constraint from managing your own finances, as you decide how to allocate your after-tax income to purchases and to savings. Because final demand is constrained by income in the CGE model, it is worthwhile also to examine the income data in a SAM.

Data in Table 4.2 report selected row accounts from the US SAM which describe income flows. Income originates from the employment of factors by production activities. The land factor, for example, earns a total of $36 billion, paid from the activity columns to the land factor row. Of this

Table 4.2 *Income flows in the US SAM ($US billions)*

	Total production activities	Land	Labor	Capital	Income tax	All other taxes	Trade balance	Regional household
Land	36							
Labor	8,205							
Capital	3,548							
Income tax		3	1,742	294				
All other taxes	1,994							
Regional household		33	6,463	1,994	2,039	2,273		
Private household								9,949
Government								2,258
Savings				1,260			831	594
Total	13,783	36	8,205	3,548	2,039	2,273	831	12,802

Note: The production activities column is the sum of the agriculture, manufacturing, and services activities columns in the US SAM. Column sums may have rounding errors.
Source: GTAP v8.1 database.

amount, the land column account reports that $3 billion is spent on land-based income taxes and the remaining, after-tax income of $33 billion is paid to the regional household's row account. Labor earnings of $8,205 billion are also divided between income taxes and payments to the regional household. Capital earnings of $3,548 billion are paid to income taxes and the regional household and, in addition, are expended on savings. This payment measures firms' replacement costs for depreciated capital equipment and machinery.

The regional household's row account shows its accumulation of $8,490 billion in after-tax factor income ($33 plus $6,463 plus $1,994 billion), income taxes ($2,039 billion), and all other taxes combined ($2,273 billion). National income, excluding depreciation, therefore totals $12,802 billion. National income is then allocated by the regional household's column account to the three categories of domestic spending: Private households receive (and spend) $9,949 billion, the government receives (and spends) $2,258 billion, and $594 billion is allocated to domestic savings (this includes combined household savings and government savings).[1] The savings row account describes the sources of investment funds, including depreciation spending,

[1] In the GTAP model that corresponds to this SAM, the allocation of regional household income is determined by a Cobb-Douglas regional utility function that allows the expenditure shares of private households, government, and savings in national income to change as the cost of private utility changes. When incomes rise, the cost of private utility increases so the expenditure share of private households falls while those of government and savings rise. In most CGE models without a regional household

domestic savings, and an inflow of $831 billion from foreign savers, due to the US balance-of-trade deficit.

Three-Stage Final Demand

In many CGE models, domestic consumers make their consumption decision in three stages, depicted in Figure 4.1. In the first stage, shown at the top level in the figure, they decide on the quantity of each *composite commodity* (imports plus domestic varieties) in their consumption basket, such as the amount of food and the number of books. Their choice depends on their subjective preferences. For example, consumers may prefer a large quantity of food relative to books. These preferences are described by a *utility function*, an equation that quantifies how much utility, or satisfaction, consumers derive from any given combination of consumption goods. Given their utility function, consumers select the basket of goods that generates the maximum achievable satisfaction given the prices of the goods and the consumers' budgets.

In the second stage, consumers minimize the cost of their commodity purchase by deciding on the shares of domestic and imported varieties that comprise each commodity. For example, once a consumer has decided on the quantity of food in her basket, she next decides on the amounts of the domestically produced or *composite import* of food that she prefers, given their relative prices. The composite import is the aggregated imports of food from all suppliers. This decision is governed by an *Armington import aggregation function*, named after the economist Paul Armington (1969), who developed this type of sourcing decision in an applied economic model.

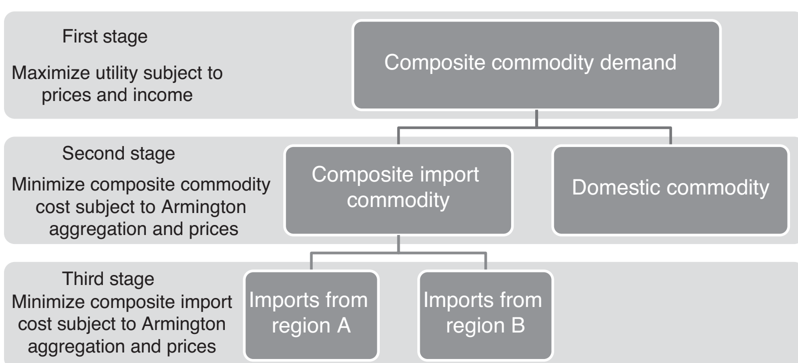


Figure 4.1 Three-stage final demand

account, private household income is equal to factor income and transfers, government income is equal to tax revenues net of transfers, and investment spending is equal to public and private savings.

Multi-country CGE models typically have a third stage that describes the lowest-cost sourcing from alternative suppliers for a given quantity of a composite import. In most standard CGE models, the import demand by each agent (firms, consumers, government, investors) are combined together, and the sourcing decision among import suppliers is carried out for the country as a whole. For example, after total food import demand is determined in the second stage, national demand is allocated across competing suppliers, such as Italy or Japan, to form the least-cost bundle of imported food. This additional stage in import demand is similar to that between the composite import and the domestic variety.

Most of our discussion in this chapter describes the utility-maximizing behavior of private households at the first stage of their consumption decision. We treat this stage of government and investment demand for commodities very briefly, since many CGE models describe their preferences in a simple fashion, by assuming that the initial budget shares in their consumption baskets remain fixed.[2] For example, if the government spends 10% of its budget on agricultural commodities, it will continue to spend 10% of any sized budget on agricultural commodities. Or, if agricultural prices rise by 10%, with income constant, the government will reduce the quantity of agricultural goods that it purchases so that the agricultural budget share remains constant. This simple specification of government spending reflects the view that economic theory does not fully explain government outlays. In the case of investment, the standard, one-period CGE model that we are studying does not account for intertemporal calculations or expectations about the future that influence today's investment decisions. Consequently, this fixed-share allocation rule for investment demand is a transparent approach that simply replicates the demand for capital goods observed in the model's base year and reported in the SAM.

Utility-Maximizing Private Households

Private households in CGE models are assumed to be utility maximizers who allocate their income across commodities based on their preferences and subject to their budget and commodity prices. Most CGE models describe the behavior of a representative household that aggregates all of the households in a region. (See Text Box 4.1 for a description of a pioneering CGE analysis with disaggregated households.) To illustrate their behavior, suppose that a household consumer has a total income of $12 (and does not save or pay taxes) that it allocates to purchasing two commodities: apples, Q_A,

[2] This is a Cobb-Douglas utility function. See Lofgren et al. (2002) for a discussion of alternative treatments of government and investment demand.

Text Box 4.1 A macro-micro CGE model of Indonesia

"Representative versus Real Households in the Macroeconomic Modeling of Inequality" (Bourguignon, Robilliard, and Robinson, 2003).

What is the research question? CGE models with disaggregated households contain two or more "representative" household types. These models can describe differences in the income effects of economic shocks across types of households but imply that households within each type are affected in the same way. However, household survey data show that changes in income inequality within each household type are at least as important as cross-type changes. Could a macro-micro analysis more realistically describe the effects of shocks on the distribution of income in a country?

What is the CGE model innovation? The authors combine the IFPRI standard CGE model with a micro-simulation model based on a survey sample of 9,800 households in Indonesia. They estimate reduced-form equations that explain households' work and occupational choices as a function of exogenous parameters such as wage, age, and education. The CGE model is solved for the effects of an economic shock on endogenous variables such as wages. These CGE model results are then used as the exogenous parameters in the equations of the micro-model to analyze impacts at the household level.

What is the model experiment? The authors explore two alternative macroeconomic shocks: a 50% decline in the world price of Indonesia's main commodity exports and a 30% decline in foreign savings inflows, similar to the effect of the 1998 financial crisis. Each CGE model scenario is run under three alternative government closures: the shares of government, investment, and private consumption in aggregate spending remain the same (suggesting a successful structural adjustment program); government spending adjusts to maintain the base government budget balance; and value-added taxes adjust to maintain the base government budget balance.

What are the key findings? The macro-micro model leads to distributional effects that are different in size, and sometimes even in sign, than a CGE model with representative households. The differences reflect that the macro-micro model accounts for phenomena that are known to be important in explaining household adjustments and resulting distributional changes, including changes in types of occupation, combinations of income sources, and differences in consumption behavior within household types.

with a price, P_A, of \$1, and oranges, Q_O, with a price, P_O, of \$2. Figure 4.2 describes the consumer's decision on how much of each product to buy. The downward-sloping straight line, Y, in the figure is the household's budget constraint. It shows all combinations of the two commodities that it can purchase for \$12. For example, points on this line include such combinations

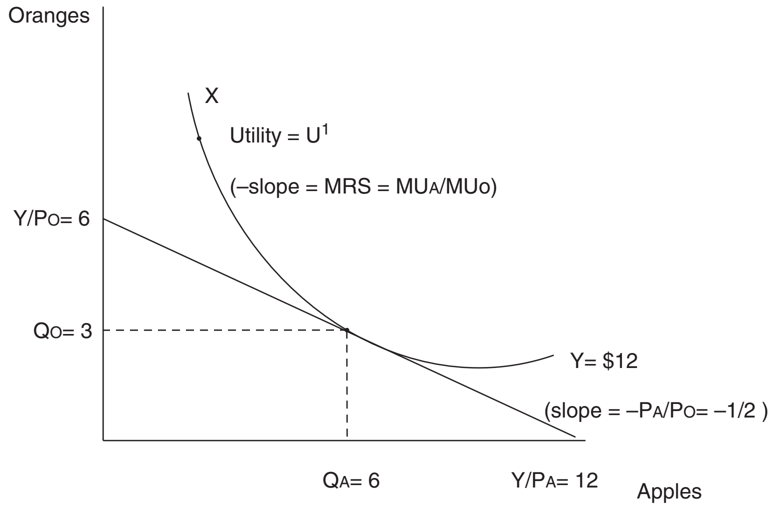


Figure 4.2 Consumer utility function with a budget constraint

as two apples ($2) plus five oranges ($10) for a total of $12; or ten apples ($10) plus one orange ($2) for a total of $12.

A budget constraint drawn to the right of Y represents expenditures greater than $12; a budget constraint drawn to its left represents expenditures of less than $12. A utility-maximizing household that earns $12 will always choose a basket of goods along its $12 budget constraint. More is always better, but the household cannot afford to reach higher budget lines, and at lower budget lines, it foregoes some achievable consumption. We observe this behavioral assumption of the CGE model in the model's SAM database in which, in the initial equilibrium, the income (the row total) for the household account is equal to its expenditure (the column total). This equivalence also will hold true in any post-shock model equilibrium.

If all income is spent on oranges, where Y meets the vertical axis, then quantity Y/P_A, or 12/2 = 6, oranges can be purchased. If all income is spent on apples, where Y meets the horizontal axis, then quantity Y/P_A, or 12/1 = 12, apples can be purchased. The slope of the budget constraint is calculated from the ratio of these two quantities (i.e., the rise over the run of the budget line) as –6/12 = –1/2. The sign is negative because the budget constraint is downward sloping; an increase in apples expenditure leads to a decrease in orange expenditure. Its slope can also be expressed as the price ratio of apples (the good on the horizontal axis) to oranges (the good on the vertical axis), since $-(Y/P_O)/(Y/P_A) = -P_A/P_O = -1/2$.

With so many feasible combinations that cost $12, the household's choice of apple and orange quantities depends on how it ranks its preferences for goods and services – that is, its utility function. We can plot this function on a graph as an *indifference curve*, such as U^1 in Figure 4.2. The indifference curve shows all possible combinations of apples and oranges that yield the same level of utility. Indifference curves drawn to the right of U^1 represent higher levels of utility while those drawn to its left represent lower levels of utility.

The slope of the indifference curve describes the consumer's willingness to substitute apples with oranges, or the *marginal rate of substitution* (MRS). Imagine, for example, that the consumer has ten oranges and only two apples at point X on the indifference curve. Based on his preferences, the consumer would be willing to forego two oranges as he moves down his indifference curve and consumes one more apple, so the MRS of oranges for one additional apple is two. As the consumer moves further down his indifference curve, and the quantity of apples consumed increases, he becomes more "apple satiated." His willingness to give up oranges in exchange for an additional apple diminishes and the MRS falls. We can also express the MRS as the ratio of the *marginal utility* of apples (i.e., the utility derived from consuming one more apple) to the marginal utility of oranges: MU_A/MU_O.[3] As more apples and fewer oranges are consumed, the marginal utility derived from eating yet one more apple falls, and the marginal utility derived from an additional orange increases as fewer oranges are consumed. The ratio MU_A/MU_O therefore falls as the consumer moves down his indifference curve.

Consumers maximize their utility by choosing the combination of apples and oranges that provides the highest attainable utility curve given their budget constraint. In Figure 4.2, this is shown as the tangency between the budget constraint Y and indifference curve U^1, where the consumer chooses three oranges ($6) and six apples ($6) at a total cost of $12. At this tangency, the slope of the budget constraint (the ratio of prices) and the slope of the indifference curve (the ratio of marginal utilities) are equal: $MU_A/MU_O = P_A/P_O$. Rearranging, $MU_A/P_A = MU_O/P_O$. This means that the consumer maximizes utility when the marginal utility per additional dollar spent on each good is equal. If not, the consumer will spend more on the good that yields a higher marginal utility and less on the other good until their marginal utilities are equalized.

In some CGE models, household consumers are assumed to be cost minimizers instead of utility maximizers. They allocate their purchases to achieve a given level of utility with the minimum possible expenditure at given prices. Imagine that, in Figure 4.2, the consumer seeks the lowest

3 The MRS is equivalent to the ratio of marginal utilities (MU_A/MU_O) because, if d refers to a marginal change, then the slope at any point on the indifference curve is –dQO/dQA, which is the rise over the run. The marginal utility of A is dU/dQA and of O is dU/dQO, so the ratio MU_A/MU_O = (dU/dQA) / (dU/dQO) = dQO/dQA, which is the negative of the slope of the indifference curve, or the MRS.

attainable budget line with the slope $-P_A/P_O = -1/2$, while constrained to remain on the U^1 indifference curve. It should be evident that utility maximization and cost minimization are equivalent ways to describe consumer choice and will yield the same ratios of demand quantities for a given level of utility.

Demand Response to Income Changes

Economic shocks in static CGE models usually lead to changes in income and in relative prices. Consumers respond by changing the quantities of goods and services that they purchase. We first consider the effect of income changes on quantities demanded. The indifference curve U^1 in Figure 4.3a describes the household's preferences for combinations of apples and oranges. The initial equilibrium is at the tangency of the budget constraint and the U^1 indifference curve, at quantities $Q_O{}^1$ and $Q_A{}^1$. An increase in income, holding relative prices fixed, shifts the budget constraint outward. It shifts outward in a parallel fashion, since the price ratio of oranges and apples has not changed. An increase in income allows the consumer to increase his purchases of both goods to quantities $Q_O{}^2$ and $Q_A{}^2$, and therefore to achieve a higher level of utility, U^2. An additional increase in income shifts the budget constraint out further, enabling the consumer to increase the quantities purchased and to achieve utility of U^3. Notice that Figure 4.3a describes a utility function in which income growth causes the quantity demanded of both goods to increase by the same proportion. For example, a 10% increase in income, holding prices constant, would result in a 10% increase in demand for both oranges and apples. This is a *homothetic* utility function with income elasticities of demand for goods equal to one. As income grows, with

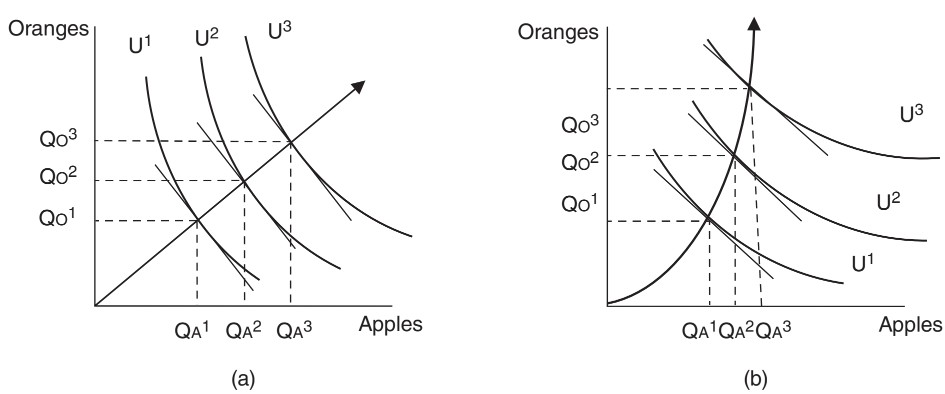


Figure 4.3 (a) Effects of income growth on consumer demand – homothetic utility function. (b) Effects of income growth on consumer demand – nonhomothetic utility function

constant prices an expansion path plots the locus of tangencies between the budget constraint and a mapping of successively higher indifference along a straight line emanating from the origin. Many CGE models assume homothetic utility functions.

Some CGE models assume *nonhomothetic* utility functions, such as that drawn in Figure 4.3b. Nonhomothetic functions allow income elasticities of demand to differ from one. Some goods may be *luxuries*, with income elasticities greater than one; others may be *necessities* with income elasticities less than one. If oranges are a luxury and apples are a necessity, then income growth, with constant prices, will lead to an increase in the ratio of oranges to apples in the consumption basket. In this case, the expansion path veers toward oranges as income grows.

Demand Response to Relative Price Changes

Economic shocks in standard CGE models usually lead to larger changes in relative prices than in income, so it is worthwhile to examine carefully how demand quantities are assumed to respond to price shocks in these models. A key determinant is the *elasticity of commodity substitution* in consumption, denoted by parameter $\sigma^P_{c,n}$. The elasticity expresses the percentage change in the quantity ratio of good C to good N given a percentage change in the price ratio of good N to good C. Returning to our example of apples and oranges, the larger is the elasticity of commodity substitution, the more willing is the consumer to shift to apples from oranges as the relative price of apples falls.

Parameter $\sigma^P_{c,n}$ describes the curvature of the indifference curve. When the parameter value is small, then the indifference curve is sharply convex, as in Figure 4.4a. In this case, an outward rotation of the budget constraint, as the price of apples falls relative to oranges, causes a relatively small change in the consumption basket, from $Q_O{}^1$ and $Q_A{}^1$ to $Q_O{}^2$ and $Q_A{}^2$, respectively. Intuitively, the greater the curvature of the indifference curve, the faster the ratio of the marginal utility from an additional apple relative to that of an additional orange (MRS) falls as the ratio of apple to orange consumption rises. Therefore, the consumer is not very willing to give up oranges for an additional apple when the relative price of apples falls. When the parameter value is large, then the indifference curve is flatter, as in Figure 4.4b. The consumer will readily trade off oranges for an additional apple, with small effects on the fruits' relative marginal utilities. Therefore, the same decline in the relative price of apples will lead to a larger increase in the ratio of apples to oranges in the consumer's basket.

Sometimes, consumer preferences are quite rigid – for example, consumers usually buy right and left gloves in pairs. A fall in the price of right-hand gloves will not change the ratio in which gloves are purchased, since

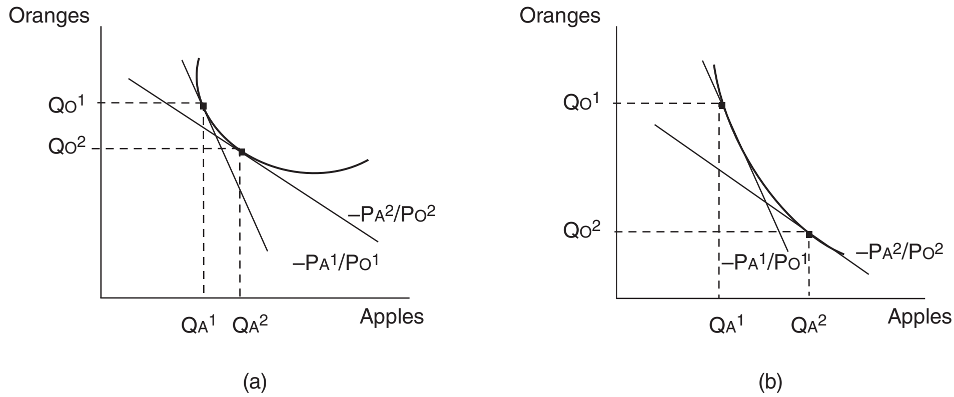


Figure 4.4 (a) Effects of price change on consumer demand, low substitution elasticity. (b) Effects of price change on consumer demand, high substitution elasticity

most consumers require right- and left-handed gloves in a fixed proportion. Such preferences are described by a Leontief utility function, whose elasticity of substitution is zero and whose indifference curve has an L-shape. Other consumers may be completely flexible in their preferences; for example, any brand of bottled water is equally satisfactory. If a consumer is always willing to trade off the same quantity of one good for the other, then the MRS between the products is constant. Because the goods are perfect substitutes, the elasticity of substitution approaches infinity and the indifference curve is drawn as a straight line.

We can decompose the effect of a price change on demand quantities into two components. First, if we assume that the own-price elasticity is negative, then the price change will cause consumers to shift the composition of their basket toward the cheaper good at any given level of utility. This is the substitution effect of a price change. It describes the movement of a consumer along the initial indifference curve as the relative prices change, holding utility constant. Figure 4.5a illustrates the substitution effect of a price shock. In this example, the consumer initially purchases an orange quantity of Q_O^1 and an apple quantity of Q_A^1, at the U^1 level of utility. Suppose the price of apples falls to P_O/P_A^2, but the consumer is constrained to remain at the same U^1 level of utility. The dotted line, drawn parallel to the new price line, is the new price ratio. The substitution effect is the movement of the consumer along the initial indifference curve to the new basket of Q_O^2 and Q_A^2.

The second component is the effect of a price change on the consumer's purchasing power. If the price of apples falls, consumers now have money left over from purchasing their original basket. They can allocate this

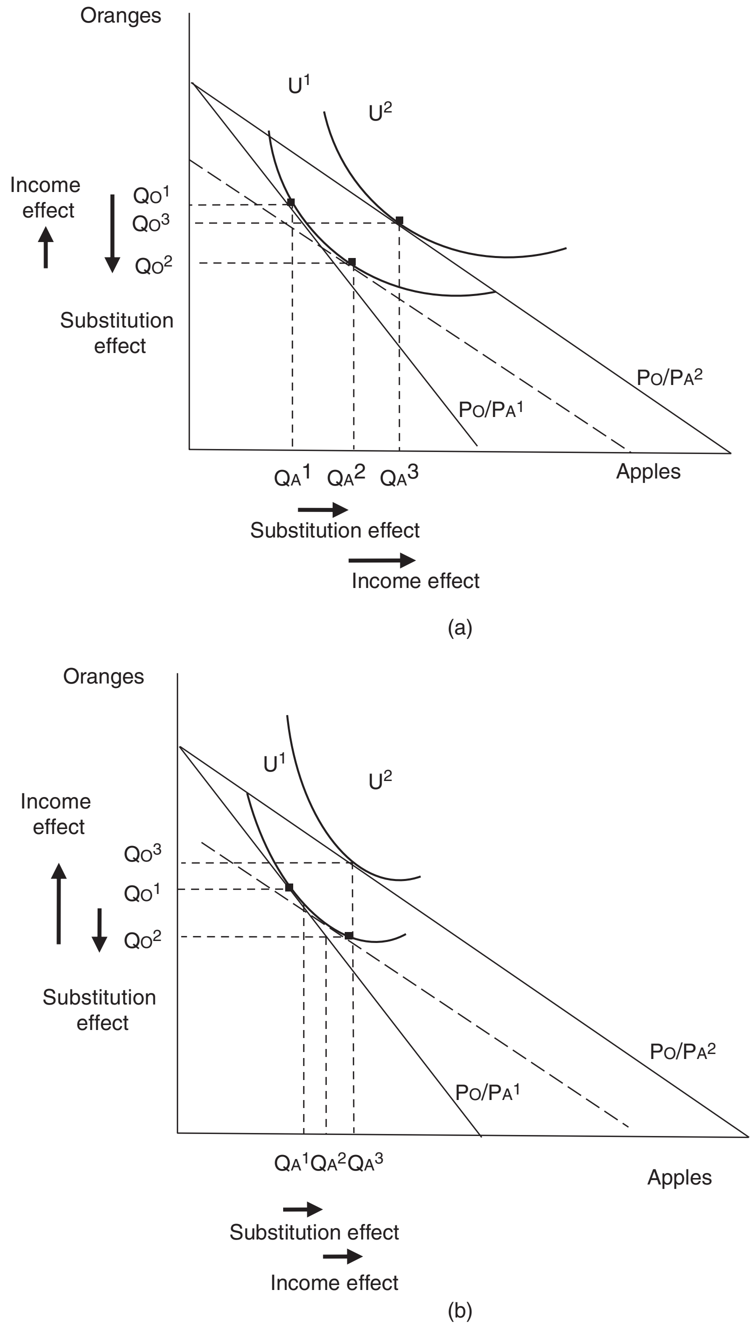


Figure 4.5 (a) Effects of price change on consumer demand – net and gross substitutes. (b) Effects of price change on consumer demand – net substitutes and gross complements

additional purchasing power toward buying more apples, more oranges, or more of both. The income effect of a price change measures the effect of the change in purchasing power on the consumption basket, holding relative prices constant. In Figure 4.5a, the income effect is the change from $Q_O{}^2$ and $Q_A{}^2$ to $Q_O{}^3$ and $Q_A{}^3$, respectively, at the new price ratio of $P_O/P_A{}^2$.

By decomposing the income and substitution effects of a price change, we can describe apples and oranges as *net substitutes* (measuring only the substitution effect) and *gross substitutes* or *gross complements* (measuring the combined substitution and income effects). Two goods are net substitutes when a fall in the price ratio of good X to good Y causes an increase in the quantity ratio of good X to good Y, holding utility constant (i.e., remaining on the initial indifference curve). In our example as shown in Figure 4.5a, apples and oranges are net substitutes, because the fall in the relative price of apples causes the ratio of apples to oranges to increase, holding utility constant. Computable general equilibrium models typically assume that goods are net substitutes in consumption.

Two goods are gross substitutes if a decline in the price of one good causes demand for the second good to fall, and gross complements if demand for the second good rises. In Figure 4.5a, apples and oranges are gross substitutes. Although the income effect leads to increased demand for both fruits, the substitution effect dominates the income effect and causes the quantity of oranges demanded to fall when the price of apples declines. Figure 4.5b describes the case of gross complements. Oranges and apples are still net substitutes, but now the income effect dominates the substitution effect on oranges, so the quantity of oranges demanded increases when the price of apples falls. Gross complementarity is more likely to occur when the price change affects a good that is important in the consumer's total expenditure, so that purchasing power changes substantially; when income elasticities are large; or when the substitution effect is small because the indifference curve is very convex.

Comparing Utility Functions Used in CGE Models

Our discussion of income and prices effects has emphasized how assumptions about consumer preferences, as described by utility functions and depicted in the curvature of indifference curves, determine how consumer demand responds to changes in income or in prices. Computable general equilibrium modelers therefore try to choose utility functions and elasticity parameter values that best describe consumer preferences in the economy that they are studying. Sometimes a modeler may need to trade off some degree of realism for feasibility when describing consumer demand. This is particularly true of modelers who want to use a standard CGE model and the utility function or demand system that it assumes, without extending the model's theory or programming. Flexibility to specify demand elasticity parameter values varies, too, since in some utility functions, these values are a "hard-wired" part of the functional form or constrained in the CGE model. For these reasons, it is useful for modelers to study the functional forms commonly used to describe consumer preferences in CGE models and to understand the practical implications for their model results.

We compare four functions that are widely used in standard CGE models: the *Cobb-Douglas*, *Stone-Geary/Linear Expenditure System (LES)*, *Constant Elasticity of Substitution (CES)* utility functions, and the *Constant Difference of Elasticities (CDE)* demand system (Table 4.3).

The simplest (but most restrictive) is the *Cobb-Douglas utility function*. The function itself implies values for elasticity parameters that the modeler cannot change. For all goods, the Cobb-Douglas own-price elasticity is –1, and the elasticities of substitution and income are 1. A unitary, negative own-price elasticity means that a change in price leads to an opposite change in quantity of an equal proportion. For example, a 10% increase in the apple

Table 4.3 *A comparison of functional forms that describe consumer preferences in CGE models*

	Elasticity			Budget shares	
Utility function	Income	Own-price	Substitution	Price change	Income change
Cobb-Douglas	Homothetic	Negative own-price	Independent	Fixed	Fixed
Stone-Geary/ Linear Expenditure System (LES)	Quasi-homothetic	Negative own-price	Net substitutes, gross complements	Flexible	Flexible
Constant Elasticity of Substitution (CES)	Homothetic	Negative own-price	Net and gross substitutes	Flexible	Fixed
Constant Difference of Elasticities (CDE)	Nonhomothetic	Negative own-price	Net substitutes, gross substitutes or complements	Flexible	Flexible

Notes: We assume that the Frisch parameter in the Stone-Geary utility function is greater than –1, and the elasticity of substitution parameter in the CES utility function is greater than zero. See Technical Appendix 4.1 on parameter value restrictions.

price leads to a 10% reduction in apple quantity demanded, holding income constant. Because the quantity change in apples offsets the price change, the apple budget share does not change. And since there is no change in spending on apples, the quantities of oranges and any other goods do not change either when the apple price falls. That is, the demand for oranges and every other good in the consumer basket is independent of a change in the price of apples. The function therefore implies that budget shares for all goods remain fixed as relative prices change. The homothetic Cobb-Douglas utility function also implies that, if income increases 10%, holding prices constant, the quantities demanded of every good also increase by 10%. Therefore, the budget shares of each commodity in the consumer basket remain constant as incomes change.

The other three functional forms allow the CGE modeler to define one or more elasticity parameters whose values lie within specified ranges (see the Technical Appendix to this chapter). The Stone-Geary utility function differs from the Cobb-Douglas function in that it accounts for a minimum subsistence level of consumption, but above that level, preferences are described by a Cobb-Douglas utility function. For this reason, all goods are gross complements because an increase in the price of a good that meets minimum subsistence requirements means that the quantities of all discretionary goods must fall. Therefore, budget shares may vary. The Stone-Geary function is *quasi-homothetic* because only the demand quantities for goods that exceed subsistence levels change by the same proportion as income. Thus, budget shares of subsistence goods increase when incomes fall, and decrease when incomes rise. The smaller the share of subsistence goods in the consumption bundle, the larger the share of the bundle that is described by a Cobb-Douglas utility function, and the more homothetic the function becomes. Text Box 4.2 presents an interesting example of how the marginal budget shares in a Stone-Geary utility function are changed to describe a sudden consumer aversion to poultry meat.

The Constant Elasticity of Substitution (CES) utility function is homothetic but allows the modeler to specify explicitly the elasticity of commodity substitution parameter that defines the shape of the indifference curve. The name of the function, constant elasticity of substitution, derives from the fact that the substitution elasticity parameter has the same value at all points along its indifference curves and at all income levels. Computable general equilibrium models usually allow the modeler to define only one substitution elasticity parameter that describes identical pairwise substitutability among all goods in the consumption basket. Therefore, all goods are net substitutes (unless the parameter is defined to be zero), and their budget shares may change when relative prices change. Because the utility function is

Text Box 4.2 Consumer fear and avian flu in Ghana

"***Economywide Impact of Avian Flu in Ghana: A Dynamic CGE Model Analysis***" (Diao, 2009).

What is the research question? HPAI H5N1 (also known as avian flu) has attracted considerable public attention because the virus is capable of producing fatal disease in humans. Control measures have focused on its prevention and eradication in poultry populations by culling flocks, but this has not prevented a sharp fall in poultry demand by fearful consumers. Are there cost-effective and evidence-based measures that both reduce disease risk and protect the livelihoods of the smallholder farmers who account for most poultry production in Ghana?

What is the model innovation? The author develops a SAM for Ghana for 2005 that divides national production into four agroecological zones and 90 representative households classed by income and rural or urban location. The model is a recursive dynamic version of the IFPRI standard CGE model, which assumes the quasi-homothetic Stone-Geary utility function. Consumer aversion to chicken is simulated by reducing poultry meat's marginal budget share, a calibrated parameter in the Stone-Geary utility function. This results in a smaller increase in poultry meat demand for any given increase in income.

What is the experiment? The production effect of avian flu is modeled as a decline in the poultry sector's capital stock (which represents the culling of chickens) that reduces production by 10% for periods of one to three years, an outcome that is consistent with studies of this industry. Little is known of the virus's potential effects on consumer attitudes so the demand shock is described as a change in the marginal budget share parameter that reduces poultry demand by 40% from the baseline time path, for periods of one to three years.

What are the results? A decline in poultry production causes a shortage in poultry supply and tends to push producer prices upward. But, the decline in consumer demand tends to cause producer prices to fall. Thus, model results show little change in poultry prices due to avian flu but much lower levels of both supply and demand.

homothetic, consumers make the same substitutions in response to relative price changes at any income level, so all goods are also gross substitutes.

An important and useful characteristic of the CDE demand system is that it is nonhomothetic. As incomes change, consumers can purchase proportionately more luxury goods and spend a smaller share of their budget on necessities, depending on the income elasticity of demand specified for each good. Its nonhomotheticity makes the CDE demand system especially well-suited to analyze experiments in which there are large income effects.

Commodities are net substitutes, but the presence of income effects means that goods can be either gross substitutes or gross complements. For example, a fall in the relative price of a necessity good with a large budget share is likely to shift consumption toward the necessity good, but the price savings will also provide a significant boost to a household's purchasing power. This income effect will cause the quantity demanded of luxury goods to increase and that of the necessity good to fall. If this income effect is large enough, the necessity and luxury goods can be gross complements. The CDE demand system also has the flexibility to specify different pairwise substitution possibilities in models that include more than two commodities.

We illustrate the practical significance of the choice of utility function and parameter values by comparing the model results of the same experiment when making three different assumptions about consumer preferences. Our experiment is a 10% increase in the productivity of factors used in the production of services. This simulates an income increase in the US economy and causes the price of services to fall relative to other goods. We use the GTAP model, which has a CDE demand system, for demonstration because we can choose CDE parameter values that will transform the CDE function into CES and Cobb-Douglas utility functions. However, we cannot replicate the Stone-Geary utility function, because it includes parameters for subsistence spending that are not accounted for in the CDE demand system.

The CDE system allows the modeler to define income and substitution parameter values. These parameters are not exactly the same as income and compensated price elasticities of demand, but they are closely related to them.[4] The CDE parameter values for the United States in our NUS333 database are reported in Table 4.4. The income parameter (INCPAR) values for the United States indicate that private household demand for services is relatively sensitive to income changes, but demand for agriculture (which is mainly foodstuffs) is not very sensitive to income changes. As the substitution parameter (SUBPAR) value becomes larger, the negative own-price and positive cross-price compensated elasticities become larger. Based on the SUBPAR values, the US private households are relatively price sensitive with respect to their food purchases but less so with respect to purchases of services and manufactures.

We first carry out the model experiment using the CDE demand system. Then, we redefine income parameters and substitution parameters to

[4] A compensated own-price elasticity describes the consumer's demand response to a price change net of the income effect; it is the movement along an indifference curve. Formulae that describe the relationship between the GTAP model's income parameters (INCPAR) and substitution parameters (SUBPAR) and income, own-price, and cross-price elasticities are derived by Hanoch (1975). For a detailed discussion of the CDE demand system, see McDougall (2003), Surry (1993), and Hertel et al. (1991).

Table 4.4 *US private household default demand parameters in NUS333 database*

	Income parameter (INCPAR)	Substitution parameter (SUBPAR)
Agriculture	0.17	0.82
Manufactures	0.88	0.20
Services	1.04	0.17

Source: GTAP v8.1 database.

correspond with a CES utility function (with a low, 0.5 elasticity of commodity substitution) and rerun the model experiment.[5] We take similar steps to define a Cobb-Douglas utility function.

In all three model experiments, national income increases by about 5%, which suggests that income effects on the commodity composition of demand may be important. Model results are reported in Table 4.5. In all three cases, the consumer price of services falls substantially relative to the prices of agricultural and manufactured goods. However, the effect on the consumer basket differs in the three cases, reflecting different assumptions about consumer preferences.

With the CDE function, income growth favors a disproportionate increase in quantity demanded for services, a luxury good, relative to the quantity of the agricultural good demanded. This income effect on demand reinforces the substitution effect on consumption, in which the increase in the consumer price for agriculture relative to services encourages a shift toward service consumption. Despite the shift in consumption toward services, its budget share declines slightly because more services can be purchased at a lower total cost. The budget share of agriculture falls because of its smaller quantity in the consumer basket.

With the homothetic CES function, the 5% increase in income leads to a more equi-proportionate increase in the quantity demanded for all three commodities, and therefore a more evenly balanced growth within the basket compared to the CDE case. The homothetic income effect helps sustain demand for agriculture, despite the increase in its price relative to the other goods. With CES preferences, therefore, the budget share of the agricultural good increases instead of falling as in the CDE case. Still, as in the CDE case, the price effect causes consumers to substitute toward the consumption of

[5] To describe a CES function, we redefine CDE utility function income parameters for all commodities and regions to be 1 and define all substitution parameters to be 0.5, which describes a relatively low elasticity of substitution and a highly convex indifference curve. To describe a Cobb-Douglas utility function, we define all income parameters as 1 and all substitution parameters as zero. See Hertel et al. (1991b).

Table 4.5 *Effects of a 10% increase in total factor productivity in the services sector on private household demand assuming different consumer preferences*

	Consumer price – % change (*ppa*)	Consumer demand quantity – % change (*qpa*)	Expenditure on commodity – % change (*qpa* + *ppa*)	Change in budget share
Constant difference of elasticities (CDE)				
Agriculture	0.59	1.96	2.55	–0.04
Manufacturing	–0.20	5.46	5.26	0.36
Services	–5.07	9.66	4.59	–0.14
Constant elasticity of substitution (CES)				
Agriculture	0.91	6.22	7.13	0.5
Manufacturing	–0.24	6.80	6.56	1.27
Services	–5.19	9.27	4.08	–0.6
Cobb-Douglas				
Agriculture	0.64	4.10	4.74	0.00
Manufacturing	–0.18	4.92	4.74	0.00
Services	–5.05	9.78	4.74	0.00

Note: We use the Johansen solution method.
Source: NUS333 model.

services. The net effect is an increase in budget shares for agriculture and manufactured goods while the budget share of services declines.

In the case of the Cobb-Douglas function, budget shares are fixed by assumption so the price effect on quantity demanded is the inverse of the change in price. In agriculture, for example, the price increases by 0.64% so the price effect on quantity demanded is –0.64%. The utility function's unitary income elasticity causes the quantities demanded for each good to change by the same proportion as the percent change in income, which is 4.74% in this experiment. On net, the change in the quantity of consumer demand is the sum of the price and the income effect, or –0.64 + 4.74 = 4.10% in the case of US agriculture.

The zero change in the agricultural budget share in the Cobb-Douglas experiment contrasts with its decline in the CDE case and its expansion in the CES case, and illustrates the potential importance of these assumptions for your analysis. The right utility function for any specific analysis will depend on the research question and the flexibility offered by the CGE model to specify the utility function and the elasticity parameter values that best describe the economy under study. In general, homothetic functions are appropriate when income changes are small, as in our example, but nonhomothetic functions are better suited for shocks in which income changes are relatively large.

Import Demand

The second stage of the consumer's decision-making determines the sourcing of each composite commodity. How much of the demand for a commodity will be met by the domestically produced variety and how much will be imported? In most CGE models, the allocation between domestic and imported goods reflects the assumption that the two varieties are imperfect substitutes. For example, Chilean consumers may feel that imported Chinese apples differ in flavor and texture from local apples. Chinese apples may be more suitable for baking in pies, while the Chilean variety is best eaten raw. These preferences would explain why there is two-way trade in apples between Chile and China, and why the prices of the two types of apples differ. Many CGE models describe these preferences using an *Armington import aggregation function*. The function describes how domestic apples and the composite imported apples are combined to produce the composite commodity, "apples," that is demanded by Chilean consumers. This import-domestic allocation is made by each type of consumer in the model – firms, private households, government, and investors.

Using private household demand as an example, the import aggregation function can be drawn as an *isoquant*, shown as curve QPA^1 in Figure 4.6. The isoquant is similar to an indifference curve in many respects. It describes all possible quantity combinations of the domestic variety and the composite import (imports aggregated from all sources) that produce the same level of

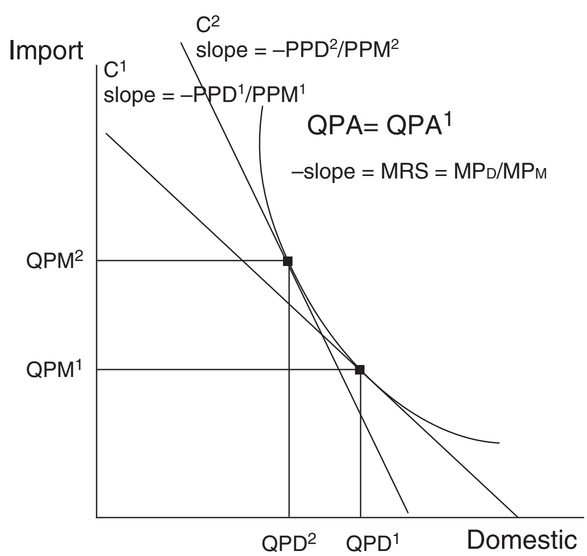


Figure 4.6 Armington aggregation function

QPA, the composite commodity. The further the isoquant lies from the origin, the larger is the quantity that it represents. The negative of its slope at any point describes the MRS, which measures the quantity of private household imports, QPM, that can be exchanged for a one-unit increase in the quantity of the domestic good, QPD, holding QPA constant. We can also express the MRS as the ratio of the *marginal product* of each variety in the production of QPA, MP_D/MP_M.[6] The marginal product is the contribution to output of an additional unit of either input, holding the other input quantity constant. As the consumer moves down the isoquant, and production of QPA becomes more intensive in the use of QPD, the marginal product of QPD falls relative to the marginal product of QPM. For example, when the consumption basket is composed mostly of Chilean apples, the addition of yet one more eating apple is not as useful to the consumer as the addition of a Chinese baking apple.

The *import-domestic (Armington) substitution elasticity*, σ^D, describes the curvature of the isoquant. The smaller is σ^D, the less substitutable are QPM and QPD in the production of QPA, and the more curved is the isoquant. Each additional unit of QPD relative to QPM causes a relatively large decline in their price ratio PPD/PPM, where PPD is the consumer price of the domestic good and PPM is the consumer price of the imported good. Relative price changes must therefore be quite large to motivate consumers to give up imports for an additional unit of the domestic variety. In the limit, when the import substitution elasticity has a value of zero, the isoquant has the L-shape of a "Leontief" function, and QPM will not be substituted for an additional unit of QPD, regardless of any change in their relative prices. When the varieties are good substitutes, and the value of parameter σ^D is large, then the isoquant is relatively flat, showing that imports are easily substituted for the domestic variety, with little effect on the ratios of their marginal products in the production of QPA. As the parameter value approaches infinity, the isoquant becomes linear and the two varieties become perfect substitutes.

C^1 is an *isocost* line with a slope of $-PPD^1/PPM^1$. The isocost line shows all combinations of the two goods that cost the same amount. Isocost lines that lie further from the origin represent higher costs. C^2 is a second isocost line, depicting a higher price ratio, PPD^2/PPM^2.

The consumer minimizes the cost of QPA by choosing the quantities of imports and domestic goods described by the tangency between the isoquant and the lowest achievable isocost line. In the initial equilibrium shown in

[6] The MRS is equivalent to the ratio of marginal products (MP_D/MP_M) because the slope at any point on the isoquant is –dQPM/dQPD, and since the marginal product of QPD is dQPA/dQPD and of QPM is dQPA/dQPM, the ratio MP_D/MP_M = (dQPA/dQPD)/(dQPA/dQPM) = dQPM/dQPD, which is the negative of the slope of the isoquant, or the MRS.

Figure 4.6, the consumer chooses quantities QPM^1 and QPD^1 at a cost of C^1. At the tangency, the ratios $MP_D/MP_M = PPD^1/PPM^1$. Rearranging (by multiplying both sides by MP_M/PPD^1), $MP_D/PPD^1 = MP_M/PPM^1$. This means that costs are minimized when an additional dollar spent on the domestic or imported variety yields the same additional quantity of the composite commodity, QPA. Suppose that the price of imports declines relative to the price of the domestic variety, as shown by the isocost line C^2. The least-cost ratio of input quantities shifts to QPM^2/QPD^2. The magnitude of the change in the quantity ratio, QPM/QPD, relative to the change in the price ratio, PPD/PPM, is determined by the isoquant's curvature as described by the import substitution elasticity parameter, σ^D . Computable general equilibrium models usually assume a CES (constant elasticity of substitution) import aggregation function to describe this type of consumer demand so that the value of parameter σ^D is the same for all ratios of sourcing at all levels of total commodity consumption.

We explore the behavior of the Armington aggregation function in a CGE model by running an experiment that increases the price of imports relative to domestic goods while assuming different import substitution parameter values. We use the NUS333 model to examine the effects on private household consumption of an increase in the US import tariff on manufactured imports from the rest of the world. The results, reported in Table 4.6, show that when the goods are relatively poor substitutes, with an import-domestic substitution elasticity of 0.8, the quantity ratio of imports to domestic goods in the consumption of manufactures falls 4.5%. When goods are assumed to be readily substitutable, with a parameter value of 4, the quantity response is much larger – the ratio of imports to domestic goods declines by almost 18%.

As you might imagine, the sizes of import substitution elasticities are an important consideration for CGE modelers who study the effects of price

Table 4.6 *Effects of an increase in the US import tariff on manufactures to 10% on the import/domestic ratio in household consumption with different Armington elasticity values (% change from base)*

	Import-domestic substitution elasticity for manufacturing		
	0.8	1.2	4.0
Import quantity *(qpm)*	–4.6	–5.7	–14.0
Domestic quantity *(qpd)*	–0.1	0.5	4.0
Import/domestic quantity ratio *(qpm-qpd)*	–4.5	–6.2	–18.0

Note: Parameter value of the elasticity of import-import substitution is defined as the import-domestic parameter value multiplied by 2.
Source: NUS333 model.

changes, such as tariff reforms, on international trade. Indeed, these elasticities have received much attention in the CGE-based literature on trade policy because of the potential sensitivity of model results to the assumed parameter values. Modelers try to address these concerns by careful selection or estimation of their parameters and by testing the sensitivity of model results to their elasticity assumptions – subjects discussed in more detail in Chapter 3.[7]

In the third stage of the consumption decision, the demand for imports is allocated across foreign suppliers, using a second Armington aggregation function that describes how imports from different sources are combined to produce the composite import. This second Armington aggregation function is "nested" within the first one, because it describes how the given quantity of a composite import determined in the second stage is allocated across import sources. This allocation decision is identical to the import-domestic allocation decision, except that the choice is between competing import suppliers of a given quantity of the composite import, and it is governed by the import-import elasticity of substitution. Unlike the second stage, however, this import sourcing decision is usually made at the national level, instead of by each agent. The demands for composite imports by households, government, and investors, and by firms for use as intermediate inputs, are first combined and then national import demand is sourced across suppliers. All agents in the economy therefore have the same import sources.

Text Box 4.3 describes import demand in supply-chain CGE models in which import sourcing is instead made independently by each agent. This approach has supported rich analyses of trade and environmental policies. However, this type of analysis is data-intensive, requiring that the SAM be extended to include an MRIO table, described in Chapter 3.

Export Demand

Export demand is the demand by foreign consumers for the home country's exports. The treatment of foreign demand in a CGE model depends on whether the model is a multi-country model or a single-country model.

The multi-country case is straightforward: The demand for exports from country X by country Y is simply the demand for imports by country Y from country X. This is the case even when the global economy is aggregated into two regions, for example, the United States and the rest of world, as in the model we use for demonstration. The slope of the foreign demand curve for

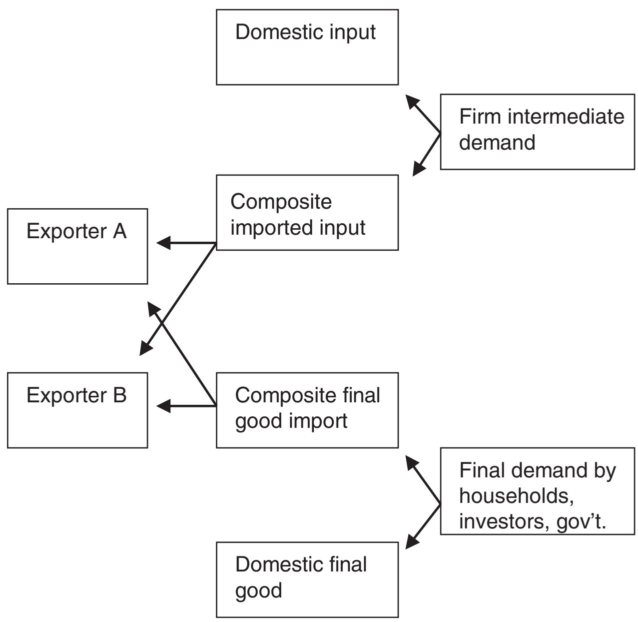
[7] Discussion and critiques of Armington import substitution elasticities include Hillberry and Hummels (2013); McDaniel and Balistreri (2003); Erkel-Rousse and Mirza (2002); Gallaway, McDaniel, and Rivera (2000); Hummels (1999); Brown (1987); and Shiells, Stern, and Deardorff (1986). See Reinert and Roland-Holst (1992); Shiells and Reinert (1993), and Hertel et al. (2004a) for examples of studies in which CGE modelers estimated the Armington import demand elasticities used in their models.

Text Box 4.3 Import sourcing in a supply-chain CGE model

"An Enhanced Analytical Framework for Evaluating the Effects of Trade Costs along Global Value Chains" (Carrico, 2017).

What is the research question? Intermediate and investment goods account for over three-quarters of global trade, and production fragmentation along global value chains has lengthened across regions. Nominally low tariff barriers to trade accumulate and amplify across extensive GVC's. Would a more accurate baseline of trade cost estimates using a multi-regional input-output (MRIO) table and a supply chain CGE model result in different analytical results of trade reform simulations, compared to a standard CGE model?

What is the CGE model innovation? Carrico develops an MRIO database that describes different import sources and composite import tariffs for firms, household consumers, and investors, and incorporates the database into a supply chain CGE model. In a standard CGE model, each domestic agent determines its import-domestic consumption shares and then their combined import demand is sourced across foreign suppliers, so all agents have identical import sourcing and composite tariffs. In the supply chain model, depicted here, firms and final demand directly source their imports from foreign suppliers, so their import sourcing and composite import tariffs can differ.



What is the model experiment? Carrico carries out the same scenario of tariff removal among the twelve original members of the Trans-Pacific Partnership (TPP) in three different CGE models: a standard CGE model, a supply-chain model in which all agents have identical import sources and composite tariffs, and a detailed supply chain model with dissimilar import sources and tariffs across agents.

Text Box 4.3 (*cont.*)

What are the key findings? Because consumers, investors and firms face different composite tariff rates, their gains and losses from trade reform differ, and there are substantial differences among models in macro results, aggregate trade flows, and agent-specific trade flows. In the detailed supply-chain model, US consumers initially face higher composite tariffs than firms and subsequently benefit relatively more than firms from the TPP's tariff elimination.

a country's export good therefore depends in part on the foreign country's Armington import substitution elasticity. The larger its value, the more elastic its import demand and therefore the more elastic the exporter's export demand curve.

Figure 4.7 illustrates the effect of foreign Armington elasticity parameters on a country's export demand. In the figure, S is the home country's supply of exports, D^1 describes a relatively elastic export demand curve (high foreign import substitution parameter), and D^2 describes a relatively inelastic export demand curve (low foreign import substitution parameter). For example, foreign countries' import substitution elasticities for dry milk powder are likely to be very high, because all varieties are nearly identical. The United States' export demand curve for dry milk powder is therefore probably

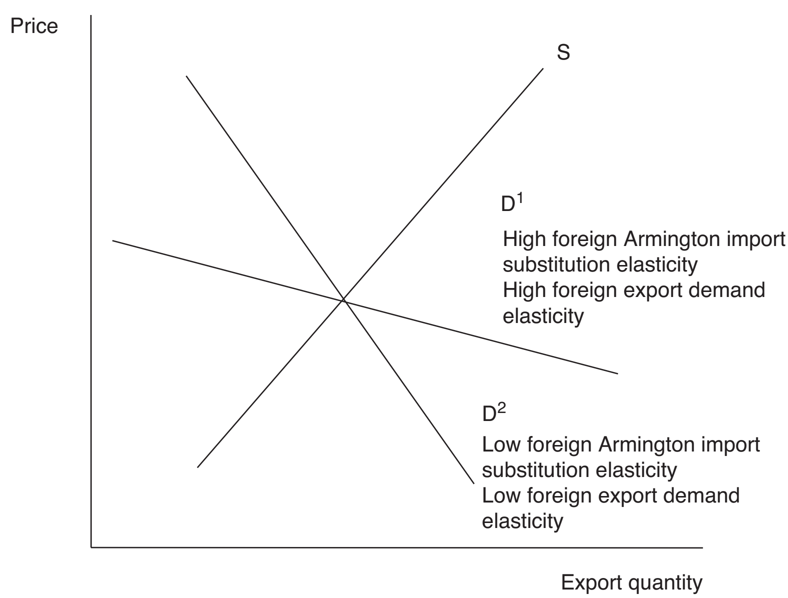


Figure 4.7 Elasticity parameters and the export demand curve

similar to demand curve D^1. In this case, even a small increase in the relative world export price of the US variety can lead foreigners to make a large substitution toward their own domestic product. Conversely, a low foreign import substitution elasticity implies an inelastic export demand curve for US dry milk powder.

Single country CGE models do not describe the foreign economy or foreign import substitution preferences. Instead, demand for the home country's export is usually described using a simple expression that describes its aggregate export of each commodity:

$$QXW/QXWCOM = (PXWCOM/PXW)^{\theta}$$

where QXW is the country's export quantity and QXWCOM is global trade in that good, so QXW/QXWCOM is the country's market share in world trade. PXWCOM is the world price and PXW is the *fob* world export price of the home country's export variety. Given the assumption that goods are differentiated by country of origin, a country's world export price can differ from the prices of its competitors. For example, the US world export price for its corn, a yellow type used mainly for animal feed, can differ from the world export price of Mexico's corn, a white variety used mainly for food.

In the single-country model, a country can be assumed to be either *small* or *large* in its world export market by selecting the appropriate *export demand elasticity*, denoted by θ. This parameter measures the percent change in a country's market share given a percent change in the ratio of the global price to its world export price. When a country is small, it is reasonable to assume that any change in its export quantity is too small to affect the global price level. PXWCOM remains fixed and the export demand elasticity approaches infinity. Any change in the country's world export price relative to the world price therefore results in large changes in export quantity and market share, so its foreign demand curve is relatively flat, similar to D^1. For example, if Uganda raises the price of its textile exports, it will not affect the world price level, but it is likely to cost Uganda a large portion of its market share in the world textile trade. Its output quantity will decline and, moving down its supply curve, its marginal costs will fall until Uganda's export price is again equal to the prevailing world price.

When the single country is assumed to be large in world markets, then its world export price can affect the world price level, and its export demand elasticity is assumed to be low. In this case, a change in the exporter's world price relative to the average world price causes only a small change in its market share. For example, suppose that a drought reduces the export supply of white corn from Mexico, one of the world's major suppliers. This leads to an increase in its world export price and in the trade-weighted world price of white corn. The lower the export demand elasticity, the less willing are foreigners to change their quantity of corn imports from Mexico as its price rises, and the steeper is Mexico's downward sloping foreign demand curve.

Consumer Welfare

"Are you better off today than you were four years ago?" This was the famous question asked by Ronald Reagan in his successful US presidential campaign. How you can tell that you are better off? Economists answer this question by quantifying a "money metric" measure of the change in a nation's well-being, or welfare, following an economic shock. Such a measure has a cash value, such as $14 billion, that describes the welfare change in terms of an income equivalent. In this example, we could say that a nation's consumers are now just as well off as if they had been given an additional $14 billion to spend before an economic shock. Such a measure is useful because it allows us to make unambiguous comparisons of alternative polices or other shocks. For example, we can conclude that a policy that increases national welfare by $14 billion leaves us better off than one that increases our welfare by $5 billion. Computable general equilibrium models are particularly well-suited to quantifying welfare effects because they describe the effects of a shock on all prices and quantities in an economy. In fact, the measurement of welfare effects is one of the most important contributions that CGE models have made in empirical economic analysis.

In this section, we describe two approaches that are commonly used to measure welfare effects in standard CGE models that have a single, representative household. We start with the most intuitive, which is the money metric equivalent of changes in "real," or the quantity of, consumption of goods and services. A quantity-based measure has intuitive appeal because it is based on the idea that larger quantities of consumption make people better off. This welfare measure includes only changes in quantities, and not the value of consumption, because value changes might be due only to price changes. For example, if I buy one candy bar both before and after its price increases from $1 to $2, the value of my consumption has doubled but my real consumption – the quantity I consume – has remained the same, at one candy bar.

We calculate the *real consumption (RC)* welfare measure as the difference between the cost of the new basket, Q^2, and the cost of the initial basket, Q^1, valuing both baskets at the same, pre-shock consumer prices, P^1 for each good *i*:

$$\text{RC welfare} = \textstyle\sum_i (P_i^1 Q_i^2) - \sum_i (P_i^1 Q_i^1)$$

Table 4.7 *Calculating the real consumption measure of welfare*

	Initial price	Initial quantity	New quantity	Cost of initial quantity at initial prices	Cost of new quantity at initial prices
T-shirts	$1.00	10	12	$10.00	$12.00
Books	$1.00	12	16	$12.00	$16.00
DVDs	$1.00	3	8	$3.00	$8.00
Total	–	–	–	$25.00	$36.00

Because the RC measure holds prices constant at their initial levels, a change in its value reflects only changes in quantities consumed. When the result is positive, real consumption has increased between periods one and two, and when the result is negative, real consumption has declined.

We can infer that an increase in real consumption is a welfare gain by drawing on the theory of revealed preference. At P^1 prices, the cost of Q^2 exceeded that of Q^1. Basket Q^2 was unaffordable and Q^1 was chosen. Following the shock, both Q^1 and Q^2 are affordable, but Q^2 must be preferred because it is chosen. The cost difference between the baskets is equivalent to the additional income that the consumer would have needed to be able to afford the preferred basket, Q^2, at pre-shock prices.

All goods in the consumer basket are included in the welfare measure because a shock in one industry can affect prices and quantities throughout an economy. As an example, an import tariff reform may lower the consumer price of imported t-shirts. When the t-shirt price falls, you can either buy a larger quantity of t-shirts or, if you prefer, you can spend the money that you have saved on t-shirts to buy more of other types of goods, such as books and DVDs. Therefore, the welfare measure must account for t-shirts, books, DVDs, and any other goods in your basket, even though the import tariff policy affects only t-shirts.

Table 4.7 illustrates how to calculate the RC welfare measure. Let's assume that we have used a three-good CGE model to analyze the effects of removing the import tariff on imported t-shirts. The original consumption basket is composed of ten t-shirts, twelve books, and three DVDs. It costs a total of $25.00. The tariff removal causes all three consumer prices to change (these prices need not be reported). In this case, the removal of the t-shirt tariff enables the consumer to buy more of all three goods. At the original prices, the new consumption basket would have cost $36.00 or $11.00 more than the initial basket. There is a welfare gain of $11.00, which is equivalent to the additional income the consumer would have needed to purchase the new basket at the preshock prices.

Some CGE modelers take a different approach, and instead develop an *equivalent variation*, EV, welfare measure. It, too, is a money metric measure, but instead of comparing the cost of pre-and post-shock consumption quantities, it compares the cost of pre-and post-shock levels of consumer utility, both valued at base-year prices. Because a CGE model contains a utility function, it is straightforward to calculate and compare the utility derived from different baskets of goods. For example, suppose the removal of the t-shirt tariff causes price changes that enable consumers to afford a new basket of goods that increases their utility from U^1 to U^2. The EV welfare effect measures the change in income that consumers would have needed to afford the new level of utility at preshock prices.[8] A positive EV welfare result indicates a welfare gain, and a negative result is a welfare loss.

To demonstrate step by step how to calculate an EV measure of welfare, we use a two-good example of apples, Q_A, and oranges, Q_O. Let's assume that consumer preferences in our CGE model are described by a Cobb-Douglas utility function:

$$U = {Q_A}^{\alpha} \, {Q_O}^{1-\alpha}$$

where parameter α is the budget share for apples and, 1 – α, is the budget share for oranges. Our model will then specify the utility-maximizing demand functions for each commodity, which are derived from the utility function. In our example, the demand functions for any expenditure level, Y, and for any prices of apples, P_A, and oranges, P_O, are as follows:

$$Q_A = \alpha(Y/P_A)$$

$$Q_O = (1 - \alpha)(Y/P_O)$$

If we assume that apples and oranges each account for a 50% budget share, expenditure in the base period is 100, and the initial price of apples is 4 and of oranges is 2, then the utility function is:

$$U = {Q_A}^{.5} {Q_O}^{.5}$$

and the utility maximizing quantities of apples and oranges are:

$$Q_A = 0.5(100/4) = 12.5$$

$$Q_O = 0.5(100/2) = 25.0$$

8 Compensating variation is an alternative utility-based measure of welfare that compares the cost of the new versus the old utility when both are valued in post-shock prices. Similarly, the real consumption measure of welfare can be calculated by comparing the costs of two baskets when both are valued in post-shock prices.

Now we are ready to run a model experiment. Let's assume that the economic shock has caused the apple price to fall to 2 but that the orange price and total expenditure remain unchanged. Based on our model's demand functions, we solve for the new, utility-maximizing quantities. Using these demand functions, verify that the quantity of apples demanded increases to 25 whereas the quantity of oranges demanded is still 25.

To calculate the equivalent variation welfare effect, our first step is to calculate the base level of utility, U^1, by substituting the base quantities for apples and oranges into the utility function:

$$U^1 = 12.5^{.5} * 25^{.5} = 17.7$$

Next, we calculate the new utility level, U^2, by substituting the new quantities into the utility function:

$$U^2 = 25^{.5} * 25^{.5} = 25.0$$

Then, we solve for the expenditure level required to achieve the new utility level at base prices by substituting the expressions for apple and orange quantities into the utility function, and solving for the total expenditure, Y. Notice that our equation incorporates the new utility level (25) and the base-year prices:

$$U^2 = 25.0 = [0.5 * (Y/4)]^{0.5} * [0.5 * (Y/2)]^{0.5}$$
$$Y = \$141.6$$

Last, we calculate the EV welfare measure, which is the change in expenditure that would have been required for consumers to afford the U^2 level of utility at preshock prices:

$$\$141.6 - \$100 = \$41.6.$$

For comparison, verify that the RC measure of welfare in this example is $50.

The RC and the EV welfare measures are closely related. We illustrate this point in Figure 4.8, which describes and compares the results from our two-good example of apples and oranges. In the figure, the initial equilibrium is at point A on the U^1 indifference curve, given the initial price ratio between apples and oranges of P^1. The decline in the apple price is shown by the rotation of the price line to P^2. This causes the utility-maximizing consumer to choose the consumption basket at point B, which provides a higher level of utility on the U^2 indifference curve. Using the RC measure, we can ask: "How much additional income would have been required to purchase the new basket, B, at the original prices?" The answer is shown as the vertical distance between the original budget line, P^1, and a budget line that is parallel to P^1 and goes through point B. Its intercept on the vertical axis at

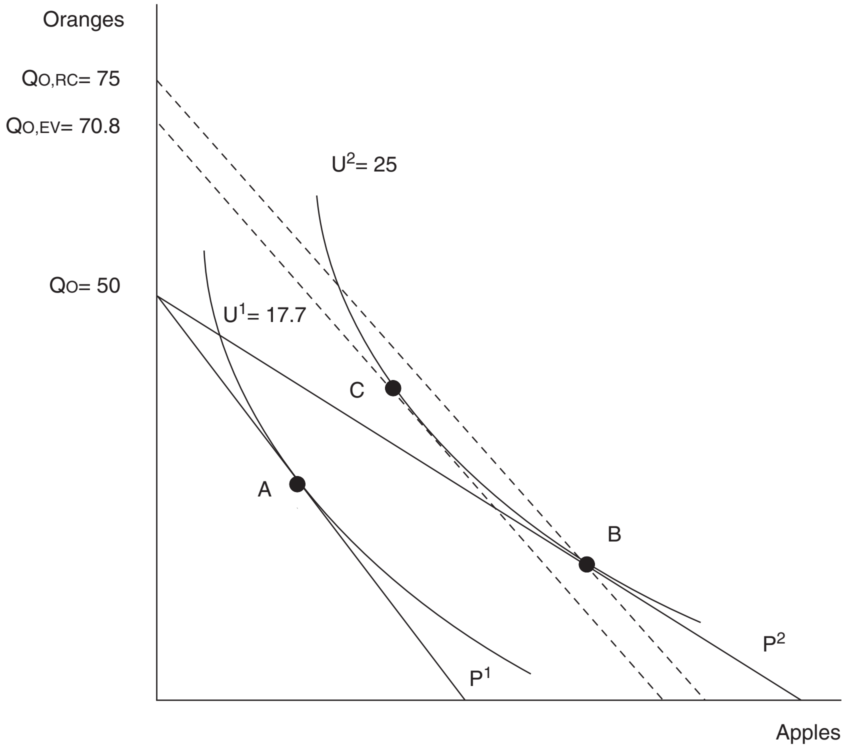


Figure 4.8 Alternative measures of consumer welfare

point $Q_{O,RC}$ measures the total level of expenditure on basket B in terms of oranges, which is \$2 ∗ 75 oranges = \$150.

Now suppose that, instead, we allowed the consumer to choose the least-cost basket of apples and oranges that generated the same U^2 level of utility as basket B, again at original prices. Given the consumer's preferences (shown by the curvature of the isoquant), that least cost bundle is at point C. Using the equivalent variation welfare measure, we can ask, "How much additional income would have been required to purchase a basket that yields the new utility level, U^2, at the original prices?" The answer is shown as the vertical distance between the original budget line and a budget line that is parallel to P^1 and goes through point C. Its vertical intercept at point $Q_{O,EV}$ describes total expenditure on basket C in terms of oranges, which is \$2 ∗ 70.8 oranges = \$141.60. In this case, if original prices had actually prevailed in period two, the consumer would have substituted between apples and oranges, spending less money on a basket, C, that was as satisfying as basket B.

The welfare measure that values the change in real consumption is the distance $Q_O - Q_{O,RC}$. It is 25 oranges, valued at \$50. It exceeds the welfare measure that values the change in utility, shown by the distance $Q_O - Q_{O,EV}$, which is 20.8 oranges, or \$41.60.

You may verify for yourself that as the elasticity of substitution becomes smaller, and indifference curve is more sharply curved, the distance between the EV and RC intercepts becomes smaller. In fact, the two approaches yield identical results when the elasticity of substitution is zero, as in a Leontief fixed-proportion utility function, with L-shaped indifference curves.

Computable general equilibrium models can differ in their approaches to welfare measurement in other ways, too. For example, the GTAP model measures equivalent variation welfare effects on behalf of the regional household. It includes the combined changes in the utility of household consumers and government from their purchase of goods and services, and in addition includes domestic savings. Savings is included because it represents future consumption possibilities. In other CGE models, without a regional household, the welfare measure often describes only changes in quantities or utility from current consumption by private household consumers and may or may not also include investment spending. The modeler must then assume compatible macro-closure rules that fix the quantities purchased by government and perhaps of investors at their base levels.[9] It is well worth your time to study and understand the welfare measure used in your model, particularly so because this important summary measure is often presented as the "bottom line" of CGE-based analyses.

Summary

Final demand is the demand for goods and services for end use by private households, government, investors, and foreign markets. Data in the row accounts of the SAM describe the sources of income for each domestic agent and investment in the CGE model. Data in the column accounts of the SAM describe how their income is spent on commodities, and report export sales to the foreign market.

Many computable general equilibrium models describe consumer demand as a three-stage decision. In the first stage, consumers allocate their income across commodities to maximize their utility, or satisfaction,

[9] See Lofgren et al. (2002) for a discussion of the links between welfare measures and model closure.

given their preferences, budgets, and prices. When income or prices change, consumers readjust their basket of commodities to again maximize their utility. We describe and compare four functional forms commonly used in CGE models to describe private households' preferences: Cobb-Douglas, Stone-Geary/LES, and CES utility functions and the CDE demand system. Most CGE models describe the first stage of government and investment demand very simply by assuming that they spend a fixed share of their budgets on each commodity (i.e., a Cobb-Douglas utility function). In the second stage of the consumption decision, consumers minimize the cost of their consumption basket by choosing between imported and domestic varieties. This allocation is described by an Armington import aggregation function. In the third stage, the demand for imports by intermediate and final demand are aggregated and sourced across import suppliers as described by a second, nested Armington import aggregation function. In this chapter, we also describe and compare export demand in multi-country and single-country models and introduce the concept of national welfare, demonstrating how to calculate real consumption and equivalent variation welfare measures.

Key Terms

Budget constraint
Budget share
Cobb-Douglas utility function
Composite commodity
Composite import
Constant difference of elasticities (CDE) demand system
Constant elasticity of substitution (CES) utility function
Elasticity, (Armington) import substitution
Elasticity, export demand
Elasticity, commodity substitution in consumption
Equivalent variation measure of welfare
Final demand
Gross complements
Gross substitutes
Homothetic utility function
Import (Armington) aggregation function
Indifference curve
Isocost
Isoquant

Large country
Luxury good
Marginal product
Marginal rate of substitution
Marginal utility
Multi-region input-output table
Necessity good
Net substitutes
Nonhomothetic utility function
Quasi-homothetic utility function
Real consumption measure of welfare
Small country
Stone-Geary Linear Expenditure System
Three-stage demand
Utility function

PRACTICE AND REVIEW

1. Using data from the NUS333 SAM,
   a. Trace the sales of US-produced agricultural goods in final demand:

   C ______________ I ______________ G ______________ E ______________

   b. Trace the sales of US-produced services in final demand:

   C ______________ I ______________ G ______________ E ______________

2. Using data from the NUS333 SAM,
   a. Calculate the budget shares of US-produced goods in households' private consumption expenditure (including sales taxes):

   Agric: ______________ Mfg: ______________ Serv: ______________

3. Explain the difference between a homothetic and a nonhomothetic utility function. If you are conducting a study of foreign aid inflows and economic growth in a developing country, explain some of the differences in model results that you might expect to see when using the two utility functions.
4. Using a graph of the Armington aggregation function, explain the role of the Armington import substitution elasticity in determining the quantities demanded for imports and domestic goods if the removal of a tariff causes the relative price of the import to fall. Compare the outcome in a case with a high substitution parameter value and a low parameter value.
5. Calculate the real consumption welfare effect using the data in Table 4.8. Has welfare improved or declined as a result of the price changes?

Table 4.8 *Practice and review – calculating the real consumption welfare measure*

	Initial price	Initial quantity	New quantity	Cost of initial quantity at initial prices	Cost of new quantity at initial prices
Agriculture	$1.00	5	6		
Manufacturing	$1.00	5	4		
Services	$1.00	2	8		
Total	–	–	–		

Technical Appendix 4.1: Elasticity Parameters in Utility Functions

Table 4.9 describes the elasticity parameters that are required for four functional forms commonly used in CGE models to describe private households' preferences. The table describes the restrictions usually placed on the elasticity parameter values to ensure that the CGE model can be solved for a unique solution. The table also includes a brief explanation of different parameter values.

Table 4.9 *Elasticity parameter values in utility functions commonly used in CGE models*

	Modeler input	Parameter restrictions	Parameter values
Cobb-Douglas	None	None	Unitary (negative) own-price; zero cross-price, and unitary substitution and income elasticities are implied by the utility function.
Stone-Geary/ Linear Expenditure System (LES)	Frisch parameter (ratio of total expenditure to discretionary expenditure)	–1 ≤ Frisch ≤ ∞	All expenditure is discretionary: Frisch = –1 All expenditure is on subsistence requirements: Frisch = ∞
	Expenditure elasticity by commodity (Ei).	0 ≤ Ei ≤ ∞	Luxury goods: Ei < 1 Necessity goods: 0 ≤ Ei < 1
	Stone-Geary/LES collapses to a Cobb-Douglas utility function when Frisch=–1 and all Ei = 1.		
Constant Elasticity of Substitution (CES)	Elasticity of substitution by commodity (σi)	0 ≤ σi ≤ ∞	Leontief complements: σi =0 Perfect substitutes: σi = ∞
	CES collapses to a Cobb-Douglas utility function when all σi =1; and to a Leontief utility function when all σi =0.		
Constant Difference of Elasticities (CDE)	INCPARi – a parameter related to the income elasticity of demand for good i.	0 < INCPARi	Larger INCPARi parameter value implies larger income elasticity of demand. Income insensitive (necessity) goods: 0 < INCPARi < 1 Income sensitive (luxury) goods: 1 < INCPARi Homothetic demand: INCPARi = 0 for all i
	SUBPARi – a parameter related to the compensated own and cross-price elasticities of substitution, defined for good i.	Either SUBPARi < 0 or 0 < SUBPARi< 1 for all i	Larger SUBPARi parameter value implies larger (absolute value) of compensated own-price elasticity. Leontief complements: SUBPAR = 1 for all i. Goods become substitutes as UBPARi and SUBPARj become smaller. Independent goods: SUBPAR = 0 for all i.

Note: CDE collapses to a Cobb-Douglas utility function when all INCPARi = 1 and SUBPARi = 0; to a Leontief utility function when INCPARi = 1 and SUBPARi, = 1; and to a CES utility function when all INCPARi = 1 and SUBPAR are identical for all i.

5

Supply in a CGE Model

In this chapter, we examine the supply side of an economy as represented in computable general equilibrium (CGE) models. The production data in the social accounting matrix (SAM) depict the production process, in which firms combine intermediate inputs with factors of production to produce goods and services. We use these data to calculate input-output coefficients, which describe the input intensity of production processes. Computable general equilibrium models break down the production technology into parts, depicting how subprocesses are nested within the overall production process. Within each nest, behavioral equations describe producers' efficiency-maximizing input demands and output levels, subject to their production technology. Export transformation functions, used in some CGE models, describe the allocation of production between domestic and export markets. We also examine the supply-and-demand structure of a CGE model with a non-diagonal make matrix.

In the Great Recession, the US government offered financial assistance to its auto manufacturers to help them survive a deep recession and a free fall in consumer demand for cars. The bailout was controversial in part because the government seemed to be choosing to support a particular manufacturing industry. The government response was that the aid package not only helped save the jobs of autoworkers but also preserved jobs in the many industries that supply parts to the automakers and that sell and service autos. This part of the US economic stimulus program built on the idea that an injection of support into one part of the economy would move in a circular flow to the rest of the economy, starting with the strong interindustry linkages between automakers and the other manufacturing and service sectors that supply its inputs.

In this chapter and the next, we explore the supply side of the economy as represented in a CGE model, emphasizing the linkages among industries through their demands for intermediate inputs and their competition for the factors of production. We start with an examination of the production data in the SAM. The production activity column accounts of the SAM describe the inputs used in industries' production processes. An activity's column is therefore much like a recipe because it lists all of the ingredients and the proportions used in making its product. Production activity row accounts describe the use of industries' outputs as inputs for other industries. In the CGE model, producers are assumed to maximize their efficiency, subject to the technological requirements of their physical production process, as they choose inputs and their levels of output. We describe technologies and producer behavior in detail in this chapter, including how, in some CGE models, a producer allocates output between domestic and export sales and among multple commodity outputs.

Production Data in a SAM

Production activities use inputs to produce goods and services. Inputs are of two types: *intermediate inputs* (such as electronic components for a television or computer) and the *primary factor inputs* (land, labor, and capital) that are necessary to turn these intermediate inputs into final products. The production activity columns in a SAM report the value of all intermediate and factor inputs and any taxes paid (or subsidies received) in the production of industry output.

To illustrate, Table 5.1 presents the three production activity columns from the NUS333 SAM (omitting the rows with zeros). Each column of the table shows the expenditure by that industry on all of its intermediate and factor inputs and on taxes. According to Table 5.1, US agricultural producers spend \$194 billion on commodities used as intermediate inputs. These are composed of \$36 billion of agricultural commodities (\$1 billion are imported and \$35 billion are produced domestically), \$71 billion of imported and domestic manufactured inputs, and \$87 billion of imported and domestic services. Notice that the table also shows how each type of good is used as an input into the other industries. The production of services, for example, requires substantial amounts of manufactured inputs.

In addition to intermediate inputs, US agricultural production requires \$136 billion of factor inputs, which include \$36 billion for land, \$47 billion for labor, and \$53 billion for capital services. On net, US agricultural producers pay \$1 billion in taxes on their use of factors, which includes their receipt of \$3 billion in subsidies on land and capital use (which have negative factor use taxes). Agricultural producers received an additional \$5 billion in subsidies to purchase intermediate inputs (a negative sales tax). Finally, because production (output) taxes change producers' costs, the activity column also reports the production taxes paid (or subsidies

Table 5.1 *Production inputs in the US SAM ($US billions)*

	Activities				
SAM entry	Agric.	Mfg.	Services	Definition	
Commodities – total	194	4,335	6,885	Intermediate inputs	
Agric. imports	1	15	5		
Mfg. imports	9	797	300		
Services – imports	1	22	236		
Agric. – domestic	35	165	21		
Mfg. – domestic	62	2,007	1,502		
Services – domestic	86	1,329	4,821		
Factors – total	136	2,010	9,643	Factor payments	Value-added
Land	36	0	0		
Labor	47	1,361	6,797		
Capital	53	649	2,846		
Factor use taxes – total	1	226	1,116	Factor use taxes	
Land	–1	0	0		
Labor	4	205	1,023		
Capital	–2	21	93		
Sales tax	–5	19	58	Sales taxes	
Production tax	1	70	511	Production tax	
Total	326	6,657	18,212	Gross value of output	

Note: Sales taxes rows in the SAM are aggregated into a single sales tax row. Numbers may not sum to total due to rounding.
Source: GTAP v.8.1 database.

received) by an industry. In agriculture, producers pay $1 billion in production taxes.

The contributions of factors (and including all tax and subsidies) to the value of the industry's finished goods is called the industry's *value-added*. For example, farm labor adds value to the agricultural sector's raw intermediate inputs, such as seeds, by planting and tending the seeds until they become the final agricultural product. In US agriculture, value-added totals $133 billion (i.e., $136 + $1 – $5 + $1 = $133 billion). Value-added plus the $194 billion value of intermediate inputs equals the gross value of output of US agriculture of $326 billion (adjusted for rounding).

Input-Output Coefficients

The data reported in the activity columns of the SAM can be used to calculate a useful descriptive statistic called an *input-output coefficient*. These coefficients describe the ratio of the quantities of intermediate and factor inputs per unit of output. They are calculated by dividing every cell of

Table 5.2 *US input-output coefficients*

	Production activities		
	Agric.	Mfg.	Services
Intermediate inputs			
Agric. – imports	0.004	0.002	0.000
Mfg. – imports	0.028	0.120	0.016
Services – imports	0.002	0.003	0.013
Agric. – domestic	0.108	0.025	0.001
Mfg. – domestic	0.192	0.301	0.082
Services – domestic	0.263	0.200	0.265
Factor inputs			
Land	0.110	0.000	0.000
Labor	0.144	0.204	0.373
Capital	0.161	0.097	0.156

Source: GTAP v.8.1 database.

Table 5.1 by its column total – the gross value of output.[1] The calculation excludes any taxes paid on inputs.

In Table 5.2, we display the input-output coefficients based on the NUS333 SAM (omitting the tax rows of the SAM). For example, the input-output coefficients for the agriculture activity indicate that 0.028 units of imported manufactured inputs are required per unit of output, and 0.108 units of domestically produced agricultural inputs are required, and so on.

The input-output coefficients in an activity's column account allow us to describe the *intermediate input intensity* or *factor intensity* of a production activity. A sector is "intensive" in the intermediate and factor inputs whose input-output coefficients are highest. For example, US agriculture is capital-intensive because it uses more units of capital per unit of output than of land or labor. This knowledge can be useful if we want to design experiments or predict and interpret model results. For example, what if the US government asks us to identify and study input subsidies that would most benefit farmers? Based on our input-output table, we could choose to focus our study on subsidies to manufactures, services, or capital inputs, because these are the inputs in which agricultural production is relatively intensive.

We can also use input-output coefficients to make scale-neutral comparisons of input intensities across industries and countries. For example, we

[1] The SAM reports value data so the input-output coefficients are value shares. But recall from Chapter 2 that if we normalize the data by assuming that it reports quantities per dollar, then we can interpret our input-output coefficients as ratios of input and output quantities.

could compare the capital input-output ratio between US agriculture, 0.161, and US manufacturing, 0.097. We can conclude that production of US agriculture is more capital intensive than that of manufacturing because it has a higher capital-output ratio. The comparison is scale neutral because we can make this observation without confusing it with the observation that manufacturing, a far larger sector in the US economy, accounts for vastly more capital usage than does agriculture.

Input-output coefficients in addition describe linkages among industries through their demands for intermediate inputs. *Upstream* industries are the domestic production activities that produce goods that are used as intermediate inputs by other *downstream* industries – as if products flowed downstream on a river from a producer toward the industries that use its output as inputs. Domestic auto parts suppliers, for example, are an upstream industry that produces parts used downstream by auto assembly industries. Based on the US SAM, services is the major upstream industry providing intermediate inputs into US agricultural and services production.

In a CGE model, intermediate input linkages create a channel through which a shock in one industry can affect the rest of the economy. For example, consider a shock that lowers the price of domestically produced services. Given the input-output coefficients reported in Table 5.2, we can see that this shock will lower the input costs of all sectors in the US economy, but particularly of services and agriculture, which use these services inputs more intensively than manufacturing.

These interindustry linkages often play an important role in explaining the results of experiments in a CGE model. However, as we will demonstrate in this chapter, a CGE model accounts for additional aspects of intermediate demand that are also important to consider. These include the relative size of each sector in the economy, the potential for imports to supplant domestic products in meeting demand for intermediates, and the ability of producers to substitute toward cheaper intermediate inputs in their production process.

Producer Behavior in a CGE Model

Behavioral equations in a CGE model govern producers' decisions about their input quantities and levels of output. In some models, producers are assumed to be cost minimizers who choose the least-cost level of inputs for a given level of output, given input and product prices and technological feasibility. Other CGE models describe producers as profit maximizers who choose quantities of both inputs and output, given input and product prices and subject to technological feasibility. The two approaches are just two sides of the same coin; both describe producers as maximizing their efficiency. Our discussion in the following sections mostly describes a cost-minimizing producer.

In addition to maximizing their efficiency, other important assumptions about producers that are commonly made in standard CGE models are that markets are perfectly competitive. Individual producers cannot influence the market prices of outputs or inputs, and they sell their output at their cost of production, making zero profits (in the economic sense). Production is also assumed to exhibit constant returns to scale. Thus, an increase of the same proportion in all inputs leads to an increase in output of the same proportion.

Technology Tree and Nested Production Functions

Because a producer's economic decisions on input and output levels are constrained by the firm's physical production technology, let's first explore in some detail how technological processes are described in a standard CGE model, before we consider economic choices any further. Technology defines the physical production process by which intermediate inputs, such as rubber tires and engines, are transformed by machinery and workers into a final product, such as an auto. This physical relationship is depicted by a *production function*. Computable general equilibrium models typically separate the production function into parts. In a diagram, it looks a lot like an upside-down tree. The trunk of the *technology tree* describes the final assembly of a good or service (see Text Box 5.1). Each tree branch is a subprocess with its own production function, or technology. The branches are called *nested production functions* because these smaller production processes are "nested" within the larger process of producing the final product. The twigs describe every input into the production process; each sprouts from the subprocess in which it is nested.

Text Box 5.1 Three variables that describe the quantity of output

Throughout this book, we use three different variables to describe the quantity of output.

QO_a *is the output quantity of a production activity, a.* A producer may make several different kinds of commodities. For example, Apple produces both phones and computers. This variable describes the total, combined output of a production activity and includes all commodities in its product mix.

$QCA_{c,a}$ *is the quantity of each commodity that is produced by a production activity.* For example, it is the quantity of phones that Apple produces or the quantity of computers that it produces.

QC_c *is the total quantity of a commodity produced by all activities combined.* For example, it is the total quantity of electricity produced in a country by all energy producers, including nuclear, coal, and solar providers.

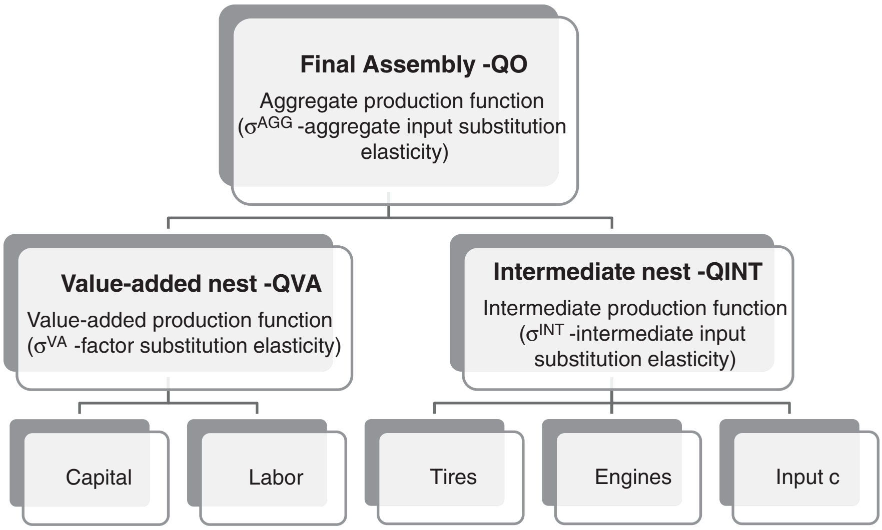


Figure 5.1 Technology tree for a nested production function

Figure 5.1 shows a technology tree that is typical of those assumed in standard CGE models. Notice how the figure shows two levels of the production process. At the bottom level are two nested production functions. One nest describes how the producer can combine quantities of labor and capital (and any other factor endowments) into a value-added bundle (QVA) that contains factor inputs. The second nest describes how quantities of intermediate inputs, such as tires and engines, are combined to form an intermediate bundle (QINT). Moving above, an aggregate production function describes how the producer combines the value-added bundle with the intermediate bundle to make the final product (QO), such as an auto.

A nested production function is a useful approach when the technologies of the component processes are substantially different. For example, an automaker may find that it is easy to substitute between workers and mechanized assembly equipment within the value-added bundle but that it is difficult to substitute more tires for one less steering wheel within the intermediate bundle. Nested production functions allow the modeler to describe realistically the different ways that subsets of inputs are combined with each other during the production process.

An additional advantage of nesting is that the selection of input combinations within each nested process is independent of the contents of other nests. This assumption about their separability simplifies the database and the solution of a CGE model considerably. Instead of making pairwise decisions among all inputs, the producer is instead assumed to make one decision about the contents of the intermediate bundle, a separate decision about the contents of the value-added bundle, and another decision about the ratio of the intermediate and value-added bundles in the final product. Changing the ratios of inputs within the intermediate bundle will not influence the ratios of inputs within the value-added bundle. And, only three substitution elasticity parameters are required: one within each nest and one at the final assembly stage.

The specific type of production function, such as a Cobb-Douglas or Constant Elasticity of Substitution (CES), that is assumed in each nest and for the final assembly, is determined by the modeler. A standard approach in CGE models is to assume functions or elasticity parameters that allow some substitution among factors of production in the value-added nest, but fixed input-output ratios in the intermediate nest and between the valued added and intermediate bundles. Later in this chapter, we describe in more detail the different types of production functions and their assumptions about input substitutability.

Sometimes, modelers choose to add additional nests to the production technology. Computable general equilibrium-based analyses of energy use and climate change, for example, usually add one or more levels of nesting to the value-added nest. Although the specific nesting structure varies across models, in general, these models include nests that describe the substitution possibilities between labor, capital, and a bundle of energy inputs. Additional nests then describe substitution possibilities among different types of energy within an energy bundle, such as coal, oil, or gas. An advantage of adding nests is that it allows the modeler to describe subsets of inputs as complements, instead of substitutes, within the production process. Technical Appendix 5.1 provides a more detailed discussion of that point in a description of nesting in CGE models focused on climate change mitigation.

Intermediate Input Demand

Now we are ready to study the producer's economic decisions, focusing on one nest at a time. We start with the demand for intermediates, which has the simplest technology. This is because many CGE modelers adopt production functions or elasticity values that assume that intermediate inputs are used in fixed proportions to produce the bundle of intermediate goods. This means that, for any given input bundle, the producer has no ability to substitute more of one intermediate input for another.[2]

[2] This treatment is widely used in CGE models. However, some models provide the modeler with the flexibility to define a nonzero elasticity of substitution between intermediate inputs. In this case, the technology in the intermediates nest is similar to that in the value-added nest, described in the next section.

For example, the production of an auto requires a bundle of intermediate inputs like rubber tires, engines, and mirrors. Furthermore, these inputs are ordinarily used in a fixed ratio. For each auto, the intermediate bundle must include four tires, one engine, and three mirrors. If the producer wishes to make another auto, he needs another bundle of auto parts – adding another wheel without an additional engine and so on would not increase the number of intermediate bundles. This technology is called a *Leontief fixed proportions production function*. It is named after Wassily Leontief, an economist well known for his work on interindustry linkages in an economy. This type of intermediate production function offers a reasonable description of many intermediate production activities. Yet, it is a strong assumption. Changing it to allow producers some flexibility to substitute among inputs, such as coal and natural gas, has been one of the main advances made in CGE-based models focused on climate change (see Text Box 5.2).

A Leontief production function is depicted graphically as an L-shaped curve, QINT, in Figure 5.2. The curve is an *isoquant* that shows all combinations of two composite (imports plus domestic) intermediate inputs – in this case, tires (QFA_T) and engines (QFA_E) – that can be used to produce a bundle of intermediate car parts of quantity $QINT^1$. The further an isoquant lies from the origin, the higher the number of intermediate bundles it represents. You can see from the isoquant's L-shape that increasing the amount of either tires or engines without increasing the quantity of the other input will not change the quantity of intermediate input bundles from level $QINT^1$.

The straight lines in Figure 5.2, C, are *isocost* lines. They show all combinations of engines and tires that cost the same total amount. The closer an isocost line lies to the origin, the lower is the total cost or outlay on tires and

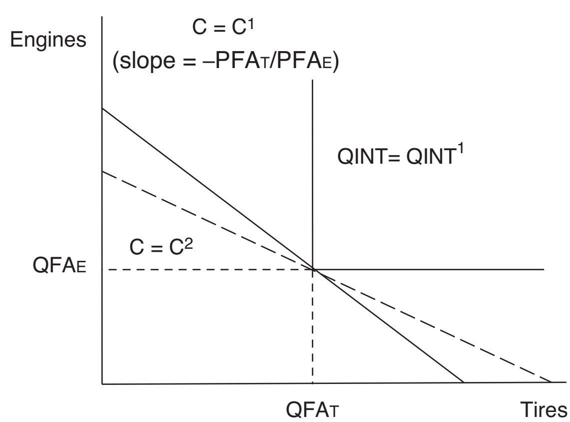


Figure 5.2 Nested production function – intermediate input demand

Text Box 5.2 Climate change, emissions taxes, and trade in the CIM-EARTH model

"Trade and Carbon Taxes" (Elliott et al., 2010b).

What is the research question? Climate change is a function of global CO_2 emissions, and the most efficient strategy to control them is to impose a uniform carbon tax wherever emissions occur. However, this approach presents a free-riding problem because nations have an incentive to not comply while gaining the benefits of reduced emissions elsewhere. How will carbon tax policies perform, given international trade, if countries adopt different carbon emissions tax rates?
What is the CGE model innovation? The researchers use CIM-EARTH, a recursive-dynamic, global CGE model with the GTAP v.7.0 database. The model places energy in the value-added nest and extends that nest to describe substitution possibilities among energy sources in the production of goods and services.
What is the model experiment? The authors define four scenarios: (1) the baseline time path is business as usual, with no carbon tax; (2) a carbon tax is applied uniformly across the globe; (3) a carbon tax is applied to emissions only in Kyoto Protocol Annex B countries (who have pledged to cut emissions); and (4) a carbon tax is applied to Annex B countries in combination with complete border tax adjustments that rebate their emissions taxes on exported goods and impose tariffs on emissions embodied in their imported goods. Carbon taxes in the last three scenarios range from $4 to $48 per ton of CO_2.
What are the key findings? A carbon tax applied worldwide at a uniform rate of $48 per ton of CO_2 reduces emissions by 40% from 2020 levels. Increasing tax rates yield ever smaller reductions in emissions because the least-costly carbon-reducing steps are taken first. A carbon tax imposed only in Annex B countries generates little more than one-third of the emission reduction achieved with a uniform, global tax, due in part to substantial "carbon leakage" as production shifts to nontaxing countries. With full import and export border tax adjustments, carbon leakage is halted.

engines. The slope of an isocost line describes the ratio of input prices – in this case, the ratio of the tire price to the engine price, $-PFA_T/PFA_E$. The producer minimizes the cost of producing the input bundle $QINT^1$ when he operates at a point of tangency between the $QINT^1$ isoquant and the lowest attainable isocost line, which is C^1 in Figure 5.2, using the input bundle QFA_E and QFA_T.

The important property of a Leontief production function for CGE modelers to remember is that when relative input prices change, there is no

Table 5.3 *Changes in quantities of the intermediate bundle and intermediate inputs when relative input prices change (% change from base)*

	Production activity		
	Agriculture	Manufacturing	Services
Intermediate input bundle (*qint*)	1.04	–0.12	0.01
Intermediate inputs (*qfa*)			
Agriculture	1.04	–0.12	0.01
Manufacturing	1.04	–0.12	0.01
Services	1.04	–0.12	0.01

Source: NUS333 model.

change in the lowest-cost ratio of inputs for any level of QINT. Adding more of just one of the inputs would increase costs without increasing the number of intermediate bundles produced because the inputs must be used in fixed proportions. For example, assume that the price of tires falls relative to the price of engines, shown by the isocost line, C^2. The lowest-cost ratio of tires and engines remains unchanged. Because the ratio of input quantities does not change when input price ratios change, we say that the *elasticity of intermediate input substitution elasticity*, σ^{INT}, is zero.

We demonstrate how a Leontief intermediate production function determines input demands in a CGE model by carrying out an experiment that changes relative intermediate input prices. We use the GTAP NUS333 model to run an experiment that imposes differing domestic sales tax rates of 5% on agricultural inputs, 10% on manufactured inputs, and 2% on services inputs used in all US production activities. Results demonstrate that demand for all inputs changes by the same proportion. That is, as the quantity of QINT bundles change in each activity, there is no change in the ratios of intermediate inputs within the QINT bundles. The original proportions remain the least-cost mix of intermediate inputs despite the relative change in their prices.

Factor (Value-Added) Demand

Computable general equilibrium models specify a *valued-added production function* to describe the technology in the nest in which producers assemble their composite bundle of value added (i.e., the combination of labor, capital, and other factors used in the final assembly stage). Most CGE modelers assume that producers have some flexibility with regard to the factor endowment quantities in their value-added bundle. For example, although the assembly of an auto requires fixed proportions of four tires and one engine,

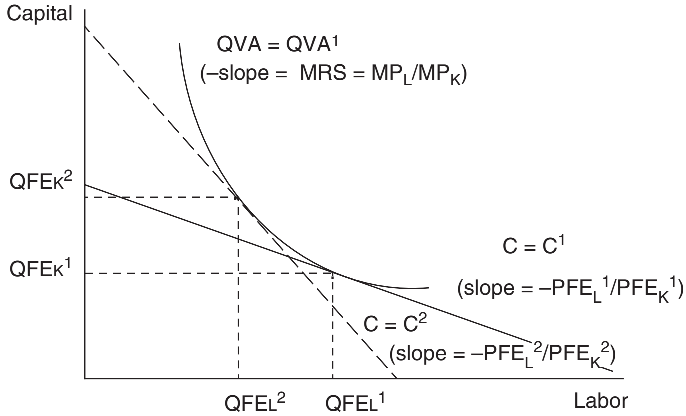


Figure 5.3 Nested production function – factor demand

the mix of capital and labor used to assemble the parts into an auto is somewhat variable. The assembly process can use a lot of manual labor and little machinery, or the process can be highly mechanized, depending on the relative cost of workers and equipment.

Figure 5.3 illustrates how producers choose the cost-minimizing factor ratio for a given quantity of value-added bundles. In the figure, an isoquant, QVA, describes the value-added production function. It depicts all technologically feasible combinations of two factors – capital, QFE_K, and labor, QFE_L – that can be used to produce the same value-added bundle, such as QVA^1. The negative of the slope at any point along the isoquant describes the marginal rate of substitution (MRS) between the two inputs. The MRS measures the amount by which capital could be reduced if the quantity of labor is increased by one unit, while keeping QVA constant. We can also express the MRS as the ratio of the marginal product of labor to the marginal product of capital, or MP_L/MP_K in the production of QVA.[3]

To visualize these concepts, assume that the producer described in Figure 5.3 moves downward along the isoquant, using less capital and more labor in the production of the value-added bundle. Notice that as the ratio of capital to workers declines, a smaller quantity of capital can be substituted for each additional worker to produce the same QVA. As an example, assume that the automaker moves downward on its isoquant, employing more labor and using less assembly equipment. As an increasing number of workers shares fewer assembly tools, each additional worker becomes a less productive input to the value-added requirements of an auto, relative to an additional

[3] This is because, if d refers to a marginal change in quantity, then the slope at any point on the isoquant is $-dQFE_K/dQFE_L$, which is the rise over the run. Because the marginal product of L is $dQVA/dQFE_L$ and of K is $dQVA/dQFE_K$, then the ratio $MP_L/MP_K = (dQVA/dQFE_L)/(dQVA/dQFE_K) = dQFE_K/dQFE_L$, which equals the MRS.

unit of equipment and tools. That is, as the QFE_K/QFE_L ratio falls, so does the inverse ratio of their marginal products, MP_L/MP_K.

The isocost line, such as C^1 in Figure 5.3, describes all combinations of labor and capital that can be purchased by a production activity for the same total cost. Its slope depicts the relative wage and capital rent at initial factor prices, $PFE_L{}^1/PFE_K{}^1$. The producer minimizes the cost of producing QVA^1 at the tangency between the isoquant and the lowest achievable isocost line, C^1, using input ratio $QFE_L{}^1/QFE_K{}^1$. At their tangency, the ratio of marginal products is equal to the price ratio: $MP_L/MP_K = PFE_L{}^1/PFE_K{}^1$. Rearranging (by multiplying both sides by $MP_K/PFE_L{}^1$) produces $MP_L/PFE_L{}^1 = MP_K/PFE_K{}^1$. Input costs are minimized for a given QVA when the marginal product from an additional dollar spent on labor is equal to the marginal product from an additional dollar spent on capital inputs. If not, producers will spend more on the more productive factor input and less on the other input, until their marginal products per dollar spent are equalized.

Now consider how the cost-minimizing factor input ratio changes if there is an increase in wages relative to capital rents. The rise in the wage-rental price ratio is shown in Figure 5.3 by the dotted isocost line, C^2, with slope $-PFE_L{}^2/PFE_K{}^2$. As workers become relatively expensive, the producer can reduce costs by substituting them with machinery. In Figure 5.3, inputs $QFE_L{}^2$ and $QFE_K{}^2$ become the cost-minimizing ratio of capital to labor in the production of QVA^1.

The *elasticity of factor substitution*, σ^{VA}, describes the relationship between changes in the capital-labor input ratio and the inverse ratio of their marginal products – that is, the curvature of the isoquant. When σ^{VA} is very large, the technology is flexible, and the isoquant becomes flatter. In this case, even large changes in factor intensities have little effect on factors' marginal products. Producers can therefore make large shifts in their capital-labor ratios to take advantage of changing relative factor prices without experiencing a sizeable change in either input's marginal product. For example, if wages fall relative to rents, an automaker could hire more labor and use far fewer tools without causing labor productivity to decline relative to that of assembly equipment.

Computable general equilibrium modelers usually express σ^{VA} in terms of factors' prices instead of their marginal products, but the two concepts are equivalent. Parameter σ^{VA} is the percentage change in the quantity ratio of capital to labor given a percentage change in the wage relative to capital rents. In the limit, when σ^{VA} approaches infinity, factors are perfect substitutes in the production process, and the isoquant is a straight line. In this case, a decrease in one input can always be offset by a proportional increase in another input without affecting either input's marginal product. A change in relative factor prices will therefore lead to large changes in factor proportions. At the other extreme, a parameter value of zero describes a value-added isoquant with an L-shape. With this technology, capital and labor are Leontief complements that must be used in fixed proportions. A change in relative factor prices does not result in a change in the factor ratio. For most industries, substitutability is likely to be relatively limited. Reviews of the econometric literature on this parameter by Balistreri et al. (2003) and Koesler and Schymura (2012) found that the range of estimates clustered around values greater than zero but less than one.

Computable general equilibrium modelers are usually restricted to specifying one elasticity parameter for each industry that governs all pairwise substitutions among the factors of production in the model. Many CGE models use a *CES* value-added production function to describe the value-added production technology, similar to the CES utility function studied in Chapter 4. It derives its name from the fact that the factor substitution elasticity remains constant throughout an isoquant (i.e., at any given factor input ratio) and at any level of output.

The most important thing to remember about a value-added production function is that the ratio of factor quantities can change when the relative prices of factors change. Note, too, that if we allow substitution of one primary factor for another in the production process, the input-output coefficients for the factors, shown in Table 5.2, also change. This is not the case for the input-output coefficients for intermediate inputs when their ratios are assumed to be fixed (the "Leontief fixed proportions").

To illustrate these value-added concepts, we use the NUS333 model to explore the effects on factor input ratios when the cost of labor increases relative to the cost of capital. Our experiment is a five-percentage-point increase, from about 15% to 20%, in the tax on labor employed in the US manufacturing activity. We compare the effects of the tax when we assume a low value of the factor substitution elasticity of 0.8 in manufacturing versus a high parameter value of 1.2, holding the quantity of value-added bundles constant (i.e., remaining on the same isoquant). You can visualize this experiment in Figure 5.3 by imagining that we are observing the producer substituting between the two inputs along (a) a highly curved isoquant in the case of the low substitution elasticity value, and (b) a flatter isoquant in the case of a high elasticity value. Our model results illustrate that the larger the elasticity parameter value, the larger is the producers' shift toward capital as the relative cost of labor costs rises (Table 5.4). Notice, too, that the increase in wages relative to rents does not differ much between the two cases. This is because, when production technology is more flexible, even a large increase in the capital-labor quantity ratio causes only a small change in the productivity (and price) of each input.

Table 5.4 *Factor substitution effects of a five-percentage-point rate increase in the labor tax in US manufacturing, with different factor substitution elasticities, holding the quantity of the value-added composite bundle constant (% change from base)*

	Manufacturing activity	
	Capital-labor ratio	Wage-rental ratio
Elasticity of factor substitution = 0.8	2.99	3.76
Elasticity of factor substitution = 1.2	4.25	3.56

Notes: Percent change in the capital-labor ratio at constant QVA is approximately ($qfe_K - qva_{mfg}$)–($qfe_L - qva_{mfg}$). Percent change in the wage-rental ratio is approximately ($pfe_L - pfe_K$).
Source: NUS333 model.

Combining Intermediate Inputs and Factors

At the top level of the assembly process, the producer combines the bundle of intermediate inputs with the bundle of factors to produce the final output. This aggregate technology is described by a production function in which the two bundles can be substituted according to an *elasticity of aggregate input substitution*, σ^{AGG}. In practice, this final stage of production is usually depicted as a Leontief fixed proportions technology, with σ^{AGG} assumed to equal zero. For any level of output, QO, a fixed ratio of intermediate and value added bundles is required. The addition of another bundle of intermediates without also adding a bundle of factors (or vice versa) will not increase output.

Input Prices and Level of Output

Until now, we have explained how the cost-minimizing producer can (or cannot) substitute among inputs as their relative prices change to produce a given level of output, and we have remained on the same isoquant. However, in our general equilibrium framework, a change in input prices will usually lead to a change in output prices and in consumer demand. As a result, the level of output can change, too, whenever input prices change. The producer may shift to a higher output level, on an outer isoquant, or reduce his output, on an inner isoquant. These output changes will also affect the quantities of inputs required, although not their ratios.

First, let's consider in more detail how a change in the price of an input works through consumer demand in the CGE model to affect the level of output. Labor union concessions, for example, might lower wage costs for automakers. If their technology allows it, automakers will substitute more labor for less equipment in their production process at any given production

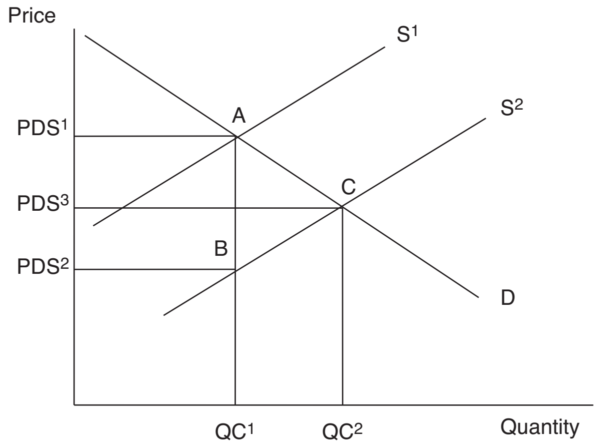


Figure 5.4 Input prices and level of output

level. The more that producers can substitute toward labor (i.e., the larger is the elasticity of factor substitution), the lower their production costs become. As production costs fall, then in perfectly competitive markets, so will the producer sales price and the consumer auto price. This point is illustrated in Figure 5.4. In the initial equilibrium, at point A, quantity QC^1 is the aggregate supply of a commodity, from all production activities, that is sold at the producer sales price PDS^1. In the absence of retail taxes, the producer sales price is equal to the consumer price. A reduction in the cost of an input is described by the downward shift in the supply curve from S^1 to S^2, with the same quantity now produced at a lower sales price, PDS^2, and shown by point B. Depending on consumer preferences, the fall in the price of the good will stimulate consumer demand. In the new equilibrium, an increase in the quantity demanded causes output to increase to quantity QC^2 at the producer price PDS^3, at point C. This increase in output, in turn, leads to an increase in producer demand by the same proportion for all inputs. That is, a 10% increase in output will lead to a 10% increase in demand for both workers and capital equipment, as well as for all intermediate inputs.

In Figure 5.5, we show more specifically how the effects of a change in one input price – in this case, a fall in capital rent – on demand for both factor inputs by a production activity can be decomposed into *substitution effects* and *output effects*.

(The alert student will find similarities between this exposition and our discussion of income and substitution effects on consumer demand in Chapter 4.) In Figure 5.5, QO^1 is the activity's initial level of output, which is produced using the capital/labor factor input ratio $QFE_K{}^1/QFE_L{}^1$. You may notice that we have drawn the figure to show capital and labor as inputs

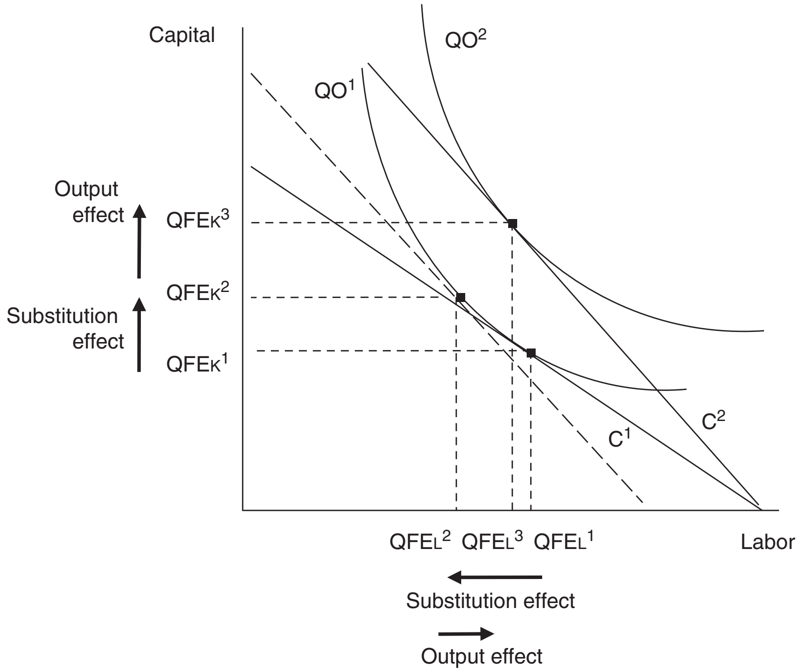


Figure 5.5 Input demand and output levels

into total output, QO, instead of QVA, the value-added bundle. This is possible because we assume that the top of the nest requires a fixed proportion of value-added bundles in the production process.

The slope of the isocost line, C^1, describes the activity's initial ratio of wages to rents, $PFE_L/PFE_K{}^1$. A fall in the price of capital is shown as isocost line C^2, with slope $-\,PFE_L/PFE_K{}^2$. A decline in the cost of capital lowers the cost of production and leads to higher demand for the final product. Output increases to QO^2, using factor inputs quantities of $QFE_K{}^3$ and $QFE_L{}^3$.

To measure the substitution effect, imagine that the producer continues to produce QO^1 but purchases inputs at the new factor price ratio, shown as the dotted line drawn parallel to isocost line C^2. The substitution effect measures the movement along the QO^1 isoquant to the tangency between the isoquant and the new isocost line. As the relative price of capital falls, more capital and less labor are used in the production of QO^1. This change in the factor ratio, from $QFE_L{}^1$ and $QFE_K{}^1$ to $QFE_L{}^2$ and $QFE_K{}^2$, is the substitution effect. The movement from $QFE_L{}^2$ and $QFE_K{}^2$ to $QFE_L{}^3$ and $QFE_K{}^3$ is the output effect. It measures the change in factor demand due to the change in production quantity from QO^1 to QO^2, holding the factor prices constant at the new price ratio. The expansion of output leads to a proportionate increase in demand for both inputs.

Table 5.5 *Effects of a fall in the price of capital relative to labor on input demand in US services industry (% change from base)*

Input	Substitution effect	Output effect	Input demand
Intermediate inputs			
Agriculture	0.0	2.1	2.1
Manufacturing	0.0	2.1	2.1
Services	0.0	2.1	2.1
Factor inputs			
Capital	7.6	2.1	9.7
Labor	–2.8	2.1	–0.7

Notes: The experiment is a 10% increase in the US capital stock. The substitution effect for intermediate inputs is approximately *qfa* – *qo* and for factor inputs is approximately *qfe* – *qo*. The output effect is variable *qo* and demand for intermediates and for factor inputs are *qfa* and *qfe*, respectively.
Source: NUS333 model.

To explore these concepts in a CGE model, we use the NUS333 model to run an experiment in which capital rents fall relative to wages. The experiment assumes a 10% increase in the US capital stock, which reduces economy-wide capital rents by 6.8% and increases US wages by 0.3%. The percentage rise in the wage/rental ratio is therefore 0.3 – (–6.8) = 7.1.

For brevity, we describe the results only for the US services industry. The lower price of capital reduces the cost of the value-added bundle used in the production of services. In the new equilibrium, the household consumer price of domestically produced services (PPD) declines by 1.6%, consumer demand for these services (QPD) increases by 1.8%, and their production (QO) rises by 2.1%.

The effects on service's intermediate and factor inputs are reported in Table 5.5. The output effect increases demand for all intermediate and factor inputs by the same proportion as the increase in services output – 2.1%. In the intermediate bundle, the substitution effects are zero because we assume a Leontief intermediate production technology with fixed input-output ratios. In the value-added bundle, the substitution effect results from an increase in the wage-rental ratio, which causes the production of services to become more capital intensive. In total, the combined substitution and output effects stimulate service's demand for capital. In the case of labor, the negative substitution effect on labor demand outweighs the positive output effect and results in a decline in services' demand for labor.

Export Supply

In CGE models, an increase in price in the export market relative to that in the domestic market usually leads a producer to shift sales of his product toward exports, and vice versa. However, in some CGE models, output is described as a composite commodity composed of the variety that is exported and the variety that is sold domestically. The two varieties are assumed to be two different goods, and the producer may not be able to readily transform his product line between them. Perhaps electric clocks require different electrical plugs when used in different countries, or the production process for beef may need to meet different consumer safety standards in each market. Computable general equilibrium models in which goods are differentiated by destination markets include an *export transformation function* to describe the technological flexibility of producers to transform their product between export and domestic sales.[4]

We depict the function as a *product transformation curve*, shown in Figure 5.6. It shows all technologically possible combinations of the export, QXW, and domestic, QDS, varieties that can be made by a production activity from a given level of resources and that comprise its composite output quantity, QO. Perhaps QXW and QDS are European and American styles of the electric clocks, and QO is the total supply of electric clocks. The farther the transformation curve, QO, lies from the origin, the larger is the quantity of production of the composite output.

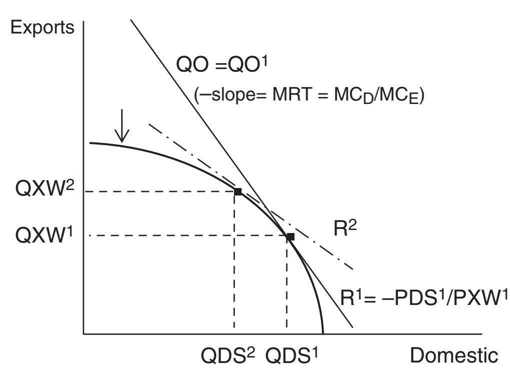


Figure 5.6 Export transformation function and a change in relative prices

[4] An early example of an export transformation function in a CGE model is the single-country Cameroon model developed by Condon et al. (1987). Others with this export treatment include the ERS-USDA CGE model (Robinson et al., 1990), the IFPRI standard model (Lofgren et al., 2002), the GLOBE model (McDonald et al., 2007), and the TUG-CGE model (Thierfelder, 2009).

The most obvious difference between this function and the value-added production function that we have already studied is that the export transformation curve is drawn concave to the origin, while isoquants are convex. As we will show, its concave shape means that an increase in the price of QDS or QWE *increases* its use in the production of QO, whereas with the convex isoquant, an increase in an input price *decreases* its use.

The export transformation curve is otherwise similar in many respects to the value-added isoquant. The negative of its slope at any point describes the *marginal rate of transformation* (MRT), which measures the producer's ability to substitute QXW for QDS in the production of a given level of output. We can also express the MRT as the ratio of the marginal costs of QDS and QXW in the production of QO, or MC_D/MC_E.

You can visualize why the two expressions for the curve's slope are equivalent by imagining a point on the curve in Figure 5.6 at which production is almost entirely specialized in exports. As the producer shifts toward domestic sales, the value of MRT becomes larger, because more units of the export must be given up for each additional unit of the domestic variety that is produced. This is because the inputs that are most productive when used in domestic goods, and the least productive when used in exports, are the first to be shifted toward the domestic variety as its output increases. As output of the domestic good expands further, it draws in inputs that are less and less productive and export production retains only its most productive inputs. Therefore, the marginal cost of producing the domestic good rises and the marginal cost of producing the export falls as production shifts toward QDS.

The line in the figure, R^1, with slope $-PDS^1/PXW^1$, is an *isorevenue* line, where PDS is the producer's sales price of the good in the domestic market and PXW is the *fob* export sales price. The isorevenue line shows all combinations of exports and domestic varieties that generate the same amount of producer revenue from the sale of the composite output. The further this line from the origin, the higher is producer revenue.

The producer's problem is to choose the ratio of export and domestic varieties for a given QO that maximizes his revenue – shown by the achievement of the highest attainable isorevenue line on any given product transformation curve. In Figure 5.6, revenue from output QO^1 is maximized at output ratio QXW^1/QDS^1. At this point, the transformation curve and the isorevenue line are tangent and $MC_D/MC_E = PDS^1/PXW^1$. Rearranging (by multiplying both sides by MC_E/PDS^1) revenue is maximized where $MC_D/PDS^1 = MC_E/PXW^1$. That is, each additional dollar of revenue from exports and domestic production incurs the same marginal cost. If not, the producer will produce more of the variety whose marginal cost is

Table 5.6 *Effects of a 5% increase in the world export price of US manufactured exports on the production of exported and domestic varieties (% change from base)*

	Export transformation elasticity	
US manufacturing	–0.8	–4.0
Export/domestic production ratio	2.7	5.8
Total manufacturing output	0.1	0.6

Source: TUG-CGE model with NUS333 database.

lower, and less of the variety whose marginal cost is higher, relative to its price.

Assume that the relative price of exports increases, as shown by the dotted line R^2 in Figure 5.6. The revenue-maximizing producer will increase the ratio of exports to domestic sales in output QO^1, to ratio QXW^2/QDS^2. The size of this quantity response depends on the curvature of the transformation curve, which is defined by the *elasticity of export transformation*, σ^X. The parameter defines the percentage change in the quantity ratio of exports to domestic goods given a percentage change in the ratio of the domestic to the export sales price for a given level of output. If the varieties are perfect substitutes in the composition of QO, then the transformation parameter (always expressed as a negative value) has an absolute value that approaches minus infinity and the transformation curve becomes linear. In this case, a small change in the price ratio will result in a large change in the product mix. As the two products become less substitutable in the production of QO, the absolute value of σ^X approaches zero.

Computable general equilibrium models that describe export transformation generally assume a constant elasticity of transformation (CET) function to describe the producer's decision making.[5] The CET function derives its name from the fact that the export transformation elasticity is constant throughout the product transformation curve, and at any level of output.

We illustrate the properties of an export transformation function in a CGE model by running an experiment that increases the world export price of US manufactured goods by 5%. We use the NUS333 database in the TUG-CGE model, a single-country CGE model developed by Thierfelder (2009) that contains a CET export transformation function.[6] We compare the effects of the price shock on the quantity ratio of exports to domestic goods using two different values of the export transformation elasticity parameter. As the parameter's absolute value becomes larger and the transformation technology

[5] See Powell and Gruen (1968) for a detailed presentation on the CET function.
[6] World export and import prices are assumed to be exogenous variables in this single-country CGE model.

becomes more flexible, a 5% increase in the world export price elicits a larger export shift in the ratio of exports to domestic sales in the output mix (Table 5.6). Notice, too, that total output increases more when producers are relatively flexible in shifting toward export opportunities. Because the inputs are relatively suitable for use in the production of either variety, the marginal cost of producing additional exports does not rise as fast as in the low-elasticity case.

Supply with a Non-diagonal Make Matrix

An increasing number of CGE models, including the GTAP model that we use for demonstration, enables modelers to describe "non-diagonal" make matrices. The make matrix is comprised of the domestic commodity columns and production activity rows in the SAM. These cells describe how domestically produced commodities in the model are "made" from the output of one or more production activities.

When there is a one-to-one correspondence between activities and commodities, the make matrix is diagonal. The output of each production activity is reported along the diagonal, and there are zero values in the off-diagonal cells. This is because each activity sells its entire output to the related domestic commodity account. For example, in our NUS333 SAM, the agriculture activity (row account) produces only agricultural output that is sold in its entirety to the domestic AGR commodity (column) account.

A non-diagonal make matrix allows the modeler to depict one production activity that makes two or more commodities, such as an agricultural production activity that produces both food and feed commodities. The modeler also has the flexibility to describe two or more production activities producing the same commodity, such as agriculture and the coal industry both producing energy. The SAMs used in these models are described in detail in Chapter 3. Here, we discuss the economics of supply behavior in a model with a non-diagonal make matrix. However, the discussion will be brief because we have already examined similar types of decision-making in a CGE model.

First, let's consider the case of a single production activity that makes two commodities, such as the agricultural producer shown in Figure 5.7, who supplies both feed and food. The producer has to decide how much of each commodity to produce in a given level of their total output (QO). They allocate their productive resources across the commodities in the same way that a producer allocates resources between the production of exports and domestic sales, as we described in the "Export Supply" section. Imagine that the product transformation curve shown in Figure 5.6 instead describes the

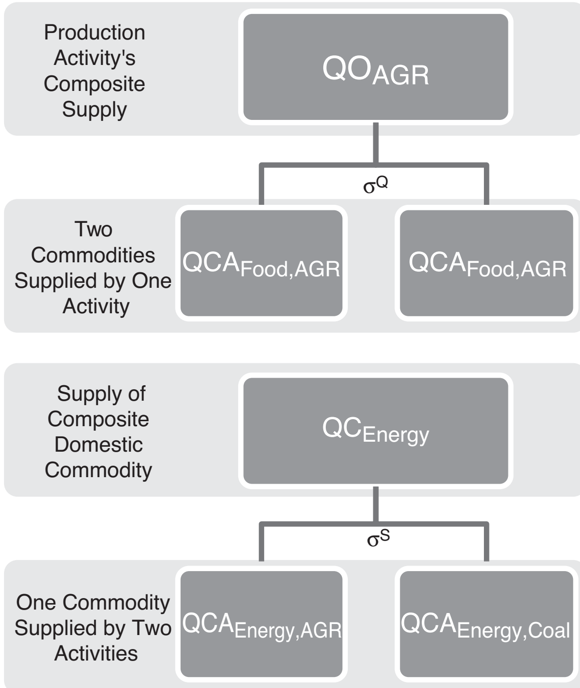


Figure 5.7 Supply behavior in a model with a non-diagonal make matrix

activity's allocation of productive resources between the output of two commodities *c* (QCA_c) and *z* (QCA_z). If the ratio of the sales price of commodity *c* (PS_c) rises relative to that of commodity *z* (PS_z), a profit-maximizing producer will increase the quantity ratio of good *c* to good *z* in the output mix.

The magnitude of the change in the ratio of commodities for a given quantity of output depends on the curvature of the product transformation curve, which is defined by the *elasticity of commodity output transformation*, σ^Q. The larger the absolute value of the elasticity parameter (a transformation elasticity is expressed as a negative), the more easily the producer can switch among commodities in a given output mix, so the larger is the change in the commodity output ratio as relative commodity prices change. Computable general equilibrium models that describe activities with multiple products typically assume a CET production function, so that the value of parameter σ^Q is the same for all ratios of commodity output at all levels of total activity output.

When more than one production activity produces the same commodity, the producers' market shares may change given a change in their relative supply prices. For example, both agriculture and the coal industry produce energy – the former from corn and switchgrass, and the latter by mining for coal. The market allocation between the two sources for a given quantity of energy supply is identical to the consumer decision about sourcing a given quantity of consumption from domestic versus import suppliers in the Armington import aggregation function, described in Figure 4.6. If we assume that the axes in that figure are now labeled Agriculture and Coal, instead of Imports and Domestic, we can use the same principles to describe the sourcing decision in the case of a non-diagonal make-use matrix. For a given quantity of a domestic commodity supplied from all producers combined (QC), the quantity ratio supplied by each activity *a* and z (QCA_a/QCA_z) will depend on their relative supply prices (PCA_z/PCA_a) and the *elasticity of commodity sourcing substitution*, σ^S. The larger the value of the elasticity parameter, the greater is the shift in market shares as relative supply prices change. Computable general equilibrium models usually assume a CES function to describe this type of allocation so that the value of parameter σ^S is the same for all ratios of sourcing at all levels of total domestic supply.

Summary

In this chapter, we examined production data in the SAM and producer behavior in the CGE model. Data in the SAM describe each industry's production technology, reporting its use of intermediate and factor inputs and any taxes paid or subsidies received. We used the SAM's production data to calculate input-output coefficients that describe the units of intermediate and factor inputs required per unit of output. Input-output coefficients are useful for characterizing production activities' intermediate and factor intensities, comparing input intensities across industries, and describing interindustry linkages from upstream to downstream industries.

Computable general equilibrium models use nested production functions. These break down the production technology into subprocesses that, when diagrammed, look like an upside-down tree. The trunk is the assembly of the final good, its branches are the subprocesses that are nested within the overall production process, and its twigs are the inputs used in each subprocess. Each subprocess and final assembly has its own production technology, cost minimization equation, and input substitution elasticity parameter. In the intermediates' nest, producers decide on the cost-minimizing levels of intermediate inputs, and in the value-added nest, producers choose the cost-minimizing levels of factor inputs. Some CGE models include export transformation functions, which describe how producers allocate their output between exports and sales in the domestic market. Computable general equilibrium models that have non-diagonal make matrices describe producers' transformation of their output among different commodities, and their market shares in total domestic supply.

Key Terms

Constant elasticity of substitution (CES) function
Constant elasticity of transformation (CET) function
Diagonal make matrix
Downstream industries
Elasticity of aggregate input substitution
Elasticity of commodity output transformation
Elasticity of commodity sourcing substitution
Elasticity of export transformation
Elasticity of factor substitution
Elasticity of intermediate input substitution
Factor intensity
Input-output coefficient
Intermediate input
Intermediate input intensity
Isocost
Isoquant
Isorevenue
Leontief fixed-proportion production function
Marginal rate of transformation
Nested production function
Non-diagonal make matrix
Output effect on input demand
Primary factor inputs
Product transformation curve
Production function
Substitution effect on factor demand
Technology tree
Upstream industries
Value-added
Value-added production function

PRACTICE AND REVIEW

1. Use the US SAM (in Appendix A), to describe the production technology of the US manufacturing sector:

Total intermediate inputs ______________________________
Total factor payments ______________________________
Total tax (and subsidy) ______________________________
Value-added ______________________________
Gross value of output ______________________________

2. Data in exercise Table 5.7 describe the inputs purchased by manufacturing and services for their production process. Calculate the input-output coefficients for the two industries and report them in the table. Answer the following questions:
   a. In which factor is the production of manufacturing most intensive?
   b. In which factor is the production of services most intensive?
   c. Which industry is more intensive in the use of services?
   d. Describe the upstream and downstream role of manufacturing.

3. Assume that you are CEO of a small firm. The introduction of a universal health insurance program has eliminated your health premium payments and lowered your cost per worker. Using a graph that describes your cost-minimizing choice of capital and labor shares in the value-added bundle, explain how the new program will change the labor-capital ratio in your production process, for a fixed level of value-added.
4. Consider the following results reported in Table 5.8, from a model with a nested production function. Can you infer from the results the percentage change in

Table 5.7 *Practice and review – input–output coefficients*

	Inputs into production		Input-output coefficients	
	Manufacturing	Services	Manufacturing	Services
Labor	12	12		
Capital	8	18		
Manufacturing	10	50		
Services	20	20		
Gross value of output	50	100		

Table 5.8 *Practice and review – effects of a change in factor price on an industry's input demand*

Input	Substitution effect	Output effect	% Change in input demand
Agriculture	0	3.5	3.5
Manufacturing	0	3.5	3.5
Services	0	3.5	3.5
Capital	–4	3.5	–0.5
Labor	6	3.5	9.5

the industry's production, the possible types of production functions used in each nest, and the likely change in relative factor prices that accounts for these results?

Technical Appendix 5.1: Inputs as Substitutes or Complements – Energy Nesting in CGE Models of Climate Change Mitigation

The production functions used in CGE models describe inputs as substitutes or Leontief complements in the production process. However, in some cases, it may be more realistic to describe some inputs as true complements in the sense that an increase in one input price causes demand for the other input to fall. The presence of complementary inputs is especially important in the analysis of climate change mitigation. Computable general equilibrium modelers studying this subject typically examine whether there are cost-effective ways to encourage a substitution away from particularly dirty sources of energy to cleaner sources that have less of an environmental impact. Their analyses usually allow some degree of substitutability between capital and energy, yet characterize these two inputs as overall complements, at least in the short run. Capital-energy substitution assumptions are important because the estimated costs of reducing carbon emissions are lower the more flexible are production technologies.

Computable general equilibrium models used for climate change mitigation analysis usually move energy from the intermediate input bundle into the value-added (VA) nest. Some models, including the example we study in this appendix, combine capital (K) and energy (E) into a composite bundle, KE, that is combined with labor in the VA nest, as illustrated in Figure 5.8.

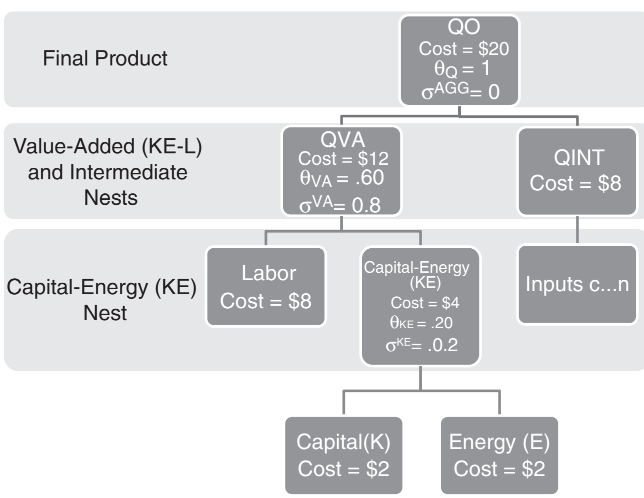


Figure 5.8 Technology tree with a KE-L nest

Table 5.9 *Within-nest and overall capital-energy substitution parameters*

	Substitution parameter			Share in total cost of production			Overall K-E substitution
	KE nest (σ^{KE})	VA nest (σ^{VA})	VA-Intermediate (top) Nest (σ^{AGG})	KE (θ_{KE})	VA (θ_{VA})	Q(θ_Q)	(σ^{KE*})
Base case	0.2	0.8	0	0.2	0.6	1	–1.66
High KE cost share	0.2	0.8	0	0.5	0.6	1	0.13
High KE substitution	0.9	0.8	0	0.2	0.6	1	1.83

Note: Formula for overall K-E substitution is: $\sigma^{KE^*} = \sigma^{KE}(\theta_{KE}^{-1}) - \sigma^{VA}(\theta_{KE}^{-1} - \theta_{VA}^{-1}) - \sigma^{AGG}(\theta_{VA}^{-1} - \theta_{Q}^{-1})$.

The modeler then adds a nest to describe how capital and energy are combined to produce the KE bundle. Modelers also add additional nests to describe substitution among energy types which, for brevity, we do not discuss.

Adding a KE nest to the value-added production function is a technique that allows modelers to describe K and E as overall complements while still allowing for a realistic amount of substitution between them. For example, suppose the price of energy rises. Within the KE nest, the quantity of energy demanded will fall and demand for capital will rise, to the extent that capital equipment can be substituted for energy. However, substitutability within the KE nest is likely to be quite low, because, generally, machinery needs a certain amount of electricity to run properly. As a result, the price of the KE bundle likely rises and the producer will shift toward labor and away from the KE bundle in the higher level, VA nest. As demand for the KE bundle falls, demand for both capital equipment and energy will fall by the same proportion. If the within-KE substitution effect dominates, then an increase in the energy price will cause demand for capital to rise – K and E are overall substitutes. If the VA substitution effect dominates, and the rise in the energy price causes demand for capital to fall, then K and E are overall complements.

Keller (1980) developed a formula to calculate the overall substitution parameter for nested inputs like capital and energy, σ^{KE^*}. His formula defines the parameter as a function of all three substitution effects – within the KE bundle, σ^{KE}; within the VA bundle, σ^{VA}; and at the top level of aggregation, σ^{AGG} – and of each nest's share in the total cost of the final product. Table 5.9 demonstrates how the overall substitution parameter is calculated, using the data shown in Figure 5.7.[7] In this example, the cost share of the KE bundle, θ_{KE}, is \$4/\$20 = 0.20, and the KE substitution parameter is 0.2. The cost share of the VA bundle, θ_{VA}, is \$12/\$20 = 0.6 and the L-KE substitution parameter is 0.8. The elasticity parameter, σ^{AGG}, between VA and intermediate inputs is zero. The cost share of the final product itself, θ_Q, is one.

Using Keller's formula, capital and energy inputs are overall complements, with an overall substitution elasticity parameter of –1.66. As illustrations, a change in the cost shares that gives more weight to the within-KE process causes its substitution effect to dominate, so capital and energy become overall substitutes, with a parameter value of 0.13. A change in relative elasticities, making capital and energy more substitutable in the KE nest, also causes the two inputs to become overall substitutes, with a parameter value of 1.83.

[7] For a more general statement of this formula for any number of nesting levels, see Keller (1980) and McDougall (2009).

6

Factors of Production in a CGE Model

In this chapter, we explore factor markets in a computable general equilibrium (CGE) model. Data in the Social Accounting Matrix (SAM) on factors of production describe factors' sources of employment and income. Important factor market concepts in the CGE model are factor mobility assumptions, the effects of factor endowment and productivity growth, complementary and substitute factors, full-employment versus unemployment model closures, and the links between changes in factor supply and industry structure and between changes in industry structure and factor prices.

Factors of production are the labor, capital, land, and other primary resources that producers combine with intermediate inputs to make goods and services. A nation's *factor endowment* is its fundamental stock of wealth because factors represent its supply of productive resources. In Chapter 5, we considered production activities' demand for factors and how these adjust with changes in relative factor prices or output levels. Many other dimensions of factor markets in a computable general equilibrium (CGE) model also deserve study.

In the next sections, we describe factor markets in standard CGE models in detail, focusing on those aspects that are of greatest practical importance for CGE modelers. We begin by studying the factor market data in the SAM. Then we consider the behavior of factor markets in the CGE model. We explain factor mobility assumptions, which govern the readiness of factors to change their employment in response to changing wages and rents across industries. We explore the effects of changes in the supply, or endowment, of factors and contrast them with changes in the "effective" endowment when factor productivity changes. We study the implications of assuming production functions, or industry technologies, that treat factors as complements (low factor substitutability) versus substitutes (high factor substitutability). We describe the CGE model's closures rules that specify full employment versus factor unemployment and demonstrate the importance of this assumption for model results. Finally, we examine the links between factor markets and the industry structure of an economy. We study how a change in factor endowments leads to changes in the industry structure, and we examine how changes in industry structure lead to changes in factor prices and factor input ratios across industries.

Factors of Production Data in a SAM

Each factor of production has its own row and column account in a SAM. For example, in the NUS333 SAM, there are three factors of production: land, labor, and capital (Table 6.1). The factor row accounts describe the receipt of income earned from employment in agriculture, manufacturing, and services production activities. For example, land receives $36 billion from employment in agricultural production. Labor receives income from all three production activities: $47 billion from employment in agriculture, $1,361 billion from employment in manufacturing, and $6,797 billion from employment in services. Capital also receives income from all three production activities.

The SAM's factor column accounts report the disposition of factor income. First, there are income taxes based on factor earnings. Land pays $3 billion in income taxes and labor pays $1,742 billion in income taxes. The SAM, and the CGE model that we use for most of our examples in this book, assume that the after-tax income of land and labor are paid to the regional household, a macroeconomic account. Capital pays $294 billion in income taxes. In addition, the capital account column reports depreciation of $1,260 billion, the replacement cost of worn-out capital that is recorded in the investment-savings account. Capital's remaining income is paid to the regional household account.

Computable general equilibrium models generally have at least two factors of production. Often, researchers disaggregate factors into many more

Table 6.1 *Factors of production data in the US SAM ($US billions)*

	Production activities			Factors		
	Agriculture	Manufacturing	Services	Land	Labor	Capital
Land	36	0	0			
Labor	47	1,361	6,797			
Capital	53	649	2,846			
Income tax	0	0		3	1,742	294
Regional household	0	0		33	6,643	1,994
Savings-investment	0	0	0	0	0	1,260
Total	na	na	na	36	8,205	3,548

Note: na means not applicable.
Source: GTAP v8.1 database.

types. For example, they may disaggregate labor into skilled and unskilled workers or urban and rural workers. Modelers also may disaggregate the capital account to separate capital equipment and structures from natural capital resources such as coal and oil. Sometimes, CGE modelers disaggregate land into types, such as cropland versus grazing land, or irrigated and nonirrigated land. You can visualize factor market disaggregation in a SAM by imagining that instead of a single labor row and labor column account, there are, for example, two labor rows and two labor columns – one each for skilled and unskilled labor. By disaggregating factors, the researcher who is interested in factor markets can pursue a richer analysis of some types of economic shocks. For example, a labor economist may be interested in differentiating the effects of immigration on skilled versus unskilled wages.

Factor Mobility

Factor mobility describes the ease with which labor, capital, and other factors can move to employment in different production activities *within a country* as wages and rents change across industries. Some multi-country CGE models also allow factor mobility *across* countries, which changes nations' factor supplies. A CGE model of this type supported a major World Bank analysis of global labor immigration, summarized in Text Box 6.1. In this chapter, we assume a nation's factors are in fixed supply, except when we explicitly consider, as in the next section, the ramifications of a change in factor endowments.

In a CGE model, factors are called *fully mobile* if they are assumed to move among jobs until wage and rent differentials across industries disappear. For example, if workers perceive that one industry offers a higher wage than another does, some number of them will exit the low-wage industry, causing its wage to rise, and enter the high-wage industry, causing its wage to fall. Their movement will continue until wages in the two industries are equal. Full factor mobility is probably a realistic view of labor and capital markets in the medium run or long run, because transition costs, such as retraining and job search costs, become less important when they are amortized over a longer time horizon. Younger workers, for example, may decide it is worth the time and money to invest in training for higher-paying jobs in industries that seem to offer a bright future over the remaining span of their careers.

Some CGE models allow factors to be *partially mobile*, moving only "sluggishly" across production activities. This assumption implies that transition costs are large enough to discourage some workers or equipment from changing employment unless pay differences are sufficient to compensate them for the cost of moving to other employment. Wages and rents can

Text Box 6.1 The economic impacts of global labor migration

Global Economic Prospects 2006**,** World Bank, Washington, DC.

What is the research question? The United Nations estimates that international migrants account for about 3% of the world's population. International labor migration can generate substantial welfare gains for migrants, their countries of origin, and the countries to which they migrate, but it may also lead to social and political stresses. What is the estimated size of the economic welfare effect of global labor migration?

What is the CGE model innovation? The authors modify the World Bank's recursive dynamic CGE model, Linkage (van der Mensbrugghe, 2005), to work with their comprehensive global database on labor migration, which differentiates between migrant and native workers and tracks remittance income sent by migrants to their countries of origin. They also adapt their welfare measure to account for the effects of cross-country differences in the cost of living on the spending power of migrant wages and remittances.

What is the model experiment? Migration flows from developing to high-income countries are assumed to increase at a rate sufficient to increase the labor force of high-income countries by 3% over the 2001–2025 period. The assumed increase, roughly one-eighth of a percentage point per year, is close to that observed over the 1970–2000 period.

What are the key findings? Migration yields large increases in welfare for both high- and low-income countries. Migrants, natives, and households in countries of origin all experience gains in income, although income falls for migrants already living in host countries. There is a small decline in average wages in destination countries, but migration's effect on the long-run growth in wages is almost imperceptible. Both the costs and the benefits of migration depend, in part, on the investment climate.

therefore diverge across production activities, and, given identical shocks, factor movements are usually smaller with partially mobile factors than in a CGE model that assumes full factor mobility.

Computable general equilibrium models that allow partial factor mobility use a *factor transformation function* for each partially mobile factor. This concave function is identical to the export transformation function described in Chapter 5, so we do not replicate it here. Using labor as an example, the function describes how a labor force of a given size can be transformed into different types of workers, such as agricultural or manufacturing workers. A *factor transformation (mobility) elasticity*, σ^F, defines the percentage change in the share of the labor force employed in production activity X given a percentage change in the ratio of the economy-wide average, after-income tax wage to the after-tax wage in X, holding the factor supply constant. For example, if the wage in activity X rises relative to the average wage, then the share of the workforce employed in activity X will rise. The factor mobility parameter value ranges between a negative number close to zero, which is an almost immobile factor, to -1, which is a fully mobile factor. The higher is this elasticity (in absolute value), the larger are the employment shifts in response to changes in wages and rents across industries. Computable general equilibrium models that describe factor mobility in this way may assume a constant elasticity of factor transformation (CET) function, so that the value of parameter σ^F is the same for all ratios of factor employment and at all levels of aggregate factor supply.

In the short run, some factors may be immobile, also called *sector-specific*. That is, factors do not move from the production activity in which they originally are employed, regardless of the size of changes in relative wages or rents across industries. This assumption is often made in the case of capital, because existing equipment and machinery are typically hard to transform for use in different industries. Similar to the case of partially mobile factors, the wage or rent of the sector-specific factor can differ across industries in the model – perhaps significantly so, because no amount of wage or rent premium can be enough to attract factors that cannot move, or low enough to motivate them to quit their current employment.

A practical implication of the factor mobility assumption is that it influences the slope of industry supply curves. All else being equal, the more mobile are factors, the more elastic is the supply curve and the larger is the supply response to any type of economic shock. One way to think about it is that a producer who can easily attract more factors with a small wage or rent increase is better able to increase output while holding down production costs, so this producer's supply curve is more elastic.

We explore the effects of alternative factor market assumptions in a CGE model by using the NUS333 model to run an experiment that introduces a 5% subsidy to private households in the United States on their purchases of domestically produced manufactured goods. The subsidy stimulates demand for manufactures, so those producers try to increase their output by hiring more labor and capital. The results reported in Table 6.2 describe the subsidy's effects on each industry's after-income tax capital rents in models with three different capital mobility assumptions: fully mobile, partially mobile, and sector-specific. When capital is fully mobile, capital owners will shift it across industries until capital rents equalize, so the capital rents increase by the same rate (1.1%) in every industry. In this case, manufacturing output increases 3.7%. When capital is only partially mobile, intersectoral differences in rental rate emerge. Because manufacturers must offer relatively higher rents to attract capital, their rents are now higher than in other sectors

Table 6.2 *Capital rents by sector with a 5% subsidy on US private household consumption of domestic manufactures, under alternative capital mobility assumptions (% change from base)*

	Agriculture	Manufacturing	Services
Fully mobile capital	1.1	1.1	1.1
Partially mobile capital	2.7	4.2	0.1
Sector-specific capital	4.3	4.9	–0.1

Note: Fully mobile capital has a factor transformation elasticity (etrae) of –1, partially mobile capital has an elasticity of –0.2, and sector-specific capital has an elasticity of –0.0001. The percent change in after-income tax capital rents earned in each production activity is variable *pes*.
Source: NUS333 model.

and their output expands by slightly less, 3.3%. The capital rent in US manufacturing rises most when capital is assumed to be sector-specific, and manufacturing output increases least in this model, by 3.2%. In this case, the increase in manufacturing output can only be achieved by increasing the ratio of workers to the fixed quantity of capital. This drives up capital's marginal product and the rent that is paid to capital owners.

Factor mobility assumptions are a useful way to categorize CGE model results as describing *short-run*, *medium-run*, or *long-run* adjustments to economic shocks. In the short run, some factors – usually capital – are immobile, and the economy's production response is therefore limited. In the medium run, factors are partially, or even fully, mobile. In this case, the adjustment period is long enough that existing stocks of capital and labor can be retooled or replaced, and workers can shift employment among industries in response to changes in wages and rents. Production therefore becomes more responsive to economic shocks. Analyses of long-run adjustment assume that all factors are fully mobile and, in addition, long-run changes in factor supply and productivity occur. The standard, static CGE models that we are studying can describe short- and medium-run adjustments, depending on their factor mobility assumptions. Dynamic CGE models that are capable of describing factor accumulation and productivity growth are needed to describe long-run adjustments to economic shocks.

Factor Endowment Change

A common assumption in standard CGE models is that a nation's factor endowments are in fixed supply. Computable general equilibrium modelers analyze shocks to factor endowments as model experiments. These shocks can occur for many reasons, such as immigration (increases the labor supply), foreign direct investment (increases the capital supply), or war (decreases both labor and capital supplies). A change in factor endowments can be a significant shock because it changes the productive capacity of an economy. Often more important from a public policy perspective are the resulting distributional effects when a change in a factor endowment leads to increased wages or rents earned by some factors but lower earnings by others.

An increase in the supply of a factor will cause its wage or rent to fall (unless demand for the factor is perfectly elastic). As an example, Figure 6.1 illustrates the effect of an increase in the aggregate supply of labor, from QE_L^1 to QE_L^2, on employment and wages. The national labor supply curve is a vertical line because we assume, as in a standard CGE model, that there is a fixed supply of workers and all of them are employed. D_L is the aggregate labor demand curve. In our example, there are initially 100 workers (QE_L^1) earning an equilibrium wage, PE_L^1, of $10 per worker. An increase in the labor supply to 110 workers causes the market-clearing wage to fall to $9.50.

We observe the effects on aggregate output and the own-price of a factor endowment change in a CGE model by using the NUS333 model to run an experiment that increases the US labor supply by 10%. The result is a 2% decline in the US wage and a 7% increase in US real GDP.

Factors as Complements and Substitutes

A change in the endowment of one factor can also affect the demand for and prices of other factors of production. For example, an increase in the supply of labor – perhaps due to immigration – will affect the wage in the host country, and the demand for and price of capital that is used in combination with labor to produce goods and services. However, we cannot say for sure

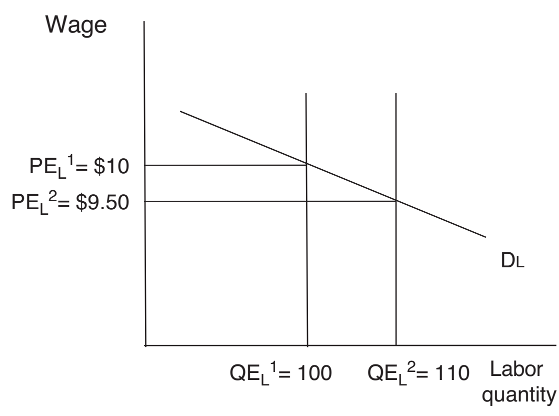


Figure 6.1 Effect of an increase in labor endowment on employment and wages

how immigration will affect capital. Whether the quantity of capital demanded and capital rents will rise or fall depends on whether labor and capital are substitutes or complements in the production process.

We have already studied factor substitutability and complementarity in our description of producers' demand for value-added in Chapter 5. To reiterate briefly, the firm's technology determines the ability of producers to substitute labor for capital in the production of a given level of output. We depicted the flexibility of technology with a *factor substitution elasticity*, σ^{VA}, which defines the percentage change in the quantity ratio of capital to labor relative to a percentage change in the ratio of wages to rents, for a given bundle of value added. If the parameter has a large value, the two factors are *substitutes*. As the elasticity approaches zero, the two factors become *complements*.

As an example, consider the case of a country that receives foreign aid in the form of capital equipment and machinery. Will this increase in its aggregate capital stock raise or lower its wages – will it help or harm its labor force? Figure 6.2 presents a four-quadrant graph that illustrates the effects of the increased supply of capital goods on the country's capital and labor markets under the alternative assumptions that capital and labor are substitutes or complements. Figures 6.2a and 6.2b describe the markets for capital and labor when the two factors are highly substitutable in the production process. Figures 6.2c and 6.2d describe the markets for capital and labor when the two factors are more complementary. Notice that the aggregate factor supply curves for both factors are shown as vertical lines, reflecting our CGE model assumptions of fixed factor endowments and full employment. In both capital market figures, an increase in the capital stock shifts the supply curve for capital to the right, from QE_K^1 to QE_K^2. In the two labor market figures, the increase in capital stock shifts the demand curves for labor in opposite directions, from D_L^1 to D_L^2.

First, we assume that capital and labor are strong substitutes (Figure 6.2a). Perhaps in this country, industries can easily produce goods using either machinery or workers, so the demand for capital, D_K, is elastic (and drawn with a relatively flat slope) and, assuming there are no taxes, the initial economy-wide capital rent is PE_K^1. An increase in the capital stock, from QE_K^1 to QE_K^2, causes the price of capital to fall so producers substitute toward more cost-saving, capital-intensive production processes. In the new equilibrium, as the quantity of capital increases from QE_K^1 to QE_K^2, the capital rent falls to PE_K^2.

The effect of the increase in capital on the labor market is shown in Figure 6.2b by the direction of the shift in the demand curve for labor. A shift to more capital-intensive processes is shown as a decline in the economy's demand for labor, from D_L^1 to D_L^2. As the adoption of more capital-

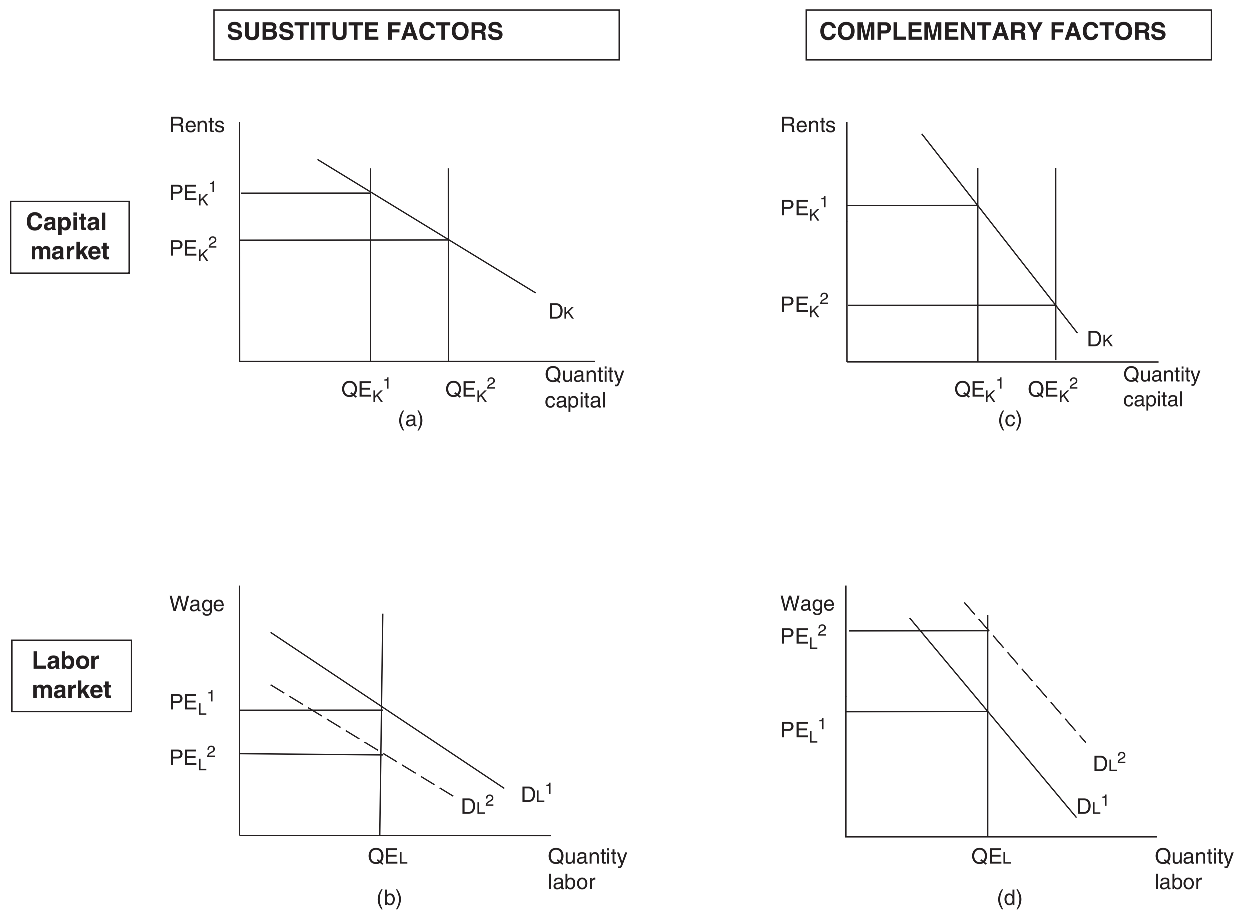


Figure 6.2 (a–d) Labor and capital as substitutes and complements

intensive production technologies reduces the demand for the fixed supply of workers, the economy-wide wage falls from PE_L^1 to PE_L^2.

Contrast this outcome with the case of factors as strong complements. For example, perhaps new capital equipment requires workers to operate it. The demand curve for capital equipment is thus relatively inelastic, with the steep slope shown by D_K in Figure 6.2c. The effect of capital stock growth on the demand for complementary labor is shown in Figure 6.2d as a rightward shift in the labor demand curve, from D_L^1 to D_L^2. In this case, the demand for labor increases, causing the wage to rise from PE_L^1 to PE_L^2.

We study the role of the factor substitution elasticity in a CGE model by using the GTAP model to carry out an experiment that increases the US labor supply by 10%. We compare the factor price results from two versions of the model. We first define capital and labor as strong substitutes and then as strong complements by changing the factor substitution elasticity parameters for all three production activities in the model.

Model results, reported in Table 6.3, show the key role of the factor substitutability assumption in determining whether a change in the supply of one factor raises or lowers the price of the other factor. When factors are strong substitutes, an increase in the US labor supply lowers US capital rents by 1.5%. If factors are assumed to be strong complements, an increase in the labor supply raises rents by 5.4%. In both cases, an increase in the US labor supply lowers wages.

Factor Productivity Change

Factor productivity describes the level of output per unit of factor input. An increase in factor productivity means that the same quantity of a factor can produce more goods and services. New training, for example, may enable an autoworker to produce twice as many vehicles as previously, whereas bad weather may cause an acre of land to yield only half the usual quantity of

Table 6.3 *Effects of a 10% increase in the US labor supply on wages and rents when factors are substitutes or complements (% change from base)*

	Substitutes	Complements
Wage (pe_L)	–1.5	–2.0
Rent (pe_K)	–1.5	5.4

Note: Substitutes case specifies factor substitution elasticities for all production activities of 125. Complements case uses default GTAP v8.1 elasticities.
Source: NUS333 model.

wheat. Productivity gains and losses can occur for a single factor (such as the labor productivity losses described in Text Box 6.2) or for a subset of factors, and in one or more industries. Many CGE-based analyses of climate change, for example, describe one of its effects as a reduction in the productivity of land used in the agricultural sector (see Text Box 6.3). A change of equal proportions in the productivity of all factors of production in an industry or in an economy is called a change in *total factor productivity* (TFP).

A change in a factor's productivity changes the *effective factor endowment*. Effective factor endowments take into account both the quantity and the

Text Box 6.2 HIV/AIDS – disease and labor productivity in Mozambique

"***HIV/AIDS and Macroeconomic Prospects for Mozambique: An Initial Assessment***" (Arndt, 2002).

What is the research question? As in other countries in the southern Africa region, a human development catastrophe is unfolding in Mozambique, where HIV prevalence rates among the adult population in 2000 are around 12%, and life expectancy is projected to decline to about 36 years. Because of the magnitude of the HIV/AIDS pandemic, it has overrun the bounds of a pure health issue and become a top priority development issue. What is the scope of its potential macroeconomic impact?
What is the CGE model innovation? The author develops a recursive dynamic CGE model, based on the IFPRI standard CGE model that updates sectoral productivity, the labor force (by skill category), and the physical capital stock to analyze the effects of HIV/AIDS over time.
What is the model experiment? There are three channels through which the HIV/AIDS pandemic is assumed to affect economic growth: (1) productivity growth effects for labor and other factors; (2) population, labor, and human capital stock accumulation effects; and (3) physical capital accumulation effects. Based on these channels, the author defines four scenarios. An AIDS scenario reduces all factors' productivity and endowments based on available estimates; a "less-effect" scenario reduces most of the HIV/AIDS impacts by about one-half. An education scenario combines the AIDS scenario with a strong effort to maintain school enrollments and the growth of the skilled labor supply. A No-Mega scenario combines the AIDS scenario with the assumption that large-scale, donor-financed investment projects are curtailed.
What are the key findings? The differences in growth rates in the four scenarios cumulate into large differences in GDP over time. GDP is between 16% and 23%, smaller than it would be in the absence of the pandemic. The major impacts on GDP are decomposed into the three channels. Although all are important, the decline in factor productivity is the largest source of the potential decline in Mozambique's GDP.

Text Box 6.3 Climate change and agricultural land productivity

"***The Distributional Impacts of Developed Countries' Climate Change Policies on Senegal: A Macro-Micro CGE Application***" (Boccanfuso, Savard, and Estache, 2013).

What is the research question? Policies to reduce greenhouse gas (GHG) emissions lead to higher prices for energy and for goods that are intensive in the use of energy inputs. Changes in energy prices also can cause changes in an economy's structure of production, leading to changes in relative factor prices. How might Senegal's most vulnerable populations be affected by GHG-mitigation policies undertaken by high-income countries that increase the world price of energy? Might these impacts undermine Senegal's goals for development and poverty reduction?

What is the CGE model innovation? The authors develop a static, single-country CGE model of Senegal that transmits model results for market and factor prices into a rich micro-simulation household module. The model also develops a detailed energy sector that focuses on the use of electricity in the production process and by households.

What is the model experiment? The model explores three scenarios: (1) a 50% increase in global fossil fuel prices because of the adoption of climate change mitigation policies in high-income countries – the domestic electricity price is fixed, with the Senegal government absorbing losses incurred by the domestic utility company; (2) a 50% increase in global fossil fuel prices and rising domestic electricity prices; and (3) scenario 2 plus a 10% decline in productivity of Senegal's agriculture due to climate change.

What are the key findings? Rising energy prices have relatively small effects on poverty and income inequality in Senegal, mainly because energy has a small share in the consumption baskets of poor households. Declining land productivity due to climate change is far more important, negatively impacting the poor by increasing food prices and reducing unskilled wages.

efficiency of a factor. For example, suppose that an initial labor force of 100 auto workers produces 1000 autos per day. If the same 100 workers can now produce 1100 autos, holding the quantity of capital constant, then the effective labor endowment has increased by 10% to 110.

The autoworkers' wage is determined by their level of productivity. Initially, their real wage, expressed in terms of autos produced per worker, is 10. If the productivity gain causes each worker's daily output to increase to 11 autos, then their value to the producer has increased by 10% and is 11 autos each. If we assume the initial wage is $10 and, to simplify, autos cost $1 each, then the productivity gain causes each worker's marginal revenue product to increase from $10 to $11.

Let's first observe how the productivity gain affects the demand for labor. The *effective wage* is the wage paid per effective worker. The producer perceives that it has fallen from $10 to $9 because their initial wage expenditure of $1000 now pays for 110 effective workers. Another way to look at it is that the producer now gets more output and revenue per actual worker for the same initial wage. This motivates producers to hire more workers.

In a general equilibrium framework, a change in a factor's productivity affects an industry's demand for all factors, as well as its level of output. In Chapter 5, we examined how a change in one input price leads to a substitution effect on the demand for both factors, to the extent allowed by their technological flexibility (and described by the elasticity of factor substitution). These same principles apply in the case of a change in a factor's productivity and its effective price. In Figure 5.5, the isocost lines describe the quantities of each factor that can be combined for the same total cost. Imagine that the slopes of the isocost lines are now the ratio of the effective wage, rather than the actual wage, to capital rent. A decrease in the effective price of labor causes the isocost line to become flatter, such as a rightward swivel of isocost C^1 from the vertical axis. The fall in the ratio of the effective wage to capital rents leads to a substitution toward labor and away from capital as the producer assembles the least-cost combination of factors in the production of QO^1. This is the *substitution effect* of an increase in labor productivity on demand for both factors in a given value-added bundle or output level.

In a perfectly competitive market, the decline in the cost of producing autos will be passed on to consumers through a lower sales price, causing demand for autos and their production to increase. The increase in output will lead to an increase in demand for both factors by the same proportion as the change in output. This is the positive *output effect* of an increase in labor productivity on demand for both factors.

However, because each actual worker can now produce 11 cars, the production of any given quantity of autos requires fewer workers. The automaker, for example, now needs fewer workers to produce 1000 cars per day. The decline in demand for workers for a given quantity of output, holding effective factor prices constant, is the negative *productivity effect* on the demand for labor. The net effect of a change in a factor's productivity on factor demand is the sum of the substitution, output and productivity effects.

We illustrate these three effects in a CGE model using the NUS333 model. Our experiment assumes a 10% increase in the productivity of the total US

Table 6.4 *Effects of a 10% increase in economy-wide US labor productivity on production activities' demand for labor and capital (% change from base)*

	Agriculture	Manufactures	Services
Labor demand (*qfe*)	–6.2	–2.1	0.5
Factor substitution effect (*qfe-qo-afe*)	1.7	2.5	2.9
Output effect (*qo*)	2.1	5.4	7.6
Productivity effect (*afe*)	–10.0	–10.0	–10.0
Capital demand (*qfe*)	1.9	–0.3	0.0
Factor substitution effect (*qfe-qo-afe*)	–0.2	–5.7	–7.6
Output effect (*qo*)	2.1	5.4	7.6
Productivity effect (*afe*)	0.0	0.0	0.0

Note: We use the Johansen solution method. Experiment is a 10% increase in variable $afeall_L$ in all production activities.
Source: NUS333 model.

labor force; for brevity, we report results only for the capital and labor markets. The factor substitution effect leads to a substitution toward labor and away from capital in all three industries as the effective wage falls (Table 6.4). The output effect in each industry is identical for both factors and is the same as the percent growth in industry output. The 10% increase in labor productivity also leads to a reduction of an equal proportion in each industry's demand for workers. Notice that there is no productivity effect on capital demand because its productivity is unchanged in this experiment. On net, the resulting changes in factor demand cause the effective wage (*pfe – afe* in GTAP model notation) to fall by 3.8%, the actual wage to rise by 6.2%, and capital rents to increase by 3.8%.

Factor Unemployment

In some countries, unemployment is a serious problem, and the common CGE model assumption of full employment of all factors may not realistically describe an economy. *Factor unemployment* can be depicted in a CGE model by changing the *factor market closure*. Recall from our discussion in Chapter 2 that model closure is the modeler's decision as to which variables adjust to re-equilibrate markets following an economic shock. With a full employment model closure, a shock to an economy causes wages and rents to adjust until the fixed supply of each factor is again fully employed. In a model with an unemployment closure, the wage or rent is assumed to be fixed, and economic shocks can lead to a change in the factor supply – that is, the size of the labor force or the stock of capital will adjust until factor supply and demand are again equal at the initial wage or rental rate.

In a model that allows unemployment, a decline in the size of the labor force, for example, means that some proportion of workers is now unemployed, so part of the nation's productive capacity is now idled. An increase in the size of the labor force means that previously unemployed workers have now found employment, so the economy's productive capacity expands. In this case, industries are able to hire as many workers or as much equipment as they need following an economic shock, without bidding up wages or capital rents. As you might expect, experiments in a model that allows factor unemployment can result in very large changes in a nation's productive capacity and real GDP. Conversely, a CGE model that assumes full employment describes the reallocation of existing workers across industries; while compositional changes in an economy can yield efficiency gains, there is no change in its productive capacity.

We explore the implications of the factor market closure assumption in a CGE model by comparing the effects of the same experiment in model versions with two different labor market closures. We use the NUS333 model to run an experiment that provides a 10% output subsidy in US manufacturing. Model results show that the alternative factor market closures depict very different adjustments by the US economy to the same economic shock (Table 6.5). Notably, when we assume an unemployment closure, there is a large expansion of manufacturing employment and output because the total US labor supply increases by 38.8%. However, if labor is assumed to be fully employed, then manufacturers must compete for workers with other industries in order to expand production. This competition drives up wages and increases manufacturers' cost of production – costs that must be passed on to consumers through higher prices. Manufacturing production therefore does not grow as much in the full-employment scenario compared to the unemployment scenario. In addition, real GDP growth is far larger (27.1%) if previously unemployed

Table 6.5 *Effects of a 10% output subsidy in US manufacturing under full employment and unemployment labor market closures (% change from base)*

	Labor unemployment closure	Full employment closure
Manufacturing employment (*qfe*)	39.1	4.4
Manufacturing output (*qo*)	28.3	4.4
Wage (*pebfactreal*)	0.0	7.4
Labor supply (*qe*)	38.8	0
Real GDP (*qgdp*)	27.1	0.1

Notes: Unemployment closure defines the US labor supply (qe_L) variable as endogenous and the real wage ($pebfactreal_L$) variable as exogenous. Initial manufacturing output tax of 1% in base model is changed to a 10% output subsidy.
Source: NUS333 model.

workers can be added to the nation's stock of productive resources, compared to only 0.1% growth in real GDP when factors are already fully employed.

Factors and Structural Change

The industry structure of an economy describes the share of each industry in total national output. For example, from Table 3.3, the structure table for the United States, we know that agriculture accounts for 1% of US GDP and services accounts for 81% of GDP. Industry structure is linked to factor markets in two ways. First, all else being equal, an increase (decrease) in the endowment of a factor causes an increase (decrease) in the relative size of industries that are most intensive in the use of that factor. Second, a change in industry structure affects relative factor prices and factor intensities. The relative price of the factor used most intensively in expanding industries rises, and the relative price of the factor used most intensively in declining industries falls, motivating both industries to substitute toward the cheaper factor.

Let's consider the first linkage in more detail. An industry is intensive in the use of the factor that accounts for the largest share of its production costs. Because the increase in the supply of a factor usually lowers its price, the cost savings will be greatest for those firms that use the factor most intensively. For example, a lower wage rate in the US economy would most benefit US services – the most labor-intensive sector in the United States. In the competitive economy that we assume in our CGE model, services producers can therefore lower their sales price by proportionately more than other industries can. This price change will tend to cause demand for and production of services to increase relative to other goods, depending on consumer preferences.

We can observe this linkage in a CGE model by using the NUS333 model to carry out an experiment that increases the US labor supply by 2%. This causes the wage in the United States to decline by 0.4%. The greatest cost savings occur in US services, in which initial labor costs account for 43% of its total production costs. Lower wages cause output to increase in all three sectors, but it increases by proportionately more in services than in other industries (Table 6.6).

Next, we consider the link between *structural change* and factor returns. The structure of a nation's output can change for many reasons. For example, over time, services have become a larger part of the US economy because of rising incomes and consumer preferences, and the role of manufacturing in US GDP has diminished. Trade shocks, such as a foreign embargo on a home country's exports, or a boom in export demand, can also cause structural change in an economy's output. Government programs, such as subsidies and taxes targeted at specific industries, can cause structural change, too.

Table 6.6 *Effects of a 2% increase in the US labor supply on the structure of US production*

	Labor share in industry cost	Percent change in output (*qo*)
Agriculture	16	0.4
Manufacturing	24	1.1
Services	43	1.5

Source: NUS333 model.

Factor prices change when industries that are expanding and contracting have different factor intensities in their production technologies.

To understand why, consider a simple, two-industry country in which the capital-intensive sector (agriculture) is expanding. The agricultural production process uses one worker and three units of capital per unit of output. The other industry (services) is labor intensive; it uses three workers and only one unit of capital for every unit of output. If agricultural production expands by one unit, it needs to hire three new units of capital and one new worker. However, when three units of capital leave the services industry, nine workers also become available for hire. There is now an excess supply of labor in the economy, which will cause wages to fall relative to rents. As labor becomes cheaper than capital, the agricultural industry has an incentive to become more labor intensive by using more workers per machine (assuming its production technology allows some factor substitution). As the services industry's capital is bid away by agriculture, and with wages falling, service producers have the same incentive to become more labor intensive (assuming their technology allows it). In the new equilibrium, if all workers and capital are re-employed (the full-employment assumption), then wages will have fallen relative to rents, and both industries will have become more labor intensive than they were initially.

We can observe the effects of structural change on factor returns and factor intensities in a CGE model by using the NUS333 model to run an experiment that introduces a 5% production subsidy to US services, a relatively labor-intensive activity. Results, reported in Table 6.7, demonstrate that structural change that favors the labor-intensive industry causes the wage to rise slightly relative to capital rents, and manufacturing and services to become more capital intensive. Capital and labor both leave agriculture by the same proportion, so there is no change in that industry's capital-labor ratio. Notice that the land rent declines substantially. This is because the factor substitution elasticity in agriculture is assumed to be very low and agricultural land is employed only in

Table 6.7 *Effects of a 5% production subsidy to US services on factor prices and factor intensities (% change from base)*

Land rent (pe_T)	–21.6
Wage (pe_L)	8.0
Capital rent (pe_K)	7.7
Capital/labor input ratio ($qfe_K - qfe_L$)	
Agriculture	0.0
Manufacturing	0.2
Services	0.2

Source: NUS333 model.

agriculture (it is in effect a sector-specific factor). As a result, the outflow of agricultural labor and capital into the expanding services industry reduces the complementary demand for farm land, and land productivity and the land rental price fall.

Summary

This chapter examined several aspects of factor markets in a CGE model. We first described the factor market data in the SAM, which reports the sources of factor income and factor expenditure on taxes, depreciation, and the regional household account. In the CGE model, factor mobility assumptions govern the readiness of factors to change their employment in response to changing wages and rents across sectors. An economy's supply response is larger when factors are more mobile. Factor endowments are usually assumed to be in fixed supply in standard CGE models, and modelers may change factor endowments as an experiment. We learned that an increase (decrease) in the supply of a factor usually causes its price to fall (rise), but that the effect on demand for and prices of other factors depends on whether the factors are substitutes or complements in the production process. We examined the substitution, output, and productivity effects of a change in factor productivity on factor demand. Full employment of all factors is a common assumption in CGE models, but this may not be a realistic depiction of labor markets in many countries. We described the alternative model closures of full employment and unemployment and show how they depict different adjustments by an economy to economic shocks. Finally, we examined the links between economic structure and factor markets. When a change in factor endowments causes relative factor prices to change, it changes the costs of production for industries and leads to an expansion (contraction) in the output of industries whose factor costs have fallen (increased) most relative to other industries. A change in the industry structure of an economy, perhaps because of changing demand or government policies, can lead to changes in the demands for and prices of inputs when the factor intensities of industries differ.

Key Terms

Complementary factors
Effective factor endowment
Effective factor price
Elasticity, factor transformation (mobility)
Elasticity, factor substitution
Factor endowment
Factor market closure
Factor mobility
Factor price
Factor productivity
Factor transformation function
Full employment
Fully mobile factors
Long run
Medium run
Mobile factors
Partially mobile factors
Sector-specific (immobile) factors
Short run
Structural change
Substitute factors
Total factor productivity
Unemployment

PRACTICE AND REVIEW

1. Provide real-life examples of an industry with a fully mobile factor and an industry with an immobile factor. In a graph, describe and compare their supply curves and the effects of an increase in demand for their products on their output price and quantity.
2. Assume that you are an industry analyst for manufacturers who build the capital equipment used in the manufacture of computer chips. You have been asked to develop and represent an industry viewpoint on a government-funded training program for engineers who can design and produce the chips using your equipment. Explain whether the engineers and your equipment are substitutes or complements in the production of computer chips. Prepare a graph that describes

the effects of the training program on the output and price of your computer chip equipment and write a short paragraph explaining your industry's position.

3. Referring to the US structure table (Table 3.3), which industry is the most labor-intensive? What are the shares of each production activity in the employment of labor? Based on this information, how do you think a production subsidy to services in the United States will affect capital rents and wages, and the labor/capital ratios in the three production activities?

7

Trade in a CGE Model

In this chapter, we present the building blocks for trade policy analysis using a computable general equilibrium (CGE) model. We begin by reviewing the trade data in the Social Accounting Matrix (SAM). Next, we introduce two concepts, the real exchange rate and terms of trade, and explain how they are represented in standard CGE models. We then focus on trade theory as we simulate and interpret the results of two types of shocks: a change in factor endowments that changes comparative advantage, and a change in world prices that changes industry structure, trade, and factor returns. We study an example of "Dutch Disease," a problem that illustrates the links between a change in world prices, the real exchange rate, and industry structure. We conclude with an explanation of the role of trade margin costs in international trade.

Since David Ricardo first developed the theory of comparative advantage, showing that nations gain from specializing in the goods that they produce at relatively lower cost, most students of economics have learned that all countries can gain from trade. Yet, many countries are reluctant to move too far or too fast toward free trade. Their reasoning is not inconsistent with Ricardo's theory. Trade and specialization lead to changes in a country's industry's structure and, in turn, to changes in the wages and rents of factors used in production. Therefore, although trade confers broad benefits on a country, it can also create winners and losers. Protecting, compensating, or managing the social and economic transition of those who lose has led many countries to qualify or delay their commitment to global free trade.

Since the early 1990s, computable general equilibrium (CGE) models have been widely used to analyze trade policy issues including unilateral trade liberalization, multilateral tariff reforms through the World Trade Organization (WTO), and preferential trade agreements such as the Trans-Pacific Partnership and the European Union's expansion and its later contraction following Brexit. The contributions made by CGE models rest on their ability to identify which industries will grow or could contract with changing trade policies, to describe whether labor or capital will gain or could lose from such policy shifts, and, perhaps most important, to measure welfare effects, which summarize the overall effects of changing trade policies on an economy's well-being.

In this chapter, we present the building blocks for trade policy analysis using a CGE model. Our objective is to show, through discussion and example, how to use trade theory to understand and interpret the economic behavior observed in a CGE model. We begin by reviewing the trade data in the SAM, which separately reports exports, imports, tariffs and export taxes, and trade margins. Next, we define two concepts, the real exchange rate and terms of trade, and demonstrate how they behave in standard CGE models. We build on these two concepts as we study two types of shocks: a change in factor endowments that changes a country's production and terms of trade, and a change in world prices that affects production and factor returns. We also study the trade and transportation costs incurred in shipping goods from the exporter to the importer, and learn how changes in these costs can influence world trade flows.

Trade Data in a SAM

Import data are reported in the SAM as an expenditure by the import variety of each commodity column account. The import data separately report spending on import tariffs, trade margin costs (insurance and freight charges), and the cost of the imports (valued in foreign *fob* export prices). For example, the United States spends a total of $34 billion on imported agricultural goods (Table 7.1). Of this amount, $1 billion is spent on import tariffs, $5 billion is spent on trade margins, and $28 billion is the amount paid to agricultural exporters in the rest of the world. The United States spends a total of $2,250 billion on imports, of which $2,140 billion is paid to exporters, $86 billion is spent on trade margins for the shipment of its imports, and $24 billion is spent on US import tariffs. The *cif* value of total U.S. imports is $2,226 billion ($2,140 billion + $86 billion).

Table 7.1 *Import data in the US SAM ($US billions)*

	Commodity–import variety			
	Agriculture	Manufacturing	Services	Total
Tax–imports	1	23	0	24
Trade margin–imports	5	81	0	86
Rest of world	28	1,797	315	2,140
Total	34	1,901	315	2,250

Source: GTAP v.8.1 database.

Table 7.2 *Export and trade balance data in the US SAM ($US billions)*

Commodity–domestic variety	Mfg. commodity domestic variety	Trade margin–export	Rest of world
Agriculture	0	0	52
Manufacturing	0	0	970
Services	0	28	345
Savings-investment (trade balance)	0	58	773
Export taxes	3	0	0
Total	–	86	2,140

Source: GTAP v.8.1 database.

The SAM decomposes export data into spending on export taxes, the value of exported trade margin services, and the value of all other exported goods and services. Exports are recorded in the domestic commodities' row accounts, shown in Table 7.2. For example, the agricultural commodity exports $52 billion worth of agricultural products to the rest-of-world account. The SAM's domestic commodity column accounts pay export taxes. In the United States, only manufacturing pays export taxes, which total $3 billion, so, for brevity, we do not include the columns for the domestic agriculture or services commodities. The column account for export trade margins reports the export of US-produced services to the global transport industry ($28 billion). The rest-of-world column account reports foreign purchases of US-produced goods and services. These exports total $1,367 billion ($52 + $970 + $345 billion), valued in US *fob* export prices (includes export taxes). US exports total $1,395 billion ($1,367 + $28 billion), in *fob* prices.

The US balance of trade in trade margins is a deficit of $58 billion ($86 billion spent on trade margin services for imports minus $28 billion of exported margin services). The US trade balance in goods and services is the value of exports minus the value of imports, both valued in world *fob* prices: $1,367 – $2,140 = –$773 billion. Both deficits are reported as positive payments by the trade margin and rest-of-world accounts to the savings-investment row of the SAM because these are inflows of foreign savings to the United States. The total US trade deficit is the sum of the two trade deficits: $831 billion or the *fob* value of exports minus the *cif* value of imports ($1,395 - $2,226 = - $831 billion).

Exchange Rates

Computable general equilibrium models differ in their treatment of the exchange rate. Some have a *nominal exchange rate* variable that describes the rate at which currencies can be exchanged for one another. Usually, it is expressed as units of domestic currency per unit of foreign currency. For example, the exchange rate (EXR) of the Canadian dollar (the domestic currency) relative to the euro (the foreign currency) is defined as the number of dollars that can be exchanged for one euro:

$$\mathrm{EXR}_{\mathrm{CAN,EU}} = \$/\mathrm{euro}.$$

When this type of CGE model includes country SAMs that are denominated in different currencies, the initial value of the exchange rate is the market rate that prevailed in the year corresponding to the SAM database. For example, the Canadian dollar–euro exchange rate would be 1.45 in a CGE model of Canada and the European Union with a 2020 database. More often, all SAMs in a CGE model are denominated in the same currency, such as US dollars, or the CGE model has a single country. In these cases, the researcher defines the initial value of the nominal exchange rate as one.

A rise in a country's exchange rate signals home currency depreciation because more domestic currency is required in exchange for the same quantity of foreign currency. For example, a rise in the Canadian dollar exchange rate from \$1.45/euro to \$1.50/euro means that its dollar has depreciated relative to the euro. Conversely, a fall in the exchange rate signals home currency appreciation.

The nominal exchange rate may seem like a financial variable, but remember that a standard, real CGE model does not account for financial assets or describe financial markets. Instead, the nominal exchange rate is a model variable that determines the *real exchange rate*, which is the relative price of traded to non-traded goods.[1] Traded goods are products that are imported or exported. Non-traded goods are products that are produced by, and sold to, the domestic market.

Let's first consider the import side. To simplify, we describe a single-country CGE model with a nominal exchange rate with the rest of the world. For clarity, we assume there are no taxes or trade margin costs and that the country is small in world markets. Recall from our discussion of import demand in Chapter 4 that consumers buy a composite commodity, such as autos, composed of the imported (traded) and domestically produced (non-traded) varieties. A change in the exchange rate affects PMS, the domestic price of the country's imported variety:

$$\mathrm{PMS} = \mathrm{EXR} * \mathrm{PXWCOM},$$

1 See Robinson (2006) for a more detailed discussion of the role of a nominal exchange rate variable in a standard CGE model in changing the relative prices of traded to non-traded goods in domestic markets. McDougall et al. (2012) describe the real exchange mechanism in the GTAP model.

where PXWCOM is the fixed world price of the import in foreign currency and EXR is the exchange rate expressed in terms of the importer's currency. Because the price of the domestically produced variety in the importing country, PDS, does not change, a change in the nominal exchange rate will change the price ratio PDS/PMS, which is the real exchange rate. Let's assume that EXR rises (i.e., a depreciation); then, the price ratio of PDS/PMS will fall. Depending on the size of the Armington import-domestic substitution elasticity, the quantity ratio of the import to the non-traded variety in the consumption bundle will decline.

As an example, assume that Mexico is a small country in the world market for its apple imports and faces a fixed world price of the import, denominated in US dollars, of $1 per apple. Given an initial EXR of one peso per dollar, its domestic price for an imported apple is one peso. Assume, too, that the Mexican peso depreciates to 1.5 pesos per dollar. Mexican consumers now must pay more (1.5 pesos) for each imported apple. As imports become relatively expensive, Mexican demand will shift toward the domestic variety, subject to consumer preferences as described by the domestic-import substitution elasticity. Conversely, if the peso appreciates, then the relative cost of imported apples in terms of pesos will fall and consumption will shift toward imports.

Likewise, recall from our discussion of export supply in Chapter 5 that the producer's decision to allocate production between domestic and export sales depends on the relative prices in the two markets. A change in the nominal exchange rate variable, expressed in terms of the currency of exporting country, will change the *fob* export price (PXW) in domestic currency that is received by producers of the exported variety:

$$\text{PXW} = \text{EXR} * \text{PXWCOM},$$

where PXWCOM is the fixed world price of the export. Because the producer price of the domestically produced variety sold in the exporting country, PDS, does not change, a rise in the exchange rate variable (depreciation) will decrease the price ratio PDS/PXW. Depending on the size of the export transformation elasticity, the export share of production will increase.

Let's assume that Mexico is small in the world market for its exports, too, and faces a fixed world price for its orange exports, denominated in dollars, of $1 each. Initially, producers receive an export price of one peso per orange. A depreciation of the peso to 1.5 pesos per dollar generates more pesos for any given quantity of exports. Mexican producers will shift their sales toward the export market, subject to technological feasibility. Conversely, exchange rate appreciation would cause a fall in peso earnings from any given quantity of exports, so producers will shift their sales toward the domestic market.

The nominal exchange rate variable may be either flexible or fixed in value, depending on the model's macro closure. In practice, modelers often assume a closure in which a flexible exchange rate variable adjusts to maintain a fixed current account balance. The current account balance is the trade balance (the *fob* values of exports minus *cif* values of imports) plus other international monetary flows. One reason that modelers choose this closure is because changes in the current account balance are determined in part by macroeconomic and financial forces that lie outside the scope of real CGE models. It is therefore straightforward and transparent simply to fix the current account balance at the level observed in the initial equilibrium. A second reason is that most countries today have floating exchange rates; however, this is not always the case, and this closure decision offers the modeler the ability to explore alternative exchange rate regimes.

Table 7.3 describes how a flexible nominal exchange rate variable adjusts to equilibrate a fixed current account balance. We assume fixed world prices and observe the quantity adjustments to import demand and export supply. Suppose, for example, that a country's imports increase, perhaps because the country has removed its import tariffs. Its current account balance will worsen as the value of imports grows relative to exports. The exchange rate variable will therefore depreciate, both causing export quantities to rise and dampening the initial increase in import quantities, until the initial current account balance is restored.

The nominal exchange rate is a macroeconomic variable because it affects the relative prices of all traded and non-traded goods by the same proportion. For example, an exchange rate depreciation of 10% would increase the import price of apples, oranges, steel, and all other imported goods by 10% relative to domestically produced apples, oranges, steel, and other goods.

Some CGE models do not have an explicit, nominal exchange rate variable, but they nevertheless include a real exchange rate mechanism. In the

Table 7.3 *Causes and effects of a change in the nominal exchange rate variable on traded quantities when the current account balance is fixed*

Cause	Change in nominal exchange rate variable	Effect on opposite trade flow
Imports rise	Depreciation	Exports rise
Imports fall	Appreciation	Exports fall
Exports rise	Appreciation	Imports rise
Exports fall	Depreciation	Imports fall

GTAP model, for example, the *pfactor* variable describes the percent change in an index of a country's factor prices relative to the world factor price index, which is the model numeraire. In competitive markets, a change in wages or rents paid by producers will cause changes in the sales prices of their goods. An increase in a country's *pfactor* variable is therefore similar to a real exchange rate appreciation, because an increase in its factor prices will lead to an increase in the price of its domestically produced goods relative to imports, and a shift in its consumption bundle toward imports. The increase in factor prices also will cause the price of its exports to increase relative to the price of domestically produced goods in its trade partner's market. Like a real exchange rate appreciation, this causes foreign consumers to shift their consumption bundle away from the appreciating country's exports. A decrease in a country's factor prices will likewise have similar effects of reducing imports and increasing its exports as a real exchange rate depreciation.

For example, consider two countries (A and B) that both produce apparel. A shock that lowers economy-wide wages in country A causes its price of apparel to fall relative to the price of apparel produced in the higher-wage country B. Indeed, all goods produced in country A using labor become cheaper in the world market than similar goods from country B. This will stimulate A's consumers to shift from imports toward domestic goods in their consumption, and will lead country B's consumers to shift toward imports from domestic goods. Thus, a change in relative factor prices leads to adjustments that are similar to those of a real exchange rate depreciation in A.

Terms of Trade

Terms of trade measure the import purchasing power of a country's exports. Any change in the terms of trade therefore affects an economy's well-being, or welfare, by changing its consumption possibilities. Terms of trade are calculated as the ratio of the *fob* prices of a country's export goods to the *cif* prices of its import goods. Export prices reflect the producer's earnings, whereas import prices are from a consumer's perspective. Import tariffs are excluded from the calculation.

As an example, consider a two-country, two-good world in which country A exports corn to country B, and B exports oil to A. If we assume zero trade margins, country A's terms of trade is the ratio of A's *fob* export price of corn to B's *fob* export price of oil, and vice versa. A terms-of-trade improvement for A means that the price for its corn export has increased relative to the price of its oil import. The corn price may have increased or the oil price may have fallen, or both may have changed, as long as the corn price rose relative to the oil price. A's terms-of-trade improvement means that the export earnings from each unit of its corn exports now has more import-purchasing power for oil imports.

Table 7.4 presents two numerical examples to illustrate this concept. Because the price data are reported in percentage change terms, the percentage change in a country's export price minus the percentage change in its import price approximately measures the percentage change in its terms of trade. In scenario 1, country A experiences a terms-of-trade gain because its export price rises relative to B's export price; but A experiences a terms-of-trade loss in scenario 2. Notice, too, that A's terms-of-trade gain is exactly equal to country B's terms-of-trade loss, so globally, the terms-of-trade changes sum to zero.

Countries usually export and import many types of goods with many trade partners. A global CGE model that tracks bilateral trade flows and includes the Armington assumption that goods are differentiated by origin tracks the bilateral trade prices for all countries and commodities in the model. In this case, a country's terms of trade can be calculated as a price index that is defined for either a commodity or for total imports and exports. Either index is calculated as a trade-weighted sum of the home country's bilateral (*fob*) export prices relative to a trade-weighted sum of the *cif* prices of its imports. The trade weights on the export side are the value shares of each trade partner in the home country's export market. The weights on the import side are the value shares of each source country in the home country's imports.[2] Terms-of-trade changes can vary widely among countries, even though globally, the terms-of-trade changes for all countries sum to zero.

A "*small*" *country* does not experience terms-of-trade effects because its world market shares are too small for changes in its export and import quantities to affect world prices. Single-country CGE models often, but not necessarily, include the assumption that a country is small in world markets

Table 7.4 *A two-country example of terms-of-trade changes*

	% Change from base			
	A's *fob* world export price of corn	B's *fob* world export price of oil	A's terms of trade	B's terms of trade
Scenario 1	25	–10	35	–35
Scenario 2	–2	8	–10	10

[2] See section "Composite Commodities, Factors, and Prices" in Chapter 2 for an example of how to calculate a trade-weighted price index.

and that its world export and import prices are fixed. However, in multi-country CGE models with Armington import aggregation functions, every country is potentially a "*large*" *country* to some extent – even countries that we ordinarily think of as small. Therefore, all countries in a multi-country model can experience terms-of-trade changes.

An important, practical implication of the use of Armington import aggregation functions in multi-country CGE models is that terms-of-trade effects are usually due to larger changes in countries' export prices than in their import prices. This insight was developed by Brown (1987), who studied terms-of-trade effects in the multi-country Michigan Model of international trade. To understand why this is so, consider what might happen if a very small country like Israel imposes a tariff on its orange imports, causing its consumers to reduce their import quantity and consume more domestically produced oranges. Israel's bilateral import prices for oranges will likely fall, but not by much, since Israel is only one of many customers in each of its suppliers' markets, and probably only a small one at that. However, even a small country like Israel is large in its export market because the Armington assumption – that products are differentiated by source country – implies that Israel is the monopoly supplier of Israeli oranges. Increased domestic demand reduces the supply of Israeli oranges available for export. When the quantity of Israeli orange exports declines, its world export price will rise, perhaps by a lot if its foreign customers are unwilling to substitute their domestic oranges, or oranges from other suppliers, for the Israeli variety (i.e., they have a low Armington import substitution elasticity).

We explore these concepts in a 2-region example, using the NUS333 model to run an experiment that increases the US manufacturing import tariff from 1.2% to 15%. We compare the terms-of-trade results for the US manufacturing sector when the US elasticity of substitution between domestic and the aggregate imported variety is assumed to have a relatively low value of 3 versus a high value of 10.

The tariff increases the price paid by US consumers for manufactured imports from the rest-of-world and causes the quantity of US imports from ROW to fall (Table 7.5). The higher the import-domestic substitution elasticity, the greater the fall in the US import quantity. The United States is a large enough customer that a decline in its import demand causes the rest-of-world's bilateral export price to fall, the more so as the import becomes more substitutable with the domestically produced variety.

On the export side, the shift of US demand toward the domestic variety causes a fall in the quantity of US manufacturing available for export. The higher the US import-domestic substitution elasticity, the larger the decline in the US export supply. The decreased availability of US exports drives up

Table 7.5 *Terms-of-trade effects on US manufacturing from a 15% US tariff on manufactured imports (% change from base)*

US Armington Import-Domestic Substitution Elasticity (ESUBD)	Mfg. import quantity (*qmw*)	Mfg. export quantity (*qxw*)	Bilateral US Mfg. import price from ROW (*pcif*)	Bilateral US Mfg. export price to ROW (*pfob*)	US terms of trade in Mfg. (*pfob*) – (*pcif*)
3	–17.5	–27.2	–0.6	4.1	4.7
10	–26.2	–45.5	–2.0	7.1	9.1

Note: US tariff on manufactured imports is increased from 1.2% to 15%. US import-import substitution elasticity among import suppliers (ESUBM) is set at twice the level of the import-domestic Armington elasticity (ESUBD).
Source: NUS333 model.

the price of US manufacturing exports, the more so as manufacturing imports become more substitutable with the domestic US product. On net, the United States has a terms-of-trade gain that becomes larger as its import substitution elasticity becomes larger. Notice that most of the US terms-of-trade gain is attributable to an increase in the US export price.

Terms-of-trade effects can be an important outcome of any type of shock to an open economy. Many CGE analyses of trade liberalization find that the terms-of-trade effects are quite large and can even dominate efficiency gains in determining the welfare effects of trade policy reform. However, even when the modeler makes the small-country assumption and fixes the terms of trade, this variable remains a relevant subject of CGE analysis because exogenous changes in the world import or export price can be introduced as an experiment. As an example, the modeler could explore the effects of an increase in the world price of a natural resource export on a small, resource-exporting country, as we do later in this chapter in our discussion of Dutch Disease.

Trade Theory in CGE Models

Economists Eli Heckscher and Bertil Ohlin developed a simple, two-good, two-factor, two-country model to explain the relationship between countries' relative factor endowments and the composition of their trade. In their stylized model, the two countries differ only in their relative factor endowments – one has a larger endowment of labor relative to capital, and the other has a larger endowment of capital relative to labor. The *Heckscher-Ohlin theorem* posits that both countries will export goods that are intensive in the factors of production that are in relatively abundant supply, and import goods that are intensive in the factors of production that are in relatively scarce supply.

This powerful insight into why countries trade has yielded additional theorems about trade. Two theorems that derive from the Heckscher-Ohlin model describe the effects of changes in factor endowments on industry structure and the terms of trade (the *Rybczynski theorem*), and the effects of changes in world prices on factor returns and income distribution (the *Stolper-Samuelson theorem*). Both theorems focus attention on the effects of changing market conditions on economic structure and factor income, and so they are of special interest to CGE modelers, because these are the outcomes that we largely focus on in our studies of trade policy.

However, the two theorems rest on very specific assumptions that are not usually met in the more realistic, applied CGE models that we are studying. For example, in our NUS333 model, the two regions both export and import the same type of good, and their production technologies differ. In many applied CGE models, there are more factors, more industries, and (in multi-country models) more countries than in the stylized theoretical models that yield these theorems. Nevertheless, grounding our interpretation of CGE model results in these theorems remains useful. In the following sections, we show how the theorems help us identify which model results are most relevant to consider, and how they provide us with insights that help us understand and explain our results. Results tend to be consistent with, although they do not necessarily follow directly from, the stylized models of international trade.

Factor Endowment Changes, Trade, and Terms of Trade

A country's factor endowments can change for many reasons. Over the long term, economies grow because of the gradual accumulation of factor supplies, as savings augment the capital stock and population growth increases the labor supply. Economic shocks also affect factor supplies such as labor immigration, capital inflows, and war and disease. And, as we learned in Chapter 6, a change in productivity changes the effective endowment of a factor. Education and training, for example, increase the effective number of workers, even if the actual number of workers remains the same.

A change in factor endowments can change a country's comparative advantage and lead to changes in the types of goods that it produces and trades. In turn, changes in a country's export supply and import demand can lead to changes in its terms of trade. These ideas were developed formally by the economist Tadeusz Rybczynski (1955). He posited that a change in the endowment of one factor has two effects. First, an increase in the quantity of one factor leads to an absolute increase in the production of the good that uses that factor intensively, and an absolute decrease in production of the good that does not use it intensively, holding world prices constant (Table 7.6).

Text Box 7.1 Rybczynski effects in a global CGE model of East Asia

"***Historical Analysis of Growth and Trade Patterns in the Pacific Rim: An Evaluation of the GTAP Framework***" (Gehlhar, 1997).

What is the research question? A CGE model's validity is often tested by scrutinizing assumptions about behavioral equations and their elasticity parameters. This analysis proposes a more rigorous test by asking whether the GTAP model is capable of explaining and reproducing historical trade flows.
What is the CGE model innovation? The author performs an exercise in "backcasting" (as opposed to "forecasting") by seeing whether the GTAP model can replicate historical, bilateral trade flows. Because the GTAP model is based on standard, neoclassical theory, the author chooses a backcasting exercise that the theory is capable of explaining – the link between factor endowments and the commodity composition of trade. In general, East Asian countries are observed to have had faster growth in their human and physical capital stocks over 1982–1992 than developed countries, and the composition of their exports has consequently shifted from labor-intensive to skill- and capital-intensive products. The author uses the CGE model to reverse East Asia's factor endowment growth and observe model results for Rybczynski-type effects on industry structure and trade.
What is the experiment? For each country/region, four types of endowments are reduced from their 1992 levels to 1982 levels: population, labor force, human capital, and physical capital. The same experiment is carried out with (1) the default import substitution elasticities, (2) a 20% increase in all import elasticities, (3) a database that disaggregates the labor force into skilled and unskilled workers, and (4) a combination of the human capital split and higher import substitution elasticity parameters.
What are the key findings? There is a strong correlation between countries' actual 1982 shares in world trade by commodities and the trade shares simulated by the model. The correlation is strongest when trade elasticities are relatively large and labor is divided into skilled and unskilled workers. The comparison of correlations across the four scenarios demonstrates that elasticities and labor market disaggregation by skill level are critical assumptions in terms of the model's predictive ability.

Table 7.6 *Endowment growth and Rybczynski effects*

Endowment growth	Exportable output	Importable output	Terms of trade
Factor used intensively in exportable	+	–	+
Factor used intensively in importable	–	+	–

This observation is known as the *Rybczynski theorem*. Second, if the country engages in trade and if the quantity of the endowment used intensively in its export good increases, then its export supply and import demand will increase and its terms of trade will deteriorate. On the other hand, if the endowment used intensively in the importable good increases, then the country's imports and exports will decline and its terms of trade will improve.

Figure 7.1 illustrates the producer's efficiency-maximizing behavior that drives the Rybczynski theorem. First, assume that there are two sectors in the economy: one that produces exportable goods and one that produces importable goods. We also assume that the exportable sector is labor-intensive, the importable sector is capital-intensive and there are no taxes or trade margin costs. The figure includes a product transformation curve, QC^1, drawn concave to the origin. It represents all possible combinations of outputs of the exportable, QX, and importable, QM, goods that can be produced with a given factor endowment. Recall from Chapter 5 that the slope of any point on a transformation curve describes the marginal rate of transformation (MRT), which is equal to the ratios of the marginal costs of the importable to the exportable: MC_M/MC_X. As the economy moves down the transformation curve and relatively more of the importable good is produced, the prices of the importable's inputs are bid up, and the ratio MC_M/MC_X increases. The parallel lines in the figure define the relative world prices of the country's import ($PXWCOM_M$) and its export ($PXWCOM_X$). For now, we assume that world prices are fixed, and the country is small in world markets, so both price lines have the same slope $-PXWCOM_M/PXWCOM_X$. In the initial equilibrium, output is at quantity ratio QM^1/QX^1. At this tangency, the ratios $MC_M/MC_X = PXWCOM_M/PXWCOM_X$. Rearranging, $MC_M/PXWCOM_M = MC_E/PXWCOM_X$. This means that the producer optimizes when the marginal costs per dollar earned from the sale of both goods are equal.

In Figure 7.1, the convex curves are consumer indifference curves that describe all possible combinations of the exportable and importable good that yield equal utility to domestic consumers. Notice that the country's utility-maximizing consumption basket on QC^1 is different from its optimal production mix. In this country, international trade gives consumers the opportunity to consume a larger ratio of importable to exportable goods than it produces.

An increase in the country's labor endowment shifts its product transformation curve outward to QC^2. Now, more of both goods can be produced. The increase in the labor supply drives down wages, which is most cost saving for the exportable sector because it is relatively labor-intensive. That is why the curve shifts out further on the exportable axis than on the importable axis. The fall in the wage causes MC_X to fall relative to MC_M at the initial product ratio of QM^1

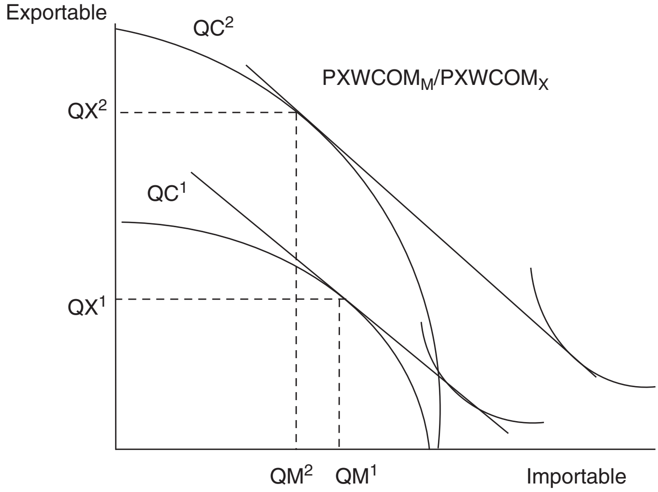


Figure 7.1 Exportable-expanding factor growth

and QX^1. The economy adjusts by shifting toward production of the labor-intensive exportable, which drives wages back up until the marginal cost per dollar earned from exportables is again equal to that from importable production. At given world prices, the optimal production mix is now QX^2 and QM^2.

The increase in supply of exportables leads to an increase in export supply, and the decline in importable production leads to higher import demand. If we now assume that the country is large enough in world markets to affect world prices, then the world price of its exportable will fall, and the world price of its importable will rise. That is, the country's terms of trade will decline.

The effect of an increase in the capital stock, used intensively in the importable good, is analyzed in a similar fashion. In this case, production of the importable increases and import demand falls. Production of the exportable and export supply both fall. The changes in the country's trade will lead to an improvement in its terms of trade.

This is the theoretical context for understanding the trade, and terms-of-trade, effects of CGE model experiments that increase the endowment of one factor. However, before we can explore Rybczynski effects in our CGE model, we first need to examine the NUS333 data to compare factor intensities across sectors and to identify which sectors are exportable or importable. Based on data from the US structure table (Table 3.3) on labor and capital shares in industry costs, we know that land accounts for 11% of the cost of producing agricultural products, but is not used in the production of manufacturing or services. Commodities are more exportable as the export share in production increases, and more importable as the import share in consumption increases. According to data from the US structure table, the agriculture sector is relatively exportable, with a higher share of exports in production than of imports in consumption. US manufacturing is a relatively importable sector, with a higher share of imports in consumption than of exports in production. Services are close to being a non-traded good, a possibility not considered in Rybczynski's stylized two-sector model and another example of how our applied model diverges from the strict assumptions of theory.

With this grounding in theory and in our model data, we can use the NUS333 model to analyze a change in a factor endowment on the two relatively tradable sectors: agriculture and manufacturing. Our experiment is a 10% increase in the US land supply, which is an increase in the endowment used in the more exportable sector. The shock causes US land rents to fall by 3%. The US experiences a small real appreciation of .01% because its factor price index increases relative to that in the rest of the world.

Other results, reported in Table 7.7, are broadly consistent with the Rybczynski effects. Production increases by more in the land-using agricultural sector than in manufactures, although output in both sectors increases because growth in the US land supply increases the productive capacity of its economy. The increase in US agricultural supply results in an expansion of US agricultural exports and a decline in agricultural imports. The supply of US manufacturing exports falls and imports increase. Terms-of-trade results, too, are consistent with Rybczynski effects. The US *fob* export price declines in the exportable sector by more than its *cif* import price from the rest-of-world, resulting in a terms-of-trade loss in agriculture. World price effects in manufacturing are too small to report. The Rybczynski prediction that the overall US terms of trade will decline is thus supported by our model.

Table 7.7 *Effects of a 10% increase in the US land supply*

	Land share in industry costs	% Change in output (*qo*)	% Change in exports (*qxw*)	% Change in imports (*qmw*)	% Change in export price (*pfob*)	% Change in import price (*pcif*)	% Change in terms of trade (*pfob* – *pcif*)
Agriculture	11.00	0.37	1.40	–0.69	–0.37	0.00	–0.37
Manufacturing	0.00	0.02	–0.01	0.03	0.00	0.00	0.00

Note: US elasticity of factor substitution is four in all sectors.
Source: NUS333 model.

Text Box 7.2 Stolper-Samuelson versus migration effects in NAFTA

"***Wage Changes in a U.S.-Mexico Free Trade Area: Migration versus Stolper-Samuelson Effects***" (Burfisher, Robinson, and Thierfelder, 1994).

What is the research question? Much of the debate over NAFTA reflected concerns about potential wage changes as described by the Stolper-Samuelson theorem (SST). The theorem suggests that NAFTA will lower unskilled wages in the United States and raise those in Mexico as free trade causes the exports and prices of Mexico's unskilled labor-intensive exports to increase and the production and price of these goods in the United States to fall. However, wages in both countries are also influenced by the impact of NAFTA in increasing labor migration flows within Mexico and between Mexico and the United States. Could an applied CGE model of a free-trade agreement between the United States and Mexico predict the wage effects from both SST effects and migration?
What is the CGE model innovation? The authors develop a CGE model of the United States and Mexico that allows labor migration between the two countries in response to changes in relative wages. The model also includes tariffs and domestic taxes and subsidies that are not directly affected by the NAFTA accord and which create a second-best environment that violates many of the assumptions of the SST.
What is the experiment? The model experiments describe tariff elimination between the United States and Mexico in (1) a realistic model with tax distortions and (2) a distortion-free model that replicates some (but not all) of the assumptions of the SST. A trade liberalization experiment is run in the model without migration to explore SST effects, and in the model with labor migration to describe combined SST and factor endowment effects.
What are the key findings? The SST effects are found to be empirically very small, and labor migration has the dominant influence on wages in the free-trade area, in some cases reversing the wage changes that would be expected based on the SST alone.

World Price Changes and Factor Income Distribution

What happens to a country's wages and capital rents when world prices change? The *Stolper-Samuelson theorem* posits that in a two-good economy, a change in the relative prices of goods will lead to a change in relative factor prices and the distribution of national income. The price of the factor used intensively in the production of the good whose relative price has risen will increase. The price of the factor used intensively in the production of the good whose relative price has decreased will fall.

The reasoning is as follows. An increase in the world price of one good will cause an economy's production to shift toward increased production of that good and away from production of the other good. If each industry employs a different mix of factors, then the composition of the economy-wide demand for factors will shift, leading to a change in relative factor prices. As an example, let's assume that the world price of agriculture (a relatively capital-intensive good) increases relative to the world price of manufactures (a relatively labor-intensive good). To expand agricultural output, farmers must hire capital and labor from the manufacturing industry. As the manufacturing industry contracts, it releases both labor and capital, but the proportion of labor is too high and the proportion of capital is too low relative to the demands of agriculture. Given its scarcity, the increased demand for capital will push capital rents up while the surplus of labor will push wages down.

We depict these changes in the economy-wide demand for capital and labor in Figures 7.2a and 7.2b. In the figures, QE_K describes the economy's supply of capital and QE_L describes its supply of labor. Both supply curves are vertical, because we assume fixed endowment quantities that are fully employed. In the initial equilibrium in Figure 7.2a, D_K^1 is the demand for capital and PE_K^1 is the initial equilibrium rental rate. A shift in industry structure toward the capital-intensive industry increases the economy-wide demand for capital to D_K^2, causing the rental rate to increase to PE_K^2. In the initial equilibrium in Figure 7.2b, D_L^1 is the demand for labor and PE_L^1 is the equilibrium wage. The shift in the country's industry structure toward the capital-intensive good causes the economy-wide demand for labor to fall to D_L^2 and the wage to decline to PE_L^2.

We can use the Stolper-Samuelson theorem to understand the results of CGE model experiments that change world prices. As an example, we use the NUS333 model to run an experiment that increases the world price of manufacturing by 10%. Based on our structure table in Chapter 3, we already know that US manufacturing is relatively labor-intensive when compared to agriculture, and that agriculture is intensive in the use of land, which is not used in manufacturing production. We might therefore expect that the increased world price of the manufactured good will lead to an increase in the US wage relative to land rents.

In our experiment, we find that that the production mix in the United States shifts toward manufacturing. Manufacturing output increases 1.6% whereas agricultural production declines 4.2%. The shift toward production of a labor-intensive product causes the US wage to increase 10.3% and the rental rate on land to decline 12.2%. The results are consistent with the predictions of the Stolper-Samuelson theorem.

Booming Sector, Dutch Disease

An increase in the world price of a country's export good would seem to offer it windfall benefits, but it can also lead to "deindustrialization," a problem

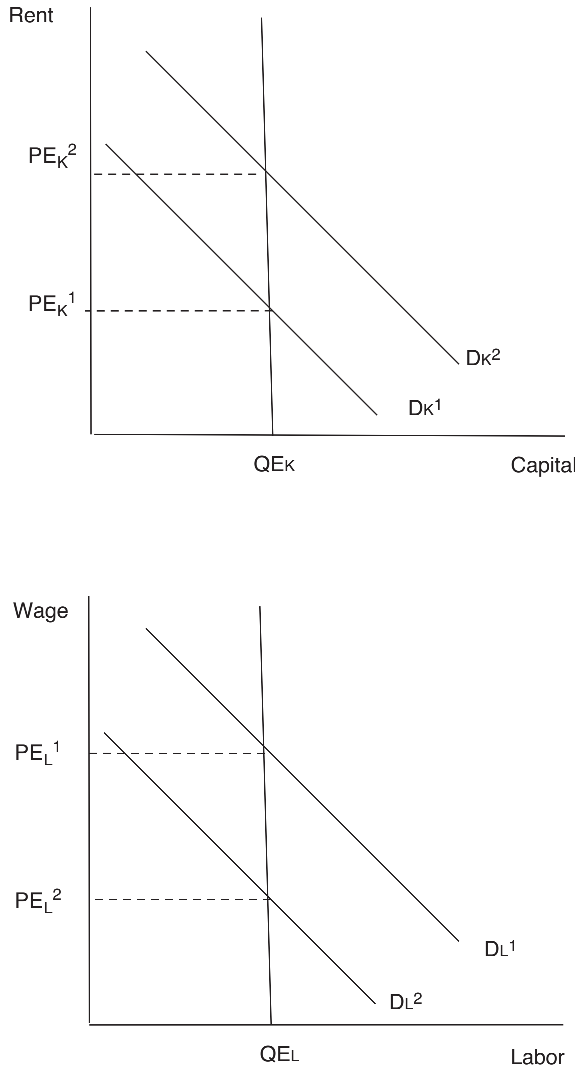


Figure 7.2 (a) Increase in economy-wide demand for capital due to an increase in the world price of the capital-intensive good. (b) Decrease in economy-wide demand for labor due to an increase in the world price of the capital-intensive good

that has received a great deal of attention from economists. This type of change in the production structure of an economy following an export boom has become known as *Dutch Disease* because it was first recognized by economists when it was experienced in the Netherlands following its discovery of natural gas. The process is described more generally by Corden and Neary (1982) as the effects of a booming export sector on the rest of the economy. Their analysis of an increase in the world price of a country's export is of interest to CGE modelers because it illustrates both the effects of a terms-of-trade shock on the country's industry structure as well as macroeconomic feedback through real exchange rate appreciation. Both are general equilibrium effects that CGE models are well suited to analyze. (See Text Box 7.3.)

The Cordon-Neary model assumes a country with three sectors, capital that is fixed in each industry, and a labor force that is mobile among all three industries. Two sectors are traded – we'll call one of them oil (the booming sector) and the other manufacturing. The third sector is services (including products like haircuts and lawn care), which are not traded. The country is small, so the prices of its oil and manufacturing are set by world markets. The price of its services is determined by domestic supply and demand.

A boom in the price of its oil export has two effects. The *resource movement effect* describes the reallocation of productive resources toward the booming

Text Box 7.3 "Dutch Disease" in Cameroon

"***The 'Dutch' Disease in a Developing Country: Oil Reserves in Cameroon***" (Benjamin, Devarajan, and Weiner, 1989).

What is the research question? Rising oil and gas prices confer substantial wealth on exporters of natural resources, but these revenues can be a mixed blessing because they have the potential to cause deindustrialization, an unwelcome structural change known as "Dutch Disease." Most analyses of Dutch Disease have studied developed countries; how might a booming natural resource sector affect a developing country?

What is the CGE model innovation? The authors use a single-country CGE model of Cameroon that captures three key features of its economy: (1) agriculture, rather than manufacturing, is the traditional export sector; (2) manufactured imports are imperfect substitutes for domestic varieties (i.e., they assume an Armington import aggregation function); and (3) the oil sector is an enclave so that, except for generating income, it has weak links to the rest of the Cameroonian economy.

What is the experiment? A boom in Cameroon's oil export industry is simulated as a $500 million inflow of foreign savings – an amount equal to its foreign oil export earnings in 1982.

What are the key findings? Similar to the experience of developed countries, Cameroon's economy experiences a structural change when its oil sector booms. Because the oil sector is an enclave, structural change is due mostly to the spending effect, as higher oil revenues increase incomes and demand, instead of the resource movement effect that pulls resources into oil production. However, instead of the deindustrialization that characterizes Dutch Disease, it is Cameroon's traditional agricultural sector that contracts.

sector. The increase in the export price enables the export sector to attract labor from manufacturing and services by paying higher wages. The country's industry structure then changes as the booming sector expands and output of services and manufacturing falls. Hence, the country begins to deindustrialize.

The *spending effect* results from the income growth due to higher export earnings. Higher income causes consumer demand for both services and manufactured goods to increase. Demand growth for manufactures can be met by increasing imports at the fixed world price, but increased demand for services, which are not traded, can only be met by increasing domestic production. The spending effect therefore leads to further deindustrialization due to competition by the expanding services sector for the resources used in manufacturing.

Both the resource movement effect and the spending effect lead to real exchange rate appreciation. The *real exchange rate* is the price of domestic services (a non-traded good) relative to manufactures (a traded good with a fixed world price). The fall in the supply of services in the resource movement effect creates a scarcity that causes the price of services to rise relative to the price of manufacturing. The spending effect leads to increased demand for services and an additional increase in the price of services relative to manufacturing. Because exchange rate appreciation makes imports more affordable, the appreciation linked to the spending and resource effects also contributes to increased imports and the decline in production of manufacturing.

To explore the Dutch Disease effects of a change in world prices in a CGE model, we use the NUS333 model to simulate a 10% increase in the world price of manufacturing (the booming sector). Our CGE model does not conform to all of the assumptions in the stylized model developed by Cordon and Neary. For example, our model includes intermediate demand, and there is two-way trade in all three goods, including services. Yet, the Dutch Disease framework remains useful because it informs us that the key effects of a boom (or bust) in world export prices are observed in changes in a country's industry structure, its real exchange rate, and trade.

Based on the Dutch Disease model, we offer this prognosis for the US economy. Output of US manufacturing (the booming sector) will increase and agricultural output will decrease. However, the effect on output of services is ambiguous, because the spending effect will tend to increase its output, but the resource movement and exchange rate appreciation will tend to decrease its output (because in our CGE model, services are both imported and exported). We also expect that the US real exchange rate will appreciate, causing foreign demand for all US exports to fall and US demand for all imports to rise.

Results, reported in Table 7.8, show evidence of "disease" – the structural change that crowds out production in the nonbooming sectors. Output in the

Table 7.8 *Dutch Disease: effects on United States of a 10% increase in the rest-of-world price of manufacturing (% change from base)*

	Production (*qo*)	Imports (*qmw*)	Exports (*qwx*)
Agriculture	–4.2	14.9	–20.2
Manufacturing	1.6	1.6	3.2
Services	–0.3	20.9	–30.2

Source: NUS333 model.

booming US manufacturing sector increases, but output falls in both agriculture and services. The real exchange rate appreciates 10.2%. US import demand therefore increases for agriculture and services, but note that manufacturing imports fall. This is because the higher world import price causes US consumers to shift their demand toward the cheaper, domestic variety of manufactured goods. Exports of both agriculture and services fall because lower domestic production reduces the supply available for exports, and because exchange rate appreciation reduces foreign demand.

Trade Margins in International Trade

Many multi-country CGE models and their underlying SAM databases explicitly account for the *trade margin* costs incurred in international trade. These costs include land, air, and sea freight costs, plus insurance and any other handling charges that are required to ship goods from the exporter's port to that of the importer. Trade margins drive a wedge between the *fob* (free on board) price received by the exporter and the *cif* (cost, insurance, freight) price paid by the importer, and therefore can affect the quantity of trade. For example, the substantial decline in shipping costs since the 1950s is considered to be an important factor in explaining the rapid expansion of global trade over the past several decades.[3] There also can be shocks to shipping costs, which multi-country CGE models are well suited to analyze. For example, Sullivan (2010) studied the effects of piracy off the East African coast, which raised insurance and shipping costs for some commodities traded between certain partners. Jabara et al. (2008) analyzed the bilateral trade effects of costly US restrictions on the use of wood pallets to prevent the trans-oceanic introduction of invasive pests.

The effects of trade margins on the quantity and prices of traded goods are illustrated in Figure 7.3. In the figure, S is the small country's

[3] Hummels (2007), for example, found that US air shipping costs declined by more than 90% between 1955 and 2004, and ocean transport costs fell from 10% to 6% of import values over the past 30 years.

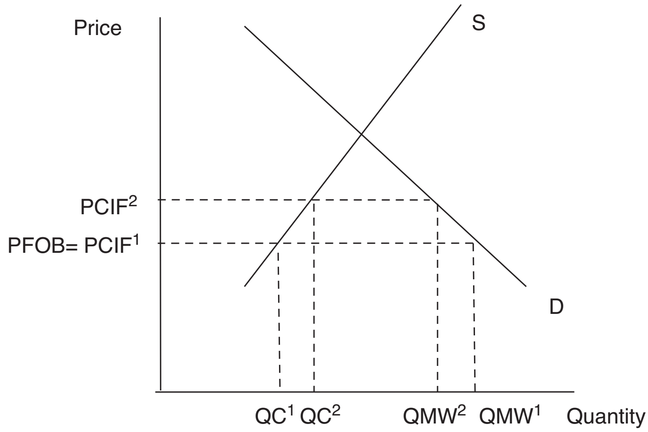


Figure 7.3 Import demand with trade and transport costs

supply curve for production of the domestic variety, and D is its demand curve for the composite good, which is an aggregate of the domestic and imported varieties. Absent any margin costs, the country produces QC^1 and imports quantity $QMW^1 - QC^1$ at the exporter's price of PFOB, which is equal to the importer's *cif* price, $PCIF^1$. However, the introduction of trade margin costs increases its import price to $PCIF^2$, causing domestic production to increase to QC^2 and reducing the import quantity to $QMW^2 - QC^2$. A shock that causes a change in the size of the trade margin cost per unit, $PCIF^2 - PFOB$, thus affects production and import quantities.

We explore the role of trade and transport margins in a CGE model by using the NUS333 model to run an experiment that reduces the margin costs on all US imports. First, consider the initial import margin costs reported in the US SAM and in Table 7.9. Margin services increase the *cif* cost of agricultural imports by 17.8% relative to their *fob* cost and increase the cost of manufactured imports by 4.5%. Margin services are only required for trade in goods, not in services.

We model a reduction in the cost of trade margins as a 10% increase in productivity in trade margin services used for US imports. This lowers the US *cif* import prices for both goods, causing their import quantities to increase and their domestic production to fall. Notice that ROW's *fob* prices for manufactures increases as a result of higher US import demand, so the benefits from the fall in margin costs therefore are split between the importer (the United States) and the exporter. The division of benefits of lower margin costs (or the burden of higher margin costs) between exporters and importers depends on the relative elasticities of the exporter's supply and the importer's demand.

Table 7.9 *Effects of a 10% decline in trade margin costs on US imports*

	Agriculture	Manufacturing
Base data		
Imports at *fob* price ($US billions)	28	1,797
Imports at *cif* price ($US billions)	33	1,878
Trade margin cost ($US billions)	5	81
Trade margin rate (%)	17.8	4.5
10% increase in productivity in trade margins (*atd*)		
US import price *pcif* (% change)	–0.18	–0.09
US import quantity *qmw* (% change)	2.67	0.79
US production quantity *qc* (% change)	–0.21	–0.11
ROW export price *pfob* (% change)	0.02	0.00

Note: Trade margin rate is the trade margin cost as a percent of the *fob* value of imports.
Source: NUS333 model.

Summary

Trade data in the SAM report trade valued in *fob* prices, import tariffs, export taxes, and the trade margin costs used in the international shipment of goods. Our discussion of trade behavior in a CGE model began by defining two concepts: the exchange rate and the terms of trade. The treatment of exchange rates differs among CGE models. The terms of trade measure a country's export prices relative to its import prices and describe the purchasing power of a country's export earnings. Terms of trade are thus a component in measuring changes in a nation's welfare. We used trade theory to ground our analyses of trade shocks in our CGE model. First, we relied on the Rybczynski theorem to explain the effects of an increase in a factor endowment on the commodity composition of trade and the subsequent effects on the terms of trade. The Stolper-Samuelson theorem informed our analysis of the effects of a change in world prices on a country's industry structure and factor prices. Our study of Dutch Disease explored a common problem in the world economy, in which a country experiences a change in its terms of trade (a boom or a bust for its main export) that causes changes in its industry structure. Finally, we explained how changes in trade margin costs affect trade volumes and world prices.

Key Terms

Dutch Disease
Heckscher-Ohlin theorem
Large country
Nominal exchange rate

Real exchange rate
Resource movement effect
Rybczynski theorem
Small country
Spending effect
Stolper-Samuelson theorem
Terms of trade
Trade margin

PRACTICE AND REVIEW

1. Suppose that technological innovation increases a country's capital productivity. It has two industries with the characteristics shown in Table 7.10:
   a. Which sector is capital-intensive and which is labor-intensive?
   b. How will the production costs of each sector be affected by an increase in capital productivity? Explain why.
   c. Which sector is exportable and which is importable?
   d. How do you expect imports and exports to be affected by the increase in capital productivity? How will this change in trade be likely to affect the terms of trade?
2. Venezuela derives much of its export earnings from oil. Use the Dutch Disease framework to explain the possible effects on production and trade of its nonoil industries following a sudden hike in global oil prices. What are the public policy issues that your analysis raises for Venezuelan policymakers?
3. Assume that a shock in world markets results in the price changes described in Table 7.11. Using the information on market shares, calculate the percentage changes in (1) the trade-weighted US *fob* export price, (2) the trade-weighted US

Table 7.10 *Practice and review – industry characteristics*

pcIndustry	Capital quantity	Labor quantity	Production quantity	Export share of production	Import share of consumption
Wine	142	1,220	100	0.50	0.10
Televisions	97	25	100	0.25	0.40

Table 7.11 *Practice and review – terms of trade*

	US corn exports		US oil imports	
	Brazil	China	Saudi Arabia	Canada
Percent change in price	6	4	4	1
Market share	0.6	0.4	0.8	0.2

cif import price, and (3) its terms of trade. Has the US terms of trade improved or deteriorated?

4. Some CGE models include an export transformation function, described in Chapter 5. In these models, terms-of-trade effects are generally smaller than in models without the export function. Why do you think that might be the case?

8

Taxes in a CGE Model

This chapter examines the treatment of trade and domestic taxes in a computable general equilibrium (CGE) model. Trade taxes are imposed on imports and exports of goods and services. Domestic taxes are taxes paid by production activities on output and factor use and by purchasers on sales of intermediate and retail goods, and income taxes. We trace the tax data in a Social Accounting Matrix (SAM) to describe the agent and the economic activity on which the tax is levied and the amount of revenue generated by each tax; we also show how to use the SAM's data to calculate tax rates. Partial equilibrium diagrams then illustrate the theoretical effects of taxes on economic activity and welfare. The results of tax policy experiments using a CGE model support the theoretical predictions and offer insight into the economy-wide effects of each tax. Three applied examples of tax policy analysis explore the second-best welfare effects of a tax, the marginal welfare impacts of a country's entire tax structure, and the elimination of import tariffs in a preferential trade agreement.

The large federal deficit in the United States has spurred intense debate on whether the sizeable tax cuts enacted since 2000 should be maintained or reversed. Taxes influence the behavior of an economy's consumers and producers in important ways. Many politicians favor lower taxes because they can lead to increased consumer spending, and provide an economic stimulus as production and employment in consumer goods industries expand to meet higher demand. Lower tax rates also may motivate producers to invest more, which helps stimulate employment in industries that produce capital equipment and increases future productivity. At the same time, lower tax rates mean less revenue for the government, reducing its role in national expenditure. Because computable general equilibrium (CGE) models can describe the effect of taxes on economic behavior, and the structure of income and expenditure in an economy, they have proven to be a useful tool for empirically analyzing how taxes affect consumers, producers, and the economy as a whole.

Governments impose taxes for many reasons. Foremost is the need to raise revenue to support the provision of public goods such as national defense and education. Governments sometimes use taxes to redress market failures such as externalities. For example, the government may impose carbon taxes to reduce the harm to public health that is associated with air pollution by private industry. Governments may impose “sin taxes” on goods or activities such as alcohol, tobacco, and gambling to discourage private behaviors deemed to be socially offensive or costly. Most governments tax imports to protect or promote selected industries, and sometimes they tax exports. Governments also use taxes to achieve societal goals, such as income equality. In this case, governments may redistribute income by imposing high taxes on high-income households while giving tax credits or income transfers to low-income households.

Taxes impose burdens on the private sector. The *direct burden* of a tax is the amount of tax revenue that it generates. A 5% sales tax on groceries, for example, imposes a direct burden of five cents for every dollar spent on groceries. The direct burden of taxation is not a loss to the economy because each tax dollar is a transfer of spending power from the taxpayer to the government, absent any administrative costs.

Taxes deserve special scrutiny because they often lead to an *excess burden*, which is the loss in economic efficiency when producers and consumers change the quantities that they produce or consume in order to avoid paying a tax. For example, the 5% sales tax on groceries may cause consumers to buy fewer groceries and more of other, untaxed goods that they enjoy less. The change in their consumption bundle is inefficient, given the nation’s productive resources and consumer preferences. The inefficiencies caused by tax-distorted consumption and production are an excess burden of taxes that is above and beyond the direct burden of paying the tax. Economists call these *allocative inefficiencies* a *deadweight loss* because these foregone opportunities are not recouped elsewhere in the economy.

Computable general equilibrium models are especially useful for tax policy analysis because they can quantify both the direct (tax revenue) and excess (efficiency effects) burdens of taxes. Because the models are economy-wide, they also capture potential interactions among all taxes in an economy. This is important because governments typically impose many types and levels of taxes at the same time. Sometimes a tax or subsidy is actually beneficial, in the sense that it offsets the inefficiencies caused by another tax. For example, the introduction of a production subsidy to manufacturers may offset efficiency losses that result from a sales tax on their purchases of inputs. Of course, the overall impact of taxes on an economy also depends on the gains to society from the government spending that is funded by the tax. Keep in mind that societal gains, such as national security or cleaner air, are not readily monetized or generally accounted for in a typical CGE model, unless the economist adapts the model for that purpose.

We categorize taxes into five broad types for the discussion that follows:

- *Trade taxes* are levied on imports and exports.
- *Production taxes* are paid by production activities based on their output.
- *Sales taxes* are paid by domestic firms on their intermediate input purchases, and by consumers and investors on their purchases of final goods and services.
- *Factor use taxes* are paid by production activities based on their factor inputs.
- *Income taxes* are paid by factors or households based on income earned from wages and rents.

The first four taxes are *indirect taxes* because they are levied on the production or purchase of goods or factors. By comparison, *direct taxes*, primarily income taxes, are levied on factors or individuals. Indirect taxes are also distinguished from direct taxes because their burden potentially can be shifted onto someone else, which is not possible with direct taxes. *Tax incidence* describes how the burden of paying for indirect taxes is shifted between buyers and sellers after prices and wages adjust. For example, when a firm pays a tax to the government based on the value or quantity of its output (a production tax), the tax burden may be shifted, in whole or in part, to consumers, by charging higher retail prices. Individuals cannot similarly shift their income tax burden to others.

For each of the five taxes, we first trace the relevant data in the Social Accounting Matrix (SAM). A review of the tax data is a useful starting point for any CGE-based tax analysis because the SAM identifies the agent in the model who pays the tax and the production or consumption decision on which the tax is assumed to be levied. For example, if a tax on land use is reported in agriculture's production activity column, it is an indirect tax paid by the producer, and it increases farmers' costs of production. Raising or lowering that tax will directly affect producers' level of output (shifting their supply curve left or right). However, if that same land tax is instead recorded as an expense in the land factor's column, then it is a direct tax, much the same as a poll tax. Raising or lowering the tax will mostly affect landowning households' after-tax income and consumer demand but not farmers' production decisions. Placement of tax data in the SAM therefore reveals a great deal about how the tax is assumed to affect economic activity in the CGE model. Economists sometimes have debates over how to represent a particular tax in a CGE model because this decision, similar to model closure rules, predetermines model outcomes.

We focus next on the economic analysis of taxes in a CGE model. We begin by developing simple partial equilibrium theories on taxation that help us formulate our expectations about the effect of each tax in our general equilibrium model. Graphical analyses of trade taxes include their terms-of-trade effects, but analyses of other taxes assume closed or small economies, with no terms-of-trade changes. These graphical analyses emphasize the direct burden (tax revenues) and the excess burden (the efficiency losses) associated with most taxes. The excess burdens appear in the graphs as "Harberger triangles," named after the economist Arnold Harberger (1964), who refined this approach to measuring the efficiency waste caused by taxes.

With this foundation in data and theory, we are equipped to explore the effects of each type of tax in a CGE model. We start by creating a small-dimensioned pedagogical model, called NTaxToy, that we use to provide a baseline or benchmark for our analysis of a tax. NTaxToy is a GTAP CGE model with a tax-free version of the NUS333 database.[1] A distortion-free base model allows us to isolate the effects of each tax without the complexities that its interactions with other taxes in the economy can introduce. We then introduce each individual tax as a shock to this model and compare the model results to our theoretical predictions. Our discussion of model results focuses first on those variables that we highlight in our partial equilibrium analyses. Then, we consider selected general equilibrium results. Although these differ somewhat for each tax, we generally emphasize changes in the commodity composition of consumer baskets, industry output, and trade flows, and in the terms of trade and national welfare (see Text Box 8.1).

Last, we undertake three examples of applied tax policy analysis. In the first two examples, we return to our NUS333 model, in which there are many existing tax distortions. Tax experiments using this model allow us to explore the interaction among taxes that lead to second-best outcomes and the marginal welfare effects of the complex US tax system. In a third applied example, we use the GTAP CGE model with a three-region database, named NUSJToy, to study the welfare impacts of an elimination of bilateral trade taxes in a preferential free-trade agreement (PTA) between Japan and the United States on the two PTA members and the rest of the world.[2]

Trade Taxes

Import Tariffs

Import tariffs are taxes that are levied on the quantity or value of imported goods and services. Import tariffs are levied in one of two ways. *Specific* tariffs are paid per unit of import, such as $1 per barrel of oil. Specific tariff

[1] We create the distortion-free NTaxToy CGE model using GTAP's Altertax utility to update all taxes and subsidies in the NUS333 v8.1 database to zero percent. The NTaxToy model used in this chapter is available for download from the GTAP website at: www.gtap.agecon.purdue.edu/resources/resdisplay.asp?RecordID=5941

[2] The NUSJToy model used in this chapter is available for download from the GTAP website at:www.gtap.agecon.purdue.edu/resources/res display.asp?RecordID=5941

Text Box 8.1 Welfare decomposition in the GTAP model

Decomposing Welfare Changes in the GTAP Model (Huff and Hertel, 2000; McDougall, 2003).

The GTAP model contains a utility developed by Huff and Hertel (2000) and McDougall (2003) that decomposes the total, equivalent variation welfare effect of model experiments. The welfare effect is a money metric measure of the value of the effects of price changes on real consumption and savings in a region. Its decomposition allows a researcher to identify welfare contributions by commodity, factor, and tax type and to account for terms-of-trade effects. The GTAP welfare decomposition describes these six components:

- *allocative efficiency effect* – the excess burden of each tax;
- *endowment effect* – due to changes in quantities of factors of production (e.g., labor and capital), which change an economy's productive capacity;
- *technology effect* – due to changes in the productivity of factors and/or intermediate inputs, which change an economy's effective endowments and productive capacity;
- *commodity terms-of-trade effect* – due to changes in the economy's world (*fob*) prices of exported goods and services relative to its world (*fob*) prices of imported goods and services;
- *investment-savings terms-of-trade effect* – due to a change in the price of domestically produced capital investment goods relative to the price of savings in the global bank; and
- *preference change effect* – due to changes in the shares of private consumption, government, and savings in national spending.

payments grow in proportion to quantity, so that the import tariff on two barrels would cost $2 and the tariff on three barrels would cost $3, and so on. Specific tariff payments do not change when prices change; for example, the importer pays $1 per barrel regardless of whether a barrel costs $25 or $125.

Ad valorem tariffs are levied as a percentage of the *cif* import value (which includes trade margin costs). For example, a 5% ad valorem import tariff on an apple with an import value of $1 increases its cost to $1.05. If the apple's *cif* import value increases to $2, its cost, including the tariff, would be $2.10. In this case, tariff revenue for the single apple increases from five cents to ten cents following the change in its price.

Import tariffs are paid by the import varieties of the commodity columns of the SAM to the import tariff row account. The tariff increases the cost of imported goods so all categories of intermediate and final demand that consume imports ultimately pay the tariff. Table 8.1 reports the import tariff revenue and the *fob* value of imports

Table 8.1 *Import tariffs and imports from the US SAM*

Data in $US billion or percent	Agriculture	Manufactures	Services
Import tariff revenue	0.52	23	0
Imports (value in *fob* prices)	28	1,797	315
Import trade margins	5	81	0
Import tariff rate	1.6	1.2	0.0

Source: GTAP v.8.1 database.

from the NUS333 SAM. The *cif* value of imports, which is not reported in the SAM, is the sum of the *fob* import value and the trade margin costs. In the case of manufacturing, the *cif* value of imports is $1.878 trillion. We calculate ad valorem import tariff rates as:

$$\text{import tariff revenue}/cif \text{ value of imports} * 100.$$

The US ad valorem tariff rate on manufacturing imports from ROW is therefore:

$$\$23 \text{ billion}/(\$1,797 \text{ billion} + \$81 \text{ billion}) * 100 = 1.2\%.$$

The US tariff rate is highest on imports of agricultural goods (1.6%) and lowest on services (zero).

Figure 8.1 illustrates the economic effects of a bilateral ad valorem import tariff on a large economy. In the figure, S describes the supply of the imported good from its trade partner. Given the Armington assumption that goods are differentiated by country of origin, there is no domestic

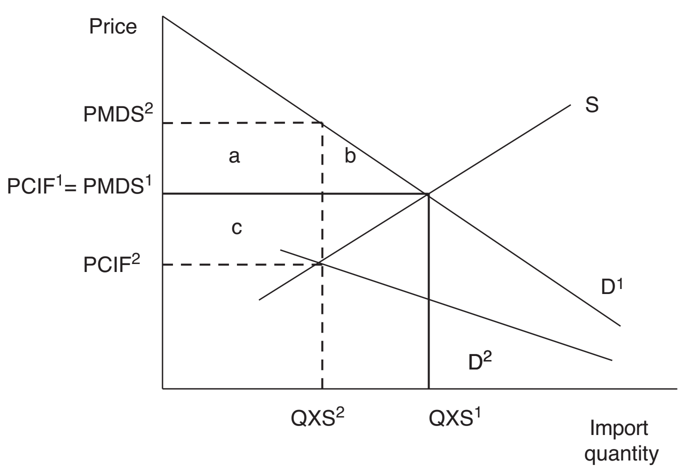


Figure 8.1 Effects of an ad valorem import tariff on the importer

production of the imported variety. D^1 is a compensated aggregate demand curve that describes the duty-free demand for imports by domestic consumers.[3] In the initial market equilibrium, the *cif* price of imports is $PCIF^1$. In the absence of a tariff, it is equal to the domestic import price, $PMDS^1$, and quantity QXS^1 is imported.

The introduction of an import tariff adds an additional cost to the import price, which rotates the demand curve downward to D^2. In the new equilibrium, consumers pay a higher domestic price of $PMDS^2$; the import quantity declines to QXS^2; and the *cif* import price net of the tariff falls to $PCIF^2$.

The tariff has three effects on the importing country. The direct burden of the tariff, shown as area $a + c$, is the amount of tariff revenue paid by consumers to the government on imports of quantity QXS^2. Tariff revenue redistributes purchasing power from consumers to the government, so this area is not a loss to the economy as a whole.

The second effect is the excess burden on the importer, shown as area *b*. It represents a consumption inefficiency, because consumers who would have been willing to purchase $QXS^1 - QXS^2$ quantity of imports at the free-market price no longer can do so. The difference between the price that consumers are willing to pay and the market price is the consumer's "surplus." For example, at QXS^2, a consumer who would have been willing to pay $PMDS^2$ actually paid only $PMDS^1$ at free-trade prices, and so gained a surplus on that unit of $PMDS^2 – PMDS^1$. The sum of the surpluses enjoyed by consumers on all units up to QXS^1, purchased at free-trade prices, is the triangular area between $PMDS^1$ and D^1. The trapezoid formed by areas *a* plus *b* is the sum of the consumer surplus that is lost when consumers reduce their import consumption to QXS^2 and pay the higher domestic price of $PMDS^2$. Because the foregone surplus shown by area *a* is transferred to the government as a part of the tax revenue, the remaining area, *b*, is the loss in consumer surplus that is not recouped elsewhere in the economy. The tariff has no effect on production efficiency because there is no domestic production of the imported variety.

For large countries, there may also be a terms-of-trade effect as described by area *c*. Our example in Figure 8.1 shows a terms-of-trade gain for the importer because the decline in its import demand causes the *cif* import price, excluding the tariff, to fall from $PCIF^1$ to $PCIF^2$ on quantity QXS^2 of imports. The size of its terms-of-trade gain depends in part on the slope of the

[3] This type of demand curve implies that the government compensates consumers dollar for dollar for their tariff expenditure, either through a lump-sum transfer of income or other mechanism. This compensation assumption is common in tax policy analysis. It allows economists to attribute all quantity changes to the substitution effect (which is the excess burden) because the compensation cancels any income effects of the tax. See Ballard and Fullerton (1992) for a survey of this approach in the economics literature

import supply curve. In general, the lower the foreign export supply elasticity (i.e., the steeper the slope of the import supply curve), the larger the importer's terms-of-trade gain from a tariff. If the importing country is too small in the exporter's market to affect its export price, then the foreign supply curve is horizontal. In this case, the import price remains at $PCIF^1$ and there is no terms-of-trade effect.

The terms-of-trade effect, like the direct burden, redistributes purchasing power. In this case, purchasing power is redistributed from foreigners to domestic consumers. In effect, the lower price accepted by foreigners compensates consumers for area *c* of their tariff payment to the government because the domestic import price ($PMDS^2$) increases by less than the full amount of the tariff. The terms-of-trade gain to the importer, area *c*, is a loss of import-purchasing power by its trade partner.

Because tax revenue simply redistributes national income, the change in national welfare includes only the excess burden, or allocative efficiency effect, of the tariff plus its terms-of-trade effect. Therefore, the net effect on the importer's welfare depends on whether its consumption efficiency loss, shown by area *b*, is greater than its terms-of-trade gain, area *c*. The effect on the exporter's welfare is unambiguously a loss, shown by its terms-of-trade decline, area *c*.

The figure also illustrates how tariffs diminish global welfare. The loss in global welfare is the sum of countries' efficiency losses, shown in our case as the importer's area *b*. Terms-of-trade effects are not included in a measure of global welfare. Because one country's terms-of-trade loss is its partner's terms-of-trade gain, this price effect just redistributes purchasing power among countries, similar to the domestic redistribution of tariff revenue. Redistribution does not affect global welfare as long as we assume – as we do in standard CGE models – that income has the same value, regardless of its distribution among consumers, governments, or countries. In a more sophisticated analysis, we might choose to relax this assumption to reflect different valuations across market participants, depending, for example, on their initial levels of income. Arguably, another dollar might mean more to consumers in countries with very few dollars to start with than it does to someone who has a great many.

By studying the theory of import tariffs before we carry out a CGE model experiment we can identify the results that are most relevant to consider and to report in our discussion, and we can develop expectations about their direction of change. With this foundation, we are ready to study a CGE analysis of the introduction of an import tariff in one industry. Our experiment is the introduction of a bilateral 15% import tariff by the United States on imports of manufactures from its trade partner, ROW. For this and most other tax experiments, we use

Table 8.2 *Effects of a bilateral 15% import tariff on manufacturing imports from ROW to the United States*

US manufacturing	
Tariff revenue ($US billion)	206.8
Import quantity from ROW (qxs_{Row}) (% change)	–19.1
Bilateral import price from ROW (% change) ($pcif_{Row,US}$)	–1.0
Bilateral terms of trade (% change) ($pfob_{US,Row}$–$pcif_{Row,US}$)	6.2
Domestic consumer price of import (% change) (*pmds*)	13.9
Efficiency effect (US $billion)	–22.2
Welfare ($US billion)	
US welfare	80.6
US terms of trade	102.9
Rest-of-world welfare	–105.5
World welfare	–24.9
Selected general equilibrium effects in United States (% change)	
Bilateral export price of mfg. to ROW ($pfob_{US,Row}$)	5.2
Real exchange rate (*pfactor*)	3.5
Agriculture export quantity (*qxw*)	–11.9
Manufacturing export quantity (*qxw*)	–34.3
Services export quantity (*qxw*)	–15.6

Note: Variable $tms_{ROW,USA}$ is set to 15%.
Source: NTaxToy model.

the NTaxToy CGE model, in which all taxes in the NUS333 database have been removed.

Results of the import tariff experiment, reported in Table 8.2, are consistent with the qualitative results shown in Figure 8.1. A contribution of our CGE model analysis is that it enables us to quantify these impacts. The tariff's direct burden is the import tariff revenue for the US government of $207 billion. The quantity of US manufacturing imports from ROW falls by 19% due to a 13.9% increase in their domestic price. The decline in import demand contributes to a terms-of-trade gain for the United States as its *cif* import price of manufactures from ROW falls by 1%. As a result, the percentage increase in the domestic price of manufactured imports is less than the 15% tariff. The excess burden, or deadweight efficiency loss, related to manufacturing totals $22 billion.

Our CGE analysis also takes into account general equilibrium effects that lie outside the scope of our theoretical, partial equilibrium model. First, we consider the manufacturing terms-of-trade effect. Recall from our discussion in Chapter 7 that the terms of trade depend on changes in both the import and export prices. Our CGE-based analysis finds that the US import tariff increases domestic demand for the US variety, which reduces the supply available for export. US manufactured exports fall by 34.3% and their scarcity causes their price to increase 5.3%. Thus, changes in *both* the US import and export prices account for the 6.2% improvement in the US terms of trade in manufactures.

The import tariff on manufactured goods affects US industry structure because an expanding manufacturing sector competes with other industries for productive resources. This competition causes US wages and rents to rise and increases US factor prices relative to those in the rest of the world. This is similar to a real exchange rate appreciation and it makes all US goods relatively expensive on world markets. Both resource competition and real appreciation contribute to a decline in US production and exports of agriculture and services, and an increase in US imports of these goods. These changes in trade flows also contribute to the aggregate US terms-of-trade gain of $102.9 billion and a total US welfare gain of $80.6 billion. The $105.5 billion decline in the rest-of-world's welfare results from its terms-of-trade losses; because there are no taxes in that region, there can be no efficiency effects due to this experiment. Global welfare, which measures the global sum of efficiency losses due to the tariff, declines by $24.9 billion.

Export Taxes

Countries sometimes impose export taxes to raise revenue from exportable industries such as mining, or to ensure that adequate supplies of vital goods, such as foodstuffs or strategic minerals, remain available for the home market. Export taxes are paid on the basis of the value or quantity of exports. They lower the price received by the producer on sales to the world market. An export tax therefore encourages producers to shift their sales from the export market to the domestic market – or to shift into the production of other goods and services.

Export taxes are reported in the SAM as an expenditure from the domestic variety of the commodity column account to the export tax row. Exports in *fob* prices, which include export taxes, are reported in the rest-of-world column account as a purchase from the domestic commodity account row. Data in the US SAM report an export tax of $3 billion on US manufacturing exports of $970 billion (including the export tax payment).

We calculate the export tax or subsidy rate as:

$$\text{Export tax revenue/value of export, } \textit{excluding} \text{ export tax} * 100.$$

For example, the export tax rate on US manufacturing exports to ROW is:

$$\$3/\$967 \text{ billion} * 100 = 0.3\%.$$

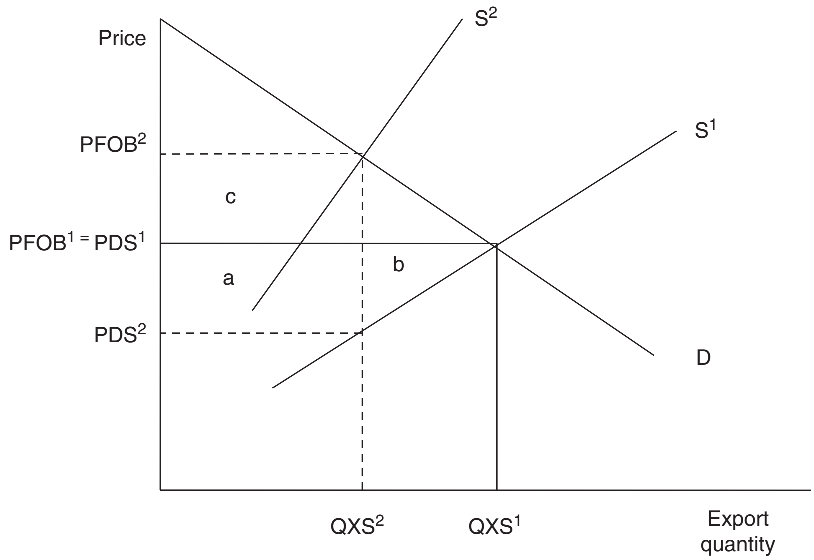


Figure 8.2 Effects of an ad valorem export tax on the exporter

Figure 8.2 illustrates the market effects of an ad valorem export tax. Although the graph looks similar to Figure 8.1, note carefully that the definitions of the supply-and-demand curves are different. In this case, S^1 describes the home country's supply of exports to its trade partner. Because we assume that products are differentiated by country of destination, there is no domestic demand for the export variety. D describes foreign demand for the home country's exports. In the initial equilibrium, quantity QXS^1 is exported at the *fob* export price of $PFOB^1$. In the absence of an export tax, $PFOB^1$ is equal to PDS^1, the producer's sales price. The introduction of an ad valorem export tax rotates the export supply curve backward to S^2. In the new equilibrium, export sales decline to quantity QXS^2, the export price increases to $PFOB^2$, and the producer sales price declines to PDS^2

Similar to import tariffs, export taxes have three effects on the exporting country. The direct burden is the amount of export tax revenue that is transferred from producers to the government, shown as area *a* + *c*. The excess burden, or efficiency effect, in the exporting country is described by area *b*. Production is inefficient because the marginal cost of producing the foregone output $QXS^1 – QXS^2$, shown by the pretax supply curve, is less than the price that foreigners are willing to pay. Another way to think about it is that, before the tax, the marginal cost to produce QXS^2 was PDS^2 but producers sold it for PDS^1, gaining a producer "surplus" for that unit of $PDS^1 – PDS^2$. The sum of these surpluses over all units of production up to QXS^1 is total producer surplus, shown by the triangular area between PDS^1

and S^1. The tax causes producers to lose producer surplus described by the trapezoid area of $a + b$. Area a is recouped by the government as tax revenue but area b is a deadweight loss, in excess of the tax burden, that is not recouped elsewhere in the economy. Notice that there is no consumption inefficiency because the export variety is not consumed domestically.

The third effect is the terms-of-trade gain, area *c*, which measures the redistribution of purchasing power from foreign consumers to domestic producers because the reduction in export supply causes the export price to rise from $PFOB^1$ to $PFOB^2$ on export quantity QXS^2. This transfer compensates producers for part of their revenue transfer to the government; in effect, producers have passed on part of the export tax burden to foreign importers through an increase in their export price. In this case, we assume a large country exporter, consistent with the Armington assumption that every country is a large country in its export market. A small country (as in many single-country CGE models) would face a horizontal world demand curve for its exports, and the producer's price would fall by the full amount of the export tax.

The net effect on the exporter's welfare depends on whether its efficiency loss, area *b*, is larger than its terms-of-trade gain, area *c*. The effect on the importing country's welfare is unambiguously a loss, shown by area *c*. The loss in global welfare is also unambiguously negative; it is the sum of all countries' efficiency losses, which in this case is area *b*.

To explore the effects of an export tax on one industry in a CGE model, we use the NTaxToy CGE model with the distortion-free database to run an experiment that introduces a bilateral 15% export tax on US manufacturing exports to ROW. We find a direct burden, the export tax revenue, of $80 billion and an excess burden, the allocative efficiency loss in US manufacturing, of $27.4 billion (Table 8.3). The US manufacturing output quantity falls by 3.7% and its export quantity falls 41.7%. The reduction in US export supply yields a US terms-of-trade gain in manufacturing. The US *fob* export price increases by more than 10%, so the producer price falls by only 4.0%.

Our general equilibrium model yields additional insights into the effect of the tax. Because most are the mirror image of the effects of the import tariff, we leave it as an exercise for you to explain the effects of a decline in US manufacturing production and exports on industry structure, trade flows, US terms of trade, the real exchange rate, and US and world welfare.

Production Taxes

Producers pay production taxes on the basis of the value or quantity of their output. These taxes are a part of their costs of production. For example, US companies engaged in oil and natural gas production pay a wide variety of production-based taxes to state, federal, and local governments. These taxes

Table 8.3 *Effects of a bilateral 15% export tax on US manufactures*

US manufacturing	
Tariff revenue ($US billion)	80.0
Efficiency effect (US $billion)	–27.4
Production (*qo*) (% change)	–3.7
Export quantity to ROW (*qxs*) (% change)	–41.7
Producer price (*ps*) (% change)	–4.0
Bilateral export price ($pfob_{US,\ ROW}$) (% change)	10.4
Bilateral terms of trade (% change) ($pfob_{US,ROW} - pcif_{ROW,US}$)	8.4
Welfare ($US billion)	
US welfare	–32.5
Rest-of-world welfare	4.9
World welfare	–27.6
Selected general equilibrium effects in the United States (% change)	
World import price of mfg. (*pmw*)	2.0
Import quantity of manufacturing (*qmw*)	–16.2
Agriculture world export quantity (*qxw*)	20.3
Services world export quantity (*qxw*)	26.2
Real exchange rate (*pfactor*)	–5.5

Note: Variable $txs_{USA,ROW}$ is set to 15%.
Source: NTaxToy model.

raise their production costs. Production taxes can also be negative (i.e., subsidies). For example, many countries provide tax credits or direct subsidies based on the production of agricultural products.

In the SAM, the production activities' column accounts pay these taxes to the production tax row account. The first two rows of Table 8.4 display these row and column accounts from the US SAM. The table also presents the net value of production, which is the value of production minus the production tax or subsidy.

We calculate production tax rates (or subsidies) as:

$$\text{Production tax/net value of production} * 100.$$

For example, the production tax rate for US services is:

$$511/17{,}701 * 100 = 2.9\%.$$

Figure 8.3a illustrates the market effects of an ad valorem production tax. In the figure, the initial market supply curve, S^1, describes domestic production, and the compensated demand curve, D, describes consumer demand. QCA^1 is the initial market equilibrium output quantity. In the absence of any taxes, the initial producer supply price, PS^1, is equal to the initial producer sales price, PDS^1, which is the same price paid by consumers. The introduction of an ad valorem production tax rotates the industry supply curve leftward to

Table 8.4 *Production taxes in the US SAM ($US billions)*

	Agriculture	Manufactures	Services
Production tax revenue	0.8	70	511
Gross value of production	326	6,657	18,212
Net value of production	324	6,588	17,701
Production tax rate	0.24	1.06	2.89

Note: Numbers may not sum due to rounding.
Source: GTAP v.8.1 database.

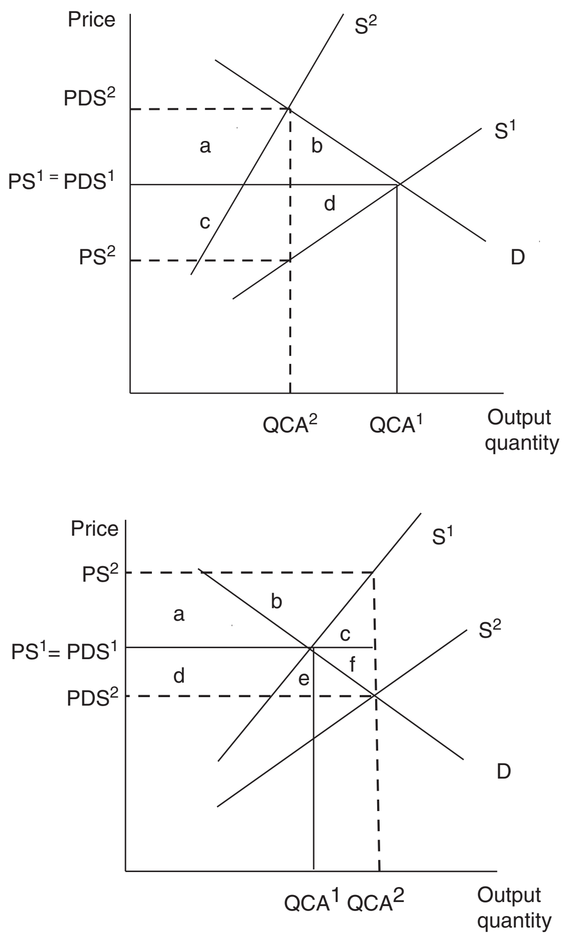


Figure 8.3 (a) Market effects of an ad valorem production tax. (b) Market effects of an ad valorem production subsidy

S^2. This results in a higher producer sales price, PDS^2, a lower pre-tax supply price for producers, PS^2, and a fall in the equilibrium quantity of supply and demand to QCA^2.

The direct burden of the production tax is area $a + c$, which is the tax revenue paid by producers to the government. Areas $a + b$ are the loss of consumer surplus and areas $c + d$ are the loss of producer surplus due to the tax. Because areas $a + c$ are recouped by the government as tax revenue, the excess burden is the combined loss in consumption efficiency, area b, and production efficiency, area d.

Areas a and c also describe the incidence of the production tax. The figure illustrates that, although producers actually pay the tax, the burden of paying for it is shared with consumers because producers have been able to raise their (gross of tax) sales price from PDS^1 to PDS^2. As you can see from the figure, the size of the tax revenue and its incidence are determined by the slopes of the supply-and-demand curves, which in turn are determined by the elasticities of supply and demand. If demand is perfectly elastic (a horizontal demand curve), then the consumer price would remain at PDS^1 and producers would absorb the full cost of the tax. If supply is perfectly elastic (a horizontal supply curve), then consumers would absorb the full cost of the tax.

Many countries subsidize rather than tax their producers. The analysis of a production subsidy differs in some respects from the analysis of a tax. In Figure 8.3b, the introduction of an ad valorem production subsidy rotates the supply curve rightward to S^2. The new equilibrium output increases from QCA^1 to QCA^2, the producer's pre-tax supply price increases to PS^2 and the producer's sales price, including the subsidy, falls to PDS^2.

In the case of a subsidy, the direct burden falls on the government because the subsidy is a transfer from the government to producers, instead of tax revenue received by the government. In the figure, government spending is the sum of areas $a + b + c + d + e + f$. However, the subsidy increases consumer surplus only by areas $d + e$ and increases producer surplus only by areas $a + b$. The increased quantity of production and consumption is inefficient because at quantities that exceed QCA^1, the marginal benefit to consumers of each additional unit is less than the marginal cost of its production. This inefficiency is described by areas $c + f$, which is the excess burden of the subsidy.

With these insights from our partial equilibrium models, we turn to an examination of the effects of a production tax in one industry in our NTaxToy model. Our experiment is the introduction of a 15% production tax on US manufacturing output. We find that the direct burden is the tax revenue of $762.9 billion and the excess burden is a $62.3 billion loss in efficiency (Table 8.5). Production declines 13%. The producer (pre-tax) supply price falls 4% fall while the producer sales price, including the tax payment, increases 10%. The increase in the sales price tell us that the tax burden has been shared between US producers and the domestic consumers to whom they sell their output, but that most has been passed on to consumers.

Table 8.5 *Effects of a 15% production tax on US manufactures*

Manufacturing	
Production tax revenue ($US billion)	762.9
Efficiency losses in mfg. ($US billion)	–62.3
Production quantity (*qca*) (% change from base)	–13.3
Producer supply price (*ps*) (% change from base)	–4.1
Producer sales price (*pds*) (% change from base)	10.3
Private household consumer price (*ppd*) (% change from base)	12.1
Selected general equilibrium effects in the United States (% change from base)	
Wages (*pe*)	–15.8
Capital rents (*pe*)	–15.9
Real exchange rate	–15.7
Manufacturing world export quantity (*qxw*)	–25.9
Manufacturing world import quantity (*qmw*)	2.1
Agricultural production (*qc*)	4.3
Services production (*qc*)	2.9
Terms of trade in manufacturing (*pxw-pmw*)	4.9
US welfare ($US billion) (EV)	–166.2

Note: Variable $to_{MFG,USA}$ is set to 15%.
Source: NTaxToy model.

Our CGE model also describes the general equilibrium effects of the tax. In the manufacturing sector, lower domestic production reduces its demand for factor inputs, causing economy-wide wages and rents to fall and the real exchange rate to depreciate. Manufactured exports to the world decline sharply as production falls and the demand for manufactured imports increases, despite exchange rate depreciation, due to the higher domestic price. On net, these trade changes cause the manufacturing terms of trade to improve. Once again, part of the tax burden on producers has been shared – in this case, with foreign consumers. Both lower factor input prices and the increase in foreign demand spurred by depreciation encourage agricultural and services production to increase. The total US welfare effect, which combines its efficiency loss and overall terms-of-trade effects, is a loss of $166 billion.

Sales Taxes

Sales taxes are paid by domestic final demand (households, investment, and sometimes government) on purchases of commodities used for consumption or investment. Production activities pay sales taxes on their purchases of intermediate inputs. The sales taxes are a part of their cost of production. Foreigners do not pay other countries' sales taxes, so a country's exports do not generate sales tax revenue.

In many countries, sales tax rates vary by commodity and type of buyer. In the United States, for example, consumers usually pay sizeable sales taxes on their purchases of autos but often pay little or no sales tax on their grocery purchases. Private household consumers pay sales taxes on many products while sales taxes on these same goods are waived for entities like churches and other nonprofit organizations. Negative sales taxes, like other negative taxes in the SAM, denote subsidies. They reduce the cost of a purchase. Some common examples of subsidies are food stamps, which low-income households can apply to their food purchases, or rebates on farmers' purchases of intermediate inputs, such as fertilizer.

The SAM reports sales taxes as a payment from the column account of the purchaser to the sales tax row account for each purchased good. As an example, Table 8.6 reports data from the NUS333 database on private households' sales taxes on their purchase of the domestically produced variety of each commodity. The taxes total \$190 billion (\$2 billion + \$137 billion + \$51 billion) on purchases of agriculture, manufactures, and services.

Sales tax rates are calculated as the ratio of the tax to the pretax value of the sale:

$$\text{commodity sales tax/pretax value of commodity purchase} * 100.$$

For example, the tax rate on households' purchases of domestic manufactured goods is calculated as:

$$137/1,355 * 100 = 10.1\%.$$

Figure 8.4 describes the effect of an ad valorem sales tax on the domestically produced variety of a commodity. In the figure, S is the supply curve and D^1 is the initial compensated demand curve for aggregate (final plus intermediate) demand in the domestic market. QDS^1 is the initial market equilibrium quantity. PD^1 is the initial market equilibrium price for consumers and, in the absence of a sales tax, it is equal to the producer sales price of PDS^1. The sales tax rotates the demand curve leftward to D^2. The new market equilibrium is at quantity QDS^2 where consumers pay the tax-inclusive sales price of PD^2 and producers receive price PDS^2.

The direct burden of the tax is shown by area $a + b$, which is the amount of sales tax revenue collected by the government on sales of QDS^2. Although the tax is paid by consumers, the figure shows that the burden is shared with producers due to the decline in the producer price to PDS^2. The excess burden of the tax, described by areas $c + d$, measures the loss in consumer and producer surplus as the market equilibrium quantity falls by $QDS^1 – QDS^2$. The decline in consumption and production is inefficient because the marginal benefit to consumers of each additional unit between $QDS^1 – QDS^2$ exceeds its marginal cost of production.

Table 8.6 *Sales taxes on US household purchases of domestically produced variety*

	Household
Domestic purchases ($US billion)	
Agriculture	53
Manufactures	1,355
Services	7,742
Domestic sales tax ($US billion)	
Agriculture	2
Manufactures	137
Services	51
Domestic sales tax rate (%)	
Agriculture	4.5
Manufactures	10.1
Services	0.65

Source: GTAP v.8.1 database.

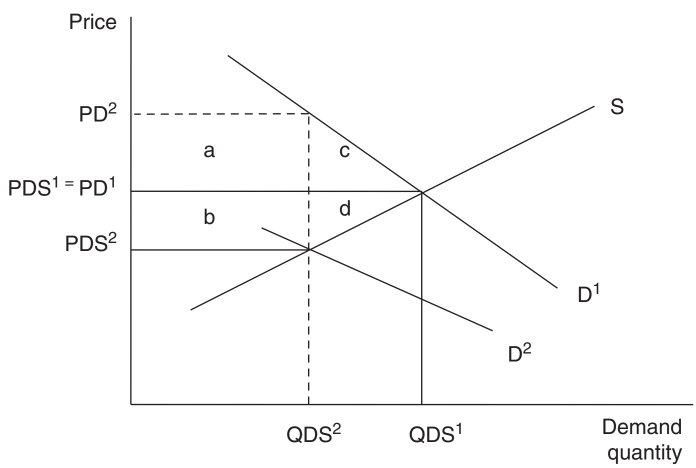


Figure 8.4 Effects of an ad valorem sales tax on the domestic market

To explore the effects of a sales tax on one commodity in a CGE model, we use the NTaxToy model to carry out an experiment that imposes a 15% sales tax on households' purchases of the domestic variety of the manufactured commodity. We find that the direct burden of the sales tax is a tax revenue of $149.5 billion (Table 8.7). Its excess burden is an efficiency loss in manufacturing of $16.5 billion as both the quantity of production and household demand fall. The household consumer price increases by nearly the full

Table 8.7 *Effects of a 15% sales tax rate on US household purchases of the domestic manufacturing commodity*

US manufacturing	
Sales tax revenue ($US billions)	149.5
Efficiency loss ($US billion)	–16.5
Household consumption (*qpd*) (% change)	–18.7
Production quantity (*qc*) (% change)	–2.8
Household consumer price (*ppd*) (% change)	14.1
Producer sales price (*pds*) (% change)	–0.8
Selected general equilibrium effects (% change from base)	
Household consumption of domestic agriculture (% change) (*qpd*)	0.7
Household consumption of domestic services (% change) (*qpd*)	0.9
Agricultural production (*qc*)	–0.3
Services production (*qc*)	0.6
Manufacturing world export quantity (*qxw*)	7.4
Manufacturing world import quantity (*qmw*)	4.0
US welfare ($US billion)	–38.2

Note: Variable $tpdall_{MFG,\ USA}$ is set to 15%.
Source: NTaxToy model.

amount of the tax, but the producer price declines only slightly – indicating that US consumers bear most of the burden of the tax.

Once again, we also consider selected general equilibrium effects of the tax. For this tax, we focus on the role of demand shifts in influencing industry structure. The sales tax changes the relative prices of consumer goods, causing private households to change the commodity composition of their baskets. When they reduce their consumption of domestic manufactures, they increase their consumption of domestically produced agriculture and services. Production of services increases. Agricultural output falls, however. A study of the input-output linkages in our SAM (Appendix A Table) helps explain why: most of the domestic agricultural product is used as an intermediate into US manufacturing. The fall in manufacturing production causes demand for, and output of, US agriculture to decline.

Trade flows are also an important part of this tax's impacts. On the import side, the sales tax on the domestic variety of manufactures causes the imported variety to become relatively cheaper, which increases the quantity of manufactured imports demanded by US households. On the export side, the fall in US demand for the domestic supply increases the quantity available for export, causing exports to rise. The changes in both trade flows contribute to a decline in the US terms of trade in manufacturing. US terms of trade in the other two sectors also fall. Total terms-of-trade losses, combined with efficiency losses, cause US welfare to decline by $38.2 billion because of the sales tax.

Factor Use Taxes

Producers pay taxes or receive subsidies based on the quantity of factors (e.g., labor, capital, and land) that they employ in their production process, or on the value of their factor payments. Data on factor use taxes are reported in the production activity column of the SAM as a payment to the factor use tax row. Factor tax rates are calculated for each factor in each industry as:

$$\text{factor tax/pretax factor payment} * 100.$$

We report these data for the agricultural and manufacturing activities from the US SAM in Table 8.8. For example, in the US SAM, the factor tax rate for land used in agriculture is:

$$-1.5/36 * 100 = -4.1\%.$$

Note that the factor tax rate is negative, which means that US farmers receive a subsidy on land use.

It is not unusual for different governmental entities within the same country to impose simultaneous factor use taxes and subsidies on the same factor. For example, landowners may pay a real estate tax to their state or local government and, if they are farmers using the land for agricultural purposes, they may also receive an acreage-based subsidy, based on the

Table 8.8 *Factor use taxes in the United States in agriculture and manufacturing*

	Agriculture	Manufacturing
Factor payment ($US billion)		
Land	36	0
Labor	47	1,361
Capital	53	649
Factor use tax ($US billion)		
Land	–1.5	0.0
Labor	3.8	205.0
Capital	–1.7	21.1
Factor use tax rate (%)		
Land	–4.1	0.0
Labor	8.2	15.1
Capital	–3.2	3.3

Source: GTAP v.8.1 database.

very same parcel of land, from the federal government. Thus, factor use tax data may report the combined rates of different tax programs.

Sometimes factor use taxes are uniform across industries, such as the Social Security tax that is paid as the same percentage of wages by all employers in the United States. Uniform factor use taxes or subsidies do not influence the distribution of factor employment across industries. However, it is often the case that factor taxes differ among industries or by use, such as different real estate tax rates for commercial and residential zones. In the United States, for example, the 8.2% tax rate on labor used in agriculture, reported in Table 8.8, is lower than the 15.1% tax rate on labor employed in manufacturing. In this case, the different labor tax rates change the relative costs of production in the two industries, discouraging employment and production in the industry with the higher labor tax.

Factor use taxes also typically differ by factor. For example, an industry's corporate tax rate on capital services may be quite high relative to its payroll tax. Tax rates on land, labor, and capital in US agriculture, reported in Table 8.8, illustrate this point. Agriculture's land and capital inputs are subsidized, but its use of labor is taxed. When factor use tax rates differ by factor then – if the production technology allows it – this too can lead to a misallocation of factors. Those factors whose employment is taxed will be underused and those factors that are subsidized will be overused relative to their most efficient level of employment in each industry.

The effect of a factor use tax on industry output is similar to that of a production tax, as already shown in Figure 8.3a, b, so we do not replicate that analysis here.[4] Instead, we direct our attention to a general equilibrium analysis of a factor use tax on one factor in one industry on factor use and output in all industries. Figure 8.5 describes the effects of a factor tax – in this case a specific (per worker) tax on labor – on the allocation of the workforce in a two-factor, two-sector model. The economy's two sectors are agriculture and manufacturing, and its two factors are labor and capital. In this beaker diagram, a rightward movement from the left origin on the horizontal axis indicates an increase in the employment of labor in manufacturing, and a leftward movement from the right origin describes an increase in the employment of labor in agriculture. Employment in the two sectors sums to the total labor force.

An assumption of the model is that labor is fully mobile across the two sectors, but that capital is fixed in each industry at its initial quantity. This assumption means that the theoretical model describes adjustment over a shorter time frame than in the CGE models with fully mobile factors that we mostly have used for demonstration. The industry demand curves for

[4] Like a production tax, a factor tax increases the cost of production and shifts the supply curve inward. However, a factor use tax can have a smaller impact on production costs than an equivalently sized production tax if producers can substitute away from the taxed factor within the value-added bundle.

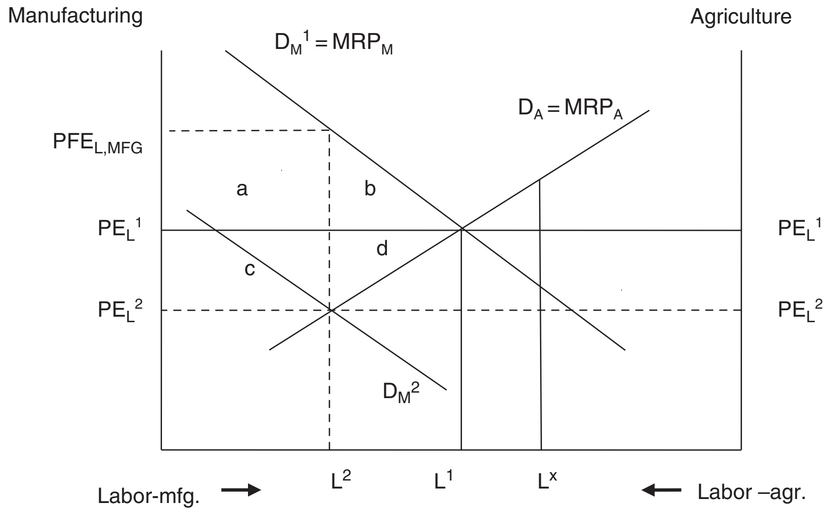


Figure 8.5 Effects of a factor tax on the economy-wide labor market

labor by the manufacturing ($D_M{}^1$) and agricultural (D_A) sectors are downward sloping. This reflects the assumption that the marginal revenue product (MRP) of labor (the additional revenue earned from the addition of one more worker) declines in both industries as the quantity of labor increases relative to the fixed quantity of capital. The MRP of each industry defines the wage that a firm is willing to pay. For example, as the ratio of farm workers to a fixed number of tractors increases, moving leftward on the horizontal axis, the marginal revenue product and wage of each additional farm worker in agriculture gradually falls.

In the initial equilibrium, the labor supply is allocated across the two industries at the quantity ratio ($QFE_{L,MFG}/QFE_{L,AGR}$) of labor, shown by L^1. This allocation of labor equalizes the wage across the two industries at $PE_L{}^1$, the economy-wide, after-income tax wage earned by workers. In the absence of any taxes, this is also the wage that is paid by employers in both sectors. Suppose the economy were not at equilibrium, and instead had a labor allocation such as L^X. At this point, the MRP of labor in agriculture, which is the vertical height of the intersection of L^X and D_A, exceeds that in manufacturing. Agriculture's higher wage will attract labor into agriculture. The decline in the ratio of workers to capital in manufacturing will cause an increase in labor's MRP in manufacturing sector, in an upward movement along $D_M{}^1$, and the higher labor-capital ratio in agriculture will lower the MRP of farm labor, in a downward movement along D_A, until the MRP of labor in both industries equalize at ratio L^1 and wage $PE_L{}^1$.

The introduction of a specific labor use tax in manufacturing shifts manufacturers' tax-inclusive labor demand curve downward, to D_M^2. As the manufacturing wage received by workers falls, for any given quantity of labor, workers move from manufacturing into agricultural employment. At the new equilibrium, the employment allocation is L^2, the economy-wide wage falls to PE_L^2, and manufacturers pay a wage plus tax of $PFE_{L,MFG}$. The wage earned in manufacturing is now lower because the tax reduces its demand for labor, and it is lower in agriculture because the increase in its labor causes the MRP of its workers to decline.

The direct burden of the factor use tax is the sum of rectangles $a + c$, which is the amount of tax revenue generated by the employment of L^2 workers in manufacturing. The excess burden of the tax related to manufacturing is the sum of triangles $b + d$. Labor employment in manufacturing is now inefficiently low because the marginal product of each additional worker between quantities L^2 and L^1 exceeds its marginal cost, measured by curve D_A.

We simulate a factor use tax in one sector in a CGE model by conducting an experiment that introduces a 15% ad valorem tax on labor employed in US manufacturing. We use the NTaxToy CGE model with the distortion-free database. We assume that the capital stock employed in each industry is fixed but that labor is fully mobile among sectors. Our CGE model differs from our theoretical model because it has a third factor of production – land. Similar to capital, we assume that a fixed quantity of land is employed in agriculture. For brevity, we do not include land in our discussion of results.

Consistent with our theoretical model, the labor tax raises employers' cost per worker in manufacturing and reduces their labor demand (Table 8.9). In the new equilibrium, manufacturing employment falls by 5.4%. Higher employment in agricultural and services employment causes declining labor productivity in those two industries, which also contributes to a decline in the economy-wide wage of more than 5%. Yet, manufacturers pay an after-tax wage that is 9.2% higher because of the tax. Increased agricultural and services employment also contribute to a change in the industrial structure of the economy. Agriculture and services output increase while manufacturing output declines.

Our CGE model quantifies the direct and excess burdens illustrated in Figure 8.5. The direct burden of the tax is $196 billion. The excess burden, or allocative efficiency effect, in manufacturing is a loss of $5.6 billion. The national welfare effect includes both the efficiency loss and a deterioration in the US terms of trade, resulting in a total US welfare loss of $33.2 billion.

Income Taxes

Income taxes, also called direct taxes, are paid by owners of the factors of production, usually as a percentage of their income from land rents, wages, and

Table 8.9 *Effects of a 15% tax on labor used in US manufacturing*

Effects on industries (% change from base)	
Employment in manufacturing (*qfe*)	–5.4
Employment in agriculture (*qfe*)	1.2
Employment in services (*qfe*)	1.1
Economy-wide wage received by workers (*pe*)	–5.1
Wage (including factor tax) paid by manufacturing (*pfe*)	9.2
Agricultural production (*qc*)	0.4
Manufacturing production (*qc*)	–3.8
Services production (*qc*)	0.8
Government revenue ($US billion)	196.0
Efficiency loss ($US billion)	–5.6
US welfare (EV) ($US billion)	–33.2

Note: Variable $tfe_{LABOR,\ USA}$ is set to 15%.
Source: NTaxToy model.

capital returns. The taxes are often uniform, meaning that a factor's tax rate is the same regardless of the industry source of income. Income taxes differ in an important respect from the indirect taxes discussed previously. Because they are not imposed directly on goods and services, they do not alter relative market prices. They do not make alcohol and tobacco more expensive than food, for example, in the way that sales taxes may do. Because income taxes generally do not directly influence relative prices, they can be less distorting of production and consumption decisions than indirect taxes. Nevertheless, even uniform income taxes can affect economic behavior in important ways.

Let's first explore the presentation of income taxes in the US SAM. The taxes are paid directly from the column accounts of the factors of production to the income tax row account (Table 8.10). Factors pay their remaining, after-tax income directly to the regional household row account. Then, the income tax column account pays all of this tax revenue ($2.0 trillion) to the regional household row account. Therefore, all factor income in the economy – which is the sum of income taxes plus after-tax income – is ultimately paid to the regional household, which in turn distributes it to the three categories of aggregate demand (private consumption, government spending, and savings).

The income tax rate for each factor is calculated as:

$$\text{Income tax/after-tax factor income} * 100.$$

As an example, the income tax rate for labor is:

Table 8.10 *Income tax data in a US SAM with a regional household ($US billion)*

	Land	Labor	Capital	Income tax
Income tax	3	1,742	294	–
Regional household (after-tax income)	33	6,463	3,254	2,039
Total factor income	36	8,205	3,548	–
Income tax rate	9.0	27.0	9.0	–

Source: GTAP v.8.1 database. Capital income includes depreciation of $1,260 billion.

$$1,742/6,463 * 100 = 27.0\%.$$

In the US SAM, the tax rate on wage income is quite high relative to the tax rates on land-based income and capital income, which are both 9.0%. The income tax rate for each factor is also uniform, and does not vary by industry of employment. For example, workers pay the same 27% income tax regardless of the industry in which they work.

Not all SAMs and CGE models have the same treatment of income taxes. Recall from Chapter 3 that the regional household is a macroeconomic account used by the GTAP model and reflected in its SAM. The account describes the sources of national income from factor payments and taxes and the composition of domestic final demand by households, government, and investment. In a CGE model with this structure, a uniform change in a factor's income tax rate (that is, the same rate change is applied to all industries that employ it) typically has no effect on the economy. To explain why, consider the income tax on labor in Table 8.10. Labor ultimately pays a total of $8.2 trillion to the regional household, composed of income taxes of $1.7 trillion plus after-tax income of $6.5 trillion. If the labor income tax rate should fall to zero, labor would still pay $8.2 trillion to the regional household, now composed entirely of after-tax income. Thus, a change in a factor's income tax does not change regional household income or the shares of households, government, and savings in national spending.

In CGE models without a regional household account, even a uniform change in an income tax rate can have structural effects on an economy if it shifts spending power among the categories of final demand. Computable general equilibrium models without a regional household generally link income directly to each component of aggregate demand. For example, households spend their after-tax factor income and governments spend their tax revenue, so an increase in an income tax lowers household spending and increases government spending. Depending on the closure in these models, income taxes also may affect investment by changing households' after-tax savings or the government surplus or deficit (which is public savings). If households, governments, and investors differ in the type of goods that they demand, then a change in income taxes and the composition of final demand will lead to changes in the industrial structure of the economy.

Income taxes also affect things like after-tax, or net, wages that can influence employment decisions. When income taxes lower net wages, some people may choose to work less and spend more time on leisure activities. A decline in net wages can also motivate some people to work more hours, instead of less, if they need the additional earnings to compensate for the fall in their after-tax income. In a standard CGE model, labor endowments are assumed to be fixed in supply, so the size of the workforce does not change as net wages change. But some CGE models enrich their depiction of labor markets by including a labor supply equation to describe a labor-leisure trade-off, in which the supply of workers increases (decreases) when wages rise (fall), as determined by an elasticity of labor supply with respect to wages. Computable general equilibrium models with this treatment of the labor market are able to represent the marginal impacts on labor force participation rates that are often observed as wage levels change. A change in the size of a country's labor force changes its productive capacity and income, leading to general equilibrium effects throughout the economy.

Income taxes, in addition, may cause households to change their allocation of income between consumption and savings and therefore affect the rate of return on savings and levels of investment. This is an intertemporal distortion because it changes the timing and amount of consumption over a lifetime and the availability of savings for investments that affect future production levels. These impacts of income taxes on savings and investment decisions, though very important, are not accounted for in the standard CGE model that we are studying. Dynamic, multi-period CGE models are needed to analyze the intertemporal effects of income taxes. A prominent example of such a model was developed by Auerbach and Kotlikoff (1987) and used to analyze US tax policies. A subsequent version of this model, developed by Jokisch and Kotlikoff (2005) and summarized in Text Box 8.2, was used to analyze the FAIR Act. (The FAIR Act is a plan to replace most types of US taxes with a single sales tax on consumers.)

So far, we have considered uniform factor income taxes. That is, workers pay the same income tax rate regardless of their place of employment, and capital owners pay the same income tax rate regardless of the industry in which they have invested their capital. But in many countries, income tax rates are not uniform. Complex tax codes often provide industry-specific tax breaks, such as accelerated depreciation on certain types of capital stock purchases for some industries. Famously, the large US corporation Amazon paid zero in corporate income tax in a recent year due in part to these special tax

Text Box 8.2 US tax reform in a dynamic, overlapping-generations CGE model

"***Simulating the Dynamic Macroeconomic and Microeconomic Effects of the FAIR Tax***" (Jokisch and Kotlikoff, 2005).

What is the research question? The Fair Tax is a proposal to replace the US federal payroll tax, personal income tax, corporate income tax, and estate tax with a progressive federal retail sales tax on consumption. Given the aging of America's population, which will lead to growing health and pension costs, could adoption of the FAIR Tax Act preclude the need for higher taxes to fund these liabilities, and even lead to welfare gains?
What is the model innovation? The authors' dynamic, overlapping generations, CGE model captures detailed demographic characteristics of the US economy, including age- and year-specific projections for three income classes of households within each generation (e.g., mortality rates, pension benefits, health costs). The model also includes year-specific projections of government revenue and expenditure.
What is the experiment? The authors model the Fair Tax as the replacement of most federal taxes by a progressive federal retail sales tax of 23% on consumption (i.e., it increases a sales price of $1 to $1.23). The plan includes a tax rebate whose size depends on households' characteristics and an increase in Social Security benefits to maintain their real purchasing power. Their tax plan reduces non-Social Security federal expenditures to help pay for the Fair Tax rebate.
What are the key findings? The Fair Tax almost doubles the US capital stock by the end of the century and raises long-run real wages by 19% compared to the base case alternative. The winners from this reform are primarily those who are least well off, and large welfare gains accrue to future generations.

provisions. When income tax rates vary by industry, changes in relative income tax rates can distort resource allocation in ways that are similar to indirect taxes.

Figure 8.6 describes how income taxes affect both the price paid by manufacturers for capital and the supply price of capital, using data from the NUS333 model. In the figure, the manufacturing activity pays a factor price (PFE) of $1.46 per unit of capital employed. This price includes a payment to the capital supplier (PEB) of $1.27 per unit plus a factor use tax of $0.19 per unit.[5] The capital supplier receives a gross return of $1.27 but pays an income tax of $0.27, so her net return per unit of capital (PES) is $1.00. In a model with

[5] Variable PE_e is the after-income-tax, economy-wide wage. It is a weighted average of $PEB_{e,a}$ the net factor earnings in each industry, such as the wage earned in the manufacturing activity shown in Figure 8.6.

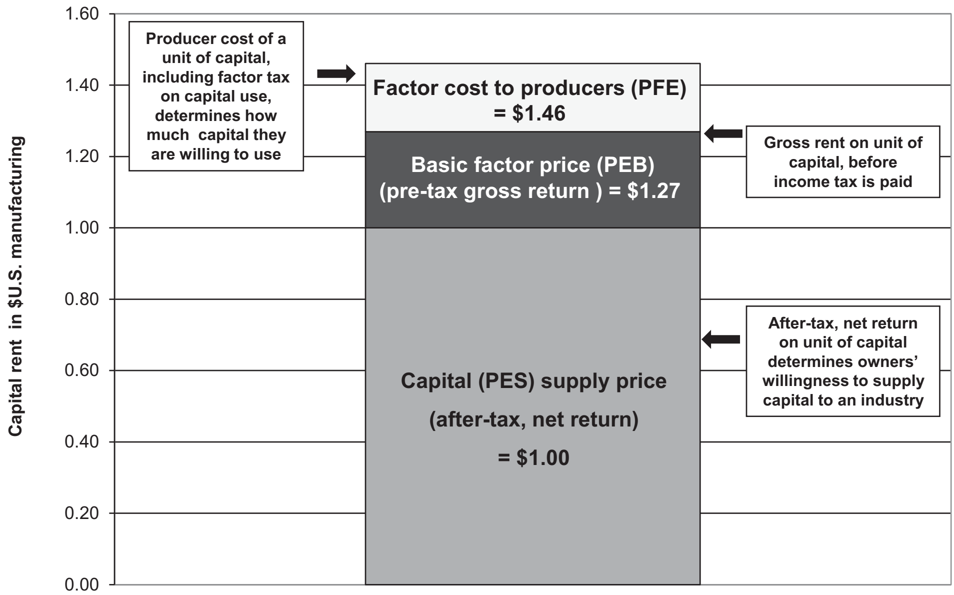


Figure 8.6 Effects of an income tax on capital used in manufacturing

fully mobile capital, capital owners will supply their capital to whichever industry offers the highest net return (after paying income tax), and capital will move among them until net returns are equalized.

We explore the case of a non-uniform income tax on the allocation of capital using the NTaxToy model to introduce a 20% income tax on capital used in US manufacturing. This could be due to a new income tax or perhaps due to the elimination of a favorable tax credit program. Results are shown in Table 8.11. Because capital is fully mobile, its suppliers move it out of manufacturing and into industries that pay higher after-tax rents. The outflow of capital from manufacturing leads its producers to increase the rents they are willing to pay, but the higher price also causes producers' demand for capital to fall. In the new equilibrium, the price of capital for manufacturers increases by 7.5%, their demand for capital declines 6.8%, and the after-tax net return to capital is equalized across production activities with an economy-wide decline of 2.3%. Other sectors become more capital-intensive in their production processes as the capital/labor ratio falls in manufacturing. Changing factor costs lead to changes in the producer sales price for all three commodities that, in turn, led to changes in aggregate domestic demand and output, and changes in the commodity composition of US trade.

Table 8.11 *Effects of a 20% income tax on capital used in US manufacturing (% change from base)*

	Agriculture	Manufacturing	Services
Factor price paid by producers(*pfe*)	–2.26	7.51	–2.26
Factor supply price (after income-tax) (*pes*)	–2.26	–2.26	–2.26
Factor demand (*qfe*)			
Labor	0.27	1.70	–0.36
Capital	0.63	–6.76	1.62
Capital/labor ratio ($qfe_K - qfe_L$)	0.36	–8.46	1.98
Producer sales price (*pds*)	–0.66	0.52	–0.95
Aggregate domestic demand (*qds*)	–0.30	–0.75	0.09
Quantity of output (*qc*)	0.34	–0.91	0.18
US world exports (*qxw*)	3.45	–1.76	4.11
US world imports (*qmw*)	–2.15	0.07	–2.14

Second-Best Efficiency Effects

So far, we have used a distortion-free model of the United States to study the direct and excess burdens of one type of tax at a time. In more realistic CGE models, and in real life, governments usually impose many taxes at the same time, and usually in many industries simultaneously. Policy changes therefore entail introducing or changing a tax in the presence of many preexisting tax distortions.

This tax setting raises an important question: Does the excess burden of a tax depend on the preexisting taxes in an economy? To answer this, we draw on the theory of the second best developed by the economists Richard Lipsey and Kelvin Lancaster (1956). According to this theory, a free-market equilibrium in one market may not lead to the most efficient, economy-wide outcome if there is already a distortion in another market due to a tax, a market failure, or other type of economic constraint. For example, suppose there is already a production subsidy in the services industry that has caused its output to exceed the economically efficient level. The government now may be considering the introduction of a production subsidy to the manufacturing industry. In this distorted setting, the manufacturing subsidy could actually improve economic efficiency in the services sector by drawing away some of its productive resources. In this case, a new, distorting manufacturing subsidy could be preferable to no manufacturing subsidy if it cancels out at least part of another subsidy's distortionary effect. Of course, there are circumstances where a new tax or subsidy can exacerbate the effects of existing tax distortions.

Table 8.12 *Second-best effects of a 10% production subsidy in US manufacturing with/without a preexisting 5% production subsidy in US services*

	Base production subsidy	New production subsidy	% Change in production (*qca*)	Excess burden ($US million)
Base equilibrium with no preexisting tax distortions				
Agriculture	0	0	–2.5	0
Manufacturing	0	10	9.6	29,025
Services	0	0	–2.1	0
Base equilibrium with a preexisting subsidy				
Agriculture	0	0	–2.5	0
Manufacturing	0	10	9.8	28,857
Services	5	5	–2.0	–16,301

Source: NTaxToy model.

Let's explore a case of second-best in our distortion-free NTaxToy model. First, we assume that there are no other tax or subsidy distortions in the economy. Our experiment is the introduction of a 10% ad valorem production subsidy on US manufacturing. The subsidy causes manufacturing output to increase by 9.6%, an oversupply relative to the free-market level (Table 8.12). The excess burden (allocative inefficiency) in manufacturing of $29.0 billion corresponds to the efficiency triangles of c + *f* in Figure 8.3b. The increased use of the economy's resources by manufacturing also causes the production of agriculture and services to decline.

Now, we assume that the economy has a preexisting, 5% subsidy on the production of services. In this setting, there is already an oversupply of services relative to the free-market level. The introduction of the manufacturing production subsidy increases manufacturing output (9.8%) and leads to an efficiency loss in the industry of $28.9 billion. However, in this case, manufacturing's expansion corrects for part of the inefficient oversupply of services. Its competition for the economy's productive resources causes services output to decline and yields a reduction of $16.3 billion in the excess burden associated with service's production subsidy. The new distortion in the manufacturing sector therefore corrects for part of a preexisting distortion in the services sector. On net, the introduction of the new, distorting manufacturing output subsidy leads to an economy-wide excess burden of only $12.6 billion.

Our simple example analyzes just two taxes. A CGE model with a more realistic SAM is likely to have a large number of taxes. The efficiency effect of a change in any one tax is therefore the sum of its own excess burden plus its second-best effects in correcting or exacerbating the excess burdens associated with every other tax in the model. The ability of a CGE model to capture these second-best effects is one of the most important contributions made by this class of model.

Marginal Welfare Burden of a Tax

The marginal welfare burden of a tax is the change in national welfare due to a very small – marginal – change in an existing tax. The change in welfare, divided by the change in tax revenue, describes the marginal welfare burden per dollar of additional tax revenue. This per dollar concept, developed by Edgar Browning (1976), has had practical use as a yardstick for determining whether a government project is worthwhile if its funding requires raising additional tax revenue. This is a realistic and important analytical problem because policymakers are typically seeking ideas for designing modest tax hikes or tax cuts from an already distorted tax base.

The yardstick builds on the idea that every additional dollar of tax revenue incurs both a direct tax burden, which is a transfer of tax revenue from private expenditure to the government, and an excess tax burden, which is the tax's deadweight efficiency cost to the economy. Browning studied the marginal excess burden of the US labor income tax, finding that raising an additional dollar of tax revenue would generate an excess burden of 9–16 cents, depending on how the tax increase is structured. He concluded that the return on a government project funded by this additional tax revenue would have to be 9–16% greater than the private expenditure that it displaced, or national welfare would decline.

Browning used a partial equilibrium model for his study of the labor income tax, but CGE models have proven to be well suited for this type of analysis. One reason is that CGE models offer a comprehensive measure of the welfare effects of a change in one tax. The model takes into account not only the excess burden of the tax that changes but also any second-best efficiency effects linked to other existing taxes. In addition, a CGE model's welfare measure includes any terms-of-trade effects due to the tax change, which may be important when the country is large in world markets.

Computable general equilibrium models also provide a comprehensive measure of the direct burden of a tax because they account for the impacts of a change in one tax on the revenue generated by all taxes in an economy. For example, an increase in the sales tax on cigarettes may cause employment and output in the tobacco industry to fall. Payroll and production taxes paid by the tobacco industry may then fall, and perhaps sales tax revenue from other goods will rise as consumers readjust their spending. Thus, the total change in tax revenue will likely include changes in revenue from many types of taxes in addition to the tobacco sales tax.

Ballard, Shoven, and Whalley (1985) developed a pioneering CGE-based analysis of the marginal welfare cost of the entire US tax system. They found that, depending on the elasticities assumed in the model, the marginal welfare cost per dollar of additional US labor income tax revenue was between 12 cents and 23 cents – substantially higher than Browning's partial equilibrium estimate. For the US tax system as a whole, they calculated a marginal welfare burden of 17–56 cents per dollar of additional tax revenue. For example, a ratio of 17% indicates that for a dollar of additional tax revenue there is an additional deadweight efficiency loss to the economy of 17 cents. In this case, a government project must yield a marginal return of at least 117% if it is to be worth its cost to the economy in terms of tax dollars spent plus lost efficiency. (You will replicate the Ballard, Shoven, and Whalley analysis in Model Exercise 8.) Devarajan, Thierfelder, and Suthiwart-Narueput (2001) carried out a similar CGE-based analysis of the marginal costs of taxes in three developing countries, described in Text Box 8.3. Their study is of special interest because most studies of marginal welfare burdens focus on developed countries.

The concept of the marginal welfare burden is illustrated in the partial-equilibrium model shown in Figure 8.7. The figure describes changes in direct and excess burdens due to marginal increases in a production tax on all suppliers of a given commodity. In the figure, S^1 is the producers' tax-free supply curve and, to simplify our analysis, D describes a perfectly elastic compensated demand curve. In the absence of the tax, QC^1 is the initial equilibrium output quantity. PDS^1 is the equilibrium supply price and, in the

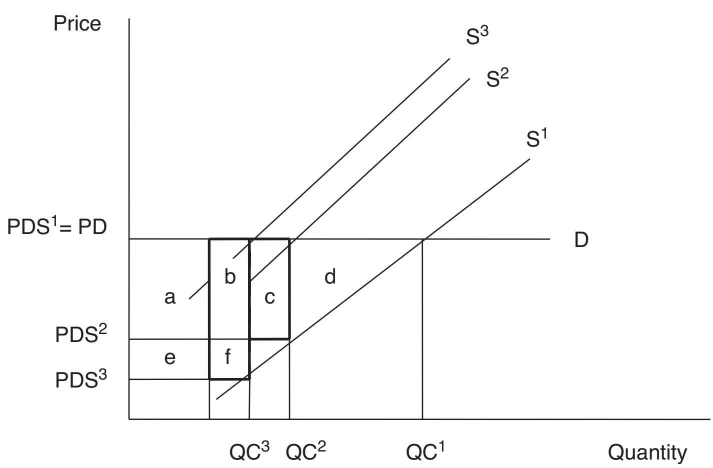


Figure 8.7 Marginal excess burden of a production tax

Text Box 8.3 Marginal welfare burden of taxes in developing countries

"***The Marginal Cost of Public Funds in Developing Countries***" (Devarajan, Thierfelder, and Suthiwart-Narueput, 2001).

What is the research question? The notion that raising a dollar of taxes could cost society more than a dollar is one of the most powerful ideas in economics. By causing agents to alter their behavior in inefficient ways as a result of the tax, the marginal cost of raising a dollar of public funds is higher than a dollar. Despite the importance of this idea, few estimates are available on the marginal welfare cost of funds in developing countries. What are the estimated costs of public funds in three developing countries – Cameroon, Bangladesh, and Indonesia?

What is the CGE model innovation? A standard, static, single-country CGE model is used for each country. Their macroclosure rules fix investment, real government spending, and the current account balance. These closure rules imply that an increase in tax revenue causes a government budget surplus (i.e., public savings rise), but because investment spending is fixed, households' savings falls and their consumption rises by the full amount of the tax revenue. In effect, households are compensated in a lump-sum fashion for higher taxes so that model results measure only the excess burden of the taxes.

What is the experiment? There are four tax experiments for each country: (1) an increase in the production tax by sector; (2) a uniform increase in all production taxes; (3) an increase in individual tariff rates; and (4) a uniform tariff rate increase. Additional factor market distortions are introduced one-by-one into the Cameroon model to illustrate second-best effects.

What are the key findings? The marginal costs of funds in the three countries are quite low, ranging between 0.5 and 2.0, which refutes the conventional wisdom that the marginal costs of funds in developing countries are likely to be high because of their relatively high tax rates. Experiments in which taxes are increased by sector confirm that the marginal cost of funds is highest in sectors where distortions are large. Policies that increase the lowest tax rates tend to reduce the marginal cost of funds because the tax structure becomes more uniform.

absence of a sales tax, it equals PD, the initial sales price paid by consumers for the domestically produced product. Now, assume that a specific (per unit) production tax of t^1, shown as the distance between $PDS^1 - PDS^2$, is already present in our initial equilibrium. The tax-inclusive supply curve corresponding to t^1 is S^2. In this tax-distorted equilibrium, consumers still pay price PD for quantity QC^2 and the producers receive price PDS^2. The total loss in producer surplus is the combined area of $a + b + c + d$, but of this total, area $a + b + c$ is transferred to the government as tax revenue, so it is not a loss to the economy. The excess burden of the tax is the area of triangle d.

Next, assume a marginal increase in the production tax to t^2, shown in the figure by the distance PS^2-PS^3. The increased tax raises producers' cost of production and shifts the new tax-inclusive supply curve to S^3. In the new equilibrium, consumers still pay price PD, but the producers receive only price PDS^3 and the equilibrium quantity declines to QCA^3. The producers lose the additional producer surplus areas of $e + f$. (The small triangular area to their right can be ignored for small changes in the tax.) The government gains new tax revenue of area $e + f$ but loses tax revenue of area c. Area c becomes an addition to area d, the excess burden of the tax, as the tax increases from t^1 to t^2.

The marginal excess burden of the tax per dollar of additional government revenue is the ratio of the change in the excess burden to the change in tax revenue. In Figure 8.6, the ratio is described as areas $c/(e + f - c)$ for the tax increase from t^1 to t^2.

Our partial equilibrium model shown in Figure 8.6 describes only the change in excess burden in one newly taxed production activity. Recall from our study of the theory of the second best that, in an economy-wide framework, a change in one tax rate may cause the excess burdens associated with other taxes in the economy to change also. In a general equilibrium model, therefore, measurement of the marginal welfare effect will include the marginal excess burden associated with all taxes in the economy, as well as any changes in the terms of trade. Changes in tax revenue, too, are the sum of changes in revenue from all tax sources.

To illustrate these points, we use the GTAP model with our regular (tax-distorted) NUS333 database to analyze the welfare effect of a marginal, 1% increase in the initial 10.1% tax on US household consumption of domestically produced manufactures. Our model results indicate that the increase in the sales tax increases the total excess burden, or efficiency loss, by \$92.5 million and causes welfare to decline by \$264 million (Table 8.13). The increased consumer tax on manufacturing contributes \$117.1 to that excess burden; other existing US taxes contribute second-best efficiency gains and losses. Total US tax revenue, from all taxes, increases by \$972 million. Thus, the marginal welfare burden of the change in tax revenue is:

$$\text{Change in welfare/Change in tax revenue} * 100.$$

$$-264/972 * 100 = -27.2\%.$$

This means that an additional dollar in revenue following the tax rate increase costs 27.2 cents in efficiency losses. The government project should be undertaken only if its marginal benefit will be at least 27.2% greater than the amount of the additional tax revenue required to finance it. Otherwise, its cost to the economy in terms of tax dollars spent plus related efficiency losses will be greater than its benefit.

Table 8.13 *Marginal welfare effect of a 1% increase in the US consumer sales tax on domestically produced manufactures ($US million)*

Excess burden by tax	
Total excess burden	–92.5
Import tax	10.8
Export tax	2.0
Production tax	9.9
Income tax	0.0
Sales tax on household consumption of MFG	–117.1
Other sales taxes	2.9
Investment tax	–0.8
Factor use tax	–0.2
Terms of trade	–171.5
Total welfare effect	–264.0

Note: Results reported in GTAP welfare decomposition utility.
Source: NUS333 model.

In an already distorted economy, it is also possible that the tax increase could lead to marginal welfare gains. In this case, the ratio is positive. If, for example, the ratio is 10%, then a public project could generate a marginal benefit that is as little as 90% of its cost in taxpayer funding and still be worthwhile because the tax increase corrects other distortions in the economy. This scenario may not be too far-fetched; our model results in Table 8.13 shows that a marginal increase in a US consumer sales tax yields second-best welfare gains associated with some preexisting US taxes.

Preferential Tariffs

Preferential trade agreements (PTAs) are pacts among like-minded trade partners to reduce or eliminate trade barriers among themselves while retaining barriers against nonmembers of the agreement. Because multilateralism, in which all countries agree to liberalize trade barriers, is a first-best, welfare-enhancing strategy, might the reduction of barriers among a subset of countries in a PTA also be welfare increasing? In this section, we study the welfare effects of a preferential elimination of import tariffs, a second-best tax problem.

The seminal theory of customs unions was developed by Jacob Viner (1950) and still serves as the foundation for economic analyses of trade preferences. He introduced the concepts of *trade creation* and *trade diversion*, which contrast the welfare-improving impacts of trade reforms within the pact with the welfare-reducing impacts of the accompanying trade discrimination against nonmembers. Viner defined trade creation as the shift in the volume of production of a traded good from a high-cost producer in the pact to a lower-cost member. The resulting increase in production efficiency unambiguously increases global welfare. Trade diversion occurs when a member shifts its source of imports from lower-cost nonmembers to higher-cost PTA partners. This reduces production efficiency and global welfare.

Subsequent refinements of Viner's ideas added an important insight.[6] Viner focused only on shifts in traded quantities toward more or less efficient producers. He overlooked the gain in consumption efficiency that occurs when consumers can purchase a larger quantity of the good than originally because of its lower, duty-free domestic price. The consumption efficiency gain from this trade expansion augments the production efficiency gains from Viner's trade creation. And if trade expands when a member shifts its sourcing from lower-cost nonmembers to its preferred partner, then even a trade-diverting PTA can be net trade-creating if the increase in consumption efficiency is greater than the loss in production efficiency. Members are likely to experience trade creation for some products and trade diversion for others. Whether the PTA is net trade creating or diverting therefore must be analyzed on a case-by-case, empirical basis.

When countries are large in their import markets, a change in their quantity of demand for imports also can lead to terms-of-trade changes. In general, an increase in a member's demand for imports from its PTA partner will cause its import price to rise and its terms of trade to deteriorate. This may be offset by terms-of-trade gains if its partner likewise increases the quantity of imports that it demands from the member. A member may garner terms-of-trade gains, too, if the fall in the quantity of imports that it demands from nonmembers causes their export prices to fall.

Customs union theory describes the welfare effect of a PTA on each member as the sum of the efficiency gains or losses that result from trade creation and diversion and its terms-of-trade change. A PTA affects nonmembers, too, through changes in their terms of trade and efficiency. Because one country's terms-of-trade gain is its trade partner's loss, terms-of-trade effects cancel out at the global level. Global welfare is therefore the sum of regions' gains and losses in production and consumption efficiency.

We examine the impact of a PTA on a member country using the partial equilibrium frameworks shown in Figures 8.8 and 8.9. Let's assume that countries A and B join a PTA, in which they eliminate bilateral tariffs, and that country C represents nonmember countries. Figure 8.8 describes the

[6] Johnson (1962) and Kendall and Gaisford (2007) offer clear expositions of customs union theory. Baldwin and Venables (1995) and Panagariya (2000) survey its more recent extensions.

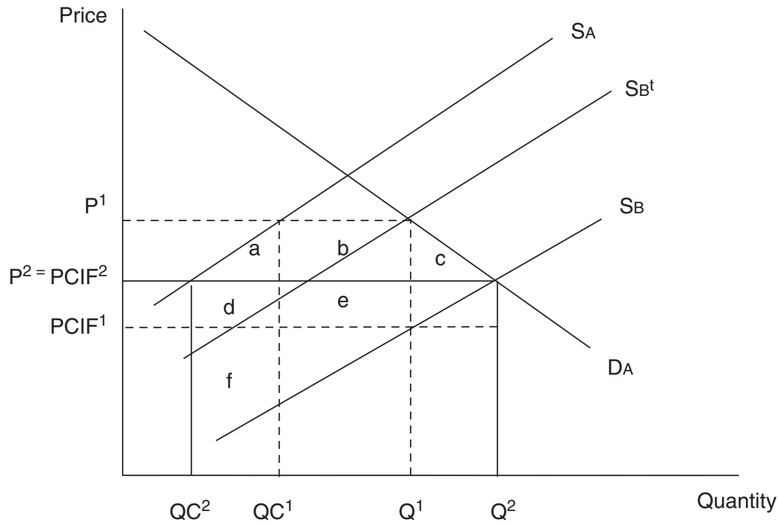


Figure 8.8 Trade creation in a preferential trade agreement

trade-creating effects of the PTA on A's welfare. In the figure, D_A is the demand in country A for a composite commodity that is satisfied through a combination of the domestically produced and imported varieties. S_A is the supply curve for production in A, S_B is the supply curve for A's import from B, and ${S_B}^t$ is the import supply curve from B inclusive of A's initial, per-unit import tariff. The vertical distance between S_B and ${S_B}^t$ measures A's per-unit tariff on a given quantity of imports from B. A's initial consumption is quantity Q^1 at the composite domestic price of P^1 and a pre-tariff, *cif* import price from B of $PCIF^1$. Quantity QC^1 is supplied by domestic production and quantity $QC^1 - Q^1$ is imported from B. Country A imports solely from B because C is the highest-cost producer (its supply curve is not shown).

After A eliminates its tariff on B, A's new equilibrium is at the intersection of A's demand curve and B's duty-free import supply curve S_B. As the domestic price of imports from B falls, A's imports from B increase to $QC^2 - Q^2$. The trade creation effect of the PTA includes the decline in A's production from QC^1 to QC^2, as domestic output is replaced by imports, and the expansion of A's consumption from Q^1 to Q^2. The price of A's composite consumption good falls to P^2 and the price of its imports from B rises to $PCIF^2$.

Country A's efficiency gains are described by triangles *a* and *c*. Triangle *a* measures the welfare effects of Viner's trade creation. It is a production efficiency gain because the supply of QC^1 to QC^2 had cost areas $a + d + f$ when produced domestically but now costs only areas $d + f$ when replaced by imports from B. Triangle *c* measures the gain in consumption efficiency resulting from the increase in the consumption quantity from Q^1 to Q^2.

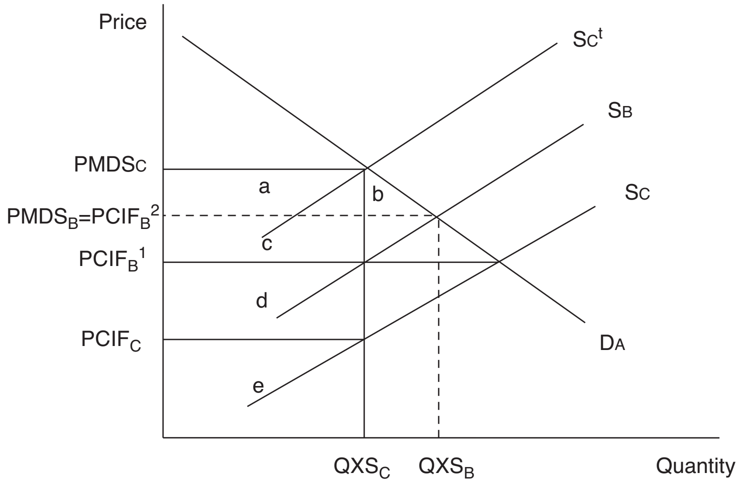


Figure 8.9 Trade diversion in a preferential trade agreement

Area $b + e$ is the loss in tariff revenue, but this does not affect welfare because it is redistributed back to A's consumers. Area *e* measures the terms-of-trade loss to A because it must now pay a higher price for its initial quantity of imports. On net, the welfare effect of the PTA on A depends on whether its efficiency gains from trade creation (area *a* and *c)* are greater than its terms-of-trade loss to B (area *e*).

The trade-diverting impacts of a PTA on a member are described in Figure 8.9. The graph describes A's imports from B and C, with the Armington assumption of zero production of the imported varieties by A. We can think of the products of B and C as being strong substitutes of the same good, although they are differentiated varieties due to our Armington assumption. In the figure, D_A is the demand for the composite import in country A. S_B is the supply curve for imports from B. Country C is the low-cost supplier with an import supply curve S_C and a tariff-inclusive import supply curve S_C^t. The vertical distance between S_C and S_C^t measures A's per-unit tariff on a given import quantity. In the initial equilibrium, A imports only from C, purchasing quantity QXS_C at an import price from C of $PCIF_C$ and A's tariff-ridden, bilateral domestic import price of $PMDS_C$. Area $a + c + d$ measures A's initial tariff revenue. Country A has zero initial imports from B because it is a high-cost supplier (its tariff-ridden supply curve is not shown).

With the formation of a PTA between A and B, B's duty-free price ($PCIF_B^1$) is lower than C's tariff-ridden price. In the new equilibrium, A's imports are now sourced only from B at quantity QXS_B. A's domestic import

Table 8.14 *Trade creation and diversion effects of a Japan–US preferential trade agreement ($US millions)*

	Change in Japan imports from		Change in US imports from	
	United States	Rest of World	Japan	Rest of world
Agriculture	4,795	–2,554	11	445
Manufacturing	18,360	–10,533	11,658	–1,334
Services	–25	432	–44	940

Note: Imports are reported as changes in trade volumes (DQXS) valued at initial domestic import prices.
Source: NUSJToy model.

price from B is $PMDS_B$; in the absence of a tariff it is equal to $PCIF_B{}^2$. Tariff revenue declines by area *a* + *c* + *d* but this has no welfare impact because it is redistributed back to consumers. Area *c* is A's terms-of-trade loss because B's price for the initial import quantity has increased from $PCIF_B{}^1$ to $PCIF_B{}^2$. Area *d* is an efficiency loss to A due to B's higher costs of production relative to C on the diverted volume of trade. The gain in A's consumer surplus due to the expansion of import consumption from QXS_C to QXS_B is described by area *b*. The net welfare effect of the PTA on A depends on whether its gain in consumption efficiency due to trade expansion is greater than the sum of its efficiency loss from the diversion of its initial quantity of trade and its terms-of-trade deterioration on imports from B.

We explore these ideas in a general equilibrium framework using, for demonstration, the NUSJToy model. Its database is the same three-activity, three-commodity, and three-factor aggregation as the NUS333 model, but it has three regions: Japan, the United States, and an aggregated rest-of-world. Our experiment describes a Japan-US preferential trade agreement in which their bilateral import tariffs are eliminated but the two members maintain their barriers against the rest of the world.

Table 8.14 reports the import quantity changes depicted as trade creation and trade diversion in Figures 8.7 and 8.8. Note that whereas our simple theoretical model describes the elimination of members' trade with non-members, our CGE model finds that both the United States and Japan continue to import goods from the rest of the world. Specialization is unlikely to occur in a CGE model because of the Armington assumption that the varieties imported by A from B and C are imperfect substitutes.

The agreement is net trade creating for Japan in agriculture and manufacturing, and for the United States in manufacturing, because the increase in the quantities of their imports from each other exceeds the diversion of their imports of these commodities from the rest of the

Table 8.15 *Decomposition of the equivalent variation welfare effects of a Japan–US preferential trade agreement ($US millions)*

	Allocative efficiency effects from bilateral tariff reform	Other allocative efficiency effects	Terms of trade	Investment savings	Total welfare gain
Japan	792	435	275	–9	1,493
United States	69	–64	2,655	474	3,134
Rest of world	–	–824	–2,932	–465	–4,221
World total	861	–452	–2	0	406

Source: NUSJToy model.

world. For example, the increase in the quantity of Japanese agricultural imports from the United States, worth $4.8 billion, diverts only $2.6 billion worth of agricultural goods imports from the rest of the world. The PTA is pure trade creating for the United States in agriculture because its imports from both partners increase. The declines in Japan and US services imports from each other, while their imports from the rest-of-world increase, are a result of the macroeconomic effects of the PTA that we discuss in more detail later.

We use the GTAP model's welfare decomposition utility to quantify the equivalent variation welfare impacts of the PTA that are associated with the changes in trade quantities. The first column in Table 8.15 describes the allocative efficiency gains for Japan and the United States that result from their removal of bilateral import tariffs. These gains measure the welfare triangles *a* and *c* in Figure 8.8, for each country, and yield the two members a combined welfare gain of $861 million.

Our general equilibrium model also accounts for the second-best interactions of the Japanese and US bilateral trade reforms with the remaining tax and subsidy distortions in their economies. These result in second-best efficiency gains of $435 million in Japan but a loss of $64 million in the United States. The PTA's terms-of-trade effects redistribute import-purchasing power among the regions. Gains in the terms of trade are mostly garnered by the United States, with small positive gains in Japan's terms of trade; both members gain at the expense of the rest of the world. The investment-savings terms of trade, which improves when the prices of domestically produced capital goods rise relative to savings, reveals mixed impacts on the PTA members.

Our multicountry CGE model also provides us with a detailed view of the effects of the PTA on nonmembers. In addition to its terms-of-trade losses to the PTA members, the aggregated rest-of-world region experiences an allocative efficiency loss of $824 billion related to the taxes and subsidies in its economy.

In our CGE model, the changes in bilateral trade flows are driven not only by the new trade preferences but also by the general equilibrium outcomes of the PTA. The shift by both members toward sourcing their services imports from the rest of the world provides a good example. Because there are no preexisting tariffs on trade in services in any of the three regions, this trade result is driven by the general equilibrium impacts of the PTA. One of these is the real exchange rate appreciation of Japan and the US relative to the rest of the world. This helps make the rest of the world the low-cost supplier and causes Japan and the United States to reduce their imports from each other and increase their imports from ROW.

Our analysis finds that the Japan-US free-trade agreement is welfare improving for its members, but welfare declines substantially in the rest of the world. Because terms-of-trade changes cancel each other out at the global level, only changes in allocative efficiency are included in a measure of a PTA's global welfare impact. With a total global efficiency gain worth $407 million, the PTA is globally welfare improving.

Summary

Our study of tax policy analysis in a CGE model began with an examination of the tax data in the SAM, because the SAM describes the agent who pays the tax, the production or consumption decision on which the tax is assumed to be levied, and tax revenues. We studied five types of taxes: trade taxes on exports and imports, and taxes on production, sales, factor use, and incomes. Our study of each tax began with a simple, partial equilibrium, theoretical model that illustrated how taxes distort production and consumption decisions and result in a direct burden (the tax revenue that it generates) and an excess burden (the loss in production and consumption inefficiency). Our theoretical approaches helped us formulate expectations about the effects of taxes on the economy under study, identify key results, and recognize the consistency of CGE model results with theoretical models of taxation. We then progressed from analyzing single taxes in partial equilibrium frameworks to analyzing taxes in general equilibrium and presented applied examples of second-best effects, the marginal burden of a tax system, and a preferential trade agreement.

Key Terms

Ad valorem tariff or tax
Deadweight loss
Direct burden

Direct tax
Excess burden
Export tax
Factor use tax
Import tariff
Income tax
Indirect tax
Marginal welfare burden
Preferential trade agreement
Production tax
Sales tax
Second-best efficiency effects
Specific tariff or tax
Tax incidence
Trade creation
Trade diversion
Welfare

PRACTICE AND REVIEW

1. Suppose the government is considering the introduction of an import tariff on one of two products; one product exhibits a high own-price elasticity of demand and the other has a low elasticity. In a graph, compare the effects of a tariff on the excess burden for the two goods. Label the axes, curves, and initial market equilibrium. On which type of good do you recommend that the tariff be imposed? Explain why.
2. Use data from the US SAM to calculate the factor use tax (or subsidy) rate for labor and capital used in the production of manufactures and of services.
   Do these factor use taxes distort the allocation of capital and labor between the manufacturing and service sectors? How do they distort the ratios of labor to capital within each industry?
3. Assume that a country introduces a 25% sales tax on the purchase of gasoline. Draw a graph of the effects of the sales tax on the supply and demand for gas. Label the axes and curves and explain your assumptions about the elasticities of supply and demand that define the slopes of your curves. Identify the direct tax burden, the excess burden, and changes in the market equilibrium price and quantity.
4. Suppose that the government increases retail sales taxes on students' purchases of selected items in the university bookstore. Government analysts project a $1 million increase in sales tax revenue that will fund a reduction in student tuition, and a marginal welfare loss of $200,000.
   a. What is the marginal welfare cost of the tax increase, per dollar of additional tax revenue?
   b. What is the minimum return that the government must make on its investment in the university to ensure that national welfare does not decline?

c. How do you think the marginal welfare cost per dollar might change if the government increases the sales tax on a good for which student demand is relatively price inelastic, such as food?

d. Assume a preexisting production subsidy in the industry that supplies the university bookstore with taxed items, such as textbooks. In a short paragraph, explain the possible second-best effect of the new tax.

5. Assume that Japan and China enter into a preferential trade agreement. In a graph, describe its trade-creating and trade-diverting impacts. Select and match the results variables in your CGE model with the key variables in your theoretical, graphical analysis. You may use the NUSJToy model to explore these model variables.

9

Regulations in a CGE Model

This chapter examines the treatment of regulations in a computable general equilibrium (CGE) model. Regulations are "command and control" policies that mandate changes in producer or consumer behavior. We study two types of regulations: nontariff measures that can create barriers to international trade and regulations designed to reduce negative externalities in production. We demonstrate the mechanisms used to introduce nontariff measures into a standard CGE model. We describe process-based and outcome-based regulations of externalities and explain their direct and indirect economic impacts. Simple partial equilibrium diagrams illustrate the theoretical effects of the regulations on economic activity and economic efficiency. The results of highly stylized regulatory policy experiments using a CGE model support the theoretical predictions and illustrate modeling methodologies.

Types of Regulations

A vehicle tailpipe emissions standard was first enacted in the United States in 1970 and it has become more stringent over time. The intent of the regulation is to reduce harmful auto emissions, which contribute to today's higher incidence of asthma and other pulmonary health problems, and may be a factor in long-term global warming. According to an analysis of the newest emission standard, a reduction in emissions generates broad gains in the US economy as a whole, not only by reducing health costs and improving the environment but also by increasing employment in industries that supply auto producers with low-emission inputs (US EPA, 2012). Because regulations imposed on a single industry can have important economy-wide impacts, and may have spillover effects on other countries as well, computable general equilibrium (CGE) models have become a standard tool for their analysis.

Regulations are command-and-control policies. Unlike taxes, which create price incentives that influence economic choices, regulations are used by the government to directly mandate certain behavior. The mandates are usually negatively enforced with fines, imprisonment, or other undesirable outcomes. Regulations, like taxes, therefore have an impact on resource allocations by producers and consumers. But because regulations do not operate through price mechanisms, as taxes do, they are more challenging to represent in a CGE model, which is fundamentally based on observable market prices and quantities.

"Regulations" is a broad term. There are many types of regulations, which can have a variety of objectives, and may be applied to producers or consumers. A full discussion of regulations and regulatory policy analysis is well beyond the scope of this chapter. Instead, we take a practical approach that focuses rather narrowly on two types of regulations that receive much of the attention in the current CGE-based literature: nontariff measures (NTMs) that can introduce barriers to international trade, such as sanitary inspection requirements for imported products; and regulations intended to correct negative externalities in production, such as emission limits. These two types of regulations are first introduced in partial equilibrium theoretical models, similar to our treatment of taxes in Chapter 8. We then empirically examine the effects of the regulations using the NUS333 model. These applications, while highly stylized, demonstrate current methodologies and illustrate both the capabilities and limitations of regulatory policy analysis in a standard CGE model. Many of these limitations have spurred innovations in CGE modeling that substantially extend models' capabilities in regulatory policy analysis.

Because regulations do not affect government revenue or expenditure, as taxes do, we cannot observe them directly in the transactions described in the SAM. They are only indirectly observable in that the flows of income and expenditure in the SAM reflect the impacts of regulations on resource allocations.

Nontariff Measures in International Trade

Types of Nontariff Measures

An NTM is defined by UNCTAD (2019) as a policy measure other than an import tariff that can potentially have an economic effect on international trade in goods by changing the quantities traded, their prices, or both. Because import tariffs on most commodities have been successfully reduced over recent decades of multilateral and preferential trade negotiations, NTMs are considered to be among the main remaining impediments to free trade. Their proliferation in recent years has created concern that some are serving as a form of disguised protection as import tariffs have come under greater discipline.

Table 9.1 *Classification of nontariff measures*

Technical Measures
A. Sanitary and phytosanitary measures.
B. Technical barriers to trade.
C. Pre-shipment Inspection and other formalities.
Nontechnical Measures
D. Contingent trade measures.
E. Quantitative restrictions.
F. Price controls.
G. Finance measures.
H. Measures affecting competition.
I. Trade-related investment measures.
J. Internal distribution restrictions.
K. Restrictions on post-sales services.
L. Subsidies and other forms of support.
M. Government procurement restrictions.
N. Intellectual property restriction.
O. Rules of origin.
P. Export-related measures.

Source: UNCTAD, 2019.

Addressing nontariff measures in ways that both liberalize trade yet still provide desirable safeguards to the health and safety of consumers and the environment has become one of the core challenges in today's trade negotiations, and therefore an important subject of CGE-based trade policy analysis.

A taxonomy developed by UNCTAD (2019) classifies NTMs into sixteen general categories (Table 9.1). Three (A–C) are defined as technical measures. Sanitary and phytosanitary (SPS) regulations, such as inspection and quarantine requirements, are designed to ensure food safety and prevent the dissemination of disease or pests across countries. Technical barriers to trade (TBTs) include labeling and certification requirements, technical and quality standards, and environmental measures. A third technical category includes pre-shipment inspections and customs formalities. Nontechnical measures are divided into 13 categories that include policies such as quantity quotas on imports or exports, rules of origin (ROO) that restrict imports by one country from its trade partner if a good is mostly assembled in third countries (see Text Box 9.1 on modeling ROO), and behind-the-border measures such as government policies that restrict government purchases to domestically produced goods (public procurement).

Text Box 9.1 Rules of origin in preferential trade agreements (PTA)

Rules of origin (ROO) are the criteria used to define the national identity of a product based on the country of origin of its inputs or the degree to which the product has been transformed. For example, a ROO may require that at least 60% of the inputs by value in a Mexican-produced auto be sourced from NAFTA members for it to be considered a product of Mexico and eligible for duty-free access into Canada and the United States. Because PTAs permit members to maintain their own tariff rates against nonmembers, ROO are used to prevent PTA members with relatively low duties on intermediate inputs from nonmembers to export their final products duty-free to other members that maintain higher tariffs on imported intermediates from non-PTA sources. ROO are considered protectionist regulations because they have the same impact as an import tariff – they distort production decisions by requiring that PTA members source their inputs predominantly from within the PTA region rather than allowing producers to freely source from the lowest-cost suppliers in the global market.

CGE modelers have taken different approaches to modeling ROO but, in general, they all capture the insight that compliance with ROO incurs costs. ROOs impose administrative costs, such as expenditures on certificates of origin and inventory monitoring, in addition to the tariff-like production and consumption inefficiencies they cause.

One way to describe the introduction of a ROO in a new trade agreement is to reduce the scheduled cut in a member's PTA tariff on the final good to represent the added compliance costs and related inefficiencies. Vanzetti and Huong (2014) used this approach in a study of Vietnam's entry into the Trans-Pacific Partnership (TPP) and its ROO for apparel. They assumed only a partial reduction in the planned US tariff cut on apparel imports from Vietnam because all yarn-forward inputs were required to be sourced from TPP members.

If the research question is how an existing ROO may be tightened or loosened, an ad valorem import tariff equivalent of its existing compliance costs is first incorporated into the model by adding the AVE of ROO costs as a surcharge to the preferential tariff rate, using the same recalibration approach as the inclusion of NTMs described in this chapter. Then, the surcharge is adjusted in an experiment to represent the change in the ROO. When available, CGE modelers can draw on case studies that estimate the AVEs of ROO compliance costs in PTAs such as NAFTA. In the absence of empirical studies, the AVEs of ROO may be estimated using information on preference utilization rates (the share of trade among members that enters under PTA rates) and the margin of preference (the difference between the tariffs on PTA members and nonmembers), following Herin (1986). If preference utilization is close to 100%, then the value of the margin of preference must exceed the cost of complying with the ROOs. A surcharge is added to the PTA tariff, with their sum remaining less than the MFN rate. If preference utilization is close to zero and exporters instead choose to accept MFN rates, then the cost of compliance must exceed the value of the margin of preference. The surcharge is added to the PTA rate, with their sum being close to or equal to the nonmember tariff rate.

Nontariff Measures in International Trade

Our discussion of NTMs in this chapter focuses on how CGE modelers are approaching the challenging problem of representing NTMs' effects on import competition and trade efficiency. An NTM provides protection from competition if it restricts the volume of imports, even when the regulation is not intended to be protectionist. For example, a Canadian SPS measure may require Canadian importers to provide additional certifications for imports of Mexican avocados if Mexico is experiencing a pest infestation. By increasing import costs, the SPS measure reduces trade volumes and the import competition faced by Canadian growers, although its objective is to protect the health of Canadian plant life.

The scarcity caused by a reduction in trade volume can generate *economic rents*, or excess profits, for importers or for exporters. Canadian avocado importers, for example, can now charge a higher domestic price for Mexican avocados because of their scarcity in the Canadian market. This wedge between Canada's domestic price and its import price is similar to the price wedge created by an import tariff. Or, if Mexican exporters can now charge a higher export price for avocados because of their reduced volume of exports, the price wedge between their producer sales price and their world export price is similar to that created by an export tax. But whereas tariff revenues are collected by the government, economic rents may be captured by the private importer or exporter, depending on how the NTM is administered.

The price wedge caused by an NTM may not only reflect economic rents but could also result from *trade inefficiencies* if time and resources are wasted at the border. For example, inventory deterioration of fresh produce or meat due to added time spent on customs formalities results in both loss of time and loss of product during border transit. These losses, similar to the deadweight losses of the taxes that we studied in Chapter 8, are not recouped by either trade partner.

Computable general equilibrium modelers make the analysis of NTMs more analytically tractable by representing the regulations as *ad valorem equivalents (AVE)* of taxes. An AVE tax rate is equivalent to a regulation if the introduction of the tax, usually of an import tariff, has the same impacts on market price and quantity as the introduction of the nontariff measure.[1] Computable general equilibrium modelers may econometrically estimate or calculate a measure's market impact and its AVE prior to developing their CGE model, or they may draw on estimates of AVEs available in the growing empirical literature on NTMs and trade. A landmark, early study

[1] See Deardorff and Stern (1997) and Ferrantino (2006) for comprehensive discussions of how the economic impacts of NTMs can be quantified as AVEs of a tax.

by Kee, Nicita, and Olarreaga (2009) developed a database of AVEs of NTMs at the tariff-line level (about 5,000 commodities) for major countries and differentiated by type of NTM. More recently, UNCTAD and the World Bank (2018) collaborated on a major project to develop a database that describes the AVEs of import tariffs of NTMs by bilateral partner and commodity. Projects such as these are providing the empirical foundation for studies of NTMs in trade-focused CGE models.

There are two main approaches to measuring the AVEs of NTMs. One is to estimate gravity models to measure the regulation's trade quantity impact – that is, researchers econometrically estimate what the import quantity would be without the regulation in place. They next combine their findings on the difference in quantities with and without the regulation with information about price elasticities of import demand, to calculate an import tariff rate that would result in an equivalent quantity gap as the regulation. The second approach is a price gap method in which researchers compare prices across countries that have or do not have the NTM, or at different points along a country's supply chain. These price comparisons allow them to determine what the market price would be without the regulation in place. They use that price markup to calculate an import tariff rate of an equivalent percentage.

The modeler then divides the AVE of the NTM into components that describe the shares of the price wedge that accrue to importers or exporters as economic rents, or result from trade inefficiency. The share of the AVE of the NTM that is captured by the importer as economic rents is represented in the CGE model as an import tariff (Table 9.2). The share that is captured by exporters as economic rents is represented in the CGE model as an export tax. For example, assuming zero trade efficiency effects, if the regulation's estimated AVE of an import tariff is 10%, and importers and exporters are assumed to share equally in the distribution of its economic rents, then a 5% surcharge is added to the importer's existing import tariff for that good, and a 5% surcharge is added to the exporter's existing export tax for the good. The CGE model database is then updated to add the surcharges to import tariffs and to export taxes to the model's benchmark equilibrium before any trade policy experiments are implemented. That is, the CGE model is "recalibrated," using appropriate elasticities and closures, so that the model database includes the new, higher tax rates but the initial economic structure and trade flows are changed as little as possible. (Model Exercise 11 provides hands-on guidance in recalibrating a CGE model in the GTAP modeling framework.)

The share of the NTM's AVE that is due to resource-wasting trade costs and border inefficiencies is sometimes called "sand in the wheels." It is typically represented in a standard CGE model as an *iceberg trade*

Table 9.2 *Approaches to modeling technical NTMs in a standard CGE model*

	CGE model representation		
	Export tax	Import tariff	Trade efficiency (iceberg trade costs)
Market effect	Economic rents that accrue to the exporting country, compliance costs for exporter	Economic rents that accrue to the importing country, compliance costs for importer	Resource-wasting trade costs
Model recalibrated?	Yes – add AVE as a surcharge to existing export tax	Yes – add AVE as a surcharge to existing import tariff	No – the introduction or removal of an NTM is described in a model experiment as a change in the efficiency of transporting goods from exporter to importer

cost.[2] As an example, assume that a technical measure related to apple imports requires more intensive inspections of apple containers in the port. Some part of the apple shipment will rot because of these extra delays; some apples, in effect, "melt" away during the border crossing just as an iceberg melts as it moves across the ocean. As a result, the exporter sends the same quantity of apples, for the same world price, but the importer receives fewer apples at that price. Trade efficiency has fallen because the same quantity of exports now yields a smaller quantity of imports. Another way to express it is that the apple export quantity is unchanged but the *effective import quantity*, defined as the original export quantity minus the iceberg loss, has declined. And since the importer now receives a smaller quantity of imports for any given world price, the *effective import price* has increased.

Unlike the tariff and tax surcharges, a CGE model database is not recalibrated to include trade efficiency effects, because the initial model equilibrium described in the SAM implicitly accounts for existing efficiency levels in the initial quantities and prices. A regulation's trade efficiency effects are

[2] This is sometimes called a "Samuelsonian" trade cost because the concept was first utilized in a trade model by Samuelson (1954). The seminal literature on the inclusion of iceberg trade costs in a standard CGE model include Hertel et al. (2001), Fox et al. (2003), Andriamananjara et al. (2003), and Fugazza and Maur (2008).

Text Box 9.2 Nontariff measures in a preferential trade agreement

Agriculture in the Transatlantic Trade and Investment Partnership: Tariffs, Tariff-Rate Quotas, and Non-Tariff Measures (Beckman et al., 2015).

What is the research question? The United States and the European Union initiated negotiations for an ambitious trade agreement that would address not only a reduction of tariffs and subsidies, which are already low, but also reduce barriers posed by protectionist nontariff measures (NTMs), which are especially prevalent in agriculture. How important is the successful removal of NTMs in achieving the full benefits of the pact on agricultural trade between the two economies?

What is the model innovation? Beckman and his team implement gravity models to estimate the ad valorem import tariff equivalents of selected NTMs that have been identified by the trade partners as protectionist impediments to bilateral trade. They then use a detailed supply-chain approach to study the incidence of each of the NTMs' price impacts and to allocate their AVEs as surcharges to export taxes or import tariffs, or as trade efficiency costs. For example, one-third of the AVE of the EU NTM on biotech corn is assigned to trade inefficiencies and two-thirds is assigned to the US export tax; no NTM costs are assigned to the EU import tariff.

What is the experiment? They model two scenarios: the "market access scenario" removes tariffs and increases tariff-rate quota (TRQ) amounts by 50%; the second scenario adds a complete removal of NTMs to the market access scenario.

What are the key findings? The authors find that total EU-US agricultural trade increases by $4.5 billion in the market access scenario. The additional removal of NTMs delivers substantial further gains in bilateral agricultural trade, worth $2.3 billion; however, binding TRQs limit some of the potential gains from NTM reforms.

introduced as an experiment only when there is a change in the technical measure. If, for example, our estimated 10% AVE of the technical NTM is due solely to trade inefficiency, then removal of the measure is described in an experiment as a 10% increase in trade efficiency.

A modeler must draw on a well-grounded institutional knowledge of how an NTM is implemented to accurately allocate the AVE of the tax across the three mechanisms in a CGE model. (See Text Box 9.2 for an example of how a supply-chain analysis is used to guide this allocation.) An exploration of these three alternatives in theoretical models will illustrate the importance of this allocation to your analytical results.

Figure 9.1a describes the effects on the importer's economy of the introduction of a nontariff measure that is represented in a standard CGE model as an ad valorem import tariff. It is a bilateral measure, imposed by one country on its trade partner. The compensated demand curve, D^1, describes initial import demand and S is the import supply curve. We adopt the Armington assumption that there is no domestic production in the importing country of the imported variety. To simplify, we also assume there are no transport costs or other taxes in the initial equilibrium.

In the initial equilibrium, quantity QXS^1 is imported from the partner and the initial equilibrium *cif* import price ($PCIF^1$) is equal to the domestic consumer price of the import ($PMDS^1$). Similar to an import tariff, the NTM's introduction rotates the import demand curve from D^1 to D^2. The vertical distance between the two curves measures the per-unit economic rent that is generated on a given quantity of imports. In the new equilibrium, the domestic price of the import increases from $PMDS^1$ to $PMDS^2$, and the quantity of imports falls to QXS^2. Area *c* measures the uncompensated loss in consumption efficiency in the importing country due to the decline in imports. Economic rents are measured by area *a* + *b*. Similar to tariff revenues, they are distributed within the importing country so do not affect welfare. The decline in import demand yields a terms-of-trade gain to the importer, shown as area *b*, as its import price falls to $PCIF^2$. The net effect on the importing country's welfare depends on whether the gain in its terms of trade (area *b*) exceeds the loss in its consumption efficiency (area *c*).

Figure 9.1b illustrates the effects on the exporter's economy of a bilateral NTM that is represented in the model as an ad valorem export tax. We assume that there is no domestic consumption of the exported variety in the exporting country and, as before, there are no transport costs or other taxes.

In the initial equilibrium, the country exports quantity QXS^1 at the *fob* world export price ($PFOB^1$), which, in the absence of export taxes, equals the exporter's producer sales price (PDS^1). The introduction of a technical NTM that generates rents for the exporter is shown as a rotation in the export supply curve from S^1 to S^2. The vertical distance between the two supply curves measures the per-unit rent generated by the NTM on a given export quantity. In the new equilibrium, quantity QXS^2 is exported, the export price increases to $PFOB^2$, and the producer sales price falls to PDS^2. Area *b* measures the exporting country's uncompensated loss in production efficiency as output falls. Area *c* + *a* looks much like the direct burden of an export tax. In this case, it measures the economic rents that are distributed within the exporter's economy. Area *a* compensates producers for part of their loss in producer surplus and area *c* describes the exporter's terms-of-trade gain on quantity QXS^2 of exports. The net effect on the exporter's welfare

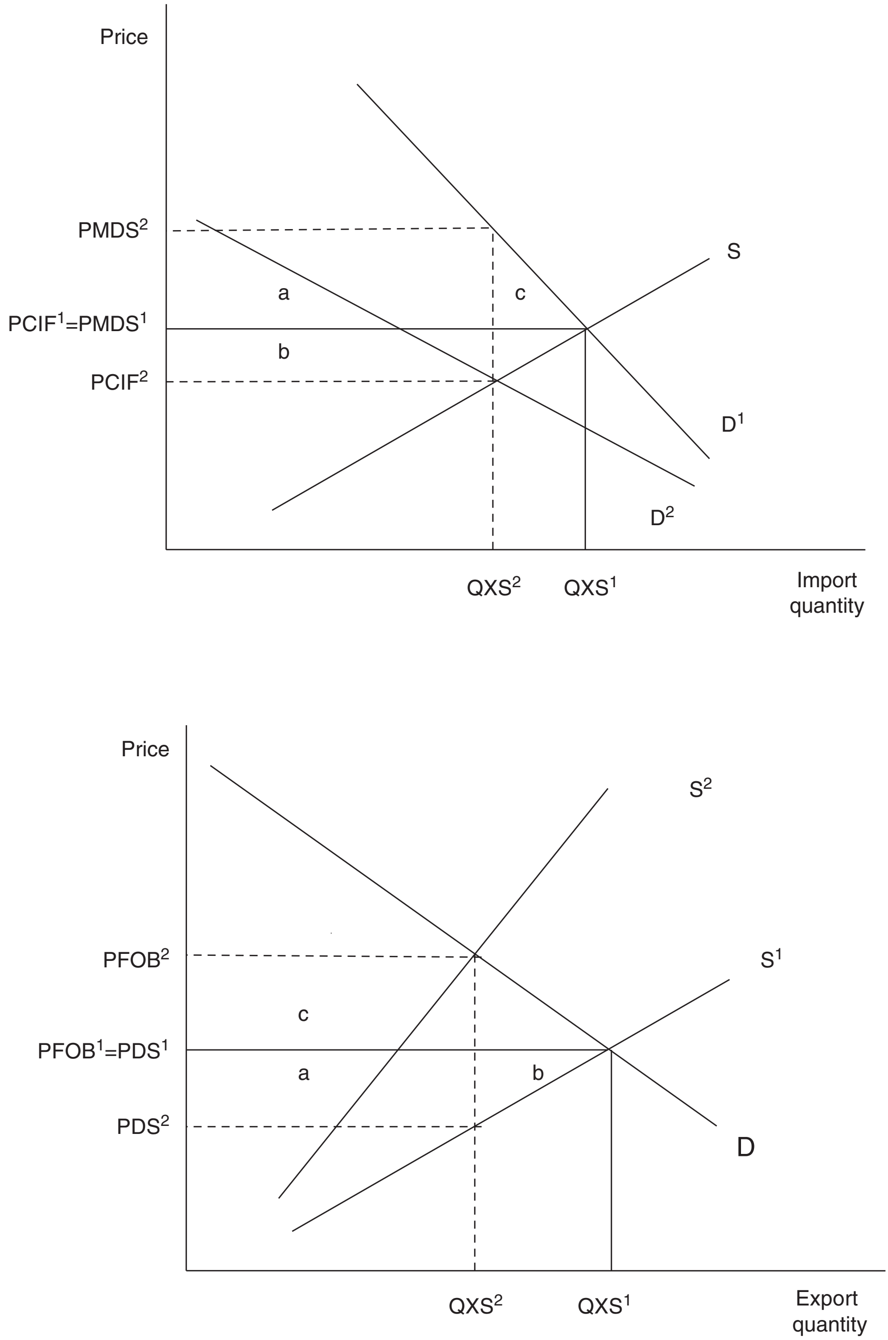


Figure 9.1 (a) Effects of an NTM modeled as an AVE of an import tariff. (b) Effects of an NTM modeled as an AVE of an export tax

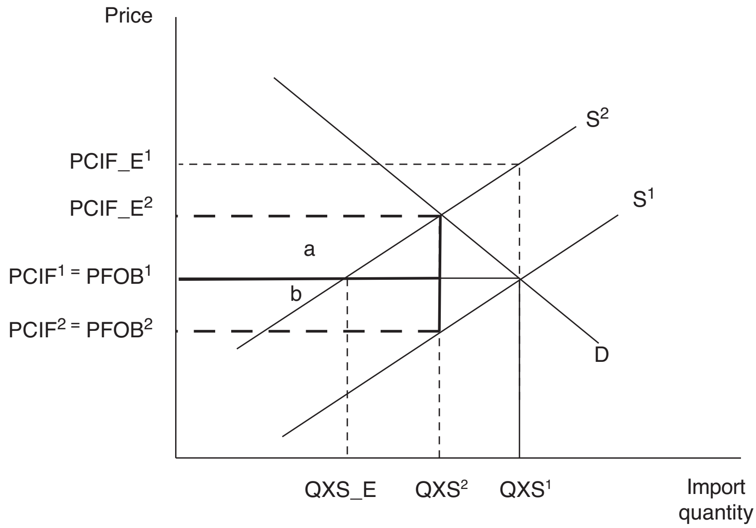


Figure 9.2 Effects of an NTM modeled as a trade efficiency loss

depends on whether the gain in its terms of trade (area *c*) exceeds the loss in its production efficiency (area *b*).[3]

Figure 9.2 describes a bilateral nontariff measure that causes a loss in trade efficiency due to iceberg trade costs. In the figure, the demand curve, D, describes the country's import demand and S^1 is its initial import supply curve. In the initial equilibrium, QXS^1 is the imported quantity and, assuming zero initial trade costs between the two partners, the importer's initial *cif* import price ($PCIF^1$) is equal to the exporter's initial *fob* export price ($PFOB^1$).

From the importer's point of view, a bilteral NTM that imposes iceberg trade costs reduces the effective quantity of the import received at price $PCIF^1$ and results in a new, effective import supply curve, S^2. The per-unit cost of the NTM is described by the vertical distance between the two supply curves. At quantity QXS^1, the exporter still charges $PFOB^1$ per unit but the importer now pays an effective import price of $PCIF\_E^1$ because of the added cost of the NTM. The per-unit iceberg trade cost, expressed in terms of the quantity of the commodity, is described by the horizontal distance between the two supply curves. At the export price of $PFOB^1$, the exporter still sells the same quantity, QXS^1, but the importing country now receives only the effective

[3] Notice that Figures 9.1a and 9.1b each contain only one deadweight loss triangle. That is because we assume in Figure 9.1a that there is no domestic production of the imported good, so there is no loss of producer surplus. In Figure 9.1b, we assume there is no domestic consumption of the exported good, so there is no loss of consumer surplus.

quantity of QXS_E. Quantity QSX^1 – QXS_E has been used up (or "melted away") in the good's transport.

The decline in the effective import supply means that the importer would need to increase its actual imports to enjoy the same level of imports as in the initial equilibrium. On the other hand, the increase in the effective import price causes the quantity of imports demanded to fall, along D. In the new equilibrium, at the intersection of the import demand curve and the effective import supply curve, S^2, the importer's effective import price has increased to $PCIF\_E^2$ from its initial *cif* import price and the quantity of actual imports demanded falls from QXS^1 to QXS^2.

The rectangular area $a + b$ in the figure measures the trade efficiency costs caused by the technical NTM in the shipment of quantity QXS^2 from the exporter to the importer. These are not recouped elsewhere in the economy. Rectangle *b* measures the terms-of-trade loss to the exporter due to the decline in its export price from $PFOB^1$ to $PFOB^2$, which compensates the importer for part of the trade efficiency loss.

We explore these ideas empirically using the NUS333 model. Our experiment is the elimination of a NTM enacted by the United States on its manufacturing imports from the rest of the world (ROW). Let's assume that we are drawing on the results of a gravity model that describes the technical NTM as having an equivalent effect as a 2% US bilateral import tariff on manufactured imports from the ROW. To draw a sharp contrast, we first assume that the protective effect of the NTM only generates economic rents that are absorbed entirely by ROW exporters. We recalibrate our model to increase the export tax on ROW's manufactured exports to the United States by two percentage points. We save the output of this update as a new CGE model version. We next assume that the measure only generates economic rents that are absorbed entirely by US importers. In this case, we recalibrate our model to increase the US import tariff on manufactured imports from the ROW by two percentage points, saving this output as a second updated model version. Finally, we assume that the measure only impacts trade efficiency, for which we do not need to update our model. Our three trade liberalization experiments are applied to the three separate model versions to (1) remove the AVE of the export tariff from the first updated model, (2) remove the AVE of the import tariff from the second updated model, and (3) increase manufacturing trade efficiency by 2% in the base NUS333 model.

Model results are reported in Table 9.3. Whether the US NTM on manufacturing is described as a surcharge to the ROW's export tax or to the US import tariff, its removal increases the quantity of US imports and causes the domestic price of the imported good in the United States to fall. However, welfare results between the two approaches differ markedly. Removal of an NTM modeled as a reduction in the ROW export tax increases US welfare, in part because it

Table 9.3 *Effects of the removal of a US NTM on manufactured imports from ROW, with a 2% AVE of an import tariff modeled in three alternative ways*

	AVE of 2% US import tariff in manufacturing modeled as		
	(1) ROW export tax	(2) US import tariff	(3) Iceberg trade efficiency cost
Changes in trade quantities and prices (% change)			
Quantity of ROW exports of MFG to the United States (*qxs*)	3.98	3.18	1.67
Effective quantity of US imports from ROW (*qxs* + *ams*)	3.98	3.18	3.67
Domestic price of US MFG imports from ROW (*pmds*)	−1.94	−1.83	0.04
Effective domestic price of US MFG imports from ROW (*pmds* − *ams*)	−1.94	−1.83	−1.96
ROW fob export price of MFG to United States (*pfob*)	−2.03	0.11	0.04
US welfare ($US billion)	31,120	−14,728	28,631
Total allocative efficiency effects	2,276	−11,791	1,540
Allocative efficiency due to US MFG NTM-import tariff removal	–	13,333	–
Trade efficiency	–	–	38,031
Total terms of trade	28,844	−16,271	−10,939
Manufacturing terms of trade	30,483	−8,221	−5,778
ROW welfare ($US billion)	−27,787	18,315	12,287
Total allocative efficiency effects	104	2,098	1,370
Allocative efficiency due to ROW MFG NTM-export tax removal	912	–	–
Trade efficiency	–	–	–
Total terms of trade	−28,804	16,218	10,929
Manufacturing terms of trade	−30,145	8,228	5,786

Note: Trade efficiency improvement is modeled as a 2% increase in variable *ams*.
Source: NUS333 model – base version and two versions with updated tax rates.

increases ROW's supply of manufacturing exports, causing its *fob* export price to fall on its sales to the United States, and the US terms of trade in manufacturing to improve. Removal of an NTM modeled as a US import tariff reduces US welfare, in part because it increases US demand for manufacturing imports from ROW, causing ROW's *fob* export price to rise and the US terms of trade to deteriorate. These stark differences in welfare outcomes illustrate the importance of the modeler's decision about the allocation of an NTM's ad valorem tax equivalent between import tariffs and export taxes.

When removal of the NTM is modeled as a trade efficiency gain, the quantity of the ROW's manufacturing exports to the United States increases by only 1.67%, but the effective quantity of US imports increases 3.67%. The increase in the effective import quantity is larger than for actual exports because the elimination of iceberg losses increases the quantity of the ROW's exports that successfully reach the US port. This reduces the effective import price of the United States because it now receives more manufactured imports from the ROW for a given *fob* export price. As a result, the United States demands more manufactured imports, pushing up the ROW's *fob* export price and providing ROW with a terms-of-trade gain in manufacturing. Removal of "sand in the wheels" NTMs can therefore benefit both the importer, whose welfare directly benefits from the increase in trade efficiency, and the exporter, through its terms-of-trade gain.

These modeling techniques offer reasonable approximations of the market impacts of a nontariff measure but it is important to note that these methodologies are continuing to evolve. One open question is how to allocate the AVEs of NTMs across tax and trade efficiency instruments. In addition to considering economic rents and trade efficiency losses, some CGE modelers include certain compliance costs such as veterinary inspections or pest treatment requirements in the export tax or import tax allocation, depending on which country incurs the cost. The use of export taxes to represent NTMs' compliance costs may be especially appropriate in light of recent research by Beckman, et al. (2015) (described in Text Box 9.1) and Cadot and Gourdon (2015), who find that most of these compliance costs are incurred before the product is exported and are already reflected in the *fob* export price. More recently, building on the UNCTAD/World Bank measures of the AVEs of both technical and nontechnical NTMs, some modelers allocate the AVEs of technical NTMs entirely to trade costs, and the AVEs of nontechnical NTMs to export or import taxes, depending on the nature of the policy.

This implementation of NTMs in a standard CGE model also has some drawbacks that a modeler should keep in mind. First, we expect that economic rents or compliance costs will accrue to the industries that supply exports, acquire imports or offer compliance services. But when a nontariff measure is modeled as an import tariff or export tax, a standard CGE model treats economic rents and costs as a general tax revenue flow rather than as industries' earnings. These industry effects are an important missing element of an economy-wide analysis of regulatory impacts. This shortcoming is particularly important in CGE models in which tax revenue is tracked directly to a government account and so directly affects government spending (whose composition likely differs from that of private industry), the size of the government surplus and deficit, and national savings and investment.

An additional limitation of modeling the rents generated by an NTM as a tariff or tax is that their size can be diminished if resource-wasting, rent-seeking activities such as bribery or lobbying dissipate their value. In this case, welfare losses would include some or all of the redistributed rectangular areas that measure economic rents in addition to the deadweight efficiency losses described by the triangles in Figures 9.1a and 9.1b.

We also have not considered the possible benefits of technical NTMs. These may be welfare-increasing if they generate societal gains such as improvements in health or the environment or if they provide consumer amenities. For example, an NTM that requires a pesticide-free certification provides food safety information that is valued by many consumers. By solving a market failure related to information about unobservable product qualities, the introduction of the technical NTM can lead to both higher import demand and higher world import prices. In another example, consumers may be willing to pay more for a product if its delivery is timely – much as the price of a Christmas tree is higher when delivered before the holiday than in the week afterward. Walmsley and Minor (2015) use an ad valorem tariff equivalent of the willingness to pay for timely delivery in their analysis of a reduction of inefficient border practices. They extend a standard CGE model to describe the NTM reform as a rightward shift in the import demand curve. This approach increases consumer demand for those products whose border transit times improve, which leads to increases in both the import price and the import quantity. In contrast, removal of an NTM in Figure 9.2a would shift the import supply curve to the right, resulting in a lower (effective) import price and an increase in import quantity. Studies of the positive demand-side impacts of NTMs are still at an early stage. And, as yet, the social benefits of technical NTMs are difficult to quantify and monetize, so they are not typically accounted for in a standard CGE model.

Finally, some NTM compliance costs are fixed costs, such as requirements for refitting or certifying a production facility, rather than variable costs, such as product labels affixed on each unit. Variable compliance costs rise (fall) with increases (decreases) in export quantities or prices. Fixed costs, instead, can present make-or-break economic hurdles that determine whether firms can enter or must exit foreign markets. Computable general equilibrium modelers have recently extended the standard CGE model framework to account for fixed export costs imposed by NTMs, building on the theoretical insights of Melitz (2003). This new generation of trade-focused CGE models is discussed in more detail in the final chapter of this book.

Regulations to Correct Negative Production Externalities

Externalities are the negative or positive spillover effects of an economic transaction between two parties on uninvolved third parties which are not reflected in market prices. Our discussion focuses on regulations that address negative externalities that stem from production, a policy problem that is an active and innovative area in CGE-based policy analysis. A negative production externality occurs when an industry's production process has negative spillover effects whose costs are not accounted for in the industry's input or output prices. For example, an industry's use of an air-polluting technology that leads to lung disease in adjoining neighborhoods creates a negative externality. The added medical costs are a burden to the industry's neighbors which are not taken into account in the firm's costs of production. Negative externalities lead to market inefficiency, because industries produce more than they otherwise would if they took social costs into account. Regulations are designed to internalize the costs and benefits of externalities into agents' economic decision-making.

Regulations designed to reduce production externalities may mandate either a specific production process or an outcome. *Process-based regulations* increase the cost of production because the industry must purchase a newly mandated input or technology, or practice a mandated technique. For example, a regulation designed to reduce the public health costs that result from industrial pollution could require that producers adopt a specific technology to scrub their emissions. Regulatory compliance imposes the pollution cleanup cost on the producer, which will cause the industry's output price to rise. Consumers respond by reducing the quantity demanded, so output and production of the emission falls. The reduction of the externality is therefore achieved in part through the regulation's negative *output effect* as the costs of the externality are internalized by the industry.

An *outcome-based regulation* allows producers to choose the least-cost means of achieving the regulatory goal. It may, for example, impose fixed limits on the level of the producers' emissions and allow them to find the least-cost means of complying. Producers may substitute among intermediate inputs to meet the standard or invest in research on innovative ways to achieve the mandate. For example, energy producers could substitute wind or solar energy for coal to meet new emissions regulations if the cost is lower than installation of scrubbers. Or they may invest in research that discovers new sources of low-cost and low-emission biofuels. Outcome-based regulations can have output effects, similar to those of process-based regulations. But, because of the flexibility that they allow for *input substitution* and *technological innovation*, they may achieve the regulations' intended benefits at a lower cost than process-based regulations do.

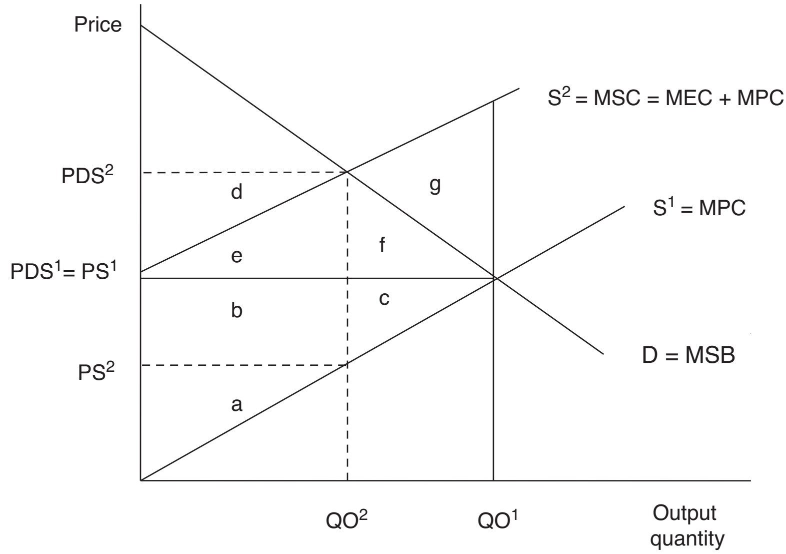


Figure 9.3 Effects on the domestic market of a regulation to correct a negative production

Output effects can be readily explored in a standard CGE model, but a realistic study of the input substitution and technological innovation effects of outcome-based regulations generally calls for significant model extensions. Technical Appendix 5.1 describes an example of such extensions in a description of the addition of nests to the value-added bundle in CGE models used to analyze climate change mitigation, which allow substitution among energy sources used as intermediate inputs. Yet, even with its limitations, a standard CGE model, such as our toy NUS333 model version, remains a useful tool for study and demonstration because it introduces you to many of the core concepts in regulatory policy analysis, which you can draw on as you advance your skills in working with more complex, regulatory-focused CGE models.

Let's first explore the theory underlying the analysis of a regulation. Figure 9.3 describes a production activity whose processes result in a negative externality. For example, it may be a firm that dumps harmful waste products into a river, which causes an increase in the nearby town's water treatment costs. If we assume zero trade, D is the aggregate demand curve or, equivalently, the marginal social benefit (MSB) derived from total consumption of the activity's products. S^1 is the activity's supply curve. It describes the firm's marginal private cost (MPC) of production, which excludes the cleanup costs that its water-polluting production process currently imposes on the town. Assuming that the costs of cleaning up the pollutants are constant per unit of output, then S^2 describes the marginal social cost (MSC) of production; it adds the marginal external cost (MEC) of civic water treatment to the activity's private costs of production. QO^1 is the initial market equilibrium output quantity of the unregulated industry and, assuming no initial taxes, the producer supply price, PS^1, is equal to the initial sales price paid by consumers, PDS^1.

From a societal perspective, output quantity QO^1 is not an efficient equilibrium. For all quantities above QO^2, too much of the good is being produced and consumed because the marginal social cost of the good's production exceeds the marginal social benefit from its consumption (MSC > MSB at all quantities above QO^2). The area measured by $a + b + c + e + f + g$ describes the total external costs to society from producing quantity QO^1. Because areas $a + b + c$ are gained in producer surplus, and areas $e + f$ are recouped in consumer surplus at price PDS^1, area g represents the uncompensated external cost loss to society from the excess production of quantity QO^2–QO^1.

Assume that a regulation is introduced that requires the industry to clean up its waste products before dumping them. The regulation might, for example, require the purchase and use of water filters. If we assume that the newly required process is the least-cost method, then the industry's marginal private cost curve shifts up from S^1 to S^2 as the marginal external costs are internalized by its expenditures on the new technology. Price PS^2 is the new, lower producer supply price net of the cleanup expenditure and price PDS^2 is the new producer sales price, including the compliance cost that is passed on to consumers. In the new market equilibrium, consumers face a loss in surplus described by area $d + e + f$. Producers lose the surplus described by area $a + b + c$, but gain area d. The added cost to producers from cleaning its emissions is the sum of areas $a + b + e$. Similar to the redistribution of tax revenue to the government, these added compliance costs are not lost to the economy because the expenditures are redistributed from the regulated producer to the industries that supply the mandated services or equipment. The net cost of the regulation is thus the uncompensated loss of production and consumption efficiency described by area $c + f$.

We must also take into account, however, that the regulation has prevented some water pollution by reducing output. The area $c + f + g$ measures the social benefit that results from this output effect. An important question in this analysis is whether the benefits of the required water treatment are at least as large as its efficiency costs to the economy. After deducting the losses in producer and consumer surplus ($c + f$), area g measures the net social benefit of the regulation with an equilibrium output at quantity QO^2 and a consumer price of PDS^2. As drawn, our graph indicates that this regulation is a socially worthwhile policy.

The compliance costs depicted in Figure 9.3 illustrate one reason why a general equilibrium perspective is needed in regulatory policy analysis. The compliance expenditures will expand output and employment in the "green" industries that provide pollution control services, offsetting the decline in output in the regulated industry.

There are several other reasons why CGE models are well suited to the analysis of negative production externalities. Factors in addition to compliance costs also contribute to changes in industry composition – for example, a regulation is likely to affect national income and therefore the quantities and types of goods that consumers demand as their incomes change. Also, changes in a country's export supply and import demand may lead to macroeconomic effects, such as a change in its exchange rate, which affects all tradable industries in the economy. Such general equilibrium impacts on *industry composition* can lead to either lower or higher total production of externalities, depending on whether and how much pollution is emitted by the other industries in an economy.

Some researchers who focus on environmental regulations have explored the problem of *second-best efficiency effects* that can result from the interaction of the regulations with an economy's existing taxes.[4] For example, a regulation that leads to lower output in a subsidized industry will have a welfare-enhancing effect if it reduces the inefficient overproduction that resulted from the subsidy. Another concern is the possible negative impact on global competitiveness and export demand of regulations that increase the production costs of regulated industries relative to unregulated foreign industries. Compliance costs that increase export prices can cause demand for the exports of the regulated country to fall, and this in turn can lead to changes in the *terms of trade*.[5]

The efficiency losses in a regulated market, described by areas *f* and *c* in Figure 9.2, are the *direct costs* of a regulation.[6] A regulation's general equilibrium effects on industry composition, second-best efficiency, and terms of trade describe its *indirect costs*.

[4] A useful reference on this topic is Paltsev et al. (2004), who provide a graphical illustration of second-best and terms-of-trade effects of environmental policies. Goulder et al. (1998) develop a comprehensive review of the literature on second-best interactions with environmental policy, and compare the second-best effects of process-based regulations (an emission-reducing, mandated technology) with other types of environmental policy instruments.

[5] In practice, the anticompetitive impacts of environmental regulations have not proven to be notable, in part because compliance costs are usually a small share of total production costs (Dean, 1992).

[6] The term *direct costs* commonly used in the CGE-based regulatory literature should not be confused with the term *direct burden* used in the public finance literature described in Chapter 8. In the regulatory literature, direct costs are the regulated industry's deadweight efficiency losses due to a regulation; in the public finance literature, direct burden refers to tax or tariff revenue that is redistributed to the government and so is not a loss to the economy.

Computable general equilibrium researchers have generally taken two approaches to describe the introduction of regulations into a model. One is the productivity approach, which describes the increase in production costs due to the mandated purchase of newly required inputs. For example, a health regulation may require a cattle producer to provide more extensive veterinary certifications for each steer that is sold. This can be represented in a CGE model as a decline in the productivity of that veterinary service input or as an increase in the input-output coefficient for the required service that is used as an intermediate input into cattle production. In either case, production costs rise because a greater quantity of some input is required to produce the same quantity of output.

Outside research on the cost of compliance and, ideally, on the type of newly required input is needed to accurately define an experiment that realistically describes the cost to producers of a regulation. Let's assume that our external research informs us that regulatory compliance increases the quantity of the cattle producer's input requirements for services by 2%. We could then describe the regulation's effect in our model as a 2% decline in the productivity of the services input used in the production of cattle. Text Box 9.3 describes an analysis of new corporate governance regulations that require some private companies to increase their purchases of auditing services. The regulation is modeled as an increase in the input-output coefficient for services used in the production technology of the regulated industries.

A second CGE modeling approach describes a regulation by imposing quantities, such as a cap on the use of a polluting input, and allowing an endogenous tax to adjust relative prices until this constraint is met. The endogenous tax rate can be interpreted as a shadow price that measures the marginal cost of compliance, or the cost of avoiding an additional unit of the externality. The industry internalizes the social cost of the externality, which increases its production costs and shifts the supply curve from S^1 to S^2 in Figure 9.3. For example, the modeler can place a cap on the quantity of coal used as an input into energy production, and solve for the input tax surcharge that achieves this outcome. This approach requires a change in the closure of a standard CGE model. The exogenous sales tax rate on the input is defined as endogenous. The quantity of the input is defined as exogenous and is reduced in the regulatory policy experiment. The solution value for the endogenous tax is calculated as the new input tax rate minus the initial tax rate – it is a tax surcharge on top of the initial input tax. The new tax revenue (area $b + e + d$ in Figure 9.3) is the cost of regulatory compliance that is redistributed within the economy to the suppliers of compliance services. The shadow-price approach is used in the MIT-EPPA model, a CGE model with a rich, nested structure that allows substitution among

Text Box 9.3 Modeling regulations as an input productivity shock

"***Could Corporate Governance Practices Enhance Social Welfare?***" (Chisari, Ferro, Maquieyra et al., 2014).

What is the research question? Following the global financial crisis, many governments imposed new regulations to improve corporate governance and reduce risks for investors. Resources must be used to comply with these new controls, but reduction of corporate risk also may reduce the cost of capital. What are the costs and benefits of the new regulations?

What is the CGE model innovation? Chisari and colleagues develop a recursive dynamic CGE model of Argentina as a case study. They model the costs of the regulations based on data on actual additional auditing expenditures. These costs vary by sector and are implemented as a change in the input-output coefficient on audit services used as intermediate inputs by the regulated industries. The model describes the benefits of regulations as a change in the cost of capital, measured as a change in the price of bonds that are purchased by private households and bought and sold by the government.

What is the experiment? The team carries out four experiments: (1) an increase in audit costs, (2) an increase in audit costs accompanied by a permanent 1% reduction in the price of bonds, (3) an increase in audit costs with a temporary 1% reduction in bond prices, and (4) an increase in audit costs with volatile changes in bond prices.

What are the key findings? Regulatory compliance in itself is costly because the economy is diverting resources from capital accumulation to pay for the extra audit expenses; this leads to a small reduction in GDP growth. But if the reforms succeed in achieving even a modest long-run reduction in capital costs, then corporate governance is worthwhile, even if this reduction is transient. However, volatility in the cost of capital reduces the benefits of stronger corporate governance.

intermediate inputs in the production of energy (Paltsev et al., 2007). Their study of an outcome-based regulation of greenhouse gas emissions accounts not only for the output effect but also for a substitution effect, which allows producers to shift among cleaner or dirtier sources into the energy input, and for technological innovation (see Text Box 9.4).

For demonstration, we implement the endogenous tax approach using the NUS333 model. We emphasize that it is a highly stylized example because our model describes only output effects, without intermediate input substitution possibilities or technological innovation. Yet, our experiment is still worthwhile because it allows us to explore the two key concepts of the direct and indirect costs of a regulation.

Let's assume that a regulation is introduced in the United States. Its objective is to require all producers of the manufactured good to reduce

Text Box 9.4 Input substitution and technological innovation in a CGE-based regulatory policy analysis

"***Assessment of US Cap-and-Trade Proposals***" (Paltsev et al., 2007).

What is the research question? The United States wants to lower greenhouse gasses emitted by energy sources, including coal, petroleum, and gas. How might emission reduction policies affect levels of energy use, substitution among energy sources, and technological innovations that reduce emissions per unit of energy produced?
What is the CGE model innovation? The team developed a recursive dynamic CGE model that provides producers with the flexibility to switch among fifteen energy sources that are characterized by varying degrees of substitutability. Technological changes over time include decreases in emissions per unit of output, and increased use of unused or minimally used alternative energy sources as they become economically competitive.
What is the experiment? A suite of experiments describe various energy policy options, including higher or lower caps on emissions. Caps are imposed by placing constraints on aggregate emissions and solving for a shadow price, or an endogenous tax wedge, that represents the price at which carbon permits would trade and generate revenue for economic agents.
What are the key findings? Results compare the equivalent variation welfare costs of alternative emission reductions policies, decomposing welfare effects into direct and indirect costs. Direct costs are the abatement costs, estimated to range between \$120 to more than \$200 by 2050 per unit of CO_2. Total welfare costs, which include the indirect benefit resulting from terms-of-trade gains, are estimated to rise between 1.1% and almost 2% by 2050. No assessment was carried out of the economic effects of climate change avoided or ancillary benefits of emissions mitigation, but these benefits would provide at least a partial offset to mitigation costs.

the externality that results from their production process by 1%. Our experiment's design stems from our model structure, in which we assume a Leontief fixed input-output relationship for intermediates. Therefore, the percentage change in any intermediate input is equal to the percentage change in output of the final good. Instead of capping the quantity of a specific dirty input used in the production of manufactures, our experiment therefore directly regulates the quantity of manufacturing output. To do so, we first change the model closure to make US manufacturing output an exogenous variable and its output tax rate an endogenous variable. Our experiment imposes a 1% reduction in US manufacturing output and our model solves for the output sales tax that achieves this objective.

Table 9.4 *Effects of a regulation to correct a negative externality in US manufacturing*

Effects on US manufacturing	
Compliance cost – surcharge on tax rate on manufacturing output (%)	2.3
Compliance cost – tax revenue ($US millions)	153,110
Production of externality (% change) (qc_{MFG})	–1.0
Producer supply price (% change) (*ps*)	–1.2
Producer sales price (% change) (*pds*)	1.0
Export quantity (% change) (*qxw*)	0.8
Import quantity (% change) (*qiw*)	–1.9
Real exchange rate (% change) (*pfactor*)	–3.3
Direct cost – allocative efficiency effect in manufacturing ($US millions)	–1,457
Indirect costs	
Production of externality in agriculture (% change) (*qc*)	1.4
Production of externality in services (% change) (*qc*)	0.2
Second-best allocative efficiency effects ($US millions)	–5,169
Terms of trade($US millions)	–33,009

Note: The tax rate surcharge is calculated as the difference between the initial and new output tax rates. The cost of compliance is calculated as the product of the updated value of output (VOB) and the tax rate surcharge. Direct cost is the allocative efficiency effect linked to the change in output tax in US manufacturing. Second-best efficiency effects are calculated as the total allocative efficiency costs minus the direct cost.
Source: NUS333 model.

The regulatory requirement for US manufacturers is achieved at a marginal cost of compliance equal to an output tax surcharge of 2.3% (Table 9.4). The $153 billion in revenue due to the tax surcharge is the added cost of compliance (area $d + e + b$ in Figure 9.3), which is redistributed throughout the economy. Higher production costs lead to a 1% increase in the price that consumers pay for manufactures (price PDS^2 in Figure 9.3), but the producer supply price, net of the compliance costs, falls by 1.2% (price PS^2 in Figure 9.3). Output falls by 1% as consumer demand responds to the increase in the consumer price. Despite its new regulatory burden, US manufacturing exports increase and its imports decrease. This is due in part to the substantial US real exchange rate depreciation, a general equilibrium effect of the regulation.

The direct cost of the regulation, of almost $1.5 billion, is the loss in efficiency (area $c + f$ in Figure 9.3) in the manufacturing sector. The regulation's indirect costs include changes in the economy-wide production of the externality that result from changes in the industry composition of the US economy. Given our Leontief technology, we can assume that any changes in use of dirty inputs by agriculture and services are identical to the changes in their output, which increase in both industries. Indirect costs also include

$5.2 billion in second-best allocative efficiency losses related to other US taxes, and a terms-of-trade loss of $33 billion. The total welfare impact of the regulation includes the regulation's direct cost, second-best efficiency effects, and terms-of-trade changes. It is a loss of nearly $40 billion to the United States. An important caveat to our study is that our model's Leontief technology does not allow input substitution – perhaps between "dirty" inputs and "clean" intermediate inputs into manufacturing; if feasible, such substitution could reduce the costs of achieving the regulatory target. Also, we assume that no technological innovation occurs that could reduce the externality created per unit of dirty inputs – this too, could reduce the costs of complying with the regulation.

An important missing element in this analysis is a calculation of the net benefit to the United States from reducing production of the externality. Regulations are usually enacted in order to achieve societal benefits, but it can be difficult to calculate their value. Benefits from reducing an externality could be measured in terms of the externality, such as tons of CO_2 emissions that are avoided, or in the number of lives saved or illnesses avoided. In some cases, the benefits described by area $c + f + g$ in Figure 9.3 can be monetized. For example, the number of lives saved may be translated into dollar values. In our example regulation, the net benefit to society from the regulation in manufacturing could be calculated by subtracting direct and indirect costs from a monetized value of its benefit. However, despite the importance of including the value of benefits in a full consideration of regulation, they are not typically accounted for in CGE analyses.

Summary

Our study of regulatory policies in a CGE model focused on nontariff measures affecting trade and on regulations designed to correct negative production externalities such as pollution. Studies of these two types of regulations are among the most timely applications and innovative modeling fields in current CGE-based research. Our examination of each type of regulation began with a simple, partial equilibrium, theoretical model that illustrated how these nonprice policy mechanisms influence resource allocations, economic efficiency, and welfare; and our discussion developed insights into their general equilibrium impacts. We described the three mechanisms for introducing an NTM into a standard CGE model: as a surcharge to an import tariff or to an export tax, or as a change in trade efficiency. We described process-based and outcome-based regulations; their output, substitution, and innovation effects; and their direct and indirect impacts. We provided highly stylized, applied applications using a standard CGE model to demonstrate methodologies, introduce core concepts, and illustrate the capabilities and limitations of standard CGE models in regulatory policy analysis.

Key Terms

Ad valorem equivalent (AVE) of a nontariff measure
Direct cost of regulation
Effective import price
Effective import quantity
Externality
Iceberg trade cost
Indirect cost of regulation
Input substitution effect
Nontariff measure (NTM)
Outcome-based regulation
Output effect of regulation
Process-based regulation
Regulation
Rent (economic)
Rules of origin
Shadow price
Substitution effect of a regulation
Technological innovation effect
Trade efficiency

PRACTICE AND REVIEW

1. Assume that a shipment of fresh strawberries is delayed at the border because of a technical nontariff measure, and that some share of the strawberries becomes moldy because of the delay. Explain how this can lead to a trade efficiency loss. In a graph, describe its effects on actual and effective demand for imports, the exporter's price of strawberries, and the importer's effective price of strawberries.
2. Assume that a new regulation requires a chemical company to clean up the toxic residues in its plant waste. In a graph, describe the effects of the regulation on consumers, producers, compliance costs, and welfare. Label the axes, curves, and initial market equilibrium. As drawn, does this regulation yield a net welfare gain to this society? What variables in your CGE model correspond to the costs and welfare impacts of the regulation shown in your graph?
3. Explain the difference between a process-based and an outcome-based regulation, defining the output, substitution, and technological innovation effects. Define the direct and indirect costs of a regulation.

10

Conclusion

Frontiers in CGE Modeling

Computable general equilibrium (CGE) models are sometimes criticized for being "black boxes" in which so many things are moving at once that results are difficult to explain and their credibility as a theoretically consistent, analytical tool is undermined. By deconstructing a standard CGE model with the aid of basic principles of economics, we hope to have dispelled some of their mystery and made them more comprehensible and useful to students and professional economists alike. Such an introductory study seems especially timely given the increased accessibility of CGE models and CGE model databases.

In this book, we studied the main components of a CGE model. We learned that producers in the model are assumed to maximize efficiency, and consumers are assumed to maximize utility. Their microeconomic behavior adds up to the macroeconomic performance of the economy. Our study of each component of the model – supply, demand, factor markets, trade, and taxes – emphasized the model's underlying economic theory and supplied practical examples from small-scale CGE models to illustrate these concepts.

We studied a "standard" CGE model that assumes a representative household consumer, a representative producer of each type of product, and uniquely determined solution values for prices and quantities. It is a static, or single-period, model that provides a before-and-after comparison of an economy after a shock, such as a new tax, but it does not describe the economy's adjustment path from the old to the new equilibrium.

All of these features of our CGE model can at times represent shortcomings or constraints. The aggregation of all households, despite the great diversity in their income sources and tastes and preferences, into one representative household consumer is quite a strong assumption. Producers, too, may be diverse in ways that are important to an analysis, perhaps producing the same product using different types of technologies or facing very different transportation costs in different regions of a country. In addition, our world is characterized by some amount of randomness, like weather variability, and this stochasticity is not reflected in our deterministic CGE model. Static models also may not fully address the concerns of policymakers about the transition process, when there can be high unemployment or other types of dislocation as an economy adapts to shocks. Economists working in the frontier areas of CGE modeling have extended the models' capabilities in all of these dimensions. Your foundation in working with a standard CGE model now leaves you well prepared to appreciate the significance of these advances.

CGE modelers have addressed the problem of how to disaggregate representative households in two different ways. One approach is to decompose the single household account in the Social Accounting Matrix (SAM) and in the CGE model into multiple accounts, in which sources of factor income and the baskets of goods purchased by each household type differ. In this way, a shock such as the decline in one industry's employment will directly affect only households whose income derives from that sector. Likewise, a tax on capital income would affect households with significant dividend income more than it would affect households with mainly wage income. Changes in income affect households' consumption and saving behavior, which then lead to general equilibrium effects on the economy as a whole.

A second approach is to link the CGE model with a "micromodel" that may contain thousands of households. The micromodel includes estimated behavioral equations, usually based on national household survey data, which describe how households' hours of work and quantities of consumption respond to changes in wages, prices, and income. The endogenous price and income results of the CGE model, the "macromodel," are then incorporated into the micromodel as exogenous shocks, which results in responses at the household level. With this approach, the distribution of macro effects across households does not feed back to influence production, employment, or other variables in the CGE model. Macro-micro models have made important contributions to the analysis of the distributional effects of policies on household income and poverty (e.g., Bourguignon, Robilliard, and Robinson, 2003, summarized in Text Box 4.2; Hertel et al., 2004b; Verma and Hertel, 2009, summarized in Text Box 10.1).

The extension of CGE models to describe diversity among producers has become particularly important in the energy and environmental economics fields. One approach utilizes non-diagonal make matrices, as described in Chapters 3 and 5. These describe multiple production activities that use different technologies to produce the same commodity. The Global Trade

Text Box 10.1 A stochastic CGE model: caloric intake in Bangladesh

"***Commodity Price Volatility and Nutrition Vulnerability***" (Verma and Hertel, 2009).

What is the research question? Agricultural production can be highly variable because of stochastic, or random, changes in weather. Production volatility in turn leads to volatility in food prices and food consumption. The authors examine how food price volatility leads to variability in caloric intake in Bangladesh. Could a special safeguard mechanism, which limits imports whenever their quantities surge, lead to increased average caloric intake or a reduction in its variability?

What is the CGE model innovation? The authors use a macro-micro model that links the GTAP CGE model with a micro-simulation model of the caloric intake of Bangladeshi households. Macroeconomic results from the CGE model are used as inputs into the micromodel of Bangladeshi households' food purchases. The authors define a stochastic shock to the total input productivity of grains and oilseeds production in the CGE model. This step creates baseline means and probability distributions for commodity prices and households' caloric intake. They validate their CGE model by testing that results from their stochastic productivity shock reproduce historical crop price volatility.

What is the experiment? The authors introduce their stochastic productivity shock with and without an offsetting special safeguard mechanism on imports.

What are the key findings? Differences among households in distributions of caloric intake, with and without import safeguards, are very small because Bangladesh does not import much of its food. The general lesson is that special safeguard policies raise food prices so they are likely to affect countries adversely, particularly their poor households.

Analysis Project (GTAP)-Power database and CGE model, for example, describe the same commodity, electricity, being produced by eight different generating sectors, including nuclear, coal, hydro, and solar power, and describes consumers choosing among the different power sources (Peters, 2016). A second approach is to allocate the national-level results of a CGE analysis across production activities using a routine that is separate from the CGE model. The USAGE-ITC model, for example, uses this "top down" approach. It includes an "add-in" that allocates endogenous national impacts from the CGE model across state-level industries and employment (see Text Box 3.2). For instance, perhaps the state of Michigan will receive 10% of the change in national US consumer demand for good X. As in the macro-micro model of households, this approach does not allow feedback from changes in state-level production and employment back to the national CGE model.

Another innovation for environment-focused CGE models is the incorporation of land use and crop cover changes at the disaggregated local level into regional and global models. In a recent review of the literature emerging from this active area of research, Hertel and others (2019) describe the developing capability of modelers to address how global drivers such as population growth and climate change lead to changes in land use and crop cover at the local level. When these local responses are widespread, they can in turn have feedback effects at the regional, national, and global levels – an interconnection termed global-local-global (GLG) feedback. Until recently, most global models described a one-way linkage in which model results at the regional level were downscaled to predict the effects of a shock at fine grid-cell levels that describe local biophysical conditions by square acre, kilometer, or other small-scale dimension. Conversely, results of models that describe changes at the grid-cell level were aggregated to the regional or global levels for use as inputs into CGEs and other large-scale models. Grid-based models that are directly coupled with CGE and partial equilibrium models are now at the frontier of GLG tools for modeling land use and crop cover changes, yielding important insights about both global impacts and local sustainability. Given the data and computational intensity of these efforts, Hertel and colleagues argue that large research institutes and teams of collaborators are the best suited to undertake this class of research.

Stochastic models are another innovative, frontier area of CGE modeling that is poised to make major contributions to the analysis of long-term climate change. Stochastic models stand in contrast to the deterministic CGE model that we have studied in this book. In a deterministic model, the solution value of every variable is uniquely determined by the equations, base data, parameter values, and shock. For example, an experiment may be a 10% change in wheat productivity, which results in a 10% change in the quantity of wheat production. Stochastic models account for the randomness that may be present in an economic environment. Perhaps year-to-year output of wheat is variable, and is expected to become increasingly variable because of climate change. A stochastic CGE model would describe the baseline output of wheat in terms of a mean value and probability distribution and the effects of a climate change shock as a change in the mean and distribution of wheat output. CGE modelers have taken different approaches to describing stochastic behavior in a CGE model. See, for example, Verma and Hertel's (2009) study of the effects of world food price volatility on caloric consumption in Bangladesh, summarized in Text Box 10.1.

Dynamic CGE models essentially capture the notion that an economy's reaction to a shock, such as a new tax, changes its long-run growth trajectory. First, the models trace a baseline time path (usually a series of annual observations for a specified time period) over which the supply and productivity of an economy's stock of capital and labor grows in the absence of a shock. A shock to the economy leads to changes in its growth trajectory by changing the timing and level of capital accumulation. Capital stock growth is altered when the experiment changes the rate of return to capital, which changes savings and investment behavior. Instead of static before and after snapshots, the results of a dynamic CGE model thus describe the difference between the baseline time path and the time path with the economic shock.[1]

There are two general types of dynamic models. A recursive dynamic CGE model traces out a time path by sequentially solving a static model, one period at a time. First the model solves for one period after the shock, similar to a static model. Then all of the solution values are used as the variables' initial values for the next period and the model is resolved, and so on. The capital stock grows over time because the change in savings that occurs in one period becomes an addition (minus depreciation) to the productive capital stock in the next time period. The modeler may also include time trends for labor force and productivity growth as the model is solved over the time path. Producers and consumers are assumed to be myopic. They minimize their costs or maximize their utility only for the current period, and they are assumed to believe that current economic conditions will prevail at all periods in the future.

Recursive dynamic CGE models are used by many governmental and international institutions to analyze important public policy problems. Prominent examples of these models are the GTAP-RD model (Aguiar et al., 2019), the World Bank's multi-country Linkage model (van der Mensbrugghe, 2005), the single-country MONASH model of Australia (Dixon and Rimmer, 2002) and its descendant, the USAGE-ITC model of the United States (Koopman et al., 2002), the World Bank's MAMS model (Gottschalk et al., 2009), and G-RDEM (Britz and Roson, 2019). Recursive dynamic models have begun to assume an important role in the analysis of long-term global climate change. Recursive dynamic climate-focused models include CIM-EARTH (Elliott et al., 2010a) and the MIT-EPPA model (Paltsev et al., 2005).

The second type of dynamic CGE model is intertemporal. It assumes that producers and consumers have rational expectations, which means that they anticipate and take into account prices and income in all time periods as they make their current decisions. Producers minimize the present value of all of their costs over the full time period of the analysis, and consumers maximize their total utility over that period. Like the recursive model, an intertemporal CGE model describes two growth paths – with and without the economic

[1] See Devarajan and Go (1998) for an introduction to dynamic CGE models.

shock. The models differ because the intertemporal type solves for prices and quantities in all time periods simultaneously. The time dimension adds many variables to the model. For example, the output of a single industry over a 30-year time path equals 30 variables. Researchers therefore make a trade-off between the time dimension and the number of countries, industries, or consumer types in the model, so that these models usually offer very aggregated and stylized representations of an economy. As a result, this type of model is not typically maintained as a core analytical tool of institutions like the US government. Nevertheless, intertemporal dynamic CGE models offer important insights and have provided the underpinnings for many influential studies of trade and tax policies (e.g., Goulder and Eichengreen, 1989; Jokisch and Kotlikoff, 2005; Rutherford and Tarr, 2003; Diao, Somaru, and Roe, 2001) and climate change (e.g., Kompas et al., 2018; McKibbin et al., 2009; Goettle et al., 2009).

Trade policy analysis continues to be an important application of CGE modeling. But as the global economy evolves, so too must the capability of CGE models to represent these new developments. Over the past decade, modelers have pushed out the frontiers of trade-focused CGE models in three areas. First, modelers recognize that regulations and other nontariff barriers are not always adequately described by the ad valorem equivalents (AVEs) of tariffs and taxes that we studied in Chapter 9. Some NTMs are more accurately described as imposing fixed compliance costs rather than the variable costs depicted by an AVE. Like a tax, a variable compliance cost depends on production levels, such as an extra inoculation required for each exported chicken. A fixed compliance cost does not change based on production levels. Such an NTM may, for example, require an exporting firm to retrofit or build a new plant in order to meet the importer's sanitation requirements. Fixed costs are important because they can present "make-or-break" hurdles that make it infeasible for some firms to enter the export market.

The extension of CGE models to include fixed compliance costs in export markets follows the theoretical work developed by Melitz (2003). Instead of a single industry, as in the standard CGE model, "Melitz-type" models describe firms within each industry that are heterogeneous in their levels of productivity in serving the export market. When an NTM introduces a fixed compliance cost, the least productive firms find such costs to be insurmountable and will exit the export market. Conversely, when an NTM is eliminated, new firms may enter the export market. One of the contributions of this class of model is that it can describe changes in trade at the "extensive" margin – that is, trade may occur for firms or products in which trade had not previously taken place. A limitation of the standard CGE model is that it can describe only changes in trade at

Text Box 10.2 A Melitz-type CGE model with fixed export costs due to an NTM

"***The Trans-Pacific Partnership and Asia-Pacific Integration: Policy Implications***" (Petri and Plummer, 2012).

What is the research question? There are multiple and overlapping efforts among subsets of Asian and Pacific countries to reduce or eliminate tariff and nontariff barriers on their intraregional trade and investment. What are the comparative effects of these alternative agreements on the economies of their members and of the rest of the world?

What is the model innovation? The authors utilize a "Melitz-type" CGE model that recognizes that firms are heterogeneous in their productivity in the production of exports. As a result, trade barriers that create fixed costs of entry into the export market are surmountable only for the most efficient firms. Trade liberalization can therefore result in trade expansion along the "extensive" margin in addition to growth in existing trade flows, along the "intensive" margin. The authors also account for the potential effects of the TPP in increasing international investment flows, and develop rich detail on nontariff measures (NTMs) that impede regional trade.

What is the experiment? The authors simulate three approaches to trade liberalization: the Trans-Pacific Partnership, a regional Asian trade agreement, and a region-wide free-trade agreement.

What are the key findings? By 2025, the TPP track would yield global annual income gains of $294 billion, the Asian track would yield gains of $500 billion, and a region-wide agreement would result in income gains of $1.9 trillion. The assumption of fixed export costs and firm heterogeneity accounts for about 40% of the projected region-wide income gains.

the "intensive" margin. That is, trade in a product may increase or decrease, but it will not take place if there is zero trade in the initial equilibrium. Thus the Melitz-type model helps solve the zero-trade problem and generally yields larger and more realistic trade gains following a trade policy reform. Petri and Plummer (2012), summarized in Text Box 10.2, developed an influential study of Asia-Pacific preferential trade initiatives using this Melitz-type of a CGE model. Dixon, Jerie, and Rimmer (2016) provide an overview and introduction to the practical implementation of new trade theory including Melitz' ideas, into a CGE model.

A second frontier area in trade policy modeling describes the growing role of services in global trade, and the concomitant role of foreign direct investment (FDI) in driving this expansion. Christen et al. (2013) and Tarr (2013) provide informative overviews of the development of this literature.

Until relatively recently, most CGE models described services as a non-traded good. Early efforts to account for services trade described it as a cross-border movement, similar to the shipment of goods, in which services such as call centers are provided by producers in one country to consumers in a foreign country. However, a characteristic of many services, particularly business services such as management consulting or organizational expertise, is that they must be provided on-site and in local proximity to the buyers. Trade in these kinds of services is therefore indirect in the sense that they are delivered by companies that have first engaged in FDI to set up local offices in the foreign country in order to provide such services to the local market.

There are two key assumptions about these firms, called foreign affiliates. One is that they have a different cost structure than do the local firms that produce similar services. In addition to using the same factor and intermediate inputs as the local firms, foreign affiliates also utilize an imported service input, which may be specialized technical or management expertise or advanced technology. The second assumption is that the skills and technologies embedded in the services produced by the affiliates make their product a productivity-enhancing intermediate input for local firms. Services liberalization scenarios describe the reduction of the tariff (or the AVEs of nontariff barriers) on the services imports used by the foreign affiliates. This lowers the affiliates' cost of producing services and the price of their services in the local market. In turn, the increased use of these services by local producers leads to economy-wide productivity gains in the host country. Typically in these models, consumers also benefit from trade reforms because of the greater variety of services they can purchase. One of the main insights from this type of CGE model is that the predicted welfare gains from trade liberalization are substantially larger, and arguably more realistic, than in traditional CGE-based analyses of trade liberalization that do not account for FDI, productivity gains, and consumers' love of variety. LaTorre (2016) provides an interesting application of this class of model that looks at the distributional impacts, by gender, of a trade reform in Tanzania that increases FDI and services trade (Text Box 10.3).

A third innovation in trade-focused CGE models is an approach that combines a CGE model, in which sectors are usually highly aggregated, with a partial equilibrium model that describes commodities at the disaggregated tariff-line level. Narayanan, Hertel, and Horridge (2009) developed this type of linked model in the GTAP framework, named GTAP-HS, to support trade negotiators and industry analysts who typically focus on outcomes for detailed commodities such as seat belts or dried mushrooms. The PE module disaggregates production, demand, and trade from one or more GTAP sectors into commodities defined at the Harmonized System (HS) tariff-line level. The reactions of the disaggregated sectors to tariff shocks are

Text Box 10.3 A model of FDI in services with gender differences

"***A CGE Analysis of the Impact of Foreign Direct Investment and Tariff Reform on Female and Male Workers in Tanzania***" (Latorre, 2016).

What is the research question? Male and female workers in Tanzania have different skills, their employment is unequally distributed across industries, and female workers face a 40% earnings gap relative to males. Given these gender differences in Tanzania's labor market, how might a reduction in barriers to foreign direct investment affect its male and female workers differently?
What is the CGE innovation? LaTorre develops a CGE model that describes FDI in the business service sector and the endogenous productivity effects that stem from changes in intermediate input demand by local firms for the business services produced by foreign affiliates. She models barriers to FDI as AVE tariffs on the imported services that are used by the foreign affiliates as inputs into their production of business services. Her model also describes wages and employment by gender across four different skill categories of female and male workers in a 52-sector model of the Tanzanian economy.
What is the experiment? Latorre describes a reduction in the regulatory barriers to FDI as a 50% reduction in the AVE import tariff on the imports of business services used as intermediate inputs by foreign affiliate firms.
What are the key findings? Reforms lead to an increase in the number of foreign affiliates, a lower cost of their output of business services, and an increase in the productivity of local firms that now use more of these services. These gains result in increased wages for all labor categories, even though foreign affiliates exhibit lower labor intensity in production than national firms. However, wage gains are higher for males than for females, and for skilled versus unskilled workers of both sexes, because the expanding foreign business services sector is relatively intensive in its use of male and skilled workers.

determined by behavioral equations and elasticity of substitution parameters that are similar to those in the CGE model that we have studied. Next, results for the detailed sectors are aggregated up into the original, larger GTAP sector. The CGE module then solves for the economy-wide impacts of changes in the aggregated quantities and prices in a consistent framework that allows feedback between the aggregated and disaggregated sectors.

As we conclude our study of CGE models with this brief summary of its extended and frontier applications, it is a good idea to now think back to the simple bicycle model of Chapter 1 and to remind ourselves that, whether we use our simple model of supply and demand or advance to the frontiers of CGE modeling, we are always trying to distill a simplified representation of a complex world.

Model Exercises

Introduction

The objective of these 11 model exercises is to provide you with step-by-step guidance in downloading a CGE model, exploring its structure and behavior, designing experiments, identifying relevant results, and interpreting findings.

The exercises are intended to:

- Engage your interest by showing the breadth of real-world problems that can be analyzed using a CGE model
- Illustrate how to use economic theory to make predictions about and to interpret model results
- Demonstrate how the design of model experiments is grounded in economic theory, data, and background research
- Introduce a broad sampling of methodological approaches including changing elasticities and model closure, decomposing shocks into subtotals, developing baseline scenarios, and running sensitivity analyses of assumptions about elasticity parameter values and shock sizes.

The case studies are suitable for use with many types of CGE models. However, the detailed instructions provided in the model exercises are designed for use with the Global Trade Analysis Project (GTAP) version 7 CGE model. The model, developed by Thomas Hertel and colleagues at Purdue University, is documented in Hertel and Tsigas (1997) and Corong et al. (2017). Its user-friendly, menu-driven interface, RunGTAP, was developed by Mark Horridge (2001) and is ideal for use by novice and advanced modelers alike.

Model Exercises 1–3 guide you in setting up, running, and learning about the GTAP CGE model using a small CGE model version, named NUS333, for demonstration (Table ME I.1). You should complete these three exercises sequentially before doing the subsequent case studies.

Model Exercises 4–11 provide case studies that complement and reinforce the concepts learned in the related chapters of the textbook. You can do all

Table ME I.1 *Skill development in model exercises*

Exercise	Economic concepts	Modeling skill
1. Set up the GTAP model	Getting started	Download GTAP model and NUS333 version, select module. run GTAP model
2. Explore the GTAP model and database	Learn about the elements of the GTAP model	Locate elements of model: sets, parameters, variables, equations, closure, and market-clearing constraints
3. Run the GTAP model	Skill-building in using the GAP model	Define and run experiments, change elasticities and closure, view results, use GTAP utilities for welfare decomposition, and systematic sensitivity analysis
4. Climate shocks and food price spikes	Comparison of utility functions. Armington import demand, factor productivity	Change income and substitution demand elasticities, impose commodity price shock
5. Food fight: agricultural production subsidies	Nested production function, production subsidies	Decompose model results, change factor substitution elasticity, use GTAP subtotal utility
6. How immigration can raise wages	Factors as substitutes and complements, factor endowment changes	Change factor endowments and factor substitution elasticities
7. Anatomy of a trade war	Theory of an import tariff, allocative efficiency, second-best welfare effects, terms of trade	Use theory to select and predict model results, decompose shocks and model results, use GTAP subtotal and welfare decomposition utilities
8. The marginal welfare burden of the US tax system	Taxation, tax burdens, welfare analysis	Use GTAP welfare decomposition and systematic sensitivity analysis utilities
9. Challenge exercise: climate change – the world in 2050	Baseline scenario, counterfactual experiment, closure, factor productivity, integrated assessment	Create a baseline scenario, define a counterfactual experiment, change factor productivity
10. Challenge exercise: "MPOWER"	Baseline scenario, changing in consumer	Create a baseline scenario, use theory to predict and analyze results, change consumer preferences, use

(*continued*)

Table ME I.1 *(cont.)*

Exercise	Economic concepts	Modeling skill
changing consumer attitudes toward tobacco use	preferences, parameter uncertainty	GTAP systematic sensitivity analysis utility
11. Challenge exercise: deep integration in a Japan–US preferential trade agreement	Preferential trade agreements, trade creation and diversion, nontariff measures	Recalibrate database to include NTMs using Altertax, use GTAP welfare decomposition utility

Table ME I.2 *Model versions used in model exercises*

Name	Description
NUS333	Model of the United States and rest of world used for demonstration in book and model exercises
NIMMIG	Model with skilled and unskilled labor used to study immigration
NTOBAC10	Model with tobacco sector used to study consumer preference shift
NTaxToy	Model of United States and rest of world with a distortion-free (tax-free) base
NUSJToy	Model of Japan, United States, and rest of world used to analyze a preferential trade agreement

Notes: NUS333 model version is included as a model version in the RunGTAP model software. All models can be downloaded as archived ZIP files from: www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5941

or any one of these exercises, and in any sequence. Model Exercises 9–11 present more challenging techniques for the advanced student. Model Exercises 4–11 are ideal for use as small, collaborative group projects. Each exercise poses questions about model results that can serve as a starting point for your exploration and study of your findings.

An important caveat about the model exercises is that they are only a teaching tool. Although the exercises introduce real-life problems and the practical modeling skills used in their analysis, the results from your small-dimensioned, toy CGE models should not be relied on as realistic.

Most of the exercises use the NUS333 model version. There are four other model versions used in the model exercises. Table ME I.2 provides a summary of each model. The NUS333 model is included in the RunGTAP model software. All models can be downloaded as archived ZIP files from the GTAP website: www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5941[1]

Results of model exercises are provided in the Answer Key. Examples of the experiment shock statements, model closures, and parameter selections that are used in each model exercise are included in the archived models.

[1] If you are new to GTAP, the website will prompt you to become a member. Membership is free of charge. Select "Create account" from the top menu bar and register as a new member. If you are already a member, log in.

Model Exercise 1: Set Up the GTAP Model

Concepts: Download GTAP Model and NUS333 Model Version, Select Module, Run GTAP Model

In this exercise, you will download RunGTAP and open and run the GTAP model "version" named NUS333. RunGTAP is the name of the Windows interface for the GTAP model. The GTAP model is comprised of a set of files written in the GEMPACK programming language that runs in the background as you use RunGTAP. At the end of this exercise, you will have a CGE model that is ready to use for analysis or to replicate most of the modeling examples reported in tables in Chapters 1–9.

The GTAP model is comprised of a set of equations that can be used with any aggregation of the GTAP database. An aggregation is called a model "version." The NUS333 model version that we use for demonstration has two regions: the United States (USA) and the rest of the world (ROW). It is named 333 because it has three production activities (agriculture, manufacturing, and services), three commodities (agriculture, manufacturing, and services), and three factors of production (land, labor, and capital). NUS333 is built using the GTAP version 8.1 database, released in February 2013, with a 2007 base year. You may carry out the model exercises with other versions of the GTAP database, but model results will differ from those reported in the answer key.[2]

You will use the NUS333 model to conduct many of the exercises in this chapter. You will also use three model versions in the modeling exercises, in addition to NUS333. These versions are NTOBAC10, NIMMIG, and NUSJToy. The "N" prefix denotes that the model versions are compatible with the new GTAPv7 CGE model, introduced in June 2017.

A. Create a Folder on Your Computer for Your Project

Create a folder on your computer in which you will save your database and all of the other files that you will create for your research project. Name the directory "MyLastName" or something else that is easy to remember.

[2] For students with some experience in GEMPACK, Pearson and Horridge (2003) provide a detailed introduction to the GEMPACK software and its use in the GTAP model. Also see Horridge (2015a and 2015b) on use of the GTAP data aggregation facility if you want to create your own model versions. Hussein (2012) is a YouTube video that demonstrates how to use the data aggregation program.

B. Download "RunGTAP" – The GTAP Model

These directions for downloading, unzipping, and installing the GTAP model are quite general. Your computer and browser may present a slightly different set of choices for how to do this. The important thing is that you download the model, unzip it, locate the SETUP.exe file, and run the installation program. The installation will create a directory on your hard drive, RunGTAP370, in which the model will be placed.

1. Go to www.GTAP.org
2. From the main menu bar:
   - Select Models/Utilities
   - Select RunGTAP, from the Models/Utilities drop-down menu
   - Select Download RunGTAP from the RunGTAP downloads section.
3. Download the file and select "Unzip and Install." Then select "Set-up," and the program will prompt you to install the program to your hard disk. The default directory is C:/RunGTAP370, but you may choose to install it in a different directory. (Another option is to download and save the file to your temp directory and install it from there, first by clicking on the zipped RunGTAP file and then by clicking on the "set-up" computer icon inside it.)
4. Open RunGTAP by clicking on the Windows icon for RunGTAP or open it from your Start menu. The title page includes a menu bar at the top and page tabs below the menu bar (Figure ME 1.1).
   The GTAP model will automatically load a model version named ACORS3x3.

C. Download the NUS333 Version of the GTAP Model

The toy model that is used for demonstration and in most model exercises is named NUS333. You can access this model in two different ways.

1. Option 1: Access and open the NUS333 model version that is included in the RunGTAP model library.
   This step opens the NUS333 model "version" of the GTAP model.
   - Open RunGTAP
   - On the top menu bar, choose "Version"
   - "Change"
   - Select "NUS333" The first time you open it, there may be a warning that an SLI file is missing or obsolete. If so, select "OK." It will be constructed the first time that you run the model.
   - OK
   - OK
2. Option 2: Download NUS333.ZIP from the GTAP website.
   - You can locate the .zip archived NUS333 model version on the web by going to this internet webpage: www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5941

Figure ME 1.1 Page tabs in GTAP model

- Download the NUS333.ZIP file into the folder that you have created for your project on your computer
- In the RunGTAP model, select “File” from the menu bar
- Select “Version archive” from the drop-down menu
- Select “Load .zip”
- Locate the folder where you saved NUS333.zip and select “Open”
- Choose a version name: enter NUS333
- OK

These steps unzip your archived model and open it as a new version in the GTAP model. Your new model version is stored in a new folder with the name of your version (i.e., NUS333) that is saved in the RunGTAP370 directory. You may get an error message that there is an obsolete or missing .SLI file and you are asked to run a test simulation. If so, click on OK. A test simulation will run and create the missing file.

3. Run a test simulation

   In the test simulation, the GTAP model runs a consistency check and a numeraire experiment using your new database, and it calibrates the tax rates that you will use for your model experiments. If you have not already carried out a test simulation, do so at this point. If this step completes successfully, your NUS333 model is ready to use for experiments.
   - Click on Tools in the upper menu bar
   - Click on “Run Test Simulation” from the drop-down menu
   - OK
4. Review the description of the NUS333 model
   - From the page tabs (not the upper menu bar) in the RunGTAP model, select “Version”

- Review the description of the NUS333 model. It contains information on the sets, experiments, closures, and solution method

5. Change the description of the NUS333 model (optional)
   If you desire to, you can change the description of the model, perhaps by adding text such as "Model used by 'My Name' in Course ECON XXX"
   - From the menu bar in the RunGTAP model, select "Tools"
   - Select "Options"
   - Check the "Developer mode" box
   - OK
   - Select Version from the page tabs (not from the menu bar above)
   - Write your own brief description of your NUS333 model. You may add text to the existing version information or erase and replace all of the text on the Version page
   - From the menu bar, select Developer
   - Select "Save Version.txt" from the drop-down menu
   - OK
   - From the menu bar, select Tools
   - From the drop-down menu, select "Options"
   - Uncheck the "Developer mode" box
   - Select "OK"

When you open the GTAP model, it always opens the last version that you worked on. If you want to work with a different model version, select "Version" from the menu bar (at the top of the page), and you will find a list of model versions, including the NUS333 and any other model versions that you have downloaded or created. Select the version that you want to open.

D. Choose GTAPv7 or "Classic" GTAP Model

Your download of the GTAP model includes 4 modules that allow you to choose whether to run the new or classic vintage of the GTAP model, and whether the model is run in its entirety or whether it is made more compact or "condensed" with condensation through substitution of some variables and parameters. The GTAP model also includes a library of model versions, including the NUS333 version that we use for demonstration in this book. The versions with an "N" prefix are compatible with the new GTAPv7 model developed in 2017. Versions without an N are compatible with the "classic" GTAP model. Both the GTAPv7 and classic GTAP models can be run in "condensed" or "uncondensed" format.

You define the module for your model version. There are four module choices:

GTAP.TAB – classic model, condensed format
GTAPU.TAB – classic model, uncondensed format

GTAPv7.TAB – GTAPv7 model, condensed format
GTAPV7U.TAB – GTAPv7 model, uncondensed format

Your module selection must be compatible with the format of your database. The GTAP data aggregation routine produces two databases – one is compatible with the classic GTAP model and the other is compatible with the GTAP v7 model. The NUS333 database is compatible with the GTAP v7 model. And, we want to work with all types of taxes available in the model. Therefore, we use the GTAPv7 uncondensed module for our NUS333 model version.

You can select the condensation format for all of your GTAP applications, or (recommended) switch to the uncondensed/condensed format only for the model version that you are working, as demonstrated in Step 1 of part E in this exercise. Note that once you select the module, you should use it consistently because all of the experiments that you subsequently design can only be used with that module.

1. Change to the uncondensed GTAP module for your NUS333 model version:
   - Select "Version" from the menu bar (see Figure ME 1.2)
   - Select "Modules" from the drop-down menu
   - In the Main model row, and the Version-Specific settings columns, click on the cell in the center (Tab file) column
   - Select "Stored in Main Folder: C:\rungtap370." This version may already be selected
   - From the drop-down box, select GTAPUv7.TAB
   - Click on OK
   - OK

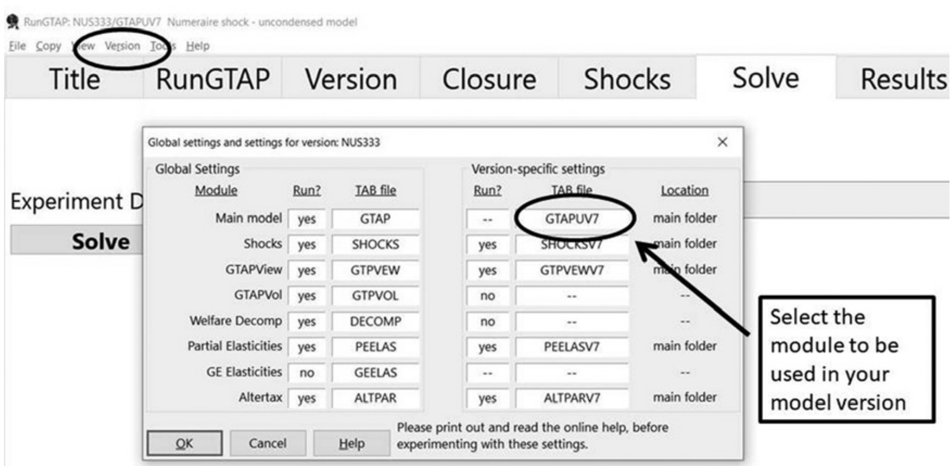


Figure ME 1.2 Changing the GTAP module

2. Run a test simulation:
   - Select “Tools” from the menu bar
   - Select “Run Test Simulation” from the drop-down menu
   - Continue to select OK if there are bad closure warnings, even if there are several

The GTAP program will now use the uncondensed GTAPv7 model for your NUS333 model version. Your model is ready to use for experiments.

Model Exercise 2: Explore the GTAP Model and Database

Concepts: Locate Elements of Model – Sets, Parameters, Variables, Equations, Closure, and Market-Clearing Constraints

The objective of this model exercise is to give you an orientation to the main components of the CGE model and its database. You will learn how to open and search the CGE model's program code, and you will locate and identify your model's sets, parameters, variables, closure, and market-clearing constraints.

A. Open the NUS333 Version of the GTAP Model

1. Open GTAP NUS333 model version
   This step opens the NUS333 "version" of the GTAP model. You downloaded this version of the model in Model Exercise 1.
   - Open RunGTAP
   - On the top menu bar, choose "Version"
   - "Change"
   - Select "NUS333"
   - OK

B. Explore the Sets in the Database

1. Open the sets file
   - On the menu bar, select "View"
   - From the drop-down menu, select "Sets"
   - This opens a HAR file that lists all sets in the model (Figure ME 2.1)
2. Identify the regions in the model database
   - Double-click on Set REG (in row 3)
   - Write the elements of REG (regions in model):

     ____
   - Click anywhere in the matrix to return to the previous menu
3. Identify the commodities in the model
   - Double-click on Set COMM (in row 4)
   - Write the elements of COMM (commodities):

     ____
   - Click anywhere in the matrix to return to the previous menu.
4. Identify the factors in the model
   - Double-click on Set ENDW (in row 7)
   - Write the elements of ENDW (factors of production):

     ____
   - Close the sets.har file by clinking on the X in the upper right corner of the HAR file

sets.har in c:\rungtap370\NUS333

File Contents Export History Search Programs Help

	Header	Type	Dimension	Coef	Total	Min	Max	Name
1	DVER	RE	1	DVER	6.00	6.00	6.00	Format of GTAP data
2	DREL	1C	1 length 55					GTAP data release identifier
3	REG	1C	2 length 12					Set REG Regions
4	COMM	1C	3 length 12					Set COMM
5	MARG	1C	1 length 12					Set MARG
6	ACTS	1C	3 length 12					Set ACTS
7	ENDW	1C	3 length 12					Set ENDW
8	ENDM	1C	3 length 12					Set ENDWM Mobile endowments
9	ENDF	1C	0 length 12					Set ENDWF Sector-specific endowm
10	ENDS	1C	0 length 12					Set ENDWS Sluggish factor
11	ENDT	1C	3 length 12					Set ENDWT Endowment Type

Figure ME 2.1 View set elements

C. Explore Table Dimensions of a HAR File

Tables have only two dimensions, rows and columns, yet many variables in the CGE model have more than two dimensions. For example, in the GTAP model, parameter rTMS(COMM,s,d) is the bilateral import tariff rate on commodities imported from source region *s* to destination region *d*. The parameter has three dimensions: It is defined for the set of commodities (COMM); the set of source regions; and the set of destination regions. The set name convention for bilateral trade in the GTAP model is that the first country in a variable name is always the exporter, or source country, of a traded commodity; and the second country in the variable name is always the importing, or destination, country of a traded commodity.

To explore variables like this one, you will need to learn how to view variables and parameters of three or more dimensions in a two-dimensional table. Understanding how to set toggles correctly is fundamental to reading your data and results correctly in the GTAP model.

Data used in the GTAP model are contained in header array (HAR) files. You select which dimensions to display in the HAR file by selecting set elements from the drop-down boxes in the upper right corner of the file (Figure ME 2.2). There is one drop-down box for each dimension of the variable. In the case of import tariffs, for example, there are three drop-down boxes: All COMM, All REG, and Sum REG. (If the variable has only two dimensions, only two drop-down boxes appear in the upper right corner of the file.)

In the following steps we show how to view in a table the US import tariff rates on each commodity from each of its trade partners. In this case we want to display data for all traded commodities (ALL COMM) and all source countries. We will display data for only one importing country, which is the United States.

In RunGTAP:

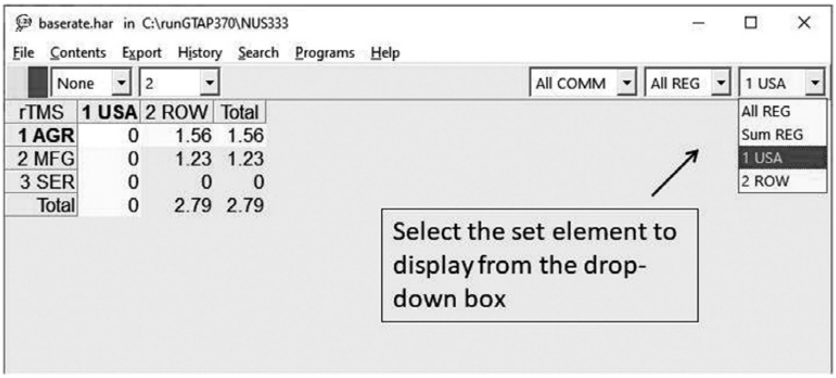


Figure ME 2.2 Select the set elements to display

- Select "View" from the menu bar
- Select "Base data" from the drop-down menu
- Select "Tax rates" from the drop-down menu
- Double-click on "rTMS" (row 13), which reports bilateral import tariff rates
- In the upper right corner of the HAR file, the left side box is All COMM. Click on its arrow button. Its drop-down box displays all elements of this set: AGR, MFG, and SER. Select "All COMM." This selection means that data for every traded commodity will be reported in the table.
- In the upper right corner of the HAR file, the center box is All REG. Its drop-down box displays all elements of set REG, the source regions for US imports. In our model, the set includes the USA and ROW. Select "All REG." This selection means that all source regions will be reported in the table, including the United States. In our two-region model, US imports are only sourced from ROW and imports from the US are zero. This is not always the case. If the importer is an aggregated region, such as Sub-Saharan Africa instead of a single country like the US, there may be nonzero imports from itself due to intra-regional trade.
- In the upper right corner of the HAR file, the right-side box is Sum REG. Its drop-down box displays all elements of set REG, the destination regions for imports. Select "USA." This selection means that data for only one element of set REG, the USA, will be displayed.
- Experiment with selecting other elements of set REG in the importer toggle. What happens if you select "All REG"?
- Close the HAR file by clicking on the X in the upper right corner

At times you may want to view a variable in a matrix in which both rows and columns are regions. In this case, the first set in the variable name is displayed in the rows and the second set in the variable name is displayed in the columns. For example, the coefficient VMSB(*c*,*s*,*d*) is the base value of imports of commodity *c* from region *s* by region *d*. If you choose to view VMSB for the MFG commodity, VMSB("MFG",*s*,*d*), a matrix, is displayed with rows and columns with identical headings for USA and ROW. The first set, *s*, is reported in the rows of the matrix, and the second set, *d*, is reported in the columns of the matrix. As practice, view the coefficient VMSB("MFG",*s*,*d*):

- Select "View" from the menu bar
- Select "Base data" from the drop-down menu
- Select "Core Data" from the drop-down menu
- Double-click on "VMSB" (row 26) which is imports at basic prices
- In the upper right corner of the HAR file, set the toggles to:

MFG | All REG | All REG

This selection displays a matrix of bilateral trade in MFG. US exports (set *s*) are reported in the US row, and US imports (set *d*) are reported in the US column. The US imports about $1.9 trillion of MFG products from ROW. You can check that you have correctly identified regions as importers or exporters by setting the toggles to report only US MFG imports from ROW:

MFG | ROW | USA

- Close the HAR file by clicking on the X in the upper right corner

D. Explore the Elasticity Parameters

In RunGTAP:

- Select "View" from the menu bar
- Select "Parameters" from the drop-down menu. This HAR file contains all of the elasticity parameters used in model equations
- Select INCPAR (row 4) and double-click
- Set the decimal point display by clicking on the right-hand toggle in the upper left corner and set it to two decimal places
- What is the INCPAR parameter for US services?
- INCPAR("USA", "SER") = _________
- Double-click anywhere in the file to return to the list of parameters
- Report the elasticities for US agriculture in Table ME 2.1
- Close the default.prm file by clicking on the X in the upper right corner

E. Explore the Tax Rate Parameters

In RunGTAP:

- Select "View" from the menu bar
- Select "Base data" from the drop-down menu
- Select "Tax rates" from the drop-down menu. This HAR file reports all of the tax rates in the GTAP model
- Double-click on the rTO (first row) to display the output tax rate on commodity *c* produced by activity *a* in region *r*. Set the region toggle to USA.

Table ME 2.1 *Elasticity parameters for US agriculture*

Elasticity	Value
Supply parameters	
Factor substitution (ESUBVA)	0.25
Intermediate input substitution (ESUBT)	
Demand parameters	
Consumer income (INCPAR)	
Consumer substitution (SUBPAR)	
Import-domestic substitution (ESUBD)	
Import-import substitution (ESUBM)	

Table ME 2.2 *Tax rates for US agriculture*

Tax rate	Definition	Value
$rTO_{AGR,AGR,\ USA}$		0.24
$rTFE_{Land,\ AGR,\ USA}$		
$rTFD_{AGR,AGR,\ USA}$		
$rTXS_{AGR,USA,\ ROW}$		
$rTMS_{AGR,ROW,\ USA}$		

- In the Table ME 2.2, report the output tax rate for US agriculture (a negative tax rate denotes a subsidy) to the second decimal place. You may need to change the decimals by clicking on the right-hand toggle in the upper left corner
- Double-click anywhere in the file to return to the list of taxes
- Write the names of the other tax rates in the GTAP model that are listed in Table ME 2.2
- For each tax, report the tax rates for US agriculture in Table ME 2.2, using two decimal places. Note the set indices that identify which element should be reported for each tax. To view them, correctly set the toggles in the upper right hand corner, following the instructions in Section C of this Model Exercise
- Close the HAR file by clicking on the X in the upper right corner of the file

F. Explore Model Closure

Model closure defines which variables are endogenous and which variables are exogenous, or fixed.

1. Find the Variable Names and Definitions in the GTAP Model

In RunGTAP:

- Select "View" from the menu bar

- Select "Variables and subsets" from the drop-down menu
- Select "Variables" from the folder tabs in the information file

Write the definition of the following variables:

pop ____
ppa ____
qes ____
qxw ____

- Close the HAR file by clicking on the X in the upper right corner of the file.

2. Find the Model Closure Statement and Identify the Endogenous and Exogenous Variables

The GTAP model assumes that all model variables are endogenous unless they are explicitly defined to be exogenous. To see which variables are defined as exogenous:

- Select "Closure" from the page tabs

Which of the variables listed in F.1 are exogenous? Which are endogenous?

Exogenous: ____
Endogenous: ____

G. Explore the Equations in the GTAP Model

You will become more familiar with the equations of the GTAP model as you gain experience in running the model and analyzing your results. For now, just open the GTAP model's underlying program code and find the road map that describes how equations are organized into blocks of model code:

In RunGTAP, select:

- "View" from the menu bar
- "Tab files" from the drop-down menu
- "Main model" (this command displays the programming code of the main GTAP model)

Search for the term "Overview of the GTAP.TAB Structure," by selecting:

- Search
- Find
- Enter the search term in the search box

This section of the model describes the organization of the modeling code in the GTAP model into preliminaries, modules with economic equations, and sections that calculate summary statistics and welfare results.

H. Explore Market-Clearing Constraints

Still in the GTAP.tab file, search for an identity equation that is an example of a market-clearing constraint that ensures that the model's results describe an economic equilibrium in supply and demand. In the search box, enter the term:

"Market clearing for domestic sales"

This equation imposes the constraint that, in each region, the change in the total supply of domestically produced commodities sold to the domestic market (*qds*) is equal to the sum of changes in demand for that commodity by domestic agents: firms (*qfd*), private households (*qpd*), government (*qgd*) and investors (*qid*).

Model Exercise 3: Skill-building in Using the Model

Concepts: Define and Run Experiments, View Model Results, Change Elasticity Parameters and Model Closure, Use GTAP Utilities for Welfare Decomposition, and Systematic Sensitivity Analysis

In this exercise, you will learn to define and run a model experiment (called a "shock") and to search for and report model results. You will learn how to change an elasticity parameter, change a model closure, and export and compare results. This exercise also shows you how to use GTAP utilities for welfare decomposition and for a systematic sensitivity analysis (SSA) with respect to elasticity parameters. Model Exercise 3 is designed to serve as a reference that you can turn back to for basic directions as you carry out Exercises 4–11. In this exercise, we focus only on the mechanics of using and controlling the GTAP model; we study the economic behavior in the model in Exercises 4–11.

A. Open NUS333 GTAP Model Version

This step opens the NUS333 "version" of the GTAP model. You downloaded this version of the model in Model Exercise 1.

1. Open GTAP NUS333 model version
   If model version NUS333 is not already open, follow these steps to switch among model versions:
   - Open RunGTAP
   - On the top menu bar, choose "Version"
   - "Change"
   - Select "NUS333"
   - OK
   - Run a test simulation

B. Prepare Your Model to Define and Run an Experiment

The following housekeeping steps may not always be necessary, but like a pilot's preflight checklist, it is a good practice to follow them before defining or running any model shock.

1. Prepare your model to define an experiment – check closure
   - Select the Closure page tab

   Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.
2. Prepare your model to define an experiment – check shocks
   - Select Shocks page tab

- Click on "Clear shocks list"

  This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.

3. Check the elasticity parameter file
   - Select Solve page tab
   - Check that the parameter file named in the upper right corner is your preferred file (in this exercise, let it remain as the default parameter file)
4. Check model solution method
   - Select Solve page tab
   - Solution Method (in the upper right corner of the page): select "Change"
   - Choose "Gragg" solution method. (Your choice of solution method may vary; this is the method we use for this exercise. It divides the shock into smaller shocks which the model solves sequentially.)
   - OK (this selects the new solution method)

C. Define a Model Experiment Using the "Shocks" Page

Experiments are defined on the "Shocks" page (see Figure ME 3.1). In this exercise, you will introduce a 10% output subsidy on the production of manufactured commodities (MFG) by the manufacturing production activity (MFG) in the United States. Note that the GTAP model defines a tax as a positive rate and a subsidy as a negative rate. (This is one of the important differences between the "classic" GTAP model and the new GTAPv7 model.)

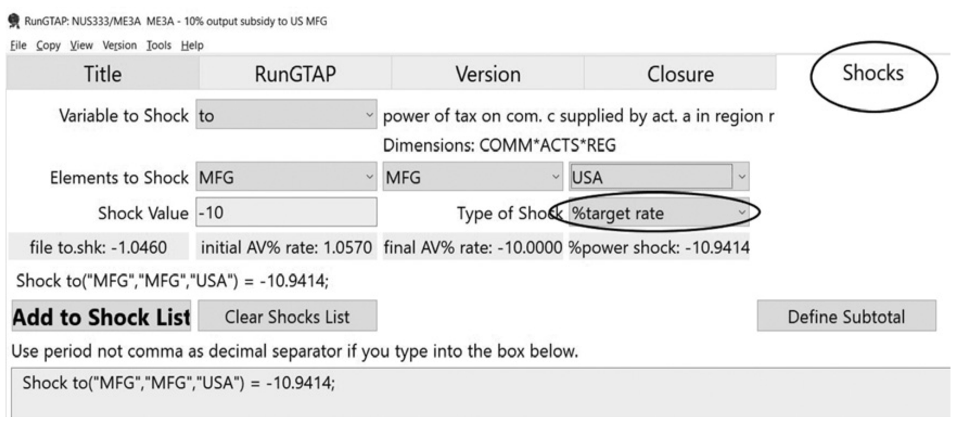


Figure ME 3.1 Subsidy of 10%to MFG production by US MFG activity

1. Select the “Shocks” page tab
   - Clear the shocks list by clicking on the button “Clear Shocks List”
   - Select from the “Variable to Shock” drop-down menu: *to*
   - In “Elements to Shock” that reads “ALL COMM,” choose MFG from the drop-down menu
   - In “Elements to Shock” that reads “ALL ACTS,” choose MFG from the drop-down menu
   - In “Elements to Shock” that reads “ALL REG,” choose USA from the drop-down menu
   - For “Shock Value” enter: –10
   - Select from the “Type of Shock” drop-down menu: % target rate
   - Click on “Add to shock list.” The change in the output tax will be expressed in the shock list in terms of the percent change in the power of the MFG output tax
   - Verify that the shock to the US MFG production of MFG is the only shock in the shocks list
2. Notice the information that appears below the shock value that you entered. What is the initial ad valorem (AV) rate of the output tax in the US manufacturing activity for its production of manufactured commodities?____________
3. Is the initial rate of “to” a subsidy or a tax? _______________________
4. Calculate the “power of the shock” and verify that the shock is defined correctly. Show your calculation: ____

D. Save a Model Experiment and Solve the Model

Select the “Solve” page tab:

1. Save the experiment file
   - Check solution method. It should be Gragg 2-4-6 extrapolation. If it is not, click on “Change,” select Gragg, and then click on “OK”
   - Check parameter file. It should be “Default.” If it is not, click on “Change,” select “Default” from the box, and click on “OK”
   - Click on “Save experiment”
   - Name the experiment: 10toMFG (see Figure ME 3.2)
   - Description: “10% output subsidy to US MFG”
   - OK (this saves the experiment file)
2. Solve the model
   - Still on the Solve page, click on the “Solve” button
   - OK (this closes the accuracy summary report box)
   - OK (this closes a solution information box)
3. Verify that your tax shock is what you think it is. Select:
   - “View” from the menu bar
   - “Updated data” from the drop-down menu
   - Updated tax rates

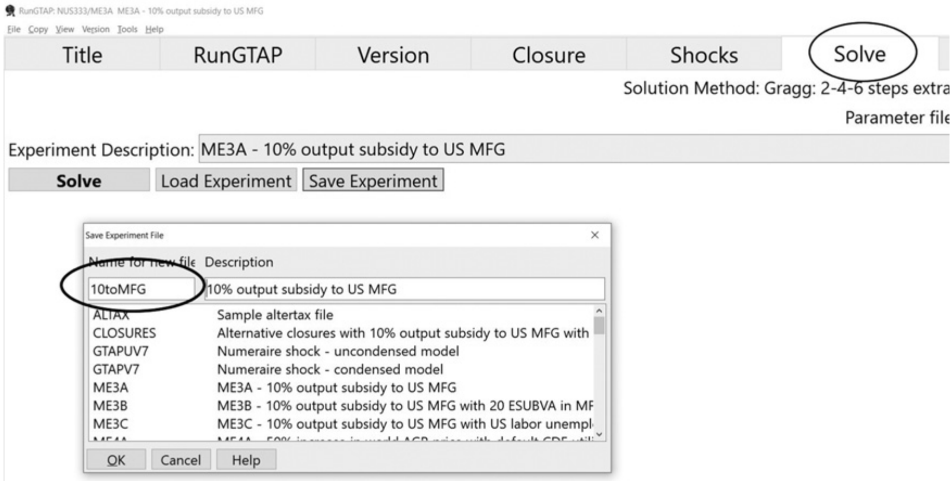


Figure ME 3.2 Solve page

- Click on the first row, rTO, to view a table of output tax rates. This table displays the sum of all regions' output tax rates by commodity and industry – not a sensible way to consider tax rates
- Change the rTO table to display only the output taxes for the United States by setting the toggles in the upper right corner to:

All COMM | All ACTS | USA

- Check the entry for row "MFG" (this is the commodity) and the column "MFG" (this is the production activity). Confirm that the output tax rate for the manufacturing commodity produced by the manufacturing activity in the USA is now a subsidy of –10.0
- Close the HAR file by clicking on the X in the upper right corner

E. Find and Report Experiment Results

Model results for most variables in the model are reported on the Results page, which is opened by clicking on the Results page tab (Figure ME 3.3). GTAP's naming convention is to use lowercase letters to denote a variable reported as a percentage change from base values, and uppercase letters to denote a variable reported in levels. For example, the variable in lowercase, $ppa_{c,r}$, is the percentage change in the private consumption price for commodity *c* in region *r*. The variable EV, in uppercase, is reported in levels. It is the change in a region's equivalent variation welfare, reported in $US millions.

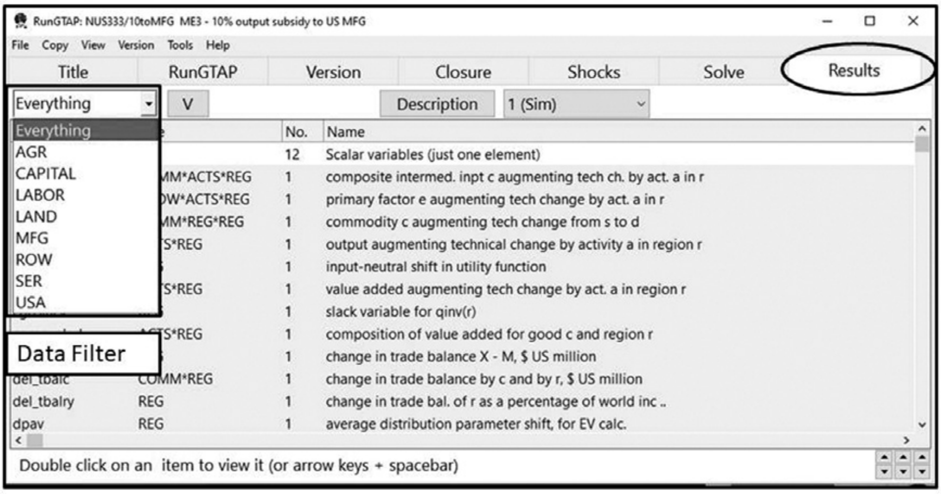


Figure ME 3.3 Results page with data filter

1. Find a variable result on the “Results” page
   - Select the Results page tab (variables are listed in alphabetical order)
   - Write the definition of the variable *qc(“MFG”, “USA”)* in Table ME 3.1
   - Double-click on variable *qc*
   - Report the result for variable *qc(“MFG”,“USA”)* in the “base results” column of Table ME 3.1
   - Write the definition of the variable *qc(“MFG”, “ROW”)* in Table ME 3.1
   - Report the result for variable *qc(“MFG”, “ROW”)* in the “Base results” column of Table ME 3.1
   - Double-click on data anywhere in the table to return to the variable list
2. Display results of variables with three dimensions using data filter

   Tables are two-dimensional displays of data, but some variables have more than two dimensions. For example, variable *qfe(e,a,r)* has three dimensions: the percent change in the quantity of factor endowment *e* used in production activity *a* in region *r*. To display results for variable *qfe*, use the data filter in the upper left corner of the results page to select the dimensions to control and the dimensions to display. In the following example, you will control dimension *r* by selecting “USA,” so that the variable *qfe(e,a,”USA”)* is displayed in a table with a dimension of *e* by *a*.
   - Locate variable *qfe* in the list of results and write its definition in Table ME 3.1
   - Double-click on variable *qfe* – you’ll get an error – “Sorry, you cannot view a 3-D matrix.” Click on OK to close the error message
   - From the drop-down menu on the upper left side, which says “Everything,” choose “USA” – this controls set *r* so that sets *e* and *a* can be displayed

Table ME 3.1 *Results of a 10% production subsidy in US manufacturing, with different elasticities and closures*

Name of variable	Definition of variable	Base results	High factor substitution elasticity in MFG	Unemployment closure
$qc_{MFG,USA}$		4.44		
$qc_{MFG,ROW}$				
$qfe_{Labor,MFG,USA}$				

Source: NUS333 model.

- Double-click on variable *qfe* and report results for labor demand in MFG by the USA in the "Base results" column of Table ME 3.1
- Double-click on data anywhere in the table to return to the variable list

F. Find and Report Welfare Decomposition Results

The GTAP model includes a utility that decomposes the equivalent variation (EV) welfare effect of an economic shock. We discuss welfare measures in detail in Chapter 4. The GTAP welfare decomposition utility disaggregates the total welfare effect into seven components: resource allocation (efficiency) effects, also called the excess burden of taxes; endowment effects due to changes in factor supplies; technical change due to productivity gains or losses; the effects of population growth; changes in terms of trade for commodities; changes in terms of trade for savings and investment goods; and changes in preferences due to changes in the structure of aggregate demand among household consumption, savings, and government. Welfare effects are reported in levels, in $US millions.

1. Open the GTAP welfare decomposition utility:
   - Select "View" from the menu bar
   - Select "Updated Data" from the drop-down menu
   - Select "Welfare Decomposition" from the drop-down menu
   - This page lists the full decomposition of EV (Figure ME 3.4)
2. View the summary of the welfare decomposition
   - Double-click on first row: EV Decomposition Summary
   - Report the welfare impacts of the 10% output subsidy in US manufacturing with the default elasticity parameters in Table ME 3.2. As a check, the first element, "Resource allocation effect," is already reported in the table
   - Double-click anywhere on the page to return to the main EV decomposition page

Table ME 3.2 *Welfare decomposition of a 10% production subsidy to US manufacturing*

Resource allocation effect	Endowment effect	Technical change	Population growth	Terms of trade	Investment–savings terms of trade	Preference change	Total
1 alloc_A1 12,655	2 endw_B1	3 tech_C1	4 pop_D1	5 tot_E1	6 IS_F1	7 pref_G1	

Source: NUS333 model.

decomp.har in C:\runGTAP370\work

File Contents Export History Search Programs Help

	Header	Type	Dimension	Coeff	Total	Name
1	A	RE*	REG*COLUMN	WELFARE	-5.48	EV Decomposition: Summary
2	A1	RE	ALLOCEFF*REG	CNTalleff	-5.47	Allocative Efficiency Effect: Summary
3	A2	RE	REG*CTAX	CNTalleffkr	-5.47	Allocative Efficiency Effect: Tax Type Summary
4	A21	RE	ACTS*REG	OTAX	-125	Output Tax Effect
5	A211	RE*	COMM*ACTS*REG*COL	OUTPUT	-846	Output Tax Effect: Explanatory Factors
6	A22	RE	COMM*ACTIVITY*REG*DIR	ATAX	101	Domestic Tax Effect: Summary
7	A221	RE	COMM*ACTS*REG*DIR	STAX	9.16	Intermed. Input Tax Effect
8	A222	RE	COMM*REG*DIR	ITAX	165	Investment Intermed. Input Tax Effect
9	A22F	RE	COMM*ACTS*REG*DIR*COL	FIRM	-744	Intermed. Input Tax Effect: Explanatory Factors
10	A22P	RE	COMM*REG*DIR*COL	PRIVATE	-583	Private Cons. Tax Effect: Explanatory Factors
11	A22G	RE	COMM*REG*DIR*COL	GOVT	396	Government Cons. Tax Effect: Explanatory Factors
12	A22I	RE	COMM*REG*DIR*COL	INVESTMENT	396	Investment Tax Effect: Explanatory Factors
13	A23	RE*	COMM*REG*REG*TYPE	TTAX	-57.8	Trade Tax Effect
14	A231	RE	COMM*REG*REG*COL*DIREC	TRADE	-3998	Trade Tax Effect: Explanatory Factors
15	A24	RE	ENDW*REG	FACTAX	76.5	Endowment Tax Effect
16	A241	RE	ENDW*ACTS*REG*COL	FACTORTAX	185	Endowment Tax Effect: Explanatory Factors
17	A25	RE	ENDW*REG	YTAX	-0.000	Income Tax Effect
18	A251	RE	ENDW*ACTS*REG*COL	INCOMETAX	409	Income Tax Effect: Explanatory Factors
19	B1	RE	REG*ENDW	CNTendowment	0.000	Endowment Effect, Gross of Depreciation
20	B2	RE*	REG	CNTkb	0	Endowment Effect: Depreciation
21	C1	RE*	REG*TECHTYPE	CNTtech	0	Technical Change Effect: Summary
22	C11	RE*	ACTS*REG	CNTtech_ao	0	(ao) Output Augm. Tech. Change Effect
23	C12	RE*	ENDW*ACTS*REG	CNTtech_afe	0	(afe) Primary Factor Augm. Tech. Change Effect
24	C13	RE*	ACTS*REG	CNTtech_ava	0	(ava) Value Added Augm. Tech. Change Effect
25	C14	RE*	ACTS*REG	CNTtech_aint	0	(aint) Composite Intermed. Input Augm. Tech. Change Effect
26	C15	RE*	COMM*ACTS*REG	CNTtech_af	0	(af) Intermed. Input Augm. Tech. Change Effect
27	C16	RE*	MARG*COMM*REG*REG	CNTtech_atmf	0	(atmfsd) Internat. Margin Augm. Tech. Change Effect
28	C17	RE*	COMM*REG*REG	CNTtech_ams	0	(ams) Bilateral Import Augm. Tech. Change Effect
29	E1	RE	COMM*REG*PRICES*FORM	WTOT	-0.038	Terms of Trade Effect
30	F1	RE	REG*COLM	CGDSCOMP	-6.30	I-S Effect: Explanatory Factors

Figure ME 3.4 Welfare decomposition utility in the GTAP model

3. View the detailed welfare decomposition

The main welfare decomposition page, shown in Figure ME 3.4, lists all available decompositions. For example, all rows with header names that begin with A1 or A2 are decompositions of allocative efficiency effects, by type of tax and by commodity. All rows with header names that start with C are decompositions of the productivity effect, and so on. You can view any decomposition in the list by clicking on it.

G. Export Model Results to Excel

You may want to compare the results of two experiments, but the GTAP model only reports results for one experiment at a time. One way to save and compare selected results is to export results, one variable at a time, to your clipboard and paste them into an Excel file that identifies the experiment that generated the results.[3]

After running an experiment,

- Select the "Results" page tab
- Double-click on the variable that you want to display

[3] As your modeling skills progress, you can use the GTAP ViewHar utility to view and compare results.

- Select "Copy" from the upper menu bar (this copies the results to your clipboard)
- Open Excel and paste your results into your file
- Label the results with the name of your experiment

H. View and Change an Elasticity Parameter

Elasticities are the exogenous parameters used in model equations to define the responsiveness of supply and demand to changes in prices or income. A change to an elasticity parameter is not an experiment or "shock." It redefines how producers and consumers are assumed to respond to a shock. For instance, you might define a shock to be a new tariff on imports. You can run the experiment using the model's base elasticity values, and then run it again using a model with larger or smaller elasticity values. You then compare the results of the *same experiment* when using two (or more) different assumed elasticity values.

This exercise shows you how to change an elasticity in the GTAP model from its default values and save it in a new parameter file. In this example, you will change the factor substitution elasticity in US manufacturing. You can use these same steps to change any elasticity in the GTAP model.

1. Define the new parameter values
   - Select "View" on the menu bar
   - Click on "Parameters" from the drop-down menu. This opens a HAR file with the elasticity parameters
   - In the upper menu bar of the HAR file, select
     > File
     > Click on "Use Advanced, editing menu" from the drop-down menu. This step allows you to edit parameters (it may already be active)

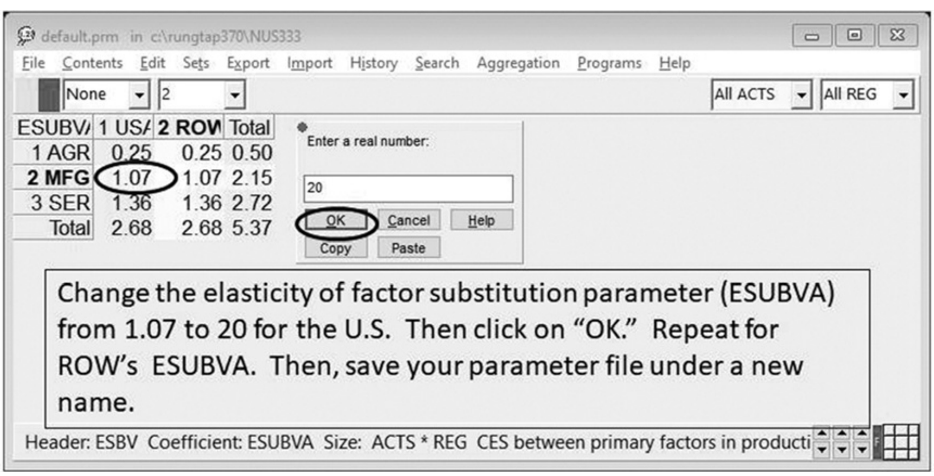


Figure ME 3.5 Changing an elasticity parameter

- Double-click on ESUBVA (the elasticity of factor substitution)
- Right-click on the data entry for MFG ESBUVA in the USA (see Figure ME 3.5)
- Enter a new ESUBVA value in US manufacturing of "20"
- Click on the OK box to save the new elasticity parameter value on this sheet. But be careful: this does not save a new parameter file – see the next step. (You may get an error message that "You modified the file but need a GEMPACK license." You may safely ignore the warning for this exercise.)

2. Save your new parameter file
   - Select "File" (still in the ESUBVA window)
   - Close
   - Yes (answers the prompt "Save Changes to default.prm?"). This will not overwrite the default.prm file. Instead, it opens a box in which you can save the changes under a different file name
   - IMPORTANT: do not overwrite your default parameter file. In the box, provide a new file name with a .prm suffix, such as "ESUBVA20MFG.prm"
   - Click on "Save." This step saves your new parameters in a file in your model version folder in the RunGTAP370 directory
   - OK
3. Re-solve the model with a new elasticity
   - Select the "Solve" page tab
   - Check that the experiment description box describes "10toMFG," which means that your experiment is loaded and ready to run
   - If a different experiment is described, select "Load Experiment" and click on "10toMFG" and then click on OK to load the experiment 10toMFG
   - Click on "Change" next to "Parameter file:Default" in the upper right corner of the page
   - Select the name of your new parameter file: ESUBVA20MFG
   - OK

   You have two options for saving your experiment and parameter file. One is to save a new version of your experiment, with a new name, which signals that this experiment uses a different parameter file. In the next several steps, we describe how to do this. Because this can create file clutter, an alternative is to reuse a single experiment, while always checking to see which parameter file is specified. That is the approach we follow in the remaining model exercises.
   - Click on "Save Experiment"
   - Give your experiment a new name, to indicate that this version uses different elasticity parameters than your original experiment. Name it something like: "10toMFG2" and describe it as "10toMFG with 20 ESUBVA in MFG"
   - OK
   - Solve
4. Verify that your shock is what you think it is, following the steps in Section D.3 of this modeling exercise
5. Report new model results in Table ME 3.1, following the same instructions as in Section E of this model exercise

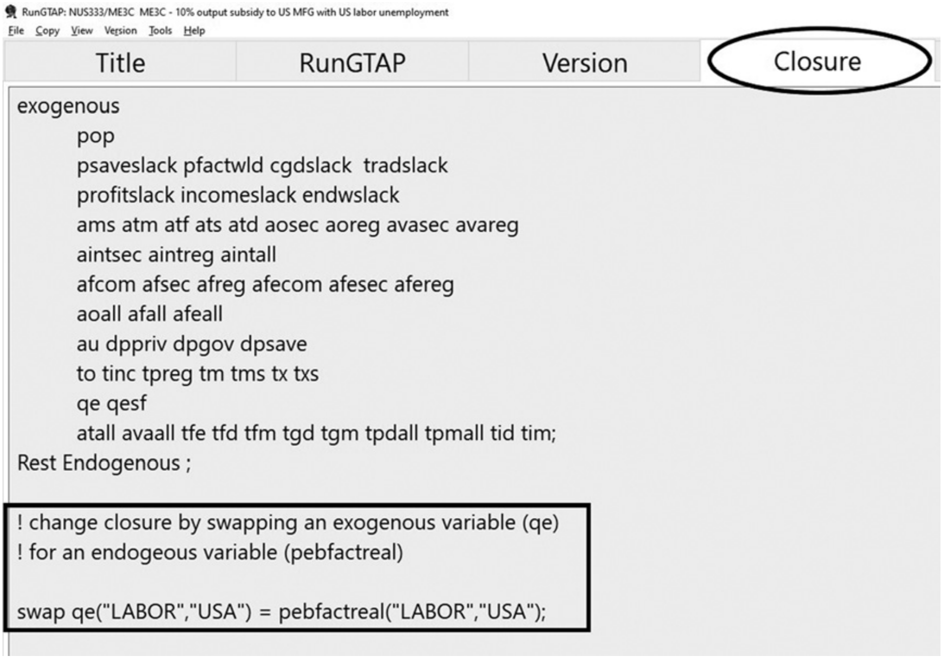


Figure ME 3.6 Changing the labor market closure

I. Change Model Closure

Model closure statements define which variables adjust (i.e., which are endogenous) and which are fixed (i.e., which are exogenous). To modify the model's standard closure statements, you must "swap" an exogenous variable for an endogenous variable. This one-for-one swap preserves the same number of endogenous variables that were originally in the model.

In this exercise section, you will modify the labor market closure. The default closure has an exogenous, fixed national endowment of labor (*qe*) and an endogenous economy-wide real wage (*pebfactreal*). You will change the closure to redefine the labor supply as an endogenous variable and the wage as an exogenous variable. Note that we are changing the closure statement for one factor market (labor) in one country (USA), as shown in Figure ME 3.6.

1. Select the Solve page
   - Click on the "Load Experiment" button
   - Select the experiment "10toMFG"
   - OK
2. Select the "Closure" page tab
   - Insert the bolded text below the final line of the closure instructions – "Rest Endogenous" (see Figure ME 3.6):
   - **swap qe("LABOR","USA") = pebfactreal("LABOR","USA");**

3. Select the "Solve" page tab
   - Check that the parameter file to be used is default.prm; if not, click on the "Change" button, select default.prm from the list, and click OK
   - Save experiment
   - Name it "10toUn" and describe it as "10% output subsidy to US MFG with US labor unemployment." This step saves both the experiment and the new closure statement. You can now rerun this experiment at any time without having to re-specify your new closure statement
   - OK
   - Solve
   - OK
   - OK
   - Verify that your tax shock is what you think it is, following the steps in section D.3 in this model exercise
   - Report new model results in Table ME 3.2
4. How do the results reported in Table ME 3.2 differ as you change an elasticity parameter and closure? In this case, which change in the model has the greatest impact on your results?
   Table ME 3.3 lists commonly used closure modifications in the GTAP model and their related swap statements.

Table ME 3.3 *Commonly modified closures in the GTAP model*

Closure in GTAP model	Explanation	Add this model code to closure statement
Factor unemployment	For region *r* and factor *e*, allows the endowment of a factor to vary and fixes that factor's real price (i.e., wage relative to CPI)	swap qe(e,r) = pebfactreal (e,r); *example:* *swap qe("labor", "USA") = pebfactreal ("labor", "USA");*
Fixed balance of trade	For region *r*, allows domestic savings to adjust to maintain the trade balance as a constant share of national income Note: Can fix trade balance of up to all but one region in model; the last market adjusts	Swap dpsave(r) = del_tbalry(r); *example:* *swap dpsave("usa") = del_tbalry("usa");*
Tax replacement or balanced government budget	For region *r*, sales tax on private commodity consumption (imports plus domestic) becomes endogenous to maintain indirect taxes as a constant share of national income	swap tpreg(r) = del_ttaxr(r); *example:* *swap tpreg("usa") = del_ttaxr("usa");*

(*continued*)

Table ME 3.3 *(cont.)*

Closure in GTAP model	Explanation	Add this model code to closure statement
Baseline scenario	For region *r*, fixes real GDP growth rate and solves for growth in TFP that is consistent with the projected real GDP growth. If swap is reversed, imposing the solution value for TFP growth will result in approximately the projected value for real GDP growth	swap qgdp(r) = afereg(r); *example:* *swap qgdp("USA") = afereg("USA");*
Export quantity control	For a commodity *c* and bilateral trade flow from exporting region *s* to destination region *d*, fixes export supply to partner; endogenous export tax measures economic rent to exporting country	swap qxs(c,s,d) = txs (c,s,d); *example:* *swap qxs ("mfg","usa","row") = txs ("mfg","usa","row");*
Import quantity control	For importing region *r*, an endogenous uniform import tariff on commodity *c* maintains fixed import quantity	swap qmw(c,d) = tm(c,d); *example:* *swap qmw("mfg","usa") = tm("mfg", "usa");*
Change in government consumption	Fix and then change the exogenous level of government spending in country *r*, with shares of consumption and savings adjusting to maintain regional income = expenditure	swap dpgov(r) = ug(r); *example:* *swap dpgov("USA") = ug("USA");*

J. Systematic Sensitivity Analysis and Stochastic Shocks

The GTAP model includes a utility developed by Arndt and Pearson (1998) that automates a systematic analysis of the sensitivity of model results to the assumed values of elasticity parameters or to the size of an experiment shock.[4] To test the sensitivity to elasticity values, the modeler chooses which elasticity parameter(s) to test and specifies the range of values over which each will be tested. For example, the modeler may have assumed a value of 2 for the import substitution elasticity, but wants to test the sensitivity of model results if the elasticity's value

[4] You need a GEMPACK license to carry out and view results from a systematic sensitivity analyses. You may download a free six-month limited license from the GEMPACK website at www.copsmodels.com/gpeidl.htm

ranges between 50% and 150% of the defined parameter value. The utility reports an estimate of the mean and standard deviation of results for every variable in the model as the elasticity value ranges between 1 and 3.

A test of the sensitivity of model results to variability in model shocks is carried out in a similar way. In this case, the modeler defines a possible range for the size of the shock value. For example, the modeler may be studying the effects of climate change on productivity in agricultural production, which he has described in the model as a negative 10% shock to agricultural land productivity. If estimates of productivity losses vary widely in the literature, the modeler may want to test a range in productivity loss between 50% and 150% of the 10% decline. In this case, the sensitivity analysis would estimate the mean and standard deviation of model results for every variable in the model, as the productivity shock ranges in value between –5% and –15%.

You can use the estimated means and standard deviations of model results to calculate confidence intervals for your model result. We use Chebyshev's theorem for these calculations because it does not require us to assume anything about the shape of the probability distribution of the results for each variable (Text Box ME 3.1).

As an example, imagine that you carried out a model experiment for which you assumed an import substitution elasticity value of 2, with the result that output of good Q increases 19.1%. You then carried out a SSA to a range of

Text Box ME 3.1 Chebyshev's theorem

At least the fraction (1– (1/k^2) of any set of data observations lies within k standard deviations of the true mean, therefore:

75% of the observations lie within 2 standard deviations of the mean
88.9% of the observations lie within 3 standard deviations of the mean
95% of the observations lie within 4.47 standard deviations of the mean
99% of the observations lie within 10 standard deviations of the mean.

If you know the mean and standard deviation, you can calculate a confidence interval. A confidence interval describes the probability that the data observations include the true mean. The end points of a confidence interval are calculated as the mean of the observations plus/minus the standard deviation multiplied by k (the number of standard deviations from the mean). For example, the end points of a confidence interval with a mean of 5, a standard deviation of 1, and a confidence level of 75% (so that k equals 2 standard deviations from the mean) is:

$$\text{Mean} \pm \text{standard deviation}^{*}\text{k} = \text{end points of the confidence interval}$$

$$5 \pm (1^{*}2) = 7,\ 3$$

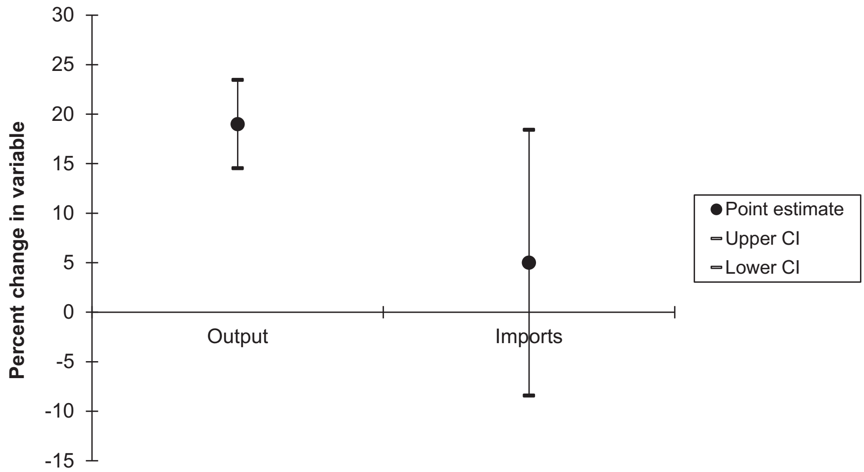


Figure ME 3.7 Confidence intervals (95%) for output and import quantities of good

between 50% and 150% of that elasticity value. Suppose your sensitivity analysis reports that the percent change in output of good Q has an estimated mean of 19 and standard deviation of 1. Using Chebyshev's theorem, you can construct a 95% confidence interval. In that case, the observations lie within 4.47 standard deviations of the mean. The upper limit of a 95% confidence interval is 23.47 (calculated as 19 + (4.47 × 1). The lower limit is 14.53 (calculated as 19 – (4.47 × 1). Similarly, you can report with 75% confidence interval that the result lies between 21 and 17, which is 19 ± 2 (two times the standard deviation of 1), and so forth. The higher the confidence level, the larger is the range of observations included in the confidence interval.

Figure ME 3.7 plots the confidence interval for our hypothetical example on a graph. It shows the point estimate for the percentage change in output, which is the result reported in your model. It also plots the upper and lower limits of the 95% confidence interval that we calculated. Plotting model results along with confidence intervals is an effective way to visually communicate information about model sensitivity and uncertainty. In this case, a positive output change is a robust model result over the range that you specified for the value of the import substitution elasticity.

On the other hand, let's assume that your analysis reports a percentage change in the import quantity of good Q of 5%, with a mean of 5 and a standard deviation of 3. Using Chebyshev's theorem, you have a 95% level of confidence that the true mean percentage change in imports lies between 18 and −8, and at least a 75% probability that the true mean lies between 11 and −1. Because the confidence intervals span positive and negative outcomes, you cannot be very confident that imports increase, instead of fall, over your specified range of alternative elasticity parameter values.

The following steps will guide you in carrying out an analysis of the sensitivity of model results to the elasticity of factor substitution. A sensitivity analysis with respect to the size of an experiment shock is analyzed in the same way, so we do not repeat the instructions for that case. Our example is a SSA of the results of a 10% output subsidy in US manufacturing to the value of the US and ROW's factor substitution (ESUBVA) elasticity parameters in the production of MFG goods.

1. In RunGTAP, reload and rerun your experiment "10toMFG"
   - Go the to "Solve" page tab
   - Click on "Load Experiment" button
   - Select "10toMFG" experiment
   - OK
   - Check that the solution method is Gragg: 2-4-6 steps extrapolation
   - Check that parameter file to be used is default.prm; if not, click on the "Change" button, select default.prm from the list, and click OK
   - Solve
   - OK
   - OK
2. Open the Systematic Sensitivity Analysis utility
   - Select "Tools" from the top menu bar
   - Select Sensitivity
   - Help on sensitivity. (This provides documentation and an intuitive explanation of this utility that you can use as a reference.)
   - Close the help document by clicking on the X in the upper right corner of the file. This returns you to the GTAP model
   - "Tools"
   - "Sensitivity"
   - "w.r.t. parameters" (the worksheet shown in Figure ME 3.8 will open)
   - Parameter to vary: ESUBVA
   - Elements to vary: All ACTS and All REG
   - Vary together? Leave these boxes unchecked. (This causes all ESUBVA's in all activities in all regions to vary independently. The documentation for the SSA tool discusses when you might choose to vary the shocks or parameters together or independently.)
   - Percent variation: 100 (the sensitivity analysis will vary the ESUBVA elasticity parameter value between close to zero and two times the base parameter value, for all three production activities in all three regions in the model)
   - Type of variation: Percent (this is the default choice)
   - Type of distribution: triangular (it is similar to a bell curve distribution and is the default choice)
   - Select "Add to list"
   - OK (this opens a page "Which quadrature to choose?" Make no changes to the default values)
   - OK (this launches the SSA)

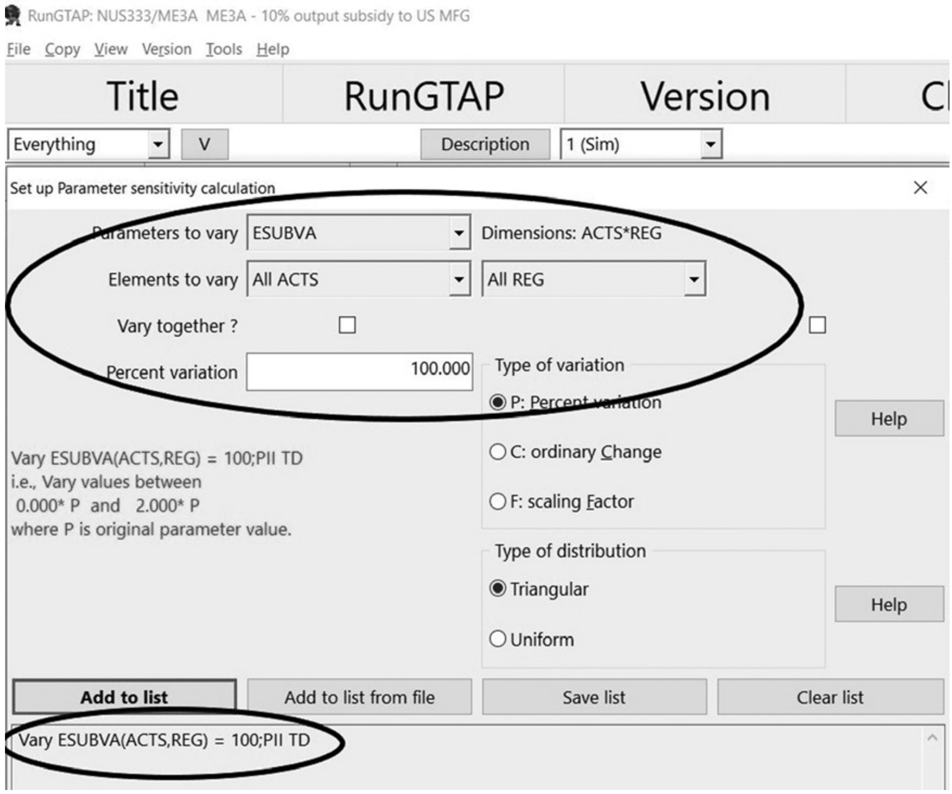


Figure ME 3.8 Systematic sensitivity analysis of an elasticity parameter

- Yes (to the prompt "Do you want to save the two solutions reporting means and deviations?")
- OK (to the prompt asking you to name the two report files)
- You can accept the default name, or you may choose to rename the report files. If you define a name, it will be applied to all report files
- Save (this saves the results to the Save Sims subfolder in your model version folder)
- Yes (this opens ViewSol utility, used to view the report files with the sensitivity analysis results)

3. Report results from the ViewSol file for US manufacturing output, *qo* ("MFG", "USA")
   - Filter results by selecting click on the "Everything" drop-down box on the upper left and selecting "USA." This selection consolidates the reports files and allows you to view the actual results, means and standard deviations for a US variable all on one page
   - Report the results
     a. Model result (reported in first column of data) ______________
     b. Mean (m1 – reported in second column of data) _______________
     c. Standard deviation (sd – reported in third column of data) _______________

Table ME 3.4 *Confidence intervals for the US manufacturing output quantity result with 100% variation in the factor substitution elasticity*

Confidence level (%)	Mean (X)	Standard deviation (sd)	No. of standard deviations from mean (k)	Upper limit (X + sd*k)	Lower limit (X – sd*k)
75			2		
88.9			3		
95			4.47		
99			10		

4. Construct confidence intervals using Chebyshev's theorem, following the example in the first row of the table. Report them in Table ME 3.4. What is your level of confidence that the effect on US manufacturing output is positive?

Model Exercise 4: Climate Shocks and Food Price Spikes

Concepts: Utility Functions, Armington Import Demand, Factor Productivity

Background

In 2019, the Intergovernmental Panel on Climate Change (IPCC) published a special report on the effects of climate change on land, drawing on the expertise of hundreds of leading experts in the many and diverse subject areas that are relevant to understanding the impacts of climate change. In their report, the authors outlined the negative impacts of a warming planet on arable land, food production, and food security. Agricultural zones that are more suitable for cool weather crops will shift closer to the north and south poles, and some zones formerly suitable for producing temperate crops will become hotter and better suited to warm-weather and tropical crop production. In addition to these gradual shifts, our warming planet will be subject to more frequent and extreme weather events, such as the extended rain in the US grain belt in 2019 that delayed and prevented planting. Droughts, excessive rainfall, heatwaves, and severe storms will increase the seasonal variability in agricultural production, leading to more frequent swings between years of food bounty and years of food scarcity.

Pressure on the world food system also will come from the demand side. The world population is expected to reach over 10 billion by 2050 – nearly a 30% increase from current population. The world's farmers will need to feed more people despite declining crop yields. Also, rising world incomes will lead to an increase in the per capita demand for grains because increased affluence leads to higher demand for meat. More grain must be used as feed, and the grain-to-food conversion ratio for meat is lower than when grain is consumed directly in products such as bread. Squeezed from both the supply and demand sides, the IPCC projects that world cereal prices could increase by almost 30% by 2050. And, year-to-year weather events are likely to lead to greater price volatility, with food prices spiking during years in which yields fall.

In this exercise, you will explore the impacts of a world food price spike by simulating a 50% increase in the world price of agricultural products. This shock is larger than is projected by the IPCC for cereals but it is similar in scale to the price spike that occurred in 2008, when prices of major agricultural commodities soared by more than 60% compared to their 2006 levels (Trostle, 2008).

How will a food price shock affect private household consumption in our model's large, ROW region? How will it affect their demand for food and the composition of their consumption basket? Will welfare rise or fall? How might this price shock affect ROW's industry structure and trade? In this case study, you will use your model results to answer these and other questions. You will also analyze the sensitivity of your results to alternative assumptions about consumer preferences.

Experiment Design

You will run a single-model experiment – an approximate 50% increase in the global price of agricultural products. This experiment will describe its cause as a negative supply shock that originates in the ROW, represented as a decline in the productivity of land in ROW. To simplify the interpretation of model results, we assume no change in agricultural land productivity in the United States. Also, we focus on the supply side and do not describe any long-term changes in dietary preferences. You will run the same model experiment twice, assuming two different utility functions. In the first experiment, scenario 1, you will use the GTAP model's CDE demand system with the default consumer demand elasticity parameters in the NUS333 database. In scenario 2, you will modify the consumer utility functions in the US and ROW by changing the INCPAR and SUBPAR parameters to replicate those of a Cobb-Douglas utility function. In the GTAP model's CDE consumer demand system, INCPAR is the income parameter and SUBPAR is the compensated, own-price demand parameter.

Instructions

1. Open NUS333 model version
   This step opens the NUS333 "version" of the GTAP model. You downloaded NUS333 in Model Exercise 1.
   - Open RunGTAP
   - On the top menu bar, choose "Version"
   - "Change"
   - Select "NUS333"
   - OK
2. Prepare your model to run an experiment – check closure
   - Select the "Closure" page tab

   Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.
3. Prepare your model to run an experiment – check shocks
   - Select "Shocks" page tab
   - Clear shock list

This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.

4. In Table ME 4.1, report your model's base parameter values for INCPAR and SUBPAR for the United States for scenario 1. First, click on the Solve page tab and ensure that the default parameter file has been selected. (See Model Exercise 2 for instructions on exploring elasticity parameters.)
5. In Table ME 4.2, report base budget shares of each commodity in household expenditure
   - Select "View" from the upper menu bar
   - "Base data" from the drop-down menu
   - "GTAPView Output"
   - Double-click on row "NVPP," which reports the cost structure of private household consumption (expenditure on each commodity)
   - Open the drop-down menu at top left, next to the box labelled "None"
   - Select "COL" from the drop-down box. This display format reports each cell as a percentage of the column total. In this case, the matrix now reports the budget shares of each commodity in total private household spending. Report the data for the ROW households in Table ME 4.2
   - Close the HAR file by clicking on the X in the upper left corner
6. Define your model experiment: Increase in world price of AGR
   - Select Shock page table
   - Variable to shock: "afeall" – this parameter is productivity of each factor in each production activity
   - Elements to shock: "LAND", "AGR," "ROW"; this changes land productivity used in AGR in ROW.

Table ME 4.1 *Income and price parameters in ROW in two scenarios of a 50% increase in the world agricultural price*

	Scenario 1		Scenario 2	
Elasticities	INCPAR	SUBPAR	INCPAR	SUBPAR
Agriculture				
Manufacturing				
Services				

Table ME 4.2 *ROW household budget shares*

	Base	Scenario 1	Scenario 2
Agriculture	0.044		
Manufacturing			
Services			

- % Change shock: –81% A decline of 81% is approximately the size of productivity shock that will lead to about a 50% increase in the world AGR price. (You may want to experiment with difference sizes of shocks to land-productivity in ROW and examine the effect on the world price of AGR.)
- Add to shock list

7. Change solution method and save the experiment
   - Select the "Solve" page tab
   - On the solve page, the solution method should be Johansen. If it is not, click on "Change." Select Johansen and then click on "OK." Your model will now solve for a single linear solution. This is useful for pedagogical purposes, but a multistep solution method is likely to be more accurate for your applied research. (See the discussion of linearization in Chapter 2.)
   - On the solve page, check that the parameter file is "Default." If it is not, click on "Change," select "Default" from the box, and click on "OK"
   - Click on "Save Experiment," name the shock "PWAgr1," and describe it as 50% increase in world price of AGR with default CDE utility function
8. Solve the model
   - Click on "Solve"
   - OK
   - OK
9. Report model results for ROW in Table ME 4.3. Results are reported under the Results page tab
10. Report your results for new budget shares
    - Select "View" from the upper menu bar
    - "Updated data" from the drop-down menu

Table ME 4.3 *Effects of a 50% increase in the consumer price of agriculture in ROW (% change from base)*

	World	Rest of world				
	World price	Consumer price	Consumer total composite consumption quantity	Consumer domestic consumption quantity	Consumer import consumption quantity	Production quantity
GTAP variable name	*pxwcom*	*ppa*	*qpa*	*qpd*	*qpm*	*qo*
CDE utility						
Agric.						
Mfg.						
Services						
Cobb-Douglas						
Agr.						
Mfg.						
Services						

Source: NUS333 model.

- Updated GTAPView Output
- Double-click on NVPP (row 16) – the updated commodity composition of household consumption
- Open the drop-down menu at the top left, nex to the box labelled "None"
- Select "COL"; this reports each cell as a share of the column sum. These are the updated budget shares of each commodity in total private household spending. Report the data for the ROW households in Table ME 4.2
- Close the HAR file by clicking on the X in the upper right corner

11. Change your utility function parameters to replicate a Cobb-Douglas function (see Model Exercise 3 for instructions on how to change elasticity values and save a new parameter file)
    - Set all INCPAR for the United States and ROW equal to exactly one
    - Set all SUBPAR for the United States and ROW equal to exactly zero
    - Save your new parameter file as "3×3CobbDouglas.prm"
12. View, and report in Table ME 4.1, your model's new parameter values for INCPAR and SUBPAR for ROW for scenario 2
13. Save your experiment and rerun the model with the new parameter values
    - Select the "Solve" page tab
    - Click on the "Change" button next to "Parameter file: default" in the upper right corner
    - Select "3×3CobbDouglas" from the list
    - OK
    - Click on "Save Experiment," name the shock "PWAgr2", and describe it as a 50% increase in world price of AGR with Cobb-Douglas utility function
    - Click on "Solve"
    - OK
14. Report your new model results for ROW in Tables ME 4.2 and ME 4.3

(a) Interpret Model Results

1. Drawing on Chapter 4 and Table ME 4.3, compare the assumptions of the two utility functions in your CGE analysis about price elasticities of demand (parameter Subpar) for agriculture. In which utility function are consumers more price sensitive? How do you anticipate the price increase will affect the quantity of private consumer demand for the composite commodity (*qpa*, imports plus domestic) AGR in both scenarios? Is this expectation consistent with the results of your general equilibrium model for both scenarios?
2. Compare the income effects implied by the utility functions and their parameter values, used in each scenario. Are the functions homothetic? For each utility function, describe whether each of the three goods are a necessity or a luxury, or if its demand quantity changes by the same proportion as income. ROW's household income (*yp*) decreases by about 1.2% in both experiments. Which

utility function is likely to drive a larger decline in household demand for AGR as a result of the income change?

3. The elasticity of substitution between two goods is calculated as the percentage change in the quantity ratio of X to Y, relative to the percentage change in the price ratio of Y to X. (Hint: recall Text Box 2.1 on how to calculate the percentage change in a ratio.) The elasticity of substitution of the Cobb-Douglas utility function has a value of –1. Use model results for consumer price (*ppa*) and private composite consumption (*qpa*) from the experiment with the Cobb-Douglas utility function to calculate the elasticity of substitution between AGR and MFG. Are your model results consistent with the assumptions of your utility function?
4. How do changes in budget shares spent on agriculture compare in the two scenarios? Explain these results using your knowledge of how the two different utility functions describe the effects of a price or income shock on budget shares. How do they compare with the original budget shares?
5. Most discussion of the world agricultural price shock focuses on consumers. How will the world price shock affect producers and the industry composition of the ROW economy? How important is your assumption about the consumer utility function in driving these results?
6. What is the Armington assumption? What is ROW's import-domestic substitution elasticity (ESUBD) for AGR in your model? Given this assumption and parameter value, how do you expect ROW demand quantities for AGR imports relative to demand for domestic goods will respond to the price shock in ROW's AGR? Is this expectation borne out by model results in both scenarios?

Model Exercise 5: Food Fight: Agricultural Production Subsidies

Concepts: Nested Production Function, Production Subsidies, Subtotal

Background

"Farm subsidies have outlived their usefulness," according to Robert Samuelson, the economic columnist for the *Washington Post* and *Newsweek*. In his column "The Endless Foodfight," Samuelson argued that the original goals of farm subsidy programs have been met in the United States and other high-income countries. In the United States, agricultural subsidies were introduced in the depths of the Great Depression in order to raise incomes in rural areas and keep food prices low. Although there have been some modifications in the subsidy program over the years, the United States still provides production subsidies to its agricultural producers. Yet, conditions for farmers today are much different than they were in the 1930s. US farm households now earn as much or more than the average urban US household, and food accounts for only a small share of the budget of the average American family. Some people may advocate subsidies as a strategy to ensure that the United States maintains its ability to feed itself and avoids dependence on food imports. However, growing food imports by the United States largely reflect Americans' rising standard of living. Imports provide US consumers with specialized agricultural and food products and year-round access to seasonal produce.

Subsidies are costly and governments pay for them by levying taxes on other parts of the economy. Agricultural subsidies in the United States and other high-income countries have an additional cost – they may weaken the global, rules-based framework sponsored by the World Trade Organization (WTO) that places agreed-upon limits to farm subsidies. The countries' use of agricultural subsidies is thought to distort global markets by increasing their farm production and lowering world agricultural prices, thereby creating unfair competition for farmers in other countries. As long as high-income countries' agricultural subsidies remain in place, many of their trade partners are unwilling to lower their tariffs and allow greater entry to their agriculture or other exports from high-income countries. The stalemate over agricultural subsidies contributed to the breakdown of the WTO negotiations in 2008 on deeper global trade liberalization.

If farm subsidies have outlived their usefulness and are increasingly costly, why do the United States and other high-income countries continue to use them? In this model exercise, you will conduct an experiment in which you eliminate all US agricultural subsidies, which include subsidies on land and capital use and intermediate inputs. Experiment results will illustrate the costs and benefits of agricultural subsidies in the United States and provide some insight as to why it is so hard to eliminate them.

Experiment Design

What is the effect of an existing tax or subsidy on an economy? One way to measure its effect is to remove it. The difference between an economy with and without the tax or subsidy provides a measurement of its economic impact. In this exercise, you will learn how to identify taxes and subsidies in the model database; you will learn to define an experiment that eliminates subsidies and you will learn to use the GTAP subtotal utility to decompose model results. Your experiment will:

1. Eliminate all factor use subsidies in US agriculture; and
2. Eliminate all subsidies on the purchase of domestically produced and imported intermediate inputs by US agricultural producers.

You will then use SUBTOTAL, a GTAP utility that allows you to decompose the results of each component of this multipart experiment.

Instructions

1. Open GTAP NUS333 model version
   This step opens the NUS333 "version" of the GTAP model. You downloaded this version of the model in Model Exercise 1.
   - Open RunGTAP
   - On the top menu bar, choose "Version"
   - "Change"
   - Select "NUS333"
   - OK
2. View tax and subsidy expenditures and rates in US agriculture
   - Click on View > Base Data > GTAP View Output
   - Double-click on NVFP Cost structure of firms (Line 15)
   - Set toggles in upper right corner to:

   All DEMD | AGR | USA | All Dir | Tax

   This matrix displays US agricultural producers' tax payments (positive values) and subsidy receipts (negative values) in $US millions. On which inputs is US agriculture taxed versus subsidized?
   - Close the HAR file by clicking on the X in the upper right corner
   - Select View > Base data > Tax rates
   - Double-click on RTFE – tax rate on primary factor *e* used in activity *a*
   - Set the toggles in the upper right corner to

Table ME 5.1 *Base and updated subsidy rates in US agriculture*

	Base rate	Updated rate
Subsidy to land – RTFE (“LAND”,”AGR”,”USA”)		
Subsidy to capital – RTFE (“CAPITAL”, “AGR”, “USA”)		
Tax on domestic intermediate inputs RTFD (C,“AGR”, “USA”)		
AGR		
MFG		
SER		
Tax on imported intermediate inputs RTFM (C, “USA”)		
AGR		
MFG		
SER		

All ENDW | AGR | USA

- Report the subsidy rates on land and capital used in US AGR in Table ME 5.1
- Double-click anywhere in the matrix to return to table to return to the main tax menu
- Double-click on RTFD – tax rate on domestic commodity *c* for use in activity *a*
- Set the toggles in the upper right corner to

AllCOMM | AGR | USA

- Report the subsidy rates on US AGR purchases of domestic intermediate inputs in Table ME 5.1
- Double-click anywhere in the matrix to return to the main tax menu
- Repeat these steps to report RTFM – tax rate on imported commodity *c* for use in activity *a*
- Close the HAR file by clicking on the X in the upper right corner

3. Prepare your model to run an experiment – check closure
   - Select the “Closure” page tab

   Check that no closure changes are lingering there. The closure should end with “Rest Endogenous.” If not, erase all text below that line.
4. Prepare your model to run an experiment – check shocks
   - Select “Shocks” page tab
   - Clear shock list

   This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.

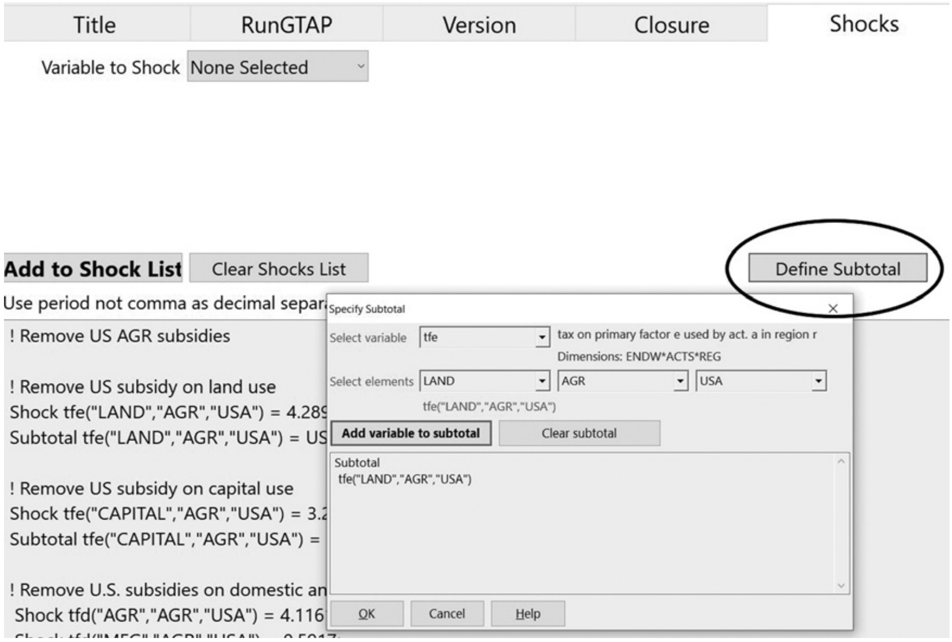


Figure ME 5.1 Define subtotals of a model shock

5. Eliminate land factor use subsidy in US agriculture
   - Choose "Shocks" page tab
   - From the drop-down menu "Variable to shock," choose variable "*tfe*"
   - Select these elements of *tfe*: LAND, AGR, and USA
   - Set a shock value of zero
   - Select "Type of shock: % target rate"
   - Click on "Add to shocks list"
6. Define land subsidy elimination as a "Subtotal" in your results
   - Click on "Define subtotal" button

   This opens a dialogue box, shown in Figure ME 5.1, where you define each subtotal. You can wait and define all of your subtotals after you have finished setting up your experiment file, or you can define each subtotal after selecting each part of your shock, as we do in these instructions.
   - Select variable: *tfe*
   - Select elements: "LAND," "AGR," and "USA"
   - Click on "Add variable to the subtotal"
   - OK
   - Name it "AGR land subsidy"
   - OK
7. Repeat steps 5 and 6 to eliminate the factor use subsidy on capital used in US agriculture (tfe ("CAPITAL", "AGR", "USA")) and to define a subtotal named "AGR capital subsidy"

8. Eliminate input subsidies on domestically produced AGR intermediate inputs used in US AGR
   - From the drop-down menu "Variable to shock," choose variable "*tfd*"
   - Select these elements of *tfd*: AGR, AGR, and USA
   - Set a shock value of zero
   - Select "Type of shock: % target rate"
   - Click on "Add to shocks list."
9. Repeat step 8 to eliminate all input subsidies on domestic MFG and SER inputs, and subsidies on imported inputs (*tfm*)
10. Define the combined removal of both *tfd* and *tfm*, for set elements All COMM, AGR, USA, as a subtotal in your results. Name this subtotal "Intermediate input subsidies"
11. Save the experiment
    - Select the "Solve" page tab
    - Check that the solution method is "Gragg 2-4-6." If it is not, click on "Change." Select Gragg and click on "OK"
    - Check that the parameter file is "Default." If it is not, click on "Change," select "Default" from the box and click on "OK"
    - Click on "Save," name the experiment "AgrSubs", and describe it as "Elimination of US AGR subsidies"
12. Solve the model
    - Remain on the "Solve" page tab
    - Click on the "Solve" button
    - OK
    - OK
13. Before viewing results, verify that your experiment has changed the tax rates as you expect by viewing the updated tax rates
    - Click on "View" from the menu bar
    - Select "Updated data" from the drop-down menu
    - Select "Updated Tax rates" from the drop-down menu
    - Report the new tax rates in Table ME 5.1, for each of the subsidies removed in this experiment. Select toggles in the upper right corner that correspond to the dimensions for each subsidy listed in Table ME 5.1
14. Report model results in Table ME 5.2 and in the first column of Table ME 5.3. To view results decomposed into the subtotals:
    - Click on the Results page tab
    - Click on the Description box in the upper center of the page – this opens a text box that provides descriptions of each of the subtotals. Click on OK to close this box
    - Click on the box on the right-hand side, "(1) Sim." Its drop-down box will list a selection of results that you can view:
      1. Sim – the total percentage change in variable due to the simulation
      2. Pre value – the value of the variable before the experiment
      3. Post value – the value of the variable after the experiment

Table ME 5.2 *Effects of US agricultural subsidy elimination on United States (% change from base)*

Variable	Variable name in GTAP	Total	Subtotals: Land subsidy effect	Capital subsidy effect	Intermediate input subsidy effect
Agricultural output quantity	*qca*(AGR AGR,USA)				
Agricultural producer price	*ps*(AGR, AGR,USA)				
Factor cost to producers					
Land	*pfe*(LAND, AGR,USA)				
Capital	*pfe*(CAPITAL, AGR,USA)				
Land supply price	*pes*(LAND, AGR, USA)				
Household consumption	*qpa*(AGR,USA)				
Export quantity	*qxw*(AGR,USA)				
Export price	*pxw*(AGR,USA)				

Table ME 5.3 *Change in input-output coefficients in US agriculture due to US subsidy removal (% change from base)*

Output and inputs	Total percent change in output and input quantities	Percent change in input-output coefficients (*qfe*–*qca*) or (*qfa*–*qca*)
AGR output (*qca*)	–1.42	Not applicable
Land used in AGR (*qfe*)		
Capital used in AGR (*qfe*)		
AGR intermediate in AGR (*qfa*)		
MFG intermediate in AGR (*qfa*)		
SER intermediate in AGR (*qfa*)		

4. Ch/Ch% – the difference between pre and post values
5. Subtotal 1 – the percentage change in variable due only to subtotal 1 shock
6. Subtotal 2 – the percentage change in variable due to only subtotal 2 shock

Subtotal 3 – the percentage change in variable due to only subtotal 3 shock

- Click on "(1) SIM." The results reported for each variable will then display the results of the full simulation
- Click on the box labeled "Everything" in the upper left corner, and select "USA" from the drop-down menu
- Click on variable *qca – supply of commodity c by activity a in region r*. This will display the output quantity results for AGR produced by AGR in the USA. Report the result in the Total column Table ME 5.2. Double-click anywhere in the table of results to return to the list of variables
- Report results for (1) SIM for all variables listed in Table ME 5.2
- Click on the drop-down with (1) SIM. Select Subtotal 1 – the percentage change in variables due to removal of the land subsidy in US agriculture. Click on the box labeled "Everything" in the upper left corner, and select "USA" from the drop-down menu. Report results for Subtotal 1 for all variables listed in Table ME 5.2
- Repeat for Subtotals 2 and 3.

Interpret Model Results

1. Are the updated subsidy rates reported in Table ME 5.1 the rates that you expect them to be? If not, check your shock statements for errors.
2. Draw a technology tree for US agriculture in the NUS333 model. Identify the inputs in each nest and the values in your model for the elasticity parameters that govern substitutability within each nest and at the top level.
3. In Table ME 5.3, use the results from the experiment to report percentage changes in input demand in AGR, and calculate the percentage changes in input-output ratios for each input. Are these findings consistent with your depiction and discussion of the technology tree in question 2? Are they consistent with the land and capital price changes (*pfe*) you reported in Table ME 5.2?
4. How does the total effect of US policy reform on AGR output compare with reforms of each separate component? If you were a policymaker, how might the availability of subtotaled results influence your thinking on the best way to phase in the reform program?
5. The model has three land prices (similar to Figure 8.6 in Chapter 8). Compare results for the percent change in the land price paid by producers in US AGR (*pfe*) to the net land rent (after income tax) accepted by land owners (*pes*). How do you think producers and landowners will feel about the removal of the land subsidy in US AGR? Why do you think that the two prices differ?
6. Based on data in the US structure table, in Chapter 3, what is the share of food in households' total expenditure on goods and services? Given that expenditure pattern, what might be the views of US consumers on agricultural subsidy reform?
7. Based on your model results, what is your view of the concern of US trade partners that US farm programs increase output and exports, which depresses world prices?

Model Exercise 6: How Immigration Can Raise Wages

Concepts: Factor Endowment Shocks, Factors as Complements and Substitutes, Factor Substitution Elasticity

Background

In 2018, there were 45 million immigrants living in the United States (US Census Bureau, 2019). The United States is a nation of immigrants and historically has been a land of refuge and opportunity for foreigners. But with the number of immigrants now reaching more than 14% of the population, a contentious public debate has opened over the costs and benefits of the newcomers. On one hand, new workers add to the nation's labor endowment, so the United States benefits from an increase in its productive capacity. On the other hand, new workers compete with native workers for jobs and may drive down wages – a key concern for US labor. In addition, there are costs associated with the public services needed by immigrants that may not be sufficiently offset by the taxes that they pay.

The growing body of economic research on immigration offers conflicting results on their net impact on the US economy and, in particular, its labor force. In an influential 2004 study, Dr. George Borjas concluded that immigration to the United States reduced the average annual earnings of native-born workers by an estimated $1,700 or roughly 4%. Wages fell because employers can easily substitute immigrant labor for native US workers in the same skill class. An immigrant auto mechanic, for example, can be substituted easily for a native-born auto mechanic. Dr. Borjas also accounted for the "cross-price effects" of immigration across skill classes. An increased number of auto mechanics, for example, leads to increased demand for native-born workers with complementary skills, such as immigrants' dentists and teachers for the immigrants' children. But he found these cross-price wage benefits to be small. In a supply-and-demand framework, he concluded that the main effect of immigration has been to shift the labor *supply* curve outward for each skill class, causing the wages of native workers to fall.

Ottaviano and Peri (2012) disagree with Borjas. In their study of immigration to the United States, they found that immigration has increased the average US wage by 1.8% and the average wage of American-born workers by 2.7%. Two factors are at work. First, they argue that immigrant and native-born workers are relatively poor substitutes in the workplace. Even when they have similar educations, they tend to choose different occupations and have different types of skills. For example, an immigrant auto mechanic is a poor substitute for a native-born health technician. As a result, immigration mainly depresses the wages of earlier immigrants. Moreover, they found that cross-price effects are large, so that the increased number of immigrant auto workers has led to increased demand and higher wages for workers with complementary skills, like dentists and teachers. In a supply-and-demand framework, they argue that the dominant effect of immigration is to shift out the *demand* curve for native workers of all education levels.

A second factor, they argue, is that firms take advantage of the growing labor market by increasing their investment. In turn, new investment leads to increased demand for labor, a complementary factor to capital. In a supply-and-demand framework, an increase in the capital stock causes an outward shift in the demand for all labor types, which also helps boost wages.

A key contribution made by the two studies was their authors' use of a general equilibrium framework to analyze the wage effects of immigration. Their studies took into account how wages in each labor market depended on its interaction with labor markets for other types of workers and, in the Ottaviano and Peri study, with increased capital investment. This exercise is designed to help you control and manipulate your CGE model in order to deconstruct and replicate the underlying assumptions made in these two influential and competing views on the economic effects of US labor immigration.

Experiment Design

In this model exercise, you will use a GTAP model version named "NIMMIG" to carry out a simulation of the general equilibrium effects of immigration on the United States. Like the NUS333 model version, this version has two regions, USA and ROW, three production activities and three commodities (AGR, MFG, and SER). If differs from NUS333 because it has different factors: unskilled labor, skilled labor, and capital. Your analysis are more limited than those of Borjas and Ottaviano and Peri because your CGE model has only two types of labor, skilled and unskilled labor, and does not differentiate between native and immigrant workers. In addition, your experiments rest on the simplifying assumption that labor migration occurs only in the unskilled labor category, although both skilled and unskilled workers immigrate to the United States.

In this exercise, you will:

1. Download and run the archived GTAP model version "NIMMIG" that includes unskilled labor, skilled labor, and capital. Follow the instructions in Model Exercise 1 to download the model version from the GTAP website.
2. Develop small theoretical models to illustrate the assumptions about labor supply and demand underlying your analysis.
3. Carry out three experiments:

BORJAS simulates a 10% increase in the unskilled labor supply, assuming that factors are highly substitutable.

OTTA1 simulates the BORJAS experiment but assumes that factors are relatively complementary.

OTTA2 adds to OTTA1 a 6% increase in the US capital stock.

Instructions

1. Download the GTAP model version NIMMIG.ZIP from the GTAP website onto your computer, following the instructions in Model Exercise 1, Section C, for downloading the NUS333.ZIP file from the GTAP website. After installing your model, run a test simulation
2. Prepare your model to run an experiment – check closure
   - Select the "Closure" page tab

   Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.
3. Prepare your model to run an experiment – check shocks
   - Select "Shocks" page tab
   - Clear shock list
   - This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce
4. In the BORJAS scenario, you assume that factors can be substituted for each other relatively easily by changing the factor substitution elasticity to 12 for all industries and both USA and ROW (ESUBVA = 12). Follow instructions in Model Exercise 3 on how to change an elasticity parameter and save it in a new parameter file, named BORJAS.prm
5. Define the BORJAS model experiment
   - Variable to shock: "*qe*"
   - Elements to shock: "UNSKILLED," "USA"
   - % Change shock: 10%
   - Select: Add to shock list
6. Save the experiment file
   - Select the "Solve" page tab
   - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box, and then click on "OK"
   - Change your parameter file by clicking on "Change" next to "Parameter file: default," and select your new parameter file name, BORJAS.prm
   - OK (this closes your parameter file dialogue box)
   - Click on "Save experiment," name the shock BORJAS, and describe it as 10% increase in unskilled labor
7. Solve the model
   - Click on "Solve"
   - OK
   - OK

8. Report factor market results in Table ME 6.1
   - Select the "Results" page tab
   - In the data filter in the upper left corner of the Results page, click on the drop-down menu in the box that displays "Everything." Select "USA"
   - Double-click on variable *pfe* – price of endowment *e* in activity *a* in region *r*. This variable is the price paid to factors by production activities
   - Report results for variable *pfe* in Table ME 6.1
   - Double-click on any cell in the table to return to the main menu for results
   - Repeat these steps to report all results in Table ME 6.1
9. Report real GDP results in Table ME 6.2
   - Select the "Results" page tab
   - In the data filter in the upper left corner of the Results page, click on the drop-down menu in the box that displays "USA." Select "Everything"
   - Double-click on variable *qgdp* – GDP quantity index. This is the percent change in real GDP
   - Report results for variable *qgdp* in Table ME 6.2

Table ME 6.1 *Effects of a 10% increase in the US supply of unskilled labor (% change from base)*

Factor price paid by producers (*pfe*)		Production activity	Demand for labor (*qfe*)		Output (*qo*)
			Unskilled	Skilled	
BORJAS – 10% increase in unskilled labor supply with high factor substitution					
Unskilled		Agriculture			
Skilled labor		Manufactures			
Capital		Services			
OTTA1 – 10% increase in unskilled labor supply with low factor substitution					
Unskilled		Agriculture			
Skilled labor		Manufactures			
Capital		Services			
OTTA2 – 10% increase in unskilled labor, 6 percent increase in capital, low factor substitution					
Unskilled		Agriculture			
Skilled labor		Manufactures			
Capital		Services			

Table ME 6.2 *Real GDP effects of a 10% increase in US unskilled labor supply*

Scenario	% Change in real GDP (*qgdp*)
BORJAS	
OTTA1	
OTTA2	

- Double-click on any cell in the table to return to the main menu for results.

10. Create a new parameter file for OTTA1 and OTTA2 that describes factors as complementary by reducing the elasticities of substitution (ESBUVA) for USA and ROW to:

$$\text{AGR} = 0.2;\ \text{MFG} = 0.5;\ \text{SER} = 0.5$$

Follow instructions in Model Exercise 3 on how to change an elasticity and save a new parameter file, named OTTA.prm.

11. Define the OTTA1 experiment file
    - Adapt the BORJAS experiment file to use the Otta.prm parameter file. On the Solve page, click on the "change" button next to "Parameter file." Select OTTA.prm
    - OK
    - Save the Borjas experiment as OTTA1
    - Select the "Solve" button, solve the model, and report your results in Tables ME 6.1 and ME 6.2 following the instructions in steps 8 and 9
12. Define the OTTA2 experiment by adding capital stock growth to the OTTA1 experiment:
    - Select the Shocks page tab
    - Select variable to shock: "*qe*"
    - Elements to shock: "CAPITAL," "USA"
    - % Change shock: 6%
    - Click on "Add to shock list"
    - Select the "Solve" page tab
    - Save the model experiment and name it OTTA2
    - Select the "Solve" button, solve the model, and report your results in Tables ME 6.1 and ME 6.2

Interpret Model Results

1. Develop a theoretical model to describe the Borjas argument. Draw a graph for each labor market, identifying the supply-and-demand curves and the initial equilibrium quantities and wages. In the graph of the unskilled labor market, show the effects of unskilled labor immigration on wages and employment. Which curve shifts? In the graph of the skilled labor market, show the effect of the increased supply of unskilled workers. Which curve shifts? In which direction will it shift if the two types of labor are substitutes, as argued by Borjas?
2. How did you change the CGE model to represent factors as substitutes or as complements? What does a larger parameter value signify?
3. Are the wage results of the BORJAS experiment consistent with those of your theoretical model? Why are the effects of immigration on skilled wages and capital rents negative when factors are good substitutes?

4. Develop a theoretical model to describe Ottaviano and Peri's argument. Draw a graph for each labor market, identifying the supply-and-demand curves and the initial equilibrium quantities and wages. In the graph of the unskilled labor market, show the effects of unskilled immigration on wages and employment. Which curve shifts? In the graph of the skilled labor market, show the effect of the increased supply of unskilled workers. Which curve shifts? In which direction will it shift if the two types of labor are relatively complementary, as argued by Ottaviano and Peri?
5. Are the wage results of the OTTA1 experiment consistent with those of your theoretical model? Why are the effects of immigration on skilled wages and capital rents positive when factors are relatively complementary?
6. Using your theoretical model describing the Ottaviano and Peri's argument, add the effects of capital stock growth. Which curve shifts in each graph? In which direction will they shift if all factors are relatively complementary, as argued by Ottaviano and Peri?
7. Are the wage results of the OTTA2 experiment consistent with those of your theoretical model? What happens in your model to the price of capital? Can you explain why?
8. Why does real GDP increase in all three scenarios? Why is real GDP growth higher in the BORJAS scenario compared to OTTA1?
9. What conclusions about modeling and the choice of elasticity parameters do you draw from your study of the two competing models of labor immigration?

Model Exercise 7: Anatomy of a Trade War

Concepts: Theory of an Import Tariff, Selecting Model Results, Allocative Efficiency, Second-Best Welfare Effects, Terms of Trade

Background

In 2018, the United States initiated "trade wars" against its major trade partners, including Europe, Japan, China, and its NAFTA/USMCA partners. The United States imposed tariff surcharges on steel and aluminum imports from most countries and added almost across-the-board tariff surcharges on US imports from China. In retaliation, US trade partners imposed reciprocal tariff surcharges. The US president responded that "trade wars are easy to win." Neoclassical theory provides some support for this view. Despite the market inefficiencies caused by a tariff, a large importing country such as the United States may have offsetting terms-of-trade gains if the decline in its demand for imports drives down its trade partner's export price. However, the potential for trade partners to return fire, by introducing retaliatory tariffs, can make the trade war harder to win.

In this model exercise, you will explore the question of whether a country can win from a trade war in a stylized case study of an increase in the US tariff on manufacturing imports from its trade partner, the ROW region, and ROW's retaliatory response. The two-region model used in this exercise has a single, highly aggregated ROW region and three highly aggregated commodities. Nevertheless, its simplified representation of a trade war fosters skills that can be applied in more detailed and realistic global CGE models.

The exercise has two learning objectives. First, you will learn how to use economic theory – the theory of an import tariff presented in Chapter 8 – to identify the most relevant variables to consider, and to predict and evaluate changes in their values after an experiment. After drawing a model of the effects of an import tariff, you can use the variables on the axes to identify the variables that are most relevant to use as starting points for evaluating model results. The impacts of an import tariff, shown by the movements in the graph, can be used to inform your expectations about the positive or negative sign of changes in the variables' values. Movements in the graph can also be used to explain the drivers of the variables' new values. Deviations from expectations can serve as a flag for checking for possible errors in defining your experiment shocks, or as a signal that general equilibrium effects, such as input-output linkages and real exchange rate movements, may be important enough to override the expected effects on import prices or quantities.

The second learning objective is to show you how to develop a deeper understanding of your findings using three methods for decomposing model results. The first decomposition method is to define a sequence of experiments that each impose a single element of a shock. In this case study, your first experiment imposes only the US tariff surcharge and omits the ROW's retaliation. This allows you to isolate and explore the contribution of the change in the US tariff to the impacts of a trade war. In a second experiment, which you will not carry out here, you could similarly impose only the ROW tariff retaliation without any change in US tariffs. Your final experiment describes the full set of the shocks that you are studying – in this case, it is the simultaneous change in manufacturing tariffs by both regions.

The second decomposition approach uses a utility available in the GTAP modeling framework. The "subtotals" utility allows you to divide a shock into smaller components. In this exercise, for example, you will divide the trade war shock into two subtotals: a change in the US manufacturing tariff on ROW, and ROW's retaliatory manufacturing tariff on the United States. You may define subtotals in any way that is useful for your research question but every component of the full shock must be included in a subtotal – neither omitted nor double-counted. The presentation of model results in the GTAP framework reports both the total impact and the contributions of each subtotal to that impact. If you have correctly included all components of the shock in your subtotal definitions, the sum of the subtotal contributions will equal the total impact of the shock.

The third approach is the welfare decomposition utility, available in the GTAP framework. It enables you to decompose the contributions of efficiency and terms-of-trade effects in the total welfare impact of a tariff and to isolate the efficiency effects of a tariff change from the second-best efficiency effects that stem from the interaction of that tariff with the whole US tax system.

Experiment Design

You will use the NUS333 model with two experiments that describe a trade war. In the first experiment, you will impose a five-percentage-point tariff surcharge on the US tariff on manufacturing imports from ROW. In the second experiment, you will impose simultaneously (1) a five-percentage-point surcharge on US manufacturing tariffs on imports from ROW and (2) a reciprocal 5% tariff surcharge on all ROW manufacturing imports from the United States. In the second experiment, you will use the GTAP SUBTOTAL utility to decompose the trade war into its two components: the US tariff surcharge and ROW retaliation.

Instructions

1. Open GTAP NUS333 model version
   This step opens the NUS333 "version" of the GTAP model. You downloaded this version of the model in Model Exercise 1.
   - Open RunGTAP
   - On the top menu bar, choose "Version"
   - "Change"
   - Select "NUS333"
   - OK
2. Prepare your model to run an experiment – check closure
   - Select the "Closure" page tab.

   Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.
3. Prepare your model to run an experiment – check shocks
   - Select "Shocks" page tab
   - Clear shock list

   This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce
4. Report base import tariff rates in Table ME 4.1
   - Select "View" from the menu bar
   - Select "Base data" from the drop-down menu
   - Select "Tax rates" from the drop-down menu

   This step opens a table that lists all taxes in the GTAP model.
   - Double-click on row "RTMS" – "Source-specific change in tax on imports of *c* from *s* to *d*"
   - Select the appropriate set elements to display in the toggles on the upper right corner.

     US tariffs on imports from ROW are shown with toggles set to:

     All COMM | ROW | USA

     ROW tariffs on imports from USA are shown with toggles set to:

     All COMM | USA | ROW

   - Write the base import tariff rates in Table ME 7.1
   - Close the HAR file by clicking on the X in the upper right corner
5. Define updated tariff rates for the trade war experiment
   Add a five-percentage-point surcharge to the US and ROW MFG tariffs, in the "Updated import tariffs" row in Table ME 7.1. Also report the (unchanged) AGR and SER tariffs in the table. You will use these tariff rates later in this exercise to check that your experiment has updated the tariffs correctly.

Table ME 7.1 *Import tariff rates in NUS333 model before and after 5% surcharge*

	United States tariff on ROW			ROW tariff on United States		
Variable name	Agr.	Mfg.	Services	Agr.	Mfg.	Services
Base import tariffs (rTMS)	1.56					
Updated import tariffs (rTMS)						

Source: Base tariffs from NUS333 model.

6. Define the first experiment: US 5% tariff surcharge on manufacturing imports from ROW
   - Select the "Shocks" page tab
   - From the drop-down menu, "Variable to shock," choose variable "*tms*"
   - Select these elements of *tms*: MFG, ROW, USA
   - Select the shock value: use the updated tariff rate in U.S. manufactures from ROW, from Table ME 7.1
   - Select Type of Shock: "% target rate"
   - Click on "Add to shocks list"
7. Save the experiment file
   - Select the "Solve" page tab
   - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box and then click on "OK"
   - Check that the parameter file is "Default". If it is not, click on "Change," select default.prm from the box and click OK
   - Click on "Save experiment," name the shock TRDWAR1, and describe it as "US tariff surcharge on MFG imports from ROW"
8. Solve the model

   Still on the "Solve" page tab, select
   - Solve
   - OK
   - OK
9. After running the experiment, check that the updated tax rates are those you expect to find in your experiment

   From the upper menu bar, select
   - Select "View" from the menu bar
   - Updated data (from the drop-down menu)
   - Updated tax rates (from the drop-down menu)

   On the tax summary page, click on the row "RTMS", "Source-specific change in tax on imports of *c* from *s* to *d*"

   To view US import tariffs, select toggles:

   All COMM | ROW | USA

Do the new tariff rates for US imports from ROW match that in Table ME 7.1? If not, double-check your shock value on the shocks page.

- Close the HAR file by clicking on the X in the upper right corner

10. Before viewing results, develop a theoretical model to identify relevant results and predict outcomes. Sketch a graphical model of the impacts of an import tariff on a large country, similar to Figure 8.1 in Chapter 8. The axes of your model identify the most relevant variables to view and the movements in the graph help you to form predictions about the expected changes in their values. Based on your graph, write in Table ME 7.2 the positive or negative sign that you expect for the changes in these variables in experiment TRDWAR1.
11. Report model results in Table ME 7.2
    - Click on the Results page tab
    - Click on the box labeled "Everything" in the upper left corner, and select "USA" from the drop-down menu
    - Click on variable $pmds_{*,*,\text{"USA"}}$ – *price of imported c supplied by region s to USA*

      Results for US imports from ROW are reported in the ROW column. Report the result for the US domestic price of MFG imports from ROW in Table ME 7.2.
    - Double-click on any cell to return to the menu of results
    - Click on variable $pcif_{*,*,\text{"USA"}}$ – *CIF world price of imported c from region to USA*. Results for US imports from ROW are reported in the ROW column. Report the result for the US *cif* price of MFG imports from ROW in Table ME 7.2
    - Double-click on any cell to return to the menu of results
    - Click on variable $qxs_{*,*,\text{"USA"}}$ – *quantity of commodity c exported from region s to USA*. Results for the quantity of US imports from ROW are reported in the ROW column. Report the result for the US import quantity of MFG from ROW in Table ME 7.2

Table ME 7.2 *Effects of a 5% tariff surcharge on US imports of manufactures from ROW (% change from base)*

Variable name	Variable definition	Expected sign of result	Result
% Change $pmds_{\text{"MFG"},\text{"ROW"},\text{"USA"}}$	US bilateral domestic price of MFG import from ROW, including tariff		
% Change $pcif_{\text{"MFG"},\text{"ROW"},\text{"USA"}}$	US bilateral CIF import price on MFG import from ROW, excluding tariff		
% Change $qxs_{\text{"MFG"},\text{"ROW"},\text{"USA"}}$	Quantity of bilateral MFG imported from ROW to US		

Table ME 7.3 *Welfare effects of US 5% tariff surcharge on MFG imports from ROW ($US millions)*

Allocative efficiency	Endowment change	Technical change	Population change	Terms of trade	Investment–savings terms of trade	Preference shifts	Total

- Double-click on any cell to return to the menu of results
- Do your results conform to your expectations based on your theoretical model?

12. Review the welfare decomposition for the effects of a US tariff surcharge on MFG imports from ROW

    From the upper menu bar, select
    - "View" from the menu bar
    - Updated data (from the drop-down menu)
    - Welfare decomposition (from the drop-down menu)
    - On the welfare summary page, double-click on the first row "EV decomposition summary"
    - Report all results for the United States in Table ME 7.3
    - Double-click on any cell to return to the welfare summary page.
    - Do your results conform to expectations based on your theoretical model? Note that the terms of trade effect in the summary table (row E1) applies to traded commodities used by firms, consumers, and government. The I–S terms of trade applies to investment goods. The two together describe total terms of trade.

13. Identify second-best allocative efficiency effects using the GTAP welfare decomposition utility tool – decompose the effects of tariff distortions

    Your theoretical model predicts that the change in the US import tariff on MFG imported from ROW will lead to a deadweight loss, or economic inefficiency. Your model results quantify an efficiency loss of about $5.6 billion. Avoid the error of attributing that entire efficiency loss to the change in the US MFG import tariff by using the welfare decomposition tool to identify the efficiency effects linked to the MFG tariff versus "second-best" allocative effects, described in Chapter 8. Second-best effects occur when the change in one tax leads to more or less efficient outcomes that result from its interaction with existing tax distortions in other markets.
    - On the welfare summary page, double-click on Allocative Efficiency Effect: Tax Type Summary. This table decomposes the efficiency effect by tax type
    - In row 2 of Table ME 7.4, report the value of the allocative efficiency loss associated with US import tariffs (the mtax column). This efficiency effect includes total changes resulting from US tariffs on all commodities and all countries, so it still includes second-best effects
    - Double-click on any number to return to the welfare summary page

14. Identify second-best allocative efficiency effects using the GTAP welfare decomposition utility tool – decompose the effects of the US MFG surcharge on ROW
    - On the welfare summary page, double-click on Trade Tax Effect: Explanatory Factors

      This table decomposes the efficiency effect by sector and by region. You can view the elements of the decomposition by setting the toggles on the upper right side of the page.
    - Set the toggles on the upper right side of the page to display allocative efficiency effects from US tariffs on all goods imported from ROW:

      All COM | ROW | USA | All Col | Import

      The table reports the welfare effect of US tariffs, in $US millions in the column labeled "welcnt" (the contribution to the total welfare effect). Calculation of the welfare effect is based on the initial and final tax rates for each commodity and the change in volume of trade.

      An import tariff reduces welfare if its price distortion leads to reduced imported quantities – a resource misallocation that causes deadweight efficiency losses. In the presence of a tariff, even if it is unchanged in the experiment, an increase in import volume is welfare-enhancing because it reduces the misallocation, whereas a further reduction of import quantities reduces welfare. Based on tariff rates and changes in import volumes, can you explain why welfare changes due to the import tariff surcharge in US AGR, even though that tariff did not change? Can you explain why there is no change in welfare associated with changes in the volume of US services imports?
    - Report the allocative efficiency effects of US tariffs on MFG imports from ROW in row 3 in Table ME 7.4
    - Close the HAR file by clicking on the X in the upper right corner
    - In row 4 of Table ME 7.4, subtract row 3 from row 1 to calculate the total allocative efficiency effect of taxes, excluding the US import tariff in MFG. This is the "second-best" welfare effect that results from the interaction between the change in the US import tariff on ROW's MFG and all other taxes in the US tax system

Table ME 7.4 *Decomposing second-best allocative efficiency effects of 5% surcharge in US MFG tariff on ROW*

Row	Type of efficiency change	Allocative efficiency effect ($US millions)
1	Total allocative efficiency effect (from Table ME 7.3)	
2	Total efficiency effect from import tariffs	
3	Effect from US MFG tariff on ROW	
4	Second-best efficiency effect (row 1 minus row 3)	

15. Define the second experiment: USA and ROW tariff surcharges on manufacturing
    - Select the “Shocks” page tab
      The US MFG tariff surcharge shock on ROW should be displayed. You will add the ROW tariff surcharge on US imports of MFG from ROW as a second shock element in this experiment.
    - From the drop-down menu “Variable to shock,” choose variable “*tms*”
    - Select these elements of *tms*: MFG, USA, ROW
    - Define a shock value using the updated tariff in Table ME 7.1
    - Select Type of Shock: “% target rate”
    - Click on “Add to shocks list”
16. Decompose the impacts of US and ROW’s tariff shocks using the GTAP Subtotal utility
    Define US MFG tariff surcharge on ROW as a “Subtotal” in your results
    - On the Solve page, click on “Define subtotal” button. This opens a dialogue box, shown in Figure ME 7.1, where you define each subtotal. You can wait and define all of your subtotals after you have finished setting up your experiment file, as we do in these instructions, or you can define each subtotal after defining the shocks to be included in it
    - Select variable: *tms*
    - Select elements: “MFG”, “ROW” and “USA”
    - Click on “Add variable to the subtotal”
    - OK
    - Name it “USA tariff”
    - OK
      Define ROW MFG tariff surcharge on USA as a “Subtotal” in your results

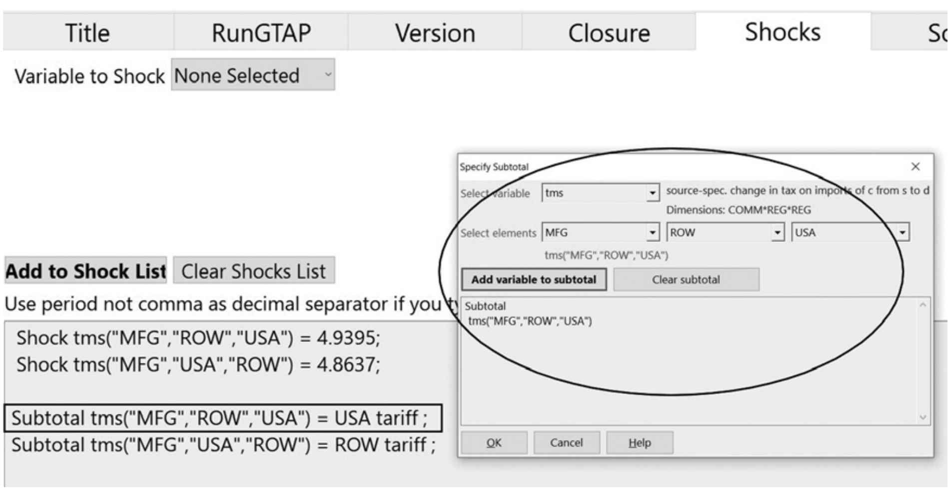


Figure ME 7.1 Defining subtotals in trade war experiment

- Select variable: *tms*
- Select elements: "MFG," "USA," and "ROW"
- Click on "Add variable to the subtotal"
- OK
- Name it "ROW tariff"
- OK

17. Save the experiment file
    - Select the "Solve" page tab
    - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box and then click on "OK"
    - Check that the parameter file is "Default". If it is not, click on "Change," select default.prm from the box and click OK
    - Click on "Save experiment," name the shock TRDWAR2, and describe it as "US and ROW tariffs on MFG"
18. Solve the model
    Still on the "Solve" page tab, select
    - Solve
    - OK
    - OK
19. After running the experiment, check that the updated tax rates are those you expect to find in your experiment, following the directions in step 9. Do the new tariff rates for ROW's MFG imports from the US match those in Table ME 7.1?
20. Report the subtotals of the welfare effects of US and ROW MFG tariff surcharges
    - Click on the Results page tab
    - Click on variable EV – equivalent variation in $US millions. The welfare results are decomposed into Sim (this is the total welfare impact), and the two subtotals that you defined for the US tariff and ROW tariff
    - Report the EV welfare results in Table ME 7.5
21. Use the welfare decomposition utility to decompose the welfare effects of the trade war
    - Select "View" from the menu bar
    - Select updated data from the drop-down menu
    - Select welfare decomposition from the drop-down menu

Table ME 7.5 *Welfare effects of trade war by region and by policy ($US millions)*

	Total	US MFG tariff surcharge on ROW	ROW MFG tariff surcharge on US
United States			
ROW			

Source: NUS333 model.

Table ME 7.6 *Decomposition of the total welfare effect of the trade war ($US millions)*

	Allocative efficiency	Terms of trade in goods and services	Terms of trade in savings–investment	Total
United States				
ROW				
World				

Source: NUS333 model.

- On the welfare summary page, click on the first row "EV decomposition summary"
- Report results in Table ME 7.6

Interpret Model Results

1. Did the results of the TRDWAR1 experiment align with the expected signs, based on your theoretical model of the effect of an import tariff? What are the pros and cons of using a theoretical model as a starting point for your empirical CGE analysis? What steps would you take if the results were unexpected? What other theoretical models from our textbook might you use when setting up this experiment and reviewing results?
2. Explain the meaning of a change in the equivalent variation measure of welfare. How important is the allocative efficiency effect versus the terms-of-trade effect? Can the US "win" from a unilateral increase in its MFG tariff on ROW in terms of the welfare impact?
3. What are allocative efficiency effects? What are second-best allocative efficiency effects? In TRDWAR1, what other taxes make important contributions to the total allocative efficiency effect? What are the second-best allocative efficiency effects, which you calculated in Table ME 7.4? How do you think the total allocative efficiency effect and total welfare impacts of the trade war on the US might vary depending on the level of other distortions in its overall tax system?
4. What does the GTAP subtotal utility do? Looking at model results for TRDWAR2, reported in Table ME 7.5, do the subtotals for each region sum to the total welfare effect of each region? If they do not, what kind of error might you have made?
5. Based on the subtotals of the welfare impacts of TRDWAR2, reported in Table ME 7.5, which elements contribute most to increasing or decreasing US welfare? Based on this decomposition of the welfare impacts, do you agree with the argument that a trade war is easy for the US to win? Why or why not?

6. What does the terms-of-trade effect measure? How important are the terms-of-trade effects in your TRDWAR2 model results? Explain why the terms-of-trade gains and losses to each region in Table ME 7.6 offset each other in your two-region model (ignore any small residual global terms-of-trade effect).
7. Using the welfare decomposition utility, on the Trade Tax Explanatory Factors page (in step 14), explain why a decline in the US volume of MFG imports from ROW leads to a welfare loss. Explain why there is a zero trade-tax welfare contribution made by US services.
8. Which elasticity parameter in your CGE model most directly influences the terms-of-trade results in your model? Explain why.

Model Exercise 8: The Marginal Welfare Burden of the US Tax System

Concepts: Taxation, Direct and Excess Tax Burdens, Welfare Decomposition, Systematic Sensitivity Analysis

Background

The US tax system was the subject of some of the earliest applications of CGE models. An influential contributor to this body of research was the economist team of Charles Ballard, John Shoven, and John Whalley. They developed a recursive dynamic CGE model that supported several analyses of US taxes, including Ballard, Shoven, and Whalley (1985). Their CGE model of the United States was based on a 1973 database with 19 industries, 12 household types, and 8 types of taxes. Their model solved first for a baseline time path of the economy's growth. Their experiments then introduced changes in US tax rates. The results of their model experiments plotted alternative time paths of US economic growth, with and without the tax changes.

In their 1985 study, the team used their CGE model to analyze the combined marginal excess burden – the deadweight efficiency losses – of all taxes in the US economy. The marginal tax rates in their model, reported as the average rates across industries and commodities, are presented in Table ME 8.1. As in your model, their tax rates are reported as the rate paid on net-of-tax income or net-of-tax expenditure. For example, if the tax paid on $1 of dividend income was 50 cents, then the individual would retain 50 cents in net-of-tax income. In this case, the tax rate would be 100% of net income.

Their experiments were a 1% increase in every tax rate in the US economy simultaneously and a 1% increase in each tax rate at a time. In this dynamic model, tax changes influenced households' savings rates and therefore the accumulation of capital and investment in the economy. Tax changes also influenced households' decision about how many hours to work. And, as in our standard, static CGE model, taxes led consumers and producers to

Table ME 8.1 *Level and dispersion of tax rates in the Ballard, Shoven, and Whalley model*

	Average marginal tax rates
Capital and property taxes	0.97
Labor (factor use) taxes	0.101
Consumer sales taxes	0.067
Output and excise taxes	0.008
Motor vehicle taxes	0.052
Personal income taxes	0.239

Source: Ballard, Shoven, and Whalley (1985).

change the quantities they produced and consumed as taxes changed the relative prices of goods and services. Together, changes in investment and the supply of labor, and resource reallocation altered the growth path of the economy. The authors also explored the sensitivity of their results to alternative elasticity parameter values for labor supply and household savings.

The team found that, depending on the elasticities, the marginal excess burden of the US tax system ranged between 17 cents and 56 cents per dollar of additional tax revenue (Table ME 8.2). This meant that government projects to be funded by the tax increase would have had to yield benefits at least 17% greater than the amount of the additional tax revenue in order to compensate for the tax-induced loss of economic efficiency. After changing one tax at a time, they concluded that the consumer sales tax was the most distorting of the US taxes (Table ME 8.3).

Based on their findings, Ballard and colleagues argued that plans for public spending on projects or on income transfers, such as welfare payments, needed to take into account the efficiency losses incurred by raising additional tax revenue. They also argued that the large marginal excess burden of taxes conversely offered opportunities, because there could be large marginal efficiency gains from small reforms in taxes.

Table ME 8.2 *Marginal excess burden per additional dollar of revenue for US taxes*

	Saving elasticity		
Labor supply elasticity	0.0	0.4	0.8
0.0	0.17	0.21	0.24
0.15	0.27	0.33	0.38
0.30	0.39	0.48	0.56

Source: Ballard, Shoven, and Whalley (1985).

Table ME 8.3 *Marginal excess burden per dollar of additional revenue from specific portions of the tax system*

Uncompensated saving elasticity	0.0	0.4	0.0	0.4
Uncompensated labor supply elasticity	0.0	0.0	0.15	0.15
All taxes	0.17	0.206	0.274	0.332
Capital taxes	0.181	0.379	0.217	0.463
Labor taxes	0.121	0.112	0.234	0.230
Consumer sales tax	0.256	0.251	0.384	0.388
Sales tax on commodities other than alcohol, tobacco, gas	0.035	0.026	0.119	0.115
Income taxes	0.163	0.179	0.282	0.314
Production taxes	0.147	0.163	0.248	0.279

Source: Ballard, Shoven, and Whalley (1985).

Experiment Design

In this exercise, you will replicate the Ballard, Shoven, and Whalley (1985) study using the NUS333 model. There are differences between your model and theirs that are likely to lead to differences in your results. Your model has a 2007 database, and you will be asked to see how its tax rates differ from the 1973 rates described in Ballard et al.'s analysis. Your model is aggregated to three production activities and three commodities and a single household so there is less scope for distortions in the relative prices of goods, and the efficiency losses from similar tax increases could therefore be smaller in your model. Also, Ballard and colleagues used a recursive dynamic CGE model while yours is a static CGE model with a fixed supply of capital. Therefore, by assumption, your model will not account for taxes' effects on the supply of savings and investment and the effects on productive capacity over time. In addition, income taxes influence labor supply in their model, whereas the labor supply is fixed in your model. On the other hand, your model has important capabilities that theirs did not. Because it is a multi-country model, your measure of the welfare effects of tax reform includes not only the excess burden of taxes but also their terms-of-trade effects. Also, the welfare decomposition utility of the GTAP model allows you to decompose the contributions of each type of tax to the total excess burden, instead of running separate experiments. Finally, the SSA utility allows you to describe confidence intervals around your results as you test for sensitivity to one parameter, the factor substitution elasticity.

In this exercise, you will:

1. Change selected elasticity parameters.
2. Define and run an experiment that increases all US taxes by 1%.
3. Use the GTAP welfare decomposition facility to decompose the contribution of each tax to the excess burden of the tax increase.
4. Carry out a systematic analysis of the sensitivity of welfare results to alternative assumptions about the factor substitution elasticity.

Instructions

1. Open GTAP NUS333 model version
   This step opens the NUS333 "version" of the GTAP model. You downloaded this version of the model in Model Exercise 1.
   - Open RunGTAP
   - On the top menu bar, choose "Version"
   - "Change"
   - Select "NUS333"
   - OK

2. Prepare your model to run an experiment check closure
   - Select the "Closure" page tab

   Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.
3. Prepare your model to run an experiment – check shocks
   - Select "Shocks" page tab
   - Clear shock list

   This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce.
4. Change these elasticity parameters and save a new parameter file (see instructions in Model Exercise 3)
   - ESUBVA (factor substitution elasticity) = 2 in all production activities in USA and ROW
   - ESUBD (demand substitution between imported and domestic) = 6 for all commodities in USA and ROW
   - ESUBM (demand substitution among imported varieties) = 10 for all commodities in USA and ROW
   - Save the new parameter file and name it "Ballard.prm"
5. Define your experiment
   - Select Shocks page tab
   - Select, sequentially, each of these tax rates: *tfe*, *tfd*, *tfm*, *tgd*, *tgm*, *to*, *tpdall, tpmall and tinc*
   - Select all elements for each tax for the US region only
   - Define shock value for each tax as 1
   - Define type of shock as "% change rate"
   - Select import tariffs by the USA on imports from ROW – tms(All COMM," ROW", "USA"). In a model with more than two regions, you would select import tariffs on all US trade partners, REG
   - Define shock value for import tariffs as 1 and its type as "% change rate"
   - Select export taxes by the USA on exports to ROW – txs(All COMM, "USA","ROW")
   - Define shock value for export taxes as 1 and type as "% change rate"
6. Your experiment page should look like Figure ME 8.1
7. Save the experiment file
   - Select the "Solve" page tab
   - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box, and then click on "OK"
   - Change your parameter file by clicking on "Change" next to "Parameter file: default," and select your new parameter file name, Ballard.prm
   - OK (this closes your parameter file dialogue box)
   - Click on "Save experiment," name the shock "Ballard," and describe it as 1% increase in all taxes
8. Solve the model
   - Click on Solve

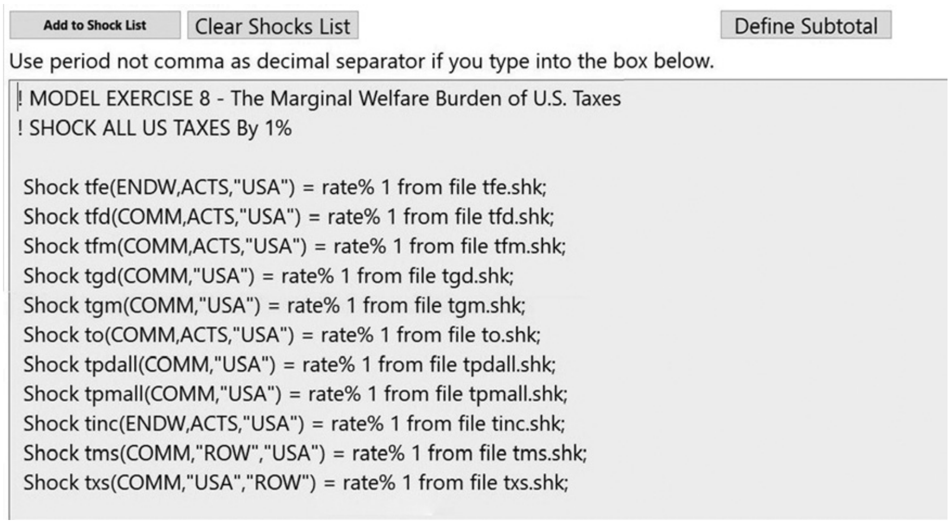


Figure ME 8.1 Shocks page in marginal welfare burden experiment

- OK
- OK

9. Report results from the welfare decomposition utility in Tables ME 8.4 and ME 8.5
   - Select "View" from the menu bar
   - Select "Updated data" from the drop-down menu
   - Select "Welfare decomposition" from the drop-down menu
   - Select "EV Decomposition Summary" (row 1) and report results in Table ME 8.4. For now, leave the last two columns in that table blank
   - Return to main menu of decomposition by double-clicking on data anywhere in the matrix
   - Select "Allocative efficiency by tax type" (row 3) and report results in Table ME 8.5
   - Close the HAR file by clicking on the X in the upper right corner
10. Calculate the change in total government tax revenue by comparing the pre and post-experiment tax revenues. Find the base tax revenue value by selecting from the top menu bar:
    - Select "View" from the menu bar
    - Base data
    - GtapView Output
    - Double-click on GDPSCR (GDP from the income sources side)
    - Report NETAXES (tax revenue) for the US in "a," below
    - Close the HAR file by clicking on the X in the upper right corner
    - Report updated tax revenue data in "b", below, by repeating these steps but choosing "Updated data" instead of "base data"
    - Close the HAR file by clicking on X in the upper right corner

Table ME 8.4 *Welfare effects of a 1% increase in US taxes ($US millions)*

Allocative efficiency	Endowment	Technology	Population	Terms of trade in goods and services	Terms of trade in investment–savings	Preference	Total welfare cost	Change in government tax revenue	Welfare cost (cents) per dollar of revere

Source: NUS333 model version.

- Calculate the change in tax revenue by subtracting the old revenue from the new revenue. Report this in "c" and in the second-to-last column of Table ME 8.4
  a. Base government tax revenue ($US millions) ____________________
  b. Updated government tax revenue ($US million) ____________________
  c. Change in government tax revenue ($US million) ____________________
- Report the change in tax revenue in Table ME 8.4
- Calculate the marginal welfare burden per dollar of tax revenue as:

Change in welfare/change in government tax revenue *100 = __________

11. Carry out a SSA of model results to changes in the elasticity of factor substitution (ESUBVA) parameter. Follow the instructions in Model Exercise 3, and use the information below as your inputs to the SSA utility
    - Parameter to vary: ESUBVA
    - Elements to vary: All ACTS, All REG
    - Percent variation: 100 (the sensitivity analysis will vary the ESUBVA elasticity parameter value between close to zero and two times the base parameter value, or 4)
    - Type of variation: Percent (this is the default choice)
    - Type of distribution: triangular (it is similar to a bell curve distribution and is the default choice)
    - Select add to list (this places your selected parameter into the list that will be varied in the SSA)
    - OK
    - OK (this accepts the default settings, including the Stroud quadrature)
    - Save (this saves your solution files)
    - OK
    - Yes (this saves your two solution files)
    - OK
    - Name your two solution files or accept their default names: *me8 – ss1 – s – sd* and *me8 – ss1 – s – m1*
    - Open and view the files with the sensitivity analysis results[5]
12. Report results from the ViewSol file for US equivalent variation measure of welfare (EV):

EV __________________
Mean ________________
Standard deviation _______

[5] Note that you must have a GEMPACK license to view the results. Temporary educational licenses are available for free from GEMPACK and the Centre of Policy Studies at Victoria University in Melbourne, Australia. Their website is www.copsmodels.com/gpeidl.htm

Interpret Model Results

1. Based on your results, what is the direct burden of the marginal tax increase? What is its excess burden (allocative inefficiency)?
2. Calculate the marginal welfare burden of the US tax system. Total welfare cost/change in government tax revenue ∗ 100 = Marginal welfare burden.
3. Define the marginal welfare burden that you calculated in problem 2. Explain how you would use your answer to problem 2 to advise policymakers considering a US tax increase to fund a government project.
4. According to results reported in Table ME 8.5, which tax contributes the largest marginal welfare effect? The smallest (excluding government tax)? Use data from the US SAM to comment on your result for the consumption tax.
5. How important is the terms-of-trade gain in goods and services in the welfare results? Explain what a change in this component of terms of trade means. Why is it included in the welfare measure?
6. How does your finding on the marginal welfare cost per dollar of marginal revenue compare with the findings of Ballard, Shoven, and Whalley? What are some of the differences between your CGE models that might account for differences in results?
7. View the initial tax rates in your model and compare them with those of Ballard, Shoven, and Whalley. Although your tax rate definition differs from that of Ballard, Shoven, and Whalley, how do you think the differences in your data might account for different model results?
8. Using the results of the SSA on the elasticity of factor substitution (ESUBVA) and Chebyshev's theorem (see Model Exercise 3), define the range of value for the US equivalent variation welfare effect in which you have 75% confidence and 95% confidence. Based on your sensitivity analysis of the elasticity, do you think that your equivalent variation welfare result is a robust finding?

Table ME 8.5 *Welfare decomposition of the allocative efficiency effect ($US million)*

Tax type	Welfare cost
Production tax (prodtax)	
Factor tax (pfactax)	
Income tax (inctax)	
Input tax (inputtax = *tfd* + *tfm*)	
Private consumption tax (contax = *tpd* +*tpm*)	
Investment tax (invtax = *tid* + *tim)*	
Government tax (govtax = *tgd* + *tgm*)	
Export tax (xtax)	
Import tax (mtax)	
Total	

Source: NUS333 model. Experiment is a 1% increase in all US taxes.

Model Exercise 9: Climate Change – the World in 2050

Concepts: Baseline Scenario, Counterfactual Experiment, Closure, Factor Productivity, Integrated Assessment

Background

The Fifth Assessment of the Intergovernmental Panel on Climate Change reports that the "(w)arming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased" (IPCC, 2013). Understanding the potentially enormous implications of climate change for humanity has united experts from both the physical and social sciences in increasingly integrated and collaborative research.

The integrated research process begins with global climate models (GCMs). GCMs utilize physical, chemical, and biological principles to simulate the interaction of the atmosphere, oceans, land surface, snow ice, and permafrost and their responses to rising levels of greenhouse gases. GCMs also take into account alternative projections of socioeconomic "pathways" that include population, income growth, energy use policies, and other variables that influence levels of greenhouse gas emissions. Using different combinations of socioeconomic pathways and assumed greenhouse gas emission levels, GCMs provide a range of projections for future changes in Earth's climate. Projected climate changes from GCM models are used as inputs into biophysical models. These models use mechanical or statistical methods to simulate the effects of projected climate change on biological and physical processes and systems such as crop yields, water supply, and human health and productivity. The projections from the biophysical models are then used as inputs into economic models, such as CGE models, to simulate economic responses to the physical impacts of climate change and to explore the effectiveness of alternative policies to either combat or adapt to it.

Informed and effective climate change policies crucially depend on the availability and credibility of sound economic analyses. Yet so far, a comparison of the results from economic models shows substantial differences in their projections of the effects of climate change on key economic variables (Nelson et al., 2014). To better understand why the models' results diverge, economists from leading research organizations around the world worked collaboratively to critically compare their research on economic responses to climate change in a project called the Agricultural Model Inter-Comparison Project (AgMIP) (Nelson et al.) Nine models, including five CGE models, were included in AgMIP. The researchers' objective was to introduce a common set of climate change and crop yield inputs into their economic models, so that any divergences in economic responses could be understood in terms of differences in the structure and parameters of the economic models.

The economists began by agreeing on seven scenarios of the biophysical crop yield changes to be introduced as shocks into their models. The crop yield shocks were based on combinations of projections from two GCMs and five biophysical models. The GCMs' scenarios combined a representative (greenhouse) gas concentration pathway (RCP) of 8.5, which is the most extreme of the emissions scenarios, with the Shared Socioeconomic Pathway #2 (SSP2). The SSP2 describes a middling pathway of global socioeconomic development, with moderate achievements and challenges in achieving economic growth and development, maintaining the capacity of global institutions, and undertaking mitigation and adaptation to climate change. The resulting outcomes from the GCMs for climate conditions in 2050 were then introduced into five crop yield models to simulate the impacts of climate change (assuming no yield benefits from rising CO_2) for four crop groups and thirteen regions. The biophysical models predicted an average crop yield decline of 17% in 2050 across the scenarios, crops, and geographic regions.

The economists were asked to compare economic variables in 2050, with and without climate change. To develop the same 2050 baseline scenario, without climate change, they all used the same projections through 2050 for population and GDP growth from the SSP2 scenario, and adopted the same exogenous projections for growth in cropland area and yields, and endowments of labor and capital. Their counterfactual climate change experiment included the same growth projections as in the baseline scenario, with the addition of crop yield shocks from the biophysical models of climate change. A comparison of results between their baseline scenario and their counterfactual, climate change experiment described the effects of climate change on economies in 2050. The differences in models' results largely stemmed from differences in their depiction of land use and yield responses, and in the propensity to trade.

All of the economic models describe producer and consumer responses to the decline in crop yields. The decrease in crop production causes prices to rise. Depending on the economic models' capabilities, producers respond to higher prices by intensifying their cultivation practices (and raising yields) and by expanding their cultivated area. These economic responses moderate the projected yield and production impacts from climate change that are estimated in the biophysical models. Consumers react to higher food prices by reducing the quantity of food demanded. Trade has a role in bridging supply and demand across regions.

A comparison of the models' results show that, on average, producers' compensating behaviors reduce the decline in mean crop yields from 17% to 11% and increase the crop land area by 11%, resulting in a mean decline in production across countries and commodities of only 2%. Food consumption declines only slightly, by 3% on average, despite an average increase in the producer prices of crops of 20%. The share of global trade in world food production increases by one percentage point, indicating that trade has a role as an adaptive mechanism. In general, models concur that a large part of the adjustment occurs in production and trade responses, although the sizes of these responses vary substantially across models. Consumption responses are relatively small and diverge little across models.

Experiment Design

In this model exercise, you are going to carry out an economic analysis of climate change that is part of an integrated modeling framework that links the impacts from global climate models, through biophysical crop models to your economic model. You will construct a baseline scenario and define a counterfactual experiment.

The baseline scenario describes the US and ROW economies in 2050 with a constant, unchanged climate. To develop the baseline, you will supply your model with projections for 2010–2050, the period analyzed by AgMIP participants, for five macroeconomic variables: real GDP, population, and supplies of land, labor, and capital (Table ME 9.1). Because your model has a 2007 base year, we add historical growth rates for 2007–2010 to the AgMIP projections for some variables to develop projections for your 2007–2050 baseline.

Real GDP growth is an endogenous variable in your model, so you cannot define a shock to its value in the same way that you can shock exogenous variables like the labor supply, or exogenous parameters like a tax rate. So,

Table ME 9.1 *Projections for baseline scenario, 2007–2050*

	Real GDP (*qgdp*)	Population (*pop*)	Labor force (*qe*)	Physical capital (*qe*)	Arable land (*qe*)
United States	109.6	32.3	24.1	60.6	–0.93
Rest of world	284.5	37.3	38.4	213.1	4.4

Sources: Projected real GDP and population for 2010–2050 are from the SSP2 scenario, SSP Database v. 0.9.3 (2012). Projected labor force and physical capital growth for 2010–2050 are from Foure et al. (2012). Arable land projections for 2007–2050 are from Bruinsma (2011). Actual growth rates for 2007–2010 for other variables are from World Bank Development Indicators, except physical capital growth, which is estimated.

before you create the baseline scenario, you will first carry out an experiment that redefines real GDP as exogenous. In this experiment, you will change the model closure to make real GDP exogenous and total output productivity endogenous in both regions. Your experiment shocks also will include all macro projections in Table 9.1, in addition to projected real GDP growth. You will solve the model to find the projected changes in productivity over 2007–2050 that are necessary for each region to reach its projected level of real GDP growth. In your baseline scenario, you will restore the original model closure, in which real GDP is endogenous and productivity growth is exogenous, and you will impose the solution values for the changes in regions' productivity growth into your baseline experiment, replacing your real GDP projections. Your baseline shocks will also include the projected changes in population and factor supplies. The solution to your baseline scenario should replicate your baseline GDP projections, although there may be small differences due to the large size of the baseline shocks. Your baseline describes the world economy in 2050 in the absence of climate change.

The counterfactual experiment describes the US and ROW economies in 2050 with climate change. The shocks in this experiment impose the same factor endowment and productivity projections as in the baseline scenario but will also include the projected effects of climate change on land supply and agricultural productivity from AGMIP. The differences in results between the baseline scenario and the counterfactual experiment, including the climate change shocks, describe the effects of climate change in 2050.

This exercise introduces you to the core elements of creating a baseline scenario and a counterfactual experiment. However, the NUS333 is a highly stylized toy model, and there are important differences between your study and the AgMIP analyses. First, some AgMIP models assume an endogenous land supply, which allows crop area to expand as crop prices rise, and these area changes are not the same everywhere. Because your CGE model assumes a fixed land supply, you will impose the average, global 11% increase in agricultural area in 2050 reported by AgMIP models on both regions in your model. Also, some AgMIP models account for farmers' intensified management practices, which moderate the mean global crop yield decline of 17% projected in the crop models. Because your CGE model does not account for endogenous yield responses, your climate change experiment will impose the final mean yield change for crops of –11% in 2050 reported by AgMIP models. Third, the AgMIP models describe an exogenous productivity growth trend in agricultural yields, which you do not include in your analysis. Also, the NUS333 model has a single agricultural sector. Imposing the climate change experiment on total agriculture in each region, rather than on specific crops, likely overstates the economy-wide impacts of the climate change shock. In addition, the ROW is a highly aggregated single region, so that the role of trade in bridging matching changes in food supply and demand cannot be fully explored.

Instructions

1. Open GTAP NUS333 model version
   This step opens the "version" of the GTAP model that uses the NUS333 database. You downloaded this version of the model in Model Exercise 1.
   - Open RunGTAP
   - On the top menu bar, choose "Version"
   - "Change"
   - Select "NUS333"
   - OK
2. Prepare your model to run an experiment – check closure
   - Select the "Closure" page tab
     Check that no closure changes are lingering there. The closure should end with "Rest Endogenous." If not, erase all text below that line.
3. Prepare your model to run an experiment – check shocks
   - Select "Shocks" page tab
   - Clear shock list
     This check ensures that there are no shocks lingering in your experiment other than those you want to introduce.
4. Change parameter values for income elasticity (INCPAR)
   Follow the instructions for changing and saving elasticity parameter values in Model Exercise 3 to change the income elasticity parameter (INCPAR) for AGR in all regions to 0.05. Save it as a new parameter file with a name like "ClimateChange." This low income elasticity of demand better describes the long-run insensitivity of consumer demand for food as their incomes increase.
5. Select model solution method and parameter file
   - Select "Solve" page tab
   - Click on "Change" (this button is to the upper right corner of page)
   - Select "Gragg"
   - Select automatic accuracy. This opens a box with options for the model's solution. Leave all the options at their default values. This method breaks the large economic changes that occur over 2007–2050 into more and smaller linear steps until results meet the solution accuracy targets
   - OK (this saves your selected solution method)
   - Click on the parameter file box, and change the file from "default" to Climatechange," the parameter file you created in step 4
6. Change model closure to swap real GDP with total output productivity (aoreg) by region
   - Select the "Closure" page tab
   - Below "Rest Endogenous" add: swap qgdp(reg) = aoreg(reg);

7. Develop the baseline scenario using macroeconomic projections in Table ME 9.1
   a. Develop real GDP shocks
      - Select the "Shocks" page tab
      - Select from the "Variable to Shock" drop-down menu: *qgdp*
      - Select from the "Elements to Shock" drop-down menu: USA
      - In "Percent Change Shock" box, enter the projected value of US real GDP growth from Table ME 9.1
      - Click on "Add to Shock list"
   b. Repeat these steps to define the real GDP shock in ROW, and the changes in both regions for population (*pop*) and endowments (*qe*) of land, labor and capital.
8. Solve the model
   - Select the "Solve" page tab
   - Click on "Save experiment," name it something like "BASE1" and describe it as "2010–2050 baseline with exogenous GDP"
   - Click on "Solve"
   - OK
   - OK
9. Report in Table ME 9.2 your results for productivity growth only (you will report changes in real GDP later)
   Select the Results page tab and view results for the productivity variable. It is described as variable *ao* on the results page. Notice that it is identical for all sectors. Report the productivity results to the second decimal place.
10. Restore original model closure and rerun the baseline scenario
    In this step, you will remove your model swap on the model closure page; this makes real GDP endogenous and the *aoreg* productivity variable exogenous.
    - Select the "Closure" page tab
    - Erase the closure swap between qgdp and aoreg
      Alternatively, you may turn off this closure swap by placing an explanation mark at the beginning of the statement. This is handy if you want to turn on/off a swap or shock statment that you want to use again
    - Select the "Shocks" page tab
    - Erase (or place an exclamation mark in from of) the qgdp shocks that define the targeted gdp growth rates
    - Select from the shocks list "aoreg"
    - Define the aoreg shocks for US and ROW using the values you reported in Table ME 9.2
    - Select the "Solve" page tab
    - Check that the solution method is Gragg automatic accuracy and that the parameter file is "ClimateChange." If not, select these options
    - Save your experiment, naming it "BASE2" and describing it as "2050 Baseline with Endogenous QGDP"
    - Solve the model

Table ME 9.2 *Solution values for percent changes in productivity and real GDP, 2007–2050*

	US	ROW
Total output productivity (*ao*)1/		
Real GDP (*qgdp*)		

1/ Results for *aoreg* are reported on the Results page tab as "*ao*." Real GDP growth rates are solution values in the baseline scenario.
Source: NUS333 model.

- Select the "Results" page tab, view results for qgdp and report them in Table ME 9.2. Note that these real GDP growth rates may vary slightly from the target growth rates. It is because the very large size of these shocks may affect model accuracy. By using the solution values as your baseline's real GDP growth values, instead of the target rates, you can be sure that any differences between the results from the baseline and your counterfactual experiment are due only to the effect of the climate shock
- Select the "Results" page tab, and report in Table ME 9.3 the results for both countries in the "Without climate change" columns

11. Define the counterfactual climate change experiment
    In this step, you will redefine the baseline experiment to include the projected crop area and yield shocks that result from climate change.
    a. Load the experiment "BASE2 – 2050 Baseline with Endogenous QGDP"
    b. Impose climate shock – increase the land used in agriculture by 11%
        - Delete (or place an exclamation mark in from of) the shocks to land supply (from Table ME9.1) that you defined in the baseline scenario
        - Calculate the net changes in agricultural land, including climate change, by adjusting the projected changes in land area by the 11% increase due to climate change. For example, the net change in US land area = (–0.93) + 11 = 10.07%. This is your new US land supply shock.
        - Select from the "Variable to shock" drop-down menu: *qe*
        - Select from the "Elements to shock" drop-down menu: Land
        - Select from the "Region" drop-down menu: USA
        - In the "% Change Shock" enter: 10.07
        - Click on "Add to Shock list"
        - Repeat to define the net change in agricultural land in ROW
    c. Impose climate shock – decrease agricultural yields in both regions by 11%
        - Select from the "Variable to shock" drop-down menu: *aoall*
        - Select from the "Elements to shock" drop-down menu: AGR and All REG
        - In the "% Change Shock" enter: –11
        - Click on "Add to Shock list"

Table ME 9.3 *Economic effects of climate change in 2050 (% changes 2007–2050)*

	United States			ROW		
	Without climate change (A)	With climate change (B)	Effect of climate change (B–A)	Without climate change (A)	With climate change (B)	Effect of climate change (B–A)
Real GDP (*qgdp*)						
Agricultural output (*qc*)						
Agriculture producer supply price (*pds*)						
Agriculture domestic sales (*qds*)						
Private household demand for AGR (*qpa*)						
Agricultural exports (*qxw*)						
Agricultural imports (*qmw*)						
Import share of agricultural consumption (*qmw–qds*)						
Export share of agricultural production (*qxw–qc*)						

Source: NUS333 model.

12. Solve the model
    - Select the “Solve” page tab
    - Check that the solution method is Gragg automatic accuracy and that the parameter file is “ClimateChange.” If not, select these options
    - Click on “Save experiment,” name it CCEXP, and describe it as “2010–50 with climate change”
    - Click on “Solve”
    - OK
    - OK
13. Report your results in Table ME 9.3 in the columns titled “With climate change”
14. Calculate the effects of climate change in 2050
    Subtract data in the column “With climate change” from data in the column “Without climate change” and report it in the column “Effect of climate change.”

Interpret Model Results

1. Explain the chain of models in your integrated economic assessment. What output is produced by each model and how is it used as an input into the next model in the integrated assessment?
2. Develop a theoretical model (as a graph of supply and demand in agriculture) to describe the effects of the climate change shocks on the US agricultural sector. Are your model results for agricultural production, private consumption (demand), and producer and consumer prices consistent with that model?
3. How did you change the closure when setting up your baseline scenario, and why? Why do you use the original closure in both your baseline scenario and in your climate change experiment?
4. What are the adjustments to climate change that you are assuming (that is, are exogenous) in your climate change experiment? What adjustments are endogenous?
5. What are the main sources of adjustment to climate change in your model? How do your results compare with those of the AgMIP findings that production and trade are key adjustment mechanisms?
6. How has the trade dependency of agricultural production and consumption changed? What do these results suggest to you regarding a trade policy strategy for the two economies to help deal with climate change?
7. What elasticity parameters or climate change shocks do you think might be important to examine further in a sensitivity analysis? Why?
8. A recent study of the effects of higher temperatures on humans projects a change in labor productivity by 2055 of –0.73% in the United States, and a global average labor productivity loss of about 2% (UNDP, 2016). Extend your climate change analysis to include these labor productivity shocks. Shock the variable afeall and define a reduction in labor productivity in all sectors in the US by –0.73% and in the rest of world by –2%. Describe your key findings.

Model Exercise 10: Successful Quitters – "MPOWER" Changing Attitudes toward Tobacco Use

Concepts: Baseline Scenario, Counterfactual Experiment, Changing Consumer Preferences, Parameter Uncertainty, and Systematic Sensitivity Analysis

Background

Tobacco addiction is a human and economic tragedy. Tobacco use now causes more than 8 million preventable deaths annually, according to the World Health Organization (WHO) (2020). Second-hand smoke is also deadly for nonsmokers, causing heart disease, cancer, and other illnesses that lead to an additional 1.2 million deaths annually. The economic burdens of healthcare and lost productivity associated with tobacco are enormous, totaling more than US $1.4 trillion annually, equivalent to 1.8% of the world's annual gross domestic product (GDP). The burden is heaviest in developing countries, which account for 80% of the world's tobacco users.

Globally, tobacco consumption has declined since the 1990s, but this broad trend masks differences among categories of countries, according to Goel and Nelson (2004). Their international comparison of smoking trends found that declining tobacco consumption is correlated with a country's stage of development. Approximately one-half of the high-and upper-middle-income countries in their data set witnessed a decline in per capita cigarette consumption in excess of 20% since the 1990s. In contrast, tobacco consumption increased over that period in half of the low-income countries in their study.

To help tackle the tobacco epidemic, the WHO Framework Convention on Tobacco Control (WHO FCTC), introduced in 2003, became the first global treaty to directly address a human health problem. Negotiated under the auspices of WHO, it also represents a paradigm shift in efforts to combat addictive substances. In addition to regulating tobacco supply, the treaty includes strategies to reduce tobacco demand. In 2007, WHO formalized its demand-reduction approach by developing the MPOWER program, an acronym for a set of programs that includes education, prevention, and cessation programs for tobacco use, bans on tobacco advertising, and increased sales taxes on tobacco products. Since MPOWER was introduced, its demand reduction measures have been adopted by countries of all sizes and income levels – an especially important accomplishment in lower-income countries where tobacco use has been increasing.

In this exercise, you will use the GTAP toy model version, NTOBAC10, to explore the economy-wide effects of the MPOWER program in reducing consumer demand for tobacco in ROW, a region that in this exercise is a proxy for lower-income countries. The model uses the GTAP v10 database, with a 2014 base year. It has two regions (USA and ROW), three factors (land, labor, and capital), and four commodities (AGR, Tobacco, MFG, and SER). First, you will develop a baseline scenario that describes projected changes in the US and ROW economies over the 2014–2030 time period. This is a "business as usual" scenario that describes changes in per capita demand for tobacco if there are no changes in tobacco-use policies. Next, you will introduce the MPOWER program, modeled as a reduction in the ROW income elasticity of demand parameter to describe a growing consumer aversion to tobacco use as incomes rise. (Text Box 10.1 describes an alternative approach to modeling preferences in an extension to a standard CGE model.) A comparison of the outcomes in the business-as-usual baseline scenario with those of the MPOWER experiment describes the effects of MPOWER on the US and ROW tobacco sectors and economies in 2030.

Changes in consumer attitudes toward particular products can have important consequences for an economy. Sometimes changing attitudes lead to a boom in consumer demand, such as the new popularity of organic foods. In other cases, consumers develop aversions, such as an avoidance of beef and dairy because of their association with methane emissions and the degradation of the environment. When the affected industries are important in a national economy, changes in consumer preferences can have significant economy-wide effects.

Experiment Design

To develop the baseline, you will supply your model with projections over the 2014–2030 time period for growth in five macroeconomic variables: real GDP, population, and supplies of land, labor, and capital (Table ME 10.1). Imposing macro-projections for 2014–2030 in your model describes a new

Table ME 10.1 *Cumulative growth rates for baseline scenario, 2014–2030*

	Real GDP (*qgdp*)	Population (*pop*)	Labor force (*qe*)	Physical capital (*qe*)	Land (*qe*)	Total factor productivity (*ava*)
United States	38.7	12.3	8.1	16.0	2.4	
Rest of world	61.1	16.2	10.3	42.0	3.7	

Sources: Growth rates for real GDP and population are from US Department of Agriculture (2018). US labor force growth rate is from the US Bureau of Labor Statistics (2019). ROW labor force projection is from ILOSTAT (2018). Land growth rate projection is from the Food and Agriculture Organization (2019). Capital stock projections are estimated, based on Foure et al. (2012). Projected TFP growth is an experiment solution value.

equilibrium in 2030, with higher levels of population, capital, labor, and output, as well as the level of tobacco consumption in 2030 in the absence of any policy interventions.

Real GDP growth is an endogenous variable in your model, so you cannot define a shock to its value in the same way that you can shock exogenous variables like the labor supply, or exogenous parameters like a tax rate. So, before you create the baseline scenario, you will first carry out an experiment that redefines real GDP as exogenous. In this experiment, you will change the model closure to make real GDP exogenous and total factor productivity (TFP) endogenous in both regions. Your experiment shocks will also include all macro projections in Table ME 10.1, in addition to projected real GDP growth. You will solve the model to find the projected changes in productivity over 2014–2030 that are necessary for each region to reach its projected level of real GDP growth. In your baseline scenario, you will restore the original model closure, in which real GDP is endogenous and productivity growth is exogenous, and you will impose the solution values for the growth in regions' TFP into your baseline shocks, instead of the real GDP projections. Your baseline shocks will also include the projected changes in population and factor supplies. The solution to your baseline scenario should replicate your baseline projections, although there may be small differences due to the size of the shock. Your baseline describes the world economy in 2030 in the absence of preference changes for tobacco.

The counterfactual experiment describes the US and ROW economies in 2030 with the MPOWER program in place. Your counterfactual experiment will include the same macro-projections to 2030 as in the baseline scenario, but will also include the implementation of the MPOWER program in ROW. You will represent the change in preferences due to its demand-reduction activities by reducing the value of INCPAR, the income demand parameter (see Text Box ME 10.1 for an alternative, "twist" approach). When this parameter is reduced, any given percentage increase in income will result in a smaller increase in consumers' tobacco purchases compared to the baseline scenario. You will reduce ROW's INCPAR to a value that reduces the quantity of tobacco consumption in ROW in 2030 by about 10%from the 2030 baseline consumption level. This is about one-half of the quantity reduction experienced in developed countries during the 1990s (Goel and Nelson).

You will select and compare results of the baseline and your MPOWER experiment to answer the questions: How will a change in consumer attitudes toward smoking in ROW affect both regions' tobacco industries and their national economies over the next decade? Given the uncertainty about the extent to which income growth may change consumer preferences, you will use the SSA utility with respect to the income parameter, INCPAR. This will allow you to describe model outcomes in terms of means, distributions, and confidence intervals.

Your model uses the GTAP version 10 database, with a base year of 2014, so macro-projections must cover a time period that starts in that base year. Table ME 10.1 presents macro-projections for 2014–2030, drawn from multiple sources, which describe the cumulative growth rates that you will use for your baseline scenario experiment. The growth rates for 2014–2018 are actual historical rates and those for 2018–2025 are projected.

There are some limitations to your analysis. One is that the model aggregates all countries except the United States in the ROW region. Because smoking rates are already falling in higher-income countries but still rising in middle-and lower-income countries, the ROW region includes countries that are experiencing diverse trends in tobacco use. A second limitation is that the GTAP database combines beverages with tobacco, so the representation of the "tobacco" sector in the model is not fully accurate. Third, it is difficult to predict how MPOWER will affect consumer preferences. The SSA with respect to the INCPAR parameter allows you to characterize the preference change as a probable range instead of a specific value.

Instructions

1. Download the GTAP model version NTOBAC10.ZIP from the GTAP website onto your computer, following the instructions in Model Exercise 1, Section C, for downloading the NUS333.ZIP file from the GTAP website. After installing your model, run a test simulation
2. View and report your model's income elasticity parameter (INCPAR)
   - From the menu bar, select: View > Parameters
   - Double-click on INCPAR – CDE expansion parameter
   - Report INCAR values for the US and ROW in Table ME 10.2
   - Close the HAR file by clicking on the X in the upper right corner
3. View and report your model's base private household budget shares
   - From the menu bar, select: View > Base data > GTAPView output
   - Double-click on NVPP – Cost Structure of Consumption
   - Click on the menu box on the upper left-hand corner of the page that says "None," and select "COL" from the drop-down menu. The "Col" view calculates each cell as a percent of the column total. In this case, the matrix displays budget shares of each commodity in total private household spending
   - Report your results to three decimal places in Table ME 10.3
   - Close the HAR file by clicking on the X in the upper right corner
4. Prepare your model to run an experiment – check closure
   - Select the "Closure" page tab

Table ME 10.2 *Base and updated INCPAR parameter values*

	Base INCPAR parameter values		Updated ROW INCPAR parameter values
	USA	ROW	ROW
AGR			
Tobacco			
MFG			
SER			

Source: NTOBAC10 model.

Table ME 10.3 *Private household budget shares under alternative scenarios*

	2014 Base		2030 Baseline		2030 in MPOWER scenario	
	USA	ROW	USA	ROW	USA	ROW
Agriculture						
Tobacco						
Manufacturing						
Services						
Total						

Source: NTOBAC10 model.

- Check that no closure changes are lingering there. The closure should end with “Rest Endogenous.” If not, erase all text below that line

5. Prepare your model to run an experiment – check shocks
   - Select “Shocks” page tab
   - Clear shock list
   - This check ensures that there are no shocks lingering in your experiment file other than those you want to introduce
6. Define the baseline scenario
   - Select “Closure” page tab
   - Make real GDP (*qgdp*) exogenous and total factor productivity (*avareg*) endogenous by adding this line after the “Rest endogenous;” line of code: swap qgdp(REG) = avareg(REG);
   - Select “Shocks” page tab
   - Using the values in Table ME 10.1, define the shock for each of these parameters, for each region. Your shocks page should look like Figure ME 10.1

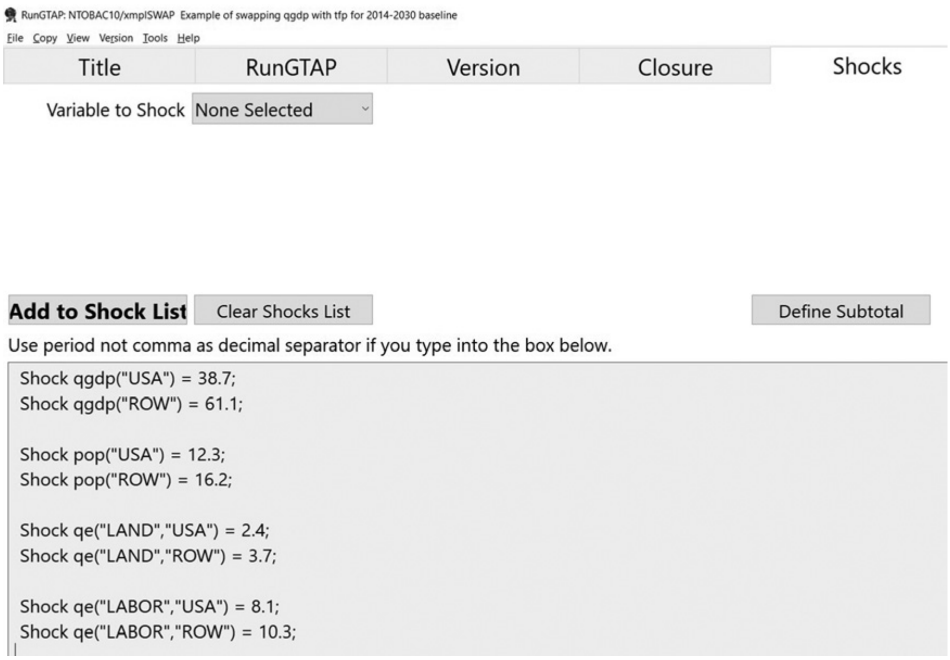


Figure ME 10.1 Shocks page for the smoking preference experiment

Real GDP: *qgdp*
Population: *pop*
Factor endowments: *qe* for land, labor, and capital in each region.

7. Save the experiment file
   - Select the "Solve" page tab
   - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box and then click on "OK"
   - Check that the parameter file is "Default". If it is not, click on "Change," select default.prm from the box, and click OK
   - Click on "Save experiment," name the shock "SWAP QGDP with AVAREG" or something similar
8. Solve the model
   - Click on "Solve"
   - OK
   - OK
9. View results for endogenous productivity growth
   - Click on results page tab
   - View results for ava (note, the difference in the variable name from avareg – both are the same variable) and report results to the first decimal place in Table ME 10.1

10. Prepare baseline scenario
    - Restore the original closure by clicking on the Closure page tab, and erasing the statement that swaps qgdp with avareg
    - Remove shocks to real GDP on the Shocks page by deleting (or placing exclamation marks in front of) the shock statement that defines the GDP growth targets
    - Define shocks to US productivity variable on the Shocks page by selecting:

      Variable to shock: avareg

      Elements to Shock: USA

      Percent change: input the solution value for the US productivity shock from Table ME 10.1
    - Follow the same steps to define shocks to ROW productivity variable on the Shocks page
11. Save the experiment file
    - Select the "Solve" page tab
    - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box, and then click on "OK"
    - Check that the parameter file is "Default". If it is not, click on "Change," select default.prm from the box, and click OK
    - Click on "Save experiment," name the shock "Baseline"
12. Solve the model
    - Click on "Solve"
    - OK
    - OK
13. Report updated private consumption budget shares in Table ME 10.3
    - To view new budget shares, follow the directions in Step 3, except select "Updated data." Report the new budget shares in the baseline scenario, to three decimal places, in Table ME 10.3
14. Report the change in baseline values of ROW *total* private tobacco consumption in 2030 in Table ME 10.4
    - On the same page as the budget shares, click on the menu box on the upper left-hand corner of the page that says "COL," and select "None" from the drop-down menu. The NONE view reports the level of private household consumption of all commodities, in $US millions. Report your results, with zero decimal places, in Table ME 10.4
    - Close the HAR file by clicking on the X in the upper right corner
15. Calculate the baseline percentage change in ROW per capita private consumption in Table ME 10.5

    Open results by clicking on the Results page tab. The GTAP model results report the percentage changes in private household consumption of each commodity *c* in each region (*qpa*) and the percentage changes in each region's population (*pop*). Report *qpa* and *pop* from your model results in Table ME 10.5. Review Text Box 2.1 in Chapter 2 on how to calculate the percent change in the quotient of two percentage change variables (total private consumption divided by population).

Table ME 10.4 *Total ROW private consumption of tobacco in 2030 in $US millions, baseline scenario compared to MPOWER*

	Baseline scenario	MPOWER	% Difference
Tobacco			

Source: GTAP model version NTOBAC10.

Table ME 10.5 *Calculating the percent changes in ROW per capita private consumption of tobacco in baseline and MPOWER scenarios, 2014–2030*

	Baseline scenario, 2014–2030			MPOWER scenario, 2014–2030		
	Private household consumption (*qpa*)	Population growth rate *(pop)*	Per capita consumption (*qpa – pop*)	Private household consumption (*qpa*)	Population growth rate *(pop)*	Per capita consumption (*qpa – pop*)
Tobacco						

Source: NTOBAC10 model.

In this case, you calculate the percentage change in per capita private household consumption as *qpa – pop*. Report the percentage change in per capita consumption in the table.

Report model results for percentage change in quantities of tobacco output and composite import changes, real GDP and TFP in Table ME 10.6. When creating a baseline, there sometimes may be be small differences between the projected real GDP and your baseline solution values, especially when the projection time period is long. If so, use your solution values in the comparison of the baseline and the counterfactual scenarios.

16. Prepare the MPOWER experiment
    - Change the INCPAR parameter value for tobacco in ROW to **0.01** and save the new parameter file as TOBAC.prm. (For detailed instructions on changing an elasticity parameter and saving a new parameter file, see Model Exercise 3.)
17. Define the MPOWER shock file
    - Open the Shocks page
    - The shocks page should contain the same shocks that you defined for the baseline scenario. The only difference between the baseline and MPOWER experiments is the assumed income elasticity of demand
18. Solve the model
    - Select the "Solve" page tab
    - Check that the solution method is Gragg 2-4-6. If it is not, click on "Change," select Gragg from the box, and then click on "OK"

Table ME 10.6 *Percent changes in output quantities, real GDP, and TFP, 2014–2030*

	Baseline scenario		MPOWER scenario	
	USA	ROW	USA	ROW
AGR output (*qc*)				
Tobacco output (*qc*)				
MFG output (*qc*)				
SER output (*qc*)				
Real GDP (*qgdp*)				
Total factor productivity (*ava*)				

Source: NTOBAC10 model.

- Change the parameter file to "TOBAC"
- Click on "Save experiment," name the shock MPOWER, and describe it as "2014–2030 with MPOWER"
- Click on "Solve"
- OK
- OK
- Report model results in Tables ME 10.3–ME 10.6. In Table ME 10.4, calculate the percentage difference between tobacco consumption in 2030 in the baseline scenario and the MPOWER scenario

19. Carry out a SSA of the degree of change in ROW attitudes about smoking as incomes grow (INCPAR). Follow the instructions in Model Exercise 3 and use the information below as your inputs to the SSA utility[6]
    - Re-run the MPOWER experiment by clocking on the Solve page and selecting:

      Load experiment > MPOWER > OK > Solve > OK > OK

    - From the upper menu bar, select "Tools"
    - From the drop-down menu, select "Sensitivity"
    - Select "wrt parameters"
    - Parameter to vary: INCPAR of TOBAC in ROW
    - Percent variation: 100%
    - Type of variation: Percent (this is the default choice)
    - Type of distribution: triangular (it is similar to a bell curve distribution and is the default choice)
    - Add to list
    - OK

[6] Note that you must have a GEMPACK license to view the results. Temporary educational licenses are available for free from GEMPACK and the Centre of Policy Studies at Victoria University in Melbourne, Australia. Their website is www.copsmodels.com/gpeidl.htm

Table ME 10.7 *Systematic sensitivity analysis of MPOWER preference changes on tobacco quantities in the rest of world*

	Model result	Mean	Standard deviation	95% Confidence interval	
				Upper	Lower
Production (*qc*)					
Private consumption (*qpa*)					

Source: NTOBAC10 model.

- OK (this selects the Stroud quadrature)
- Yes – saves all solution files
- OK – choose a name for the means file

20. Save – Name your two solution files or (recommended) accept their default names: *me8 – ss1 – s – sd* and *me8 – ss1 – s – m1*
    - Yes – look at results of the SSA
21. In Table ME 10.7, report the mean and standard deviation results for two variables: percent change in tobacco output, *qo*, in ROW and percent change in quantity of consumer demand, *qpa*, for tobacco in ROW
    - Click on the filter on the upper left labeled "Everything" and select ROW from the drop-down menu
    - Report experiment results for ROW's tobacco *qo* (from the first column)
    - Report the mean value for ROWs tobacco *qo* (from the second column)
    - Report the standard deviation of ROW's *qo* (from the third column)
    - Follow the same steps to report sensitivity results for ROW's household consumption quantities, *qpa*
22. Calculate the 95% confidence interval for both results, using Chebyshev's theorem (see Text Box ME 3.1)

Interpret Model Results

1. Explain the principles of building a baseline scenario using macroeconomic projections. Why do you carry out a closure swap between the real GDP and TFP variables as you prepare the baseline scenario, but swap it back to the original closure in the baseline and counterfactual scenarios? Why do you compare the results of the baseline and counterfactual scenarios?
2. Provide an intuitive explanation of the INCPAR parameter. Compare the base values for ROW's INCPARs for all three goods. Given these parameter values, how do you anticipate that income growth will affect their relative budget

Text Box ME 10.1 Preference Twists in CGE Models

There are many ways that preferences can change that have nothing to do with changing relative prices. For example, consumers consume less candy when dietary guidelines change. Preferences for imported versus domestic varieties of commodities, such as cars, can change as brands gain and lose popularity. Producers, too, can have changing preferences for their mix of labor and capital for reasons that have nothing to do with factor prices. One modeling approach to changing preferences is to introduce a preference "twist," developed by Dixon and Rimmer (2002). Imagine sticking a pin in the equilibrium point shown in Figure 4.2. Then swivel the indifference curve around that point. Because the original curve and the swiveled curve cross, they both describe the same level of utility. If you swivel the curve in one direction, then the ratio of oranges to apples is higher at the same level of utility and the same price ratio. If you swivel the curve in the other direction, then the ratio of applies to oranges is higher at the same utility and price ratio. Modelers introduce a preference twist by adding a parameter to equations that describe consumer and producer demand. For example, consumer demand for imported versus domestic commodity *c* becomes a function of the relative prices of the imported and domestic varieties, the Armington elasticity and the twist parameter. The value of the parameter can be estimated using historical data on changes in preferences over time, so that changes in the future include the same structural shifts in preferences as in the past. Or, modelers can change the twist parameter as part of an experiment to describe the effects of preference shifts that are expected to occur.

shares in your baseline scenario (with no preference change)? Are these expectations consistent with your model results?

3. Develop your predictions for model results by drawing a figure similar to Figure 4.3b that describes ROW's consumer demand for tobacco versus its consumer demand for services.
   a. Label the axes and curves, and label the initial market equilibrium as A (shown in Figure 4.3b as Q_O^1 and Q_A^1) to represent the 2014 consumer basket.
   b. Draw the effect of the increase in income over 2014–2030 on the consumer basket, assuming the base values of ROW's INCPAR parameters. (Assume relative prices remain constant.) Label the new market equilibrium as B.
   c. Draw the effect of an increase in income over 2014–2030 assuming the new INCPAR parameter with the MPOWER program. (Assume relative prices remain constant.) Label the new market equilibrium as C. How does the consumption basket at C compare to that at equilibrium point B?
   d. Are the results for ROW budget shares from your two CGE model scenarios, which you reported in Table ME 10.2, consistent with your simple theoretical model?

4. How do you expect that the changes in budget shares between the baseline and MPOWER scenarios will affect ROW's industry structure? Are your results for percentage change in industry output (*qo*) consistent with this expectation?
5. View the SAM in the NTOBAC10 database by opening the file "GTAPSAM.har" that is included in the ZIP archive that you downloaded in Step 1. You will find it in the file version folder in your RunGTAP directory – C:\RunGTAP70\NTOBAC10. In the HAR file, double-click on the row named "Aggregate Sam." View the ROW SAM by selecting "ROW" in the toggle in the upper right corner. Based on data from the SAMs for activity output in each country, how would you characterize the role of the tobacco sector in ROW's economy? Based on these shares, how would you describe the likely size of economy-wide effects in ROW of changes in its tobacco preferences? What are some examples of a consumer preference shift that could have more important economy-wide effects than smoking cessation?
6. Write a short paragraph that describes your level of confidence in your model results for ROW's tobacco output, *qo*, and consumer demand for tobacco, *qpa*. *Challenge:* present your results and your confidence interval in a graph, similar to that presented in Model Exercise 3.

Model Exercise 11: Deep Integration in a Japan–US Preferential Trade Agreement

Concepts: Preferential Trade Agreements, Trade Creation, Trade Diversion, Nontariff Measures, Altertax

Background

In September 2019, Japan and the United States finalized a limited bilateral trade agreement consisting of tariff cuts on agricultural and manufactured goods and commitments on digital trade. Both sides see the pact as an initial step in deepening their bilateral trade relationship and they intend to soon begin negotiations on a more comprehensive preferential trade agreement (PTA) (Congressional Research Service, 2019). In this model exercise, you will analyze the potential effects on Japan, the United States, and the ROW of a "deep integration" of the US and Japan economies if they succeed in achieving a comprehensive agreement to both eliminate bilateral tariffs and reduce nontariff measures (NTMs) that inhibit their trade.

An analysis of the potential economic impacts of deep integration in a PTA is a challenging undertaking compared to modeling the elimination of import tariffs. Import tariff rates are readily available to researchers because they are published by governments and other organizations. In the CGE model, the economic effect of a tariff is to increase the domestic price of imports by the same proportion as the *ad valorem* tariff rate, which generally causes import quantities to fall and reduces economic efficiency and welfare. Eliminating a tariff has the opposite effects. In contrast, there are many different types of NTMs, such as import licensing and technical regulations, and their restrictive effects on trade are not transparent. Nevertheless, their trade effects must be measured and explicitly incorporated into the CGE model before the modeler can accurately and confidently analyze the impacts of their reduction or removal.

Because tariff rates have fallen over recent decades, the treatment of NTMs has become more central to both trade negotiations and CGE-based trade policy analyses. To support these activities, the estimation of NTMs' trade impacts has become an active area of research. UNCTAD and the World Bank (2018) collaborated on a landmark study that estimates the trade-restrictive effects of NTMs by commodity and bilateral trade flow. Based on these impacts, they measured the *ad valorem* equivalents (AVE) of import tariffs of NTMs. An AVE describes the tariff rate that would have the same effect on reducing import volume as the NTM. The UNCTAD/World Bank study describes two different groups of NTMs, following the UNCTAD (2019) classification of NTMs. The first group includes technical

Table ME 11.1 *Ad valorem equivalents of NTM barriers on Japan–US trade*

	Japan barriers on imports from United States			US barriers on imports from Japan		
		AVE of NTM			AVE of NTM	
	Tariff	Technical	Nontechnical	Tariff	Technical	Nontechnical
Agriculture	17.06	3.40	0.10	0.50	0.70	0.00
Manufacturing	4.18	0.20	0.10	1.19	1.30	0.60

Sources: Tariff data from GTAP v10.1 database; AVEs of NTMs are traded weighted averages of AVEs from UNCTAD/World Bank (2019).

measures, such as sanitary and phytosanitary requirements and labeling and inspection requirements. The second group includes nontechnical measures such as price or quantity controls on imports, and rules of origin.

The AVEs of NTMs in Japan–US trade from the UNCTAD/World Bank database are reported in Table ME 11.1, divided into the AVEs of technical NTMs and nontechnical NTMs. With these tariff equivalents, NTMs can be represented in your CGE model in conceptually the same way as an import tariff, export tax, or a productivity shock to trade and transportation margins. The implications of the three alternative representations are described in detail in Chapter 9.

In this model exercise, you will learn how to incorporate AVEs of NTMs into your CGE model by recalibrating your model to add the AVEs of nontechnical NTMs as surcharges to existing tariffs and taxes, and treating AVEs of technical measures as trade efficiency losses. You also will learn how to define model scenarios that decompose the effects of traditional tariff reform versus reductions in NTM barriers. Perhaps most important, your case study will show you how to identify the results in the model that allow you to answer the essential question posed by Viner and Meade about a PTA – Is the pact net trade-creating or trade-diverting?

Experiment Design

You will carry out your analysis using the NUSJToy model, downloaded from the GTAP website. The NUSJToy model has three regions (United States, Japan, and rest of world) and the same three activities and three commodities (AGR, MFG, and SER) and the same three factors (land, labor, and capital) as the NUS333 model that we have used throughout this book.

The analysis has three steps:

1. You will prepare for your analysis by using the GTAP tariff and tax rates and estimated AVEs of NTMs to calculate the changes in rates and trade productivity parameters to be implemented in your PTA experiments.
2. You will use GTAP's Altertax utility (Malcolm, 1998) to recalibrate your model, adding the AVEs of bilateral nontechnical NTMs as surcharges to the import tariffs and export taxes in Japan–US trade. After running the Altertax experiment, you will save the results as a new base model to be used with your PTA experiments.
3. You will run a set of three PTA experiments: (a) eliminate all bilateral Japan–US import tariffs and export taxes while maintaining NTMs, (b) reduce NTMs by 25% while maintaining bilateral tariffs and taxes, and (c) deep integration: combine an elimination of tariffs and taxes with a 25% reduction in bilateral NTMs.

In your own research, one of your first steps will be to develop an institutional knowledge of how specific NTMs are implemented, so that you will have a basis for allocating their representation to import tariffs, export taxes, or trade productivity. Because our toy model is highly aggregated, we make the simplifying assumption that the rents and compliance costs associated with nontechnical measures are evenly split between the importing and exporting countries. For example, Japan's 0.1% AVE of its nontechnical NTM in agriculture is split between a 0.05% surcharge on Japan's import tariff on agricultural products imported from the United States, and a 0.05% surcharge on the US export tax on its agricultural exports to Japan. Reforms of technical NTMs will be treated as productivity shocks to trade and transport margins. The pedagogical advantage of this allocation scheme is that it will provide you with experience with all three instruments used to represent NTMs in a standard CGE model.

You will report three results for each experiment: (1) real GDP effects, (2) changes in bilateral trade quantities, and (3) welfare impacts. And, you will learn how to calculate trade creation and trade diversion effects. A comparison of the results of experiments 1 and 2 allows you to compare the importance of tariffs/subsidies elimination versus NTM reforms in the impacts of the trade agreement.

There are some important limitations to this modeling exercise. It offers a highly stylized representation of deep integration in a potential Japan–US PTA. The three large aggregated sectors mask the importance of specific sensitive sectors in Japan–US trade, such as rice and automobiles, which have extremely high tariffs or NTMs. Also, we assume that reforms of NTMs reduce all bilateral AVEs by 25%, although some NTMs can only be applied globally (such as sanitary requirements) and are unlikely to be reduced for a bilateral trade partner, and political sensitivity for some NTMs is unlikely to allow their full reduction. In addition, our exercise removes both import tariffs and export taxes due to the PTA. However, PTAs are likely to address only export subsidies, which create greater import competition with a country's trade partners, and not export taxes.

Instructions

1. Download the GTAP model version NUSJToy.ZIP from the GTAP website onto your computer, following the instructions in Model Exercise 1, Section C, for downloading the NUS333.ZIP file from the GTAP website. After installing your model, run a test simulation
2. Define the Altertax and PTA experiments
   Before beginning your analysis, you must recalibrate your model to include the AVEs of nontechnical NTMs. Your three PTA experiments then will alter these tariff and tax rates in different ways. Use Table ME 11.2 to make your calculations. Report all numbers to the second decimal place. You will note that only the agriculture and manufactures sectors are included in this table. That is because there are no taxes or tariffs on trade in services in our model, and our analysis does not include NTMs in services trade.
   a. View the original bilateral import tariffs and export taxes in your model and report them in column A of Table ME 11.2
      - Select "View" from the menu bar at the top of the page
      - Select "Base Data" from the drop-down menu
      - Select "Tax Rates" from the drop-down menu
      - Double-click "RTMS – source-specific change in the tax on imports of *c* from *s* to *d*"
      - View and report in column A of Table ME 11.2 Japan's import tariffs on the United States by setting toggles to

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      - View and report in in column A of Table ME 11.2 US import tariffs on Japan by setting the toggles to

        All COMM | JPN | USA

      - Double-click on any number to return to the list of tax rates
      - Double-click "RTXS – dest.-specific tax/subsidy rates on exports of *c* from *s* to *d*"
      - View and report in column A of Table ME 11.2 Japan's export tax rates on exports to the United States by setting toggles to

        All COMM | JPN | USA

      - View and report in column A of Table ME 11.2 US export tax rates on exports to Japan by setting the toggles to

Table ME 11.2 *Define import tariff and export subsidy rates for the Altertax and Japan–US PTA experiments*

	A	B	C	D	E	F	G
	Base tariff/ tax rates	AVEs of NTMs	Allocate AVE of NTM (50/50 to import tariff/ export tax)	Altertax tariff and tax rates	EXP1 – tariff/tax removal only	EXP 2 – NTM reduction only	EXP 3 – deep integration: tariff/ tax removal plus NTM reduction
				Japan tax rates			
Column name	J – A	J – B	J – C	J – D	J – E	J – F	J – G
Import tariff rates							
Formula			50% * J – B	J – A + J – C	J – C	J – A + (0.75*J – C)	0.75 * J – C
AGR	17.06	0.10	0.05	17.11	0.05	17.10	0.04
MFG		0.10					
Export tax rates							
Formula			0.50 * US – B (import tariff)	J – A + J – C	J – C	J – A + (0.75*J – C)	0.75 * J – C
AGR		0.00					
MFG		0.00					
				US tax rates			
Column name	US – A	US – B	US – C	US – D	US – E	US – F	US – G
Import tariff rates							
Formula			50% * US – B	US – A + US–C	US – C	US – A + (0.75*US –C)	0.75 *US – C
AGR		0.00					
MFG		0.60					
Export tax rates							
Formula			0.50 * J – B (import tariff)	US – A + US–C	US – C	US – A + (0.75*US –C)	0.75 *US – C
AGR		0.00					
MFG		0.00					

Sources: GTAP v10 database, UNCTAD/World Bank (2019) and author calculations.

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b. The AVEs of nontechnical NTMs are already reported in column B of Table ME 11.2. Verify that these AVEs of import tariffs are the rates reported for Japan and the United States in Table ME 11.1
c. Follow the instructions in the formula row of Table ME 11.1 to calculate data for the other columns of the table. One row is already completed and can be referred to for demonstration Report all rates to two decimals.
   - Allocate AVEs (column C): allocate the AVEs of nontechnical NTMs in a 50/50 split as a surcharge to the importer's bilateral tariff and as a surcharge to *its partner's* export tax. This treatment describes the rent/compliance costs of an importer's NTM falling on both its own importers and on the exporting region that must meet its NTM import requirements
   - Altertax tariff and tax rates (column D): for each country, add the AVEs from column C to the tariff and tax rates in column A. These are the new tariff and tax rates that you will impose when you recalibrate your model The rates include the tax and tariff surcharges due to the nontechnical NTMs
   - For experiment 1 – PTA tariff/tax removal only (column E): the original import tariffs and export taxes are removed and only the AVEs of NTMs remain in place. The values for experiment 1 are the same as in column C
   - For experiment 2 – PTA NTM removal only (column F): the new rates are the sum of the original tariff/tax rates plus 75% of the AVE (assuming 25% of the AVE of NTM is reduced)
   - For experiment 3 – Deep integration (column G): the PTA eliminates tariffs and 25% of the AVE of NTMs, leaving 75% of the AVE of NTMs
d. Calculate the changes in trade efficiency due to the PTA in Table ME 11.3. First, report the AVEs of technical NTMs for both countries. Then, calculate a 25% reduction in the AVEs and report the new AVEs in the table. One example for Japan is shown in the table, for demonstration

Table ME 11.3 *Define the changes in AVE tariff equivalents of technical NTMs (trade efficiency) in PTA experiments*

	Japan import barriers – % change in trade efficiency		US import barriers – % change in trade efficiency	
Formula	A	B = 0.25 * A	A	B = 0.25 * A
Model experiment	AVE of technical NTM	EXP 2 and 3: AVE with 25% increase in trade efficiency	AVE of technical NTM	EXP 2 and 3: AVE with 25% increase in trade efficiency
AGR	3.40			
MFG				

Source: UNTAD/World Bank (2019) AVE import tariff equivalents of nontechnical NTMS.

e. Check your answers in Tables ME 11.2 and ME 11.3 against the answer key before completing the rest of this model exercise
3. Use Altertax to update import tariffs and export taxes to add AVEs of NTMs
   - Select "Tools" from the upper menu bar
   - Select "Altertax" from the drop-down menu
   - You may choose to press "Help" to learn more about this utility
   - OK
   - OK (this loads the Altertax closure and parameter files)
   - OK (this will open up the closure page with new Altertax closures)
4. Explore the Altertax closure and parameters:
   a. View the closure statement (This page should automatically open when you open the Altertax utility. If not, select Closure from the page tabs.)

   Notice the additional closure statements that fix the US and Japan trade balances at their base levels. This minimizes changes in trade flows due to newly adjusted tax rates.

   b. View the new elasticity parameters
      - Select "View" from the upper menu bar
      - Select "Parameters" from the drop-down box
      - Select INCPAR. Notice that all income elasticity parameters have been set to 1. A unitary income elasticity minimizes changes in the shares of goods in the consumer basket due to changes in income that result from newly adjusted taxes. You may wish to explore other elasticity parameters and think about how their Altertax parameter values work to preserve the original structure, or shares, in an economy
      - Click on the X in the upper right corner to close ViewHAR

5. Set up the Altertax experiment to add AVEs of NTMs as surcharges to original import tariffs and export subsidies
   a. Redefine Japan tariffs on imports from the United States
      - Select the "Shocks" page tab
      - Select from the "Variable to Shock" drop-down menu: *tms*
      - Select from the "Elements to Shock" drop-down menu:

        AGR | USA | JPN

      - In "Shock Value" box, enter: 17.11 (import tariff rate including AVE of NTMs from the Altertax column (column D) of Table ME 11.2)
      - In "Type of Shock," enter: % target rate
      - Click on "Add to Shock list"
      - Repeat this update for MFG imports by Japan from the US
   b. Redefine Japan taxes on manufacturing exports to the United States
      - Select from the "Variable to Shock" drop-down menu: *txs*

  - Select from the "Elements to Shock" drop-down menu:

    MFG | JPN | USA

  - In "Shock Value" box, enter: 0.3 (export tax rate including AVE of NTM from the Altertax column (column D) of Table ME 11.2)
  - In "Type of Shock," enter: % target rate
  - Click on "Add to Shock list"

c. Repeat these steps to redefine US import tariff and export subsidy rates, using your calculations in the Altertax column of Table ME 11.2. Note that no change in the tax rate is required for Japan's AGR exports to the US

6. Solve the model
   - Select the "Solve" page tab
   - Notice that the Altertax utility automatically defines the solution method as Gragg: 2-4-6 and defines the parameter file to be altertax
   - Click on "Save experiment," name the shock AltPTA. Use its default description of "Altertax"
   - OK
   - Click on "Solve"
   - OK
   - OK
7. Verify your shock by reviewing updated tax and subsidy rates. These rates should all be approximately equal to your calculated rates in Table ME 11.2. Follow the directions in step 2.a, except select View > Updated Data > Updated Tax Rates
8. Save the results of the Altertax update as your new base model
   - Select "Version" from the menu bar at the top of the page
   - Select "New"
   - Next (this opens options to define the new version)
   - Select these options to define your new version
     - Based on: "Same aggregation as the current version"
     - Adapt current version "Use updated database from last simulation"
     - Name the updated model "NUSJv2"
   - Next
   - Next
   - Finished
   - OK (The GTAP software will create your model and run a numeraire experiment as a consistency check. When this step is complete, your new model with updated tax and subsidy rates is ready to use for trade liberalization experiments.)
   - Verify that the base Japan and US bilateral import tariffs and export taxes are equal to your calculated Altertax rates in column D of Table ME 11.2, following the directions in step 2.a to view base tax rates

9. Set up Experiment PTA1 – elimination of import tariffs and export subsidies
   a. Follow the checklist in Model Exercise 3 on preparing your model to define and run an experiment
   b. Select the Shocks page tab.
   c. Eliminate Japan import tariffs on AGR imports from the United States
      - Select from the "Variable to Shock" drop-down menu: *tms*
      - Select from the "Elements to Shock" drop-down menu:

        AGR | USA | JPN

      - In "Shock Value" box, enter: 0.05 from Experiment 1 (column E) in Table ME 11.2
      - In "Type of Shock," enter: % target rate
      - Click on "Add to Shock List"
   d. Repeat this for all US and Japan bilateral import tariffs and export taxes
   e. Save the experiment
      - Select Closure page. Check that the closure is the standard closure. If not, copy and paste closure from GTAPU7 numeraire experiment.
      - Select the "Solve" page tab
      - Check that the solution method is: Gragg (with 1 subinterval)
      - Check that the parameter file is the Default parameter file
      - Click on "Save" and name the experiment "PTA1"
   f. Solve the model
   g. Verify your shock by reviewing the updated tax rates. Follow the directions in step 2.a, except select View > Updated Data > Updated Tax Rates
10. Report results of Experiment PTA1
   a. Report changes in real GDP in Table ME 11.4
      - Click on the "Results" page tab
      - From the alphabetical list of variables, click on "*qgdp* – GDP quantity index"
      - Report *qgdp* results from the sim column. The sim column displays the percentage change in the variable due to the experiment
      - Double-click anywhere in the table to return to list of variables

Table ME 11.4 *Changes in real GDP (in %) due to Japan–US PTA*

		Stemming from	
Country	EXP 3 – Deep integration	EXP 1 – Tariff/tax elimination only	EXP2 – NTM reduction only
Japan			
United States			

Note: Results for GTAP variable *qgdp*.
Source: NUSJv2 model.

Table ME 11.5 *Percent changes in quantity of bilateral imports due to PTA*

Country	EXP 3 – Deep integration	Stemming from EXP 1 – Tariff/tax elimination only	Stemming from EXP2 – NTM reduction only
	Japan to United States		
Agriculture			
Manufacturing			
Services			
	United States to Japan		
Agriculture			
Manufacturing			
Services			

Note: Results report GTAP variable $qxs_{c,s,d}$
Source: NUSJv2 model.

b. Report the percentage changes in import quantities in Table ME 11.5
   - From the alphabetical list of variables, click on "*qxs* – export sales of commodity *c* from *s* to region *d*." This will open an error box, "Sorry, you cannot view a 3-D matrix unless filtering on an element name." Click on OK to close the message
   - Filter the results by selecting the drop-down box on the upper left-hand side, labeled "Everything." Select Japan from the list. This will open a list of variables
   - Select *qxs*(*,*,JPN) from the list of variables. This variable reports the percentage change in quantity of imports of commodity *c* from region *s* to Japan
   - Report the percentage change in JPN import quantities from the USA
   - Change the filter from JPN to USA
   - Report the percentage change in US import quantities from JPN
   - Close the HAR file by clicking on the X in the upper right corner

11. Set up Experiment PTA2: Reduce NTMs 25% but retain import tariffs and export subsidies
   a. Reduce nontechnical NTMs modeled as import tariffs and export subsidies by 25%. Follow the same steps as in experiment one, except that you will change bilateral import tariffs and export subsidies to the levels described as Experiment 2 (column F) in Table ME 11.2
   b. Reduce technical NTMs by increasing bilateral trade efficiency by 25%
      - Select from the "Variable to Shock" drop-down menu: *ams*
      - Change the trade productivity variable for AGR imports by Japan from the United States. From the "Elements to Shock" drop-down menu, select:

AGR | USA | JPN

- In "Shock Value" box, enter: 0.85, the change in trade efficiency in Table ME 11.3
- Click on "Add to Shock List"

c. Repeat this shock to trade productivity for all Japanese and US bilateral trade using your calculations from Table ME 11.3

d. Save the experiment
- Select Closure page. Check that it is the standard closure
- Select the "Solve" page tab
- Check that the solution method is: Gragg (with 1 subinterval)
- Check that the parameter file is the Default parameter file
- Click on "Save" and name the experiment "PTA2" describing it as "Reduce NTMs only in Japan–US PTA"

e. Solve the model
- Click on "Solve"
- OK
- OK

f. Verify your shock by reviewing the updated tax and subsidy rates, following step 2.a, and the change in the *ams* parameter, reported on the Results page

12. Report results of Experiment 2 in Tables ME 11.4 and 11.5
13. Set up Experiment 3: Deep Integration PTA scenario: Eliminate import tariffs and export subsidies, and reduce NTMs by 25%)
    a. Follow the aforementioned directions to reduce the (NTM inclusive) Japan and US import tariffs and export subsidies to the levels that you calculated in the Experiment 3 (column G) of Table ME 11.2
    b. Follow the directions in step 11 to increase trade productivity on EU–US bilateral trade by 25%, as calculated in Table ME 11.3
    c. Follow the aforementioned directions to save your experiment and solve the model
    d. Verify your shock by reviewing the updated tariff and subsidy rates, and the change in the *ams* parameter
    e. Report your results in Tables ME 11.4 and 11.5

14. Report the welfare effects of Experiment 3 in Table ME 11.6
    - Select "View" from the menu bar at the top of the page
    - Select "Updated Data" from the drop-down menu
    - Select "Welfare decomposition" This will open the overview page of the welfare utility
    - From the list of welfare components, double-click on "EV Decomposition: Summary," in the first row of the list
    - Report welfare results for Japan and the United States in the table
    - Close the file by clicking on the red X in the upper right corner

Table ME 11.6 *Welfare impacts of a Japan–US PTA – deep integration ($US millions)*

	Allocative efficiency	Technical efficiency	Terms of trade (goods)	Terms of trade (saving investment)	Total
United States					
Japan					

Source: NUSJv2 model, experiment 3.

Table ME 11.7 *Trade creation and trade diversion due to Japan–US PTA ($US millions)*

	Change in import volume			
	Japan imports from US	Japan imports from ROW	Net trade creation / diversion	Net trade-creating?
Agriculture				
Manufacturing				
Services				
	US imports volume from Japan	US imports from ROW		
Agriculture				
Manufacturing				
Services				

Note: Net trade creation/diversion is calculated as the change in import volume with partner plus the change in import volume with nonmembers of PTA, in constant prices.
Source: NUSJv2 model.

15. Report the trade creation and diversion effects of Experiment 3 in Table ME 11.7
    a. Report changes in volumes of Japan imports, in $US millions
       - On the upper menu bar, select
         View > Updated data > Volume changes
       - Double-click on DQXS. This reports the change in volume of exports of c from s to d. This is the change in "real imports" because the pre- and post-shock quantities are valued in initial prices, in $US millions
       - View the change in import volumes by Japan by setting the toggles in the upper right corner to

         All COMM | All REG | JPN

       - Report the results for Japan in Table ME 11.7

b. View the change in import volumes by the US by changing the toggle for JPN to USA. Report the results for the US in Table ME 11.7
c. Calculate the net trade creation and trade diversion of the Japan–US PTA in Table ME 11.7. It is the sum of the change in import volumes from PTA partners and non-partners expressed in constant dollars

Interpret Model Results

1. Define "NTM." Explain the three ways that an AVE of an NTM can be represented in standard CGE models. What are some limitations of these approaches?
2. What is meant by trade inefficiency? How does an "iceberg" trade cost describe trade inefficiency? Provide a real-world example of how an NTM can reduce trade efficiency.
3. What are your sources of data for the AVEs of NTMs in this experiment? How were they allocated across tariffs, export subsidies, and trade costs? How important is this allocation, and what factors do you think might be important to consider in making this decision?
4. Compare the empirical importance of the liberalization of NTMs versus removal of import tariffs/export taxes in a Japan–US PTA.
5. Is the PTA welfare-improving for Japan, the United States, and the world? Explain the most important contributors to the welfare gains and losses for each region.
6. Define the concepts of trade creation and trade diversion. Is a PTA that achieves deep integration net trade creating or trade diverting for Japan and the United States? What variable(s) in your model describe trade creation and diversion effects?
7. The contribution of the change in trade productivity to regional welfare is reported in the welfare decomposition utility as a change in technical efficiency. Which country has the most restrictive technical NTMs, as measured by the AVEs in Table ME 11.1? Which has the largest productivity gain? How do you think that this productivity gain might explain the terms-of-trade gain in its trade partner?
8. What is the effect of the PTA on the real exchange rate (*pfactor*)? Explain how this result may impact the changes in trade in services among Japan, the United States, and ROW that you observe in your model results.

Practice and Review Answer Key

Chapter 1

1. P = 4, QO = QD = 4.
2. P = 5, QO = QD = 6

Table 1.2 *Partial versus general equilibrium analysis (answer key)*

	Bicycle equilibrium price is higher/ lower than \$1.50	Bicycle equilibrium quantity is greater/ less than 15	Which curve shifts and in which direction?
Increase in price of rubber tires	\$1.50	15	Supply (S^1) shifts upward/ left
Bicycle workers accept lower wages	Lower	Greater	Supply (S^2) shifts downward/ right
Consumer demand shifts to imported bicycles	Lower	Less than	Demand shifts downward/ left
Decline in exports causes depreciation and higher imported input costs	Higher	Less than	Supply (S^2) shifts upward/ left
Bicycle seat price falls due to fall in demand from bicycle producers	Lower	Greater than	Supply (S^2) shifts downward/ right

Chapter 2

1. P_c, $P_{\text{"manufactures"}}$
2. Quantity of agricultural imports by Brazil from the United States or quantity of agricultural exports from the United States to Brazil.
3. D.1. Equilibrium of D^2 at S^1 has a higher equilibrium price and a lower quantity than equilibrium of S^2 and D^2.

   D.2. The supply curve is more elastic when (1) factor substitution elasticity is larger, (2) factor mobility elasticity is larger in absolute value, and (3) export transformation is larger in absolute value.
4. Equilibrium at S^2 and D^1 has a lower equilibrium price and quantity than equilibrium at S^2 and D^2. Demand for the domestic good is more elastic when (1) own-price and commodity substitution elasticities are larger and (2) import substitution elasticities are larger.

Table 2.7 *Normalized prices and quantities of apples (answer key)*

	Base values			50% Change in quantity			
	Price	Quantity	Value	Price	Quantity	Value	% Change in value
Actual	2	12	24	2	18	36	50
Normalized	1	24	24	1	36	36	50

Table 2.8 *Calculating the US composite import price (answer key)*

	France	Germany	South Africa
Exporter's market share of US corn imports	50	25	25
Exporter bilateral *fob* export price (PFOB)	$1.25	$0.85	$1.90
Trade margin	$0.25	$0.15	$0.10
US bilateral *cif* import price (PCIF)	$1.50	$1.00	$2.00
Import tariff	$0.50	$0.40	$0.10
Bilateral domestic price of import (PMDS)	$2.00	$1.40	$2.10
Trade-weighted domestic price of import (import share * PMDS)	0.50 * $2.00 = $1.00	0.25 * $1.40 = $0.35	0.25 * $2.10 = $0.53
Domestic price of composite import (PMS) (sum of weighted PMDSs)	$1.00 + $0.35 + $0.53 = $1.88		
Import sales tax for households	$0.12		
US households composite import price (PPM)	$2.00		

7. The price transmission elasticity of the French bilateral *fob* export price with respect to the US consumer import price 10/50 = 0.20.

Chapter 3

1. a. Mfg. gross output = $6,657 billion
   b. Mfg. value added = factor payments + all taxes and subsidies = $2,323
   c. Mfg. GDP = Mfg. value added + taxes paid on mfg. imports and exports, and mfg. sales taxes paid by households, government and investors = $2,547
   d. Mfg. intermediate input costs = $4,333
   f. Total labor costs in services = factor payment + factor tax = $7,820
   g. Labor's share of industry costs in services = ($6,797 + $1,023)/$18,212 = 43%.
2. a. Agr. import cost = (imports + tariff + trade margin) = $34 billion
   b. Agr. domestic variety = $326
   c. Agr. total supply of composite commodity = $360
   d. Agr. exports = $52
   e. Import share of private household's agricultural consumption = import cost/ total household agricultural consumption = ($13 + $1) / ($13 + $53 + $1+ $2) ∗100 = 20%
   f. (52/326) ∗ 100 = 16%

Table 3.10 *Practice and review – interpreting a MRIO table (answer key)*

	Importer end-user		Total exports	Share of exports used as intermediate inputs by partner
	Intermediate use	Final demand		
A exports of C1	25	5	30	83
A exports of C2	20	5	25	80
B exports of C1	15	10	25	60
B exports of C2	15	15	30	50

Chapter 4

1. a. Agriculture: C = 53, G = 0, I = 0, E = 52.
   b. Services: C = 7,742, G = 2,258, I = 1,604, E = 345 + 28.
2. Agr = (53+2) / 9,949 = 0.54; MFG = (1,355 + 137) / 9,949 = 15; SER = (7,742 +51) / 9,949 = 78.3.

3. A homothetic utility function assumes that consumers will change their demand for all goods and services by the same proportion as the change in income. A nonhomothetic utility function can describe goods as luxuries or necessities, for which growth in demand will not change by the same proportion as income. The main differences between the two utility functions in an analysis of economic growth is that the nonhomothetic function will lead to higher demand for luxury goods and lower demand for necessities relative to the change in income, which will cause a shift in production and trade toward luxury products. The homothetic function will lead to a more equi-proportionate growth in demand, production, and trade for each good.
4. A large value for the Armington parameter describes a flatter isoquant, becoming linear as the parameter value approaches infinity. When the parameter value becomes smaller, the isoquant becomes more curved. In the limit, the parameter value approaches zero and the curve is L-shaped. When the tariff is removed, a larger parameter causes a larger change in domestic-import quantity ratios.
5. The real consumption welfare change in welfare is $6. The price changes have increased national welfare.

Table 4.8 *Practice and review calculation of the real consumption welfare measure (answer key)*

	Initial price	Initial quantity	New quantity	Cost of initial quantity at initial prices	Cost of new quantity at initial prices
Apples	$1.00	5	6	$5.00	$6.00
Oranges	$1.00	5	4	$5.00	$4.00
Candy bars	$1.00	2	8	$2.00	$8.00
Total	–	–	–	$12.00	$18.00

Chapter 5

1. Total intermediates: 4,335

   Total factor payments: 2,010

   Total taxes: 315

   Value-added: 2,325

   Gross output: 6,660 (with rounding error)
2. a. Mfg. is labor-intensive.
   b. Services is capital-intensive.
   c. Manufacturing is the most service-intensive production activity in the economy.

Table 5.7 *Input-output coefficients (answer key)*

	Inputs into production		Input-output coefficients	
	Manufacturing	Services	Manufacturing	Services
Labor	12	12	0.24	0.12
Capital	8	18	0.16	0.18
Manufacturing	10	50	0.20	0.50
Services	20	20	0.40	0.20
Gross value of output	50	100	1.00	1.00

d. Upstream role: manufacturing is an important input supplier of intermediate inputs to services, accounting for most of its intermediate input requirements. Downstream role: manufacturing depends on services, which accounts for most of its intermediate input requirements.

3. See Figure 5.3. Lower wage costs relative to the price of capital rotates the isocost curve from C1 to C2. The labor capital ratio rises from L^1 K^1 to L^2 K^2 in the production of value-added bundle QVA^1.
4. This CGE model probably has a Leontief-fixed proportion production function because there is no substitution among intermediates, and demands for intermediate inputs change by the same proportion as output. The model has a value-added production function that allows substitution among factors because the factor input ratio changes. Because production becomes more labor-intensive, wages must have fallen relative to rents.

Chapter 6

1. Figure 2.1 describes the relatively elastic supply curve of an industry with a mobile factor and the relatively inelastic supply curve of an industry with an immobile, sector-specific factor. A demand shock leads to a larger quantity effect and smaller price effect for an industry when factors are mobile compared to when factors are immobile.
2. Assuming that the equipment is a capital input that is complementary to engineering labor in the production of computer chips, an increase in the supply of engineers should increase demand for the equipment. The increase in the number of engineers shifts the demand curve for the capital good outward and results in a higher price and quantity for the equipment. You should advise the industry to support the training program.
3. Services is the most labor-intensive sector and the largest employer in the US economy. A production subsidy that leads to an increase in services output is likely to increase wages relative to rents and cause all three sectors to become more capital-intensive.

Chapter 7

1. a. Televisions are capital-intensive, and wine is labor-intensive.
   b. Capital costs will fall and this will lower the costs of production of TVs more than of wine because capital accounts for a larger share of TV production costs. Output of wine output will be greater than of TVs.
   c. Wine is relatively exportable and televisions are relatively importable.
   d. An increase in production of the importable will reduce the country's demand for imports, so the world import price is likely to fall. A decrease in production of the exportable will decrease its supply of exports, so its world export price is likely to rise. This country's terms of trade will likely improve because its world export price will increase relative to its world import price.
2. The Dutch Disease model describes (1) resource endowment effects, (2) spending effects, and (3) real exchange rate changes. The resource endowment effect describes resource competition by the expanding oil sector, which causes output in other industries to fall. The spending effect describes the increased demand for goods and services as incomes grow. Both effects lead to real exchange rate appreciation and increased import competition for Venezuela's industrial sector, and the potential for deindustrialization.
3. Percent change in US *fob* export price = $(0.6 * 6) + (0.4 * 4) = 5.2$

   % change in US *cif* import price = $(0.8 * 4) + (0.2 * 1) = 3.4$

   % change in US terms of trade = $(5.2 - 3.4) = 1.8$. The US terms of trade improves.

Chapter 8

1. In the graph, the import with a more price-elastic demand is described by a flatter demand curve and a larger excess burden than the import with price-inelastic demand. The welfare cost of the tariff will be smaller for the less elastic import.
2. For both sectors, the factor use tax is 15.1% for labor and 3.3% for capital. Because the factor use taxes are the same in both industries, they do not distort factor allocation between them. The taxes make labor expensive relative to capital and create an incentive for both industries to become more capital-intensive.
3. See Text Figure 8.4.
4. a. $200,000/$1,000,000 * 100 = 20 cents.
   b. The government must earn a return of 120% on its project, or the cost in terms of tax dollars spent and inefficiencies linked to the taxes will be greater than the project's benefits.
   c. The marginal excess burden will be smaller if the tax is levied on price-inelastic goods, because distortions of the student's consumption basket will be smaller.

d. The subsidized textbook industry is likely producing quantities that are greater than is economically efficient, given the nation's resources and preferences. A sales tax in the bookstore will likely reduce demand for and output of textbooks, and reduce the inefficiency linked to the textbook subsidy.

5. Members of a free-trade area reduce or eliminate tariffs on each other's goods but maintain their own tariffs against nonmembers. See Figure 8.7 for graphs that depict trade creation effects. Important variables to review in describing the welfare impacts of the PTA are related to the variables in the graphs: changes in the real value (quantities) of imports, allocative efficiency welfare gains from import tariff removal that describe the efficiency triangles in the graphs, and terms-of-trade impacts that describe the terms-of-trade effects in the graph.

Chapter 9

1. Deterioration of the strawberry shipment can be modeled as an iceberg trade cost, which is a loss in trade efficiency. A graph of this problem looks like Figure 9.2.
2. A graph of this problem looks like Figure 9.3. The net effect of the regulation is to lower output and charge a higher price, resulting in an allocative efficiency loss of area $f + c$ and a societal gain of area $f + c + g$ due to the reduction in output; the figure describes a net benefit of area g from reducing production of the externality. The allocative efficiency effect in model results corresponds to area $f + c$. A standard CGE model does not measure the benefits shown by area $c + f + g$.
3. A process-based regulation requires an industry to purchase a specific input or technology, or practice a mandated technique. If it increases production costs and price, it will lead to a negative output effect. An outcome-based regulation allows producers to find the least costly way of achieving the regulatory goal. In addition to the output effect, it may include substituting among inputs or technological innovation that reduces the externality per unit of output. A regulation's direct cost is the loss in allocative efficiency. Its indirect costs are the changes in total production of externalities resulting from changes in industry size and composition, second-best efficiency effects, and terms-of-trade changes. A standard CGE model can examine process-based regulations' direct and indirect costs.

Model Exercise Answer Key

Model Exercise 2

B.2 REG = US, ROW are the regions in the database
B.3 COMM = AGR, MFG, and SER are the commodities in the database
B.4 ENDW = LAND, LABOR, and CAPITAL are the set of factors of production in the database
C. An error message: "You cannot view more than two dimensions"
D. INCPAR("USA", "SER") = 1.04

Table ME 2.1 *Elasticity parameters for US agriculture (answer key)*

Elasticity	Value
Supply parameters	
Factor substitution (ESUBVA)	0.25
Intermediate input substitution (ESUBT)	0.00
Demand parameters	
Consumer income (INCPAR)	0.17
Consumer substitution (SUBPAR)	0.82
Import-domestic substitution (ESUBD)	2.38
Import-import substitution (ESUBM)	4.80

Table ME 2.2 *Tax rates for US agriculture (answer key)*

Tax rate	Definition	Value
$rTO_{AGR,AGR,\ USA}$	Tax rate on commodity c supplied by activity a in region r (tax on AGR output of AGR activity in USA)	0.24
$rTFE_{Land,\ AGR,\ USA}$	Tax rate on primary factor e used by activity a in region r (tax on land use in AGR activity in USA)	–4.11
$rTFD_{AGR,AGR,\ USA}$	Tax rate on domestic com. c for use by activity a in region r (tax on use of domestic AGR input into AGR activity in USA)	–3.95
$rTXS_{AGR,USA,\ ROW}$	Dest.-specific tax/subsidy rate on exports of *c* from *s* to *d* (tax on AGR commodity exported by USA to ROW)	0.00
$rTMS_{AGR,ROW,\ USA}$	Source-specific tax/subsidy rate on imports of c from s by d (tax on AGR commodity imported from ROW by USA)	1.56

F.1. Variable definitions:

pop = regional population
ppa = private consumption price for commodity *c* in region *r*
qes = supply of endowment *e* for use by activity *a* in region *r*
qxw = aggregate exports of commodity *c* from region *r*, *fob* weights

F.2. Population is exogenous and all the rest of the variables listed in F.1 are endogenous

Model Exercise 3

C2. *to* is the output tax rate, it is 1.057 for MFG in USA
C3. 1.057 is a tax, not a subsidy
C4.
Power of base tax = 1+(1.0570/100) = 1.01057
Power of new tax = 1+(−10/100) = 0.9
% change in power of tax: (0.9−1.01057)/1.01057*100 = −10.9414

Table ME 3.1 *Results of a 10% production subsidy to US manufacturing, with different elasticities and closures (answer key)*

	Definition of variable	Base results	High factor substitution elasticity in MFG	Unemployment closure
qc („MFG", "USA")	Total supply of MFG commodity by USA	4.44	4.45	28.31
qc ("MFG", "ROW")	Total supply of MFG commodity by USA	0.23	0.23	1.45
qfe("LABOR", "MFG", "USA")	Demand for labor by MFG in USA	4.45	4.48	39.09

Source: NUS333 model.

Table ME 3.2 *Welfare decomposition of a 10% production subsidy to US manufacturing (answer key)*

Resource allocation effect	Endowment effect	Technical change	Population growth	Terms of trade	Investment–savings terms of trade	Preference change	Total
1 alloc_A1	2 endw_B1	3 tech_C1	4 pop_D1	5 tot_E1	6 IS_F1	7 pref_G1	
12,655	0	0	0	67,601	103,545	0	183,801

Source: NUS333 model.

a. *qo*(“MFG”, “USA”) = 4.44
b. Mean = 4.43
c. Standard deviation = 0.04

Table ME 3.4 *Confidence intervals for the US manufacturing output quantity result with a 100% variation in the factor substitution elasticity (answer key)*

Confidence level	Mean (X)	Standard deviation (sd)	No. of standard deviations from mean (k)	Upper limit (X + sd*k)	Lower limit (X –sd*k)
75%	4.43	0.04	2	4.51	4.35
88.9%	4.43	0.04	3	4.55	4.31
95%	4.43	0.04	4.47	4.61	4.25
99%	4.43	0.04	10	4.83	4.03

Model Exercise 4

Table ME 4.1 *Income and price parameters in ROW in two scenarios of a 50% increase in the world agricultural price (answer key)*

	Scenario 1		Scenario 2	
Elasticities	INCPAR	SUBPAR	INCPAR	SUBPAR
Agriculture	0.47	0.83	1	0
Manufacturing	0.83	0.43	1	0
Services	1.13	0.33	1	0

Table ME 4.2 *ROW household budget shares (answer key)*

	Base	Scenario 1	Scenario 2
Agriculture	0.044	0.063	0.044
Manufacturing	0.341	0.337	0.341
Services	0.615	0.600	0.615

1. The utility functions assume negative own-price elasticities. With income constant, as the price rises, demand should fall. In the CGE model, the demand quantity falls in both scenarios.
2. The CDE demand system is nonhomothetic. AGR is a necessity good, SER is a luxury good, and MFG is a necessity that is more responsive to income changes than AGR. The C-D function is homothetic so that, holding prices constant, the income effect changes demand quantities for all three goods by the same proportion as income.

Table ME 4.3 *Effects of a 50% increase in the consumer price of agriculture in ROW (% change from base) (answer key)*

	World	Rest of world				
	World price	Consumer price	Consumer composite commodity quantity	Consumer domestic quantity	Consumer import quantity	Production quantity
GTAP variable name	*pxwcom*	*ppa*	*qpa*	*qpd*	*qpm*	*qo*
CDE utility						
Agric.	50.03	54.50	−11.36	−14.36	13.06	−9.32
Mfg.	0.64	0.53	−2.87	−2.91	−2.78	−0.99
Services	−2.75	−3.20	−0.56	−0.49	−1.68	−0.40
Cobb-Douglas						
Agric.	40.99	44.94	−46.15	−48.70	−25.38	−21.94
Mfg.	0.65	0.56	−1.76	−1.78	−1.70	−0.56
Services	−2.14	−2.53	1.33	1.38	0.35	0.48

Source: NUS333 model.

3. Elasticity of substitution of ROW AGR/MFG: (−46.15 + 1.76) / (44.94 – 0.56) = −1.
4. The CDE demand system allows flexible budget shares. In the CDE scenario, the agricultural budget share rises because the AGR price rises, and the decline in quantity demanded falls by proportionately less than the price increase. The CD utility function imposes fixed budget shares, so the change in AGR quantity offsets percentage changes in price and income.

Model Exercise 5

Table ME 5.1 *Base and updated subsidy rates in US agriculture (answer key)*

	Base rate	Updated rate
Subsidy to land – rTFE(“LAND”,”AGR”,”USA”)	−4.11	0
Subsidy to land – rTFE(“LAND”,”AGR”,”USA”)	−3.17	0
Tax on domestic intermediate inputs rTFD (C,“AGR”, “USA”)		
AGR	−3.95	0
MFG	−0.59	0
SER	−4.10	0
Tax on imported intermediate inputs RTFM(C, “USA”)		
AGR	−4.11	0
MFG	−1.94	0
SER	−4.49	0

See the technology tree in Figure 5.1. Your tree for US AGR will look similar, with a value-added nest containing capital, labor, and land, governed by the default factor substitution elasticity (ESUBVA = 0.25) and an intermediate input bundle that contains AGR, MFG, and SER inputs, governed by an intermediate input substitution elasticity (ESUBC) of zero. The two composite bundles are combined to produce AGR, and are governed by an aggregate input substitution elasticity (ESUBT) of zero.

Factor price changes lead to factor substitution, but no substitution occurs among intermediates or between the intermediate and value-added composite bundles.

Table ME 5.2 *Effects of US agricultural subsidy elimination on United States (% change from base) (answer key)*

			Subtotals		
Variable	Variable name in GTAP	Total	Land subsidy effect	Capital subsidy effect	Intermediate input subsidy effect
Agricultural output quantity	*qca*(AGR AGR,,USA)	–1.42	0	–.40	–1.01
Agricultural producer price	*ps*(AGR, AGR,USA)	1.71	0	0.49	1.23
Factor cost to producers					
Land	*pfe*(LAND, AGR,USA)	–5.94	0	–0.56	–5.38
Capital	*pfe*(CAPITAL, AGR,USA)	3.16	0	3.23	–0.07
Land supply price	*pes(*LAND, AGR, USA)	–9.81	–3.99	–0.55	–5.27
Household consumption	*qpa* (AGR,USA)	–0.27	0	–0.08	–0.19
Export quantity	*qxw* (AGR,USA)	–5.71	0	–1.62	–4.09
Export price	*pxw* (AGR,USA)	1.71	0	0.49	1.23

Table ME 5.3 *Change in input-output coefficients in US agriculture due to US subsidy removal (% change from base) (answer key)*

Output and inputs	Percent change in output and input quantities	Percent change in input-output coefficients (*qfe* – *qca*) or (*qfa* – *qca*)
AGR output (*qca*)	–1.42	Not applicable
Land (*qfe*)	0.00	1.42
Capital(*qfe*)	–2.26	–0.84
AGR intermediate (*qfa*)	–1.42	0.00
MFG intermediate (*qfa*)	–1.42	0.00
SER intermediate (*qfa*)	–1.42	0.00

3. AGR becomes more land-intensive and less intensive in the use of capital. This results in a decline in the marginal product of land relative to the marginal products of labor and capital; therefore, land rents (*pfe*) fall relative to wage and capital rents. Intermediate input-output ratios are unchanged, consistent with the Leontief intermediate input technology in the NUS333 model.
5. The percent change in the land price paid by US AGR producers declines 5.94% and the supply price received by landowners declines 9.81%. The increase in land factor intensity leads to lower marginal productivity and the landowners' supply price of land to AGR. The producer's land cost does not decline as much as the supply price because producers lose the 4% subsidy to their land use, which raises their cost of renting land.
6. Food prices will rise, but agriculture accounts for only 1% of US household spending, so US consumers are not likely to be substantially affected by an agricultural reform program.

Model Exercise 6

1. See Figures 6.2a and b in Chapter 6.
2. Change the factor substitution (ESUBVA) elasticities. A larger parameter value describes a more flexible production technology, with a relatively large substitution in factor input quantities given a percentage change in the inverse of their relative prices.
3. When firm technologies are assumed to allow easy substitution among factors, an increase in supply and fall in the wage of unskilled workers will lead to a substitution that intensifies their use in the production process and a fall in demand for and prices of the other two factors.
4. See Figures 6.2c and d in Chapter 6.

Table ME 6.1 *Effects of a 10% increase in the US supply of unskilled labor (% change from base) (answer key)*

	Factor price paid by producers (*pfe*)	Production activity	Demand for labor (*qfe*) Unskilled	Demand for labor (*qfe*) Skilled	Output (*qo*)
BORJAS – 10% increase in unskilled labor supply with high factor substitution					
Unskilled	–1.23	Agriculture	10.54	0.5	3.95
Skilled labor	–0.44	Manufactures	10.10	0.10	4.57
Capital	–0.44	Services	9.97	–0.02	3.91
OTTA1 – 10% increase in unskilled labor supply with low factor substitution					
Unskilled	–9.38	Agriculture	1.15	–2.75	–1.42
Skilled labor	10.30	Manufactures	6.48	–3.49	0.83
Capital	9.72	Services	10.94	0.55	4.48
OTTA2 – 10% increase in unskilled labor, 6 percent increase in capital, low factor substitution					
Unskilled	–8.42	Agriculture	7.74	3.72	6.61
Skilled labor	10.76	Manufactures	10.73	0.68	6.83
Capital	–1.34	Services	9.86	–0.11	5.27

Table ME 6.2 *Real GDP effects of a 10% increase in US unskilled labor supply*

Scenario	% Change in real GDP
BORJAS	4.01
OTTA1	3.85
OTTA2	5.54

5. Producers must hire more skilled labor and capital to complement their increased use of unskilled workers, which increases demand for skilled labor and capital and raises their wage and rental prices.
6. An increase in the capital stock will shift the demand curves for both unskilled and skilled labor outward, if factors are assumed to be relatively complementary. Wages of both labor types will increase in OTTO2 relative to the results of OTTO1.
7. The price of capital falls because the supply of capital increases.
8. Real GDP grows because the endowment of productive resources grows. Comparing the identical shocks in BORJAS and OTTA1, real GDP growth is larger when the production technology is more flexible and factors more substitutable, allowing producers to take better advantage of an increase in an endowment and a fall in its price.

Model Exercise 7

Table ME 7.1 *Import tariff rates in NUS333 model before and after 5% surcharge (answer key)*

	United States tariff on ROW			ROW tariff on United States		
Variable name	Agr.	Mfg.	Services	Agr.	Mfg.	Services
Base import tariffs (rTMS)	1.56	1.23	0.00	6.36	2.87	0.00
Updated import tariffs (rTMS)	1.56	6.23	0.00	6.36	7.87	0.00

Source: NUS333 model.

Table ME 7.2 *Effects of a 5% tariff surcharge on US imports of manufactures from ROW (% change from base)*

Variable name	Variable definition	Expected sign of result	Result
% change $pmds_{\text{"MFG","ROW","USA"}}$	US bilateral domestic price of MFG import from ROW, including tariff	+	4.65
% change $pcif_{\text{"MFG","ROW","USA"}}$	US bilateral CIF import price on MFG import from ROW, excluding tariff	–	–0.28
% change $qxs_{\text{"MFG","ROW","USA"}}$	Quantity of bilateral MFG imported from ROW to US	–	–7.47

Table ME 7.3 *Welfare effects of US 5% tariff surcharge on MFG imports from ROW ($US mill).*

Allocative efficiency	Endowment change	Technical change	Population change	Terms of trade	Investment–savings terms of trade	Preference shifts	Total
–5,648	0	0	0	24,533	13,331	0	32,216

6. Terms-of-trade gains and losses describe the redistribution of purchasing power around the world. A terms-of-trade gain is a gain to one country and an equal loss to its partner, so globally, terms-of-trade gains and losses sum to zero.

Table ME 7.4 *Decomposing second-best allocative efficiency effects of 5% surcharge in US MFG tariff on ROW*

Row	Type of efficiency change	Allocative efficiency effect ($US millions)
1	Total allocative efficiency effect (from Table ME 7.3)	–5,648
2	Total efficiency effect from import tariffs	–5,100
3	Effect from US MFG tariff on ROW	–5,112
4	Second-best efficiency effect (row 1–row 3)	–536

Table ME 7.5 *Welfare effects of trade war by region and by policy ($US millions)*

	Total	US MFG tariff surcharge on ROW	ROW MFG tariff surcharge on US
United States	–33,434	32,149	–65,583
ROW	12,409	–45,070	57,479

Source: NUS333 model.

Table ME 7.6 *Decomposition of the total welfare effect of the trade war (answer key) ($US millions)*

	Allocative efficiency	Terms of trade in goods and services	Terms of trade in savings–investment	Total
United States	–13,119	–15,195	–5,120	–33,434
ROW	–7,774	15,096	5,087	12,409
World	–20,892	–99	–33	–21,025

Source: NUS333 model.

7. The pre-existing US tariff on MFG imports from ROW means that the import volume was already below the level preferred by US consumers in a free market. The US MFG tariff surcharge leads to a further decline in the US import volume, which is a further movement away from the free-market level. There is no welfare efficiency effect linked to services because there is no tariff distortion in US service imports from ROW.
8. Trade elasticity parameters (Armington elasticities) between domestic and imports and among import sources are usually the most influential parameters. To answer this question with confidence, you can do a sensitivity analysis in which you sequentially change each parameter value and examine the effects on the terms of trade.

Model Exercise 8

10. a. Base tax revenue = 4,312,364
    b. Updated tax revenue = 4,345,921
    c. Change in government tax revenue = 33,557
13. a. EV = −810.30
    b. Mean = −809.32
    c. Standard deviation = 3.13

Table ME 8.4 *Welfare effects of a 1% increase in US taxes, $US millions (answer key)*

Allocative Efficiency	Endowment	Technology	Population	Terms of trade in goods and services	Terms of trade in invest–savings	Preference	Total welfare cost	Change in government tax revenue	Welfare cost (cents) per dollar of revenue
−259.7	0	0	0	−401.5	−149.2	0	−810.3	33,557	2.4

Source: NUS333 model.

Table ME 8.5 *Welfare decomposition of the allocative efficiency effect, $US million (answer key)*

Tax type	Welfare cost
Production tax (prodtax)	−28.6
Factor tax (pfattax)	−17.2
Income tax (inctax)	0.0
Input tax (inputtax – *tfd* + *tfn*)	−4.1
Private consumption tax (contax – *tpd* + *tpm*)	−117.7
Investment tax (invtax – *tid* + *tim)*	−50.3
Government tax (govtax – *tgd* + *tgm*)	0.0
Export tax (etax)	6.5
Import tax (mtax)	−48.3
Total	−259.7

Source: NUS333 model.

1. The direct burden is the increase in tax revenue of $33,557 million; its excess burden is an efficiency loss of $259.7 million.
2. Total welfare cost/change in government tax revenue ∗ 100 = Marginal welfare burden 810.3/ 33,557 ∗ 100 = 2.4%.
3. The marginal welfare cost is the welfare change per additional dollar of tax revenue. It includes both allocative efficiency and terms-of-trade effects. This cost is 2.4 cents per dollar, so the government should be advised that its project must return at least 102.4 percent of its costs, or welfare will decline.

4. Private consumption taxes have the most distorting effect and export taxes have the least effect.
5. Terms of trade for goods and services is the most important component of the welfare changes due to the US marginal tax increase. Terms of trade measure the import-purchasing power of exports, so it is included in the EV welfare measure.
6. The marginal welfare cost per dollar is substantially lower than the Ballard et al.'s finding. One reason is that the model has only three sectors. Taxes lead to allocative inefficiency by changing relative prices of goods such as groceries and autos. The more aggregated the model, the smaller the scope for a tax to change relative prices. Another reason is that the GTAP model does not capture dynamic effects of income taxes on savings and capital accumulation or the supply of labor.

8. 75% confidence range = −809.32 ± (2 ∗ 3.13) = −815.58 to −803.06
   95% confidence range = −809.32 ± (4.47 ∗ 3.13) = −823.31 to −795.33.

The negative sign of the EV result is robust with respect to the factor substitution elasticity.

Model Exercise 9

Table ME 9.2 *Solution values for percent changes in productivity and real GDP in baseline scenario 2007–2050 (answer key)*

	US	ROW
Total output productivity in AGR (*aoall*)1 /	31.94	42.31
Real GDP (*qgdp*) (solution value)	109.5	284.3

1/ Source: GTAP CGE model version NUS3x3.

1. An integrated economic assessment begins with global climate models, which provide projected physical climate changes as inputs into biophysical models. Biophysical models describe the effects of these projections on biological processes including plant yields and human health. Economic models use these biological projections as shocks to economic models to explore the economic impacts of climate change.
4. Exogenous adjustments to climate change in this experiment are the growth in land area and decline in agricultural yields. Endogenous adjustments are the changes in production, consumption, trade, and prices.
7. Given the importance of trade and production as adjustment mechanisms, factor substitution and import substitution elasticities should be subjected to sensitivity analysis. Given the uncertainty about the physical effects of climate change, you could also carry out a sensitivity analysis of the size of the yield and land endowment shocks.

Table ME 9.3 *Economic effects of climate change in 2050 (% changes 2007–2050) (answer key)*

	United States			ROW		
	Without climate change (A)	With climate change (B)	Effect of climate change (B – A)	Without climate change (A)	With climate change (B)	Effect of climate change (B – A)
Real GDP (*qgdp*)	109.5	109.0	–0.5	284.3	281.8	–2.5
Agricultural output (*qc*)	52.8	53.1	0.3	70.8	70.3	–0.5
Agriculture producer supply price (*pds*)	–32.3	–20.7	–53.0	–21.3	–8.5	12.8
Agriculture domestic sales (*qds*)	17.9	18.0	0.1	71.6	70.7	–0.9
Private household demand for AGR (*qpa*)	45.6	41.6	–4.0	63.8	59.2	–4.6
Agricultural exports (*qxw*)	236.1	237.6	1.4	62.7	66.0	3.3
Agricultural imports (*qmw*)	1.0	5.4	4.4	98.2	101.2	3.0
Import share of agricultural consumption (*qmw–qds*)	–16.9	–12.6	4.3	26.6	30.5	3.9
Export share of agricultural production (*qxw–qc*)	183.3	184.5	1.1	–8.1	–4.3	3.8

Source: NUS333 model.

Model Exercise 10

Productivity parameter results:

US = 25.6; ROW= 28.9

1. INCPAR is a parameter related to the income elasticity of demand, which describes the percentage change in quantity demanded given a percentage change in income. The INCPAR for tobacco and AG/MFG are less than one, and that for services is greater than one. All else equal, this means that demand for tobacco and AG/MFG will increase by proportionately less than the increase in income, whereas consumption of services will increase by proportionately more than the change in income. Therefore, the services budget shares are expected to expand while the shares of tobacco and AG/MFG decline in both scenarios.

4. Antismoking preferences will cause the equilibrium quantities and price at B to be lower than at A. Verify this result in your model by comparing percent changes in tobacco price and output quantities in the two experiments.
5. The share of tobacco value added in both countries' gross output is small, so economy-wide effects, such as effects on production in other industries, employment, and macro-variables such as the wage and exchange rate are likely to also be small.

Table ME 10.2 *Base and updated INCPAR parameter values (answer key)*

	Base INCPAR parameter values		Updated ROW INCPAR parameter values
	USA	ROW	ROW
AGR	0.23	0.41	No change
Tobacco	0.42	0.43	0.01
MFG	0.81	0.77	No change
SER	1.07	1.18	No change

Source: NTOBAC10 model.

Table ME 10.3 *Private household budget shares under alternative scenarios (answer key)*

	2014 Base		2030 Baseline		2030 in MPOWER scenario	
	USA	ROW	USA	ROW	USA	ROW
Agriculture	0.007	0.050	0.006	0.048	0.006	0.048
Tobacco	0.023	0.046	0.022	0.042	0.022	0.038
Manufacturing	0.174	0.270	0.173	0.262	0.173	0.263
Services	0.796	0.634	0.799	0.648	0.799	0.650
Total	1.000	1.000	1.000	1.000	1.000	1.000

Source: NTOBAC10 model.

Table ME 10.4 *Total ROW private consumption of tobacco in 2030 in $US millions, baseline scenario compared to MPOWER (answer key)*

	Baseline scenario	MPOWER	% Difference
Tobacco	1,760,741	1,620,270	–8.0

Source: NTOBAC10 model.

Table ME 10.5 *Calculating the percent changes in row per capita private consumption of tobacco in baseline and MPOWER scenarios, 2014–2030 (answer key)*

	Baseline Scenario, 2014–2030			MPOWER Scenario, 2014–2030		
	Private household consumption (*qpa*)	Population growth rate *(pop)*	Per capita consumption (*qpa – pop*)	Private household consumption (*qpa*)	Population growth rate *(pop)*	Per capita consumption (*qpa – pop*)
Tobacco	44.6	16.2	28.4	33.2	16.2	17.0

Source: NTOBAC10 model.

Table ME 10.6 *Percent changes in output quantities, real GDP, and TFP, 2014–2030 (answer key)*

	Baseline scenario		MPOWER scenario	
	USA	ROW	USA	ROW
AGR output (*qc*)	36.6	49.4	36.0	48.7
Tobacco output (*qc*)	36.7	49.8	36.1	42.6
MFG output (*qc*)	23.5	61.9	23.5	61.9
SER output (*qc*)	41.7	62.3	41.7	62.5
Real GDP (*qgdp*)	38.7	61.1	38.7	61.1
Total factor productivity (*ava*)	25.6	28.9	25.6	28.9

Source: NTOBAC10 model.

Table ME 10.7 *Systematic sensitivity analysis of MPOWER preference changes on tobacco quantities in the rest of world (answer key)*

				95% Confidence interval	
	Model result	Mean	Standard deviation	Upper	Lower
Production (*qo*)	42.6	42.6	0.07	42.9	42.3
Private consumption (*qpa*)	33.2	33.2	0.11	33.7	32.7

Source: NTOBAC10 model.

Model Exercise 11

1. An NTM is a policy measure other than an import tariff that can potentially have an economic effect on international trade in goods by changing the quantities traded, their prices, or both. It is typically represented in standard CGE models as rents accruing to exporters or importers or as an iceberg trade cost. Among the limitations of this approach is that rents and compliance costs are modeled as government revenue in a standard CGE model and that some NTMs may be demand-enhancing rather than supply-reducing.
2. Trade inefficiency describes the unproductive waste of resources in the transit of goods. An iceberg trade cost describes the lost resources in terms of the good that is transported. A real-world example might be inventory depreciation due to lost time at the border.
6. The two graphs should replicate Figures 8.9 and 8.10 in the text.

Table ME 11.2 *Define import tariff and export subsidy rates (answer key)*

	A Base tariff/tax rates	B AVEs of nontechnical NTMs	C Allocate AVE of NTM (50/50 to import tariff/ export tax)	D Altertax tariff and tax rates	E EXP1 – tariff/ tax removal only	F EXP 2 – NTM reduction only	G EXP 3 – Deep integration: tariff/tax removal plus NTM reduction
Japan tax rates							
Import tariff rates							
Column name	J – A	J – B	J – C	J – D	J – E	J – F	J – G
Formula			50% * J – B	J – A + J – C	J – C	J – A + (0.75*J – C)	0.75 * J – C
AGR	17.06	0.10	0.05	17.11	0.05	17.10	0.04
MFG	4.18	0.10	0.05	4.23	0.05	4.22	0.04
Export tax rates							
Formula			0.50 * US – B (import tariff)	J – A + J – C	J – C	J – A + (.75*J – C	0.75 * J – C
AGR	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MFG	0.00	0.00	0.30	0.30	0.30	0.23	0.23
US tax rates							
Import tariff rates							
Column name	US – A	US – B	US – C	US – D	US – E	US – F	US – G
Formula			0.50 * US – B	US – A + US–C	US – C	US – A + (0.75*US –C)	0.75 *US – C
AGR	0.50	0.00	0.00	0.50	0.00	0.50	0.00
MFG	1.19	0.60	0.30	1.49	0.30	1.42	0.23
Export tax rates							
Formula			50% * J – B (import tariff)	US – A + US–C	US – C	US – A + (0.75*US –C)	0.75 *US – C
AGR	0.00	0.00	0.05	0.05	0.05	0.04	0.04
MFG	0.42	0.00	0.05	0.47	0.05	0.46	0.04

Table ME 11.3 *Define the changes in technical NTMs (trade efficiency) for PTA experiments (answer key)*

	Japan import barriers – % change in trade efficiency		US import barriers – % change in trade efficiency	
Formula	A	B = 0.25 * A	A	B = 0.25 * A
Model experiment	AVE of technical NTM	EXP 2 and 3: AVE with 25% increase in trade efficiency	AVE of technical NTM	EXP 2 and 3: AVE with 25% increase in trade efficiency
AGR	3.40	0.85	0.70	0.18
MFG	0.20	0.05	1.30	0.33

Notes: Base value of trade productivity is implicitly equal to one.
Sources: UNTAD/World Bank (2019) and author calculations.

Table ME 11.4 *Changes in real GDP (in percent) due to Japan–US PTA*

		Stemming from	
Country	EXP 3 – Deep integration	EXP 1 – Tariff/tax elimination only	EXP2 – NTM reduction only
Japan	0.03	0.03	0.01
United States	0.00	0.00	0.00

Note: Results for GTAP variable *qgdp*.
Source: NUSJv2 model.

Table ME 11.5 *Percent changes in quantity of bilateral imports due to PTA*

		Stemming from	
Country	EXP 3 Total – deep integration	EXP 1 – tariff/subsidy elimination only	EXP 2 – NTM reduction only
		Japan to United States	
Agriculture	72.8	69.5	2.4
Manufacturing	39.0	38.1	0.6
Services	0.1	0.0	0.1
		United States to Japan	
Agriculture	7.8	7.0	0.7
Manufacturing	12.1	9.1	2.8
Services	–0.9	–0.6	-0.3

Note: Results report GTAP variable $qxs_{c,s,d}$
Source: NUSJv2 model.

Table ME 11.6 *Welfare impacts of a Japan–US PTA – deep integration ($US millions)*

	Allocative efficiency	Technical efficiency	Terms of trade (goods)	Terms of trade (saving investment)	Total
United States	108	435	3,043	612	4,196
Japan	1,419	126	1,436	1	2,982

Source: NUSJv2 model, experiment 3.

Table ME 11.7 *Trade creation and trade diversion due to Japan–US PTA ($US millions)*

	Change in import volume			
	Japan imports from US	Japan imports from ROW	Net trade creation / diversion	Net trade-creating?
Agriculture	4,997	-2,687	2,310	
Manufacturing	20,690	-10,124	10,566	
Services	29	822	851	
	US imports volume from Japan	US imports from ROW		
Agriculture	12	472	484	
Manufacturing	14,513	-1,526	12,987	
Services	-92	1,282	1,190	

Note: Net trade creation/diversion is calculated as the change in import volume with partner plus the change in import volume with nonmembers of PTA, valued in constant prices.
Source: NUSJv2 model.

Appendix A
Social Accounting Matrix for the United States, 2007 $US Billions

	Commodities												Indirect taxes				
	Imported variety			Domestic variety			Production activity			Factors of production			Trade Taxes		Sales tax on imported variety		
	AGR	MFG	SER	AGR	MFG	SER	AGR	MFG	SER	Land	Labor	Capital	Import tariff	Export tax	AGR	MFG	SER
Import-AGR	0	0	0	0	0	0	1	15	5	0	0	0	0	0	0	0	0
Import-MFG	0	0	0	0	0	0	9	797	300	0	0	0	0	0	0	0	0
Import-SER	0	0	0	0	0	0	1	22	236	0	0	0	0	0	0	0	0
Domestic-AGR	0	0	0	0	0	0	35	165	21	0	0	0	0	0	0	0	0
Domestic-MFG	0	0	0	0	0	0	62	2,007	1,502	0	0	0	0	0	0	0	0
Domestic-SER	0	0	0	0	0	0	86	1,329	4,821	0	0	0	0	0	0	0	0
Activity-AGR	0	0	0	326	0	0	0	0	0	0	0	0	0	0	0	0	0
Activity-MFG	0	0	0	0	6,657	0	0	0	0	0	0	0	0	0	0	0	0
Activity-SER	0	0	0	0	0	18,212	0	0	0	0	0	0	0	0	0	0	0
Land	0	0	0	0	0	0	36	0	0	0	0	0	0	0	0	0	0
Labor	0	0	0	0	0	0	47	1,361	6,797	0	0	0	0	0	0	0	0
Capital	0	0	0	0	0	0	53	649	2,846	0	0	0	0	0	0	0	0
Import tariff	1	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Export tax	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
Sales tax-AGR import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sales tax-MFG import	0	0	0	0	0	0	0	4	7	0	0	0	0	0	0	0	0
Sales tax-SER import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sales tax-AGR dom.	0	0	0	0	0	0	–1	0	0	0	0	0	0	0	0	0	0
Sales tax-MFG dom.	0	0	0	0	0	0	0	11	45	0	0	0	0	0	0	0	0
Sales tax-SER dom.	0	0	0	0	0	0	–4	4	6	0	0	0	0	0	0	0	0
Factor use tax-land	0	0	0	0	0	0	–1	0	0	0	0	0	0	0	0	0	0
Factor use tax-labor	0	0	0	0	0	0	4	205	1,023	0	0	0	0	0	0	0	0
Factor use tax-capital	0	0	0	0	0	0	–2	21	93	0	0	0	0	0	0	0	0
Production tax	0	0	0	0	0	0	1	70	511	0	0	0	0	0	0	0	0
Income tax	0	0	0	0	0	0	0	0	0	3	1,742	294	0	0	0	0	0
Regional household	0	0	0	0	0	0	0	0	0	33	6,463	1,994	24	3	1	59	0
Household	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Government	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Savings-investment	0	0	0	0	0	0	0	0	0	0	0	1,260	0	0	0	0	0
Trade margin-import	5	81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trade margin-export	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rest of world	28	1,797	315	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	34	1,901	315	326	6,660	18,212	326	6,657	18,212	36	8,205	3,548	24	3	1	59	0

	Indirect taxes									Final demand						
	Sales tax on domestic variety			Factor use taxes				Direct tax					Trade/transport margins			
	AGR	MFG	SER	Land	Labor	Capital	Production tax	Income tax	Regional household	Private household	Gov't	Saving/ investment	Import margin	Export margin	Rest of world	Total
Import-AGR	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0	34
Import-MFG	0	0	0	0	0	0	0	0	0	501	0	294	0	0	0	1,901
Import-SER	0	0	0	0	0	0	0	0	0	51	0	4	0	0	0	315
Domestic-AGR	0	0	0	0	0	0	0	0	0	53	0	0	0	0	52	326
Domestic-MFG	0	0	0	0	0	0	0	0	0	1,355	0	764	0	0	970	6,660
Domestic-SER	0	0	0	0	0	0	0	0	0	7,742	2,258	1,604	0	28	345	18,212
Activity-AGR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	326
Activity-MFG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6,657
Activity-SER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18,212
Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	36
Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8,205
Capital	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,548
Import tariff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24
Export tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Sales tax-AGR import	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Sales tax-MFG import	0	0	0	0	0	0	0	0	0	43	0	5	0	0	0	59
Sales tax-SER import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sales tax-AGR dom.	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1
Sales tax-MFG dom.	0	0	0	0	0	0	0	0	0	137	0	12	0	0	0	204
Sales tax-SER dom.	0	0	0	0	0	0	0	0	0	51	0	1	0	0	0	58
Factor use tax-land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	–1
Factor use tax-labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,232
Factor use tax-capital	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	112
Production tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	581
Income tax	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,039
Regional household	1	204	58	–1	1,232	112	581	2,039	0	0	0	0	0	0	0	12,802
Household	0	0	0	0	0	0	0	0	9,949	0	0	0	0	0	0	9,949
Government	0	0	0	0	0	0	0	0	2,258	0	0	0	0	0	0	2,258
Savings-investment	0	0	0	0	0	0	0	0	594	0	0	0	0	58	773	2,686
Trade margin-import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86
Trade margin-export	0	0	0	0	0	0	0	0	0	0	0	0	86	0	0	86
Rest of world	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,139
Total	1	204	58	–1	1,232	112	581	2,039	12,802	9,949	2,258	2,686	86	86	2,139	

Source: GTAP version 8.1.

Appendix B
Price and Quantity Variables in a Standard CGE Model

Price variable	Definition	Quantity variable	Definition	Set domain
Production				
PCA[1/]	***Supply price (basic)*** of commodity *c* produced by production activity *a* in region *r*. It is the cost of production (PS) plus production tax	QCA	Supply of commodity *c* produced by production activity *a* in region *r*	c,a,r
PDS[1/]	***Producer sales price (basic)*** of commodity *c* produced in region *r*. It is the cost of production (PS) plus production tax	QC–total output QDS–domest. sales QFD–firms QGD–govt. QPD–households QID–invest. QXS–exports QST–margins	Quantity of commodity *c* produced in region *r*, and domestic quantities sold to aggregate domestic demand (QDS), **F**irms, **G**ov't., **P**rivate households, **I**nvestors, e**X**ports and trade margins services	c,r
PO[2/]	***Unit cost of production*** in activity *a* in region *r* (excludes production tax)	QO	Quantity of output of domestic activity *a* in region *r*	a,r

(*continued*)

PS[2/]	***Producer supply price*** equals the unit cost of production of commodity *c* by activity *a* in region *r* (excludes production taxes)	QCA	Supply of commodity *c* produced by production activity *a* in region *r*	c,a,r
PINT	***Composite input price*** for bundle of intermediate inputs used in activity *a* in region *r* where weights are inputs' cost shares in total input expenditure	QINT	Quantity bundle of intermediate inputs used in activity *a* in region *r*	a,r
PVA	***Composite value-added price*** for bundle of factor endowments used in activity *a* in region *r* where weights are factors' cost shares in total value added expenditure	QVA	Quantity bundle of factor endowments used in activity *a* in region *r*	a,r
Consumption				
P PFA PGA PPA	***Composite consumer market price*** of composite commodity *c* consumed in region in aggregate (a composite price index) and by **F**irms, **G**ov't.,	Q QFA QGA QPA	Quantity of composite commodity *c* (imports plus domestic) consumed in region *r* in aggregate and	c,r, except domains for firms are c, a, r

(continued)

Price variable	Definition	Quantity variable	Definition	Set domain
PIA	**P**rivate households, **I**nvestors, is the weighted sum of composite price of imports (P**F**M, etc.) and consumer domestic price (P**F**D, etc.)	QIA	by **F**irms, **G**ov't., **P**rivate households, **I**nvestors	
PD PFD PGD PPD PID	***Consumer domestic price*** of domestically produced commodity *c* consumed in region *r* in aggregate (a composite price index) and by **F**irms, **G**ov't., **P**rivate households, **I**nvestors (includes retail sales tax)	QDS QFD QGD QPD QID	Quantity of domestically produced commodity *c* consumed in region *r* in aggregate and by **F**irms, **G**ov't., **P**rivate households, **I**nvestors	c,r, except domains for firms are c, a, r
PM PFM PGM PPM PIM	***Composite consumer import price*** of composite imported commodity *c* consumed in region *r* in aggre gate (a composite price index) and by **F**irms, **G**ov't., **P**rivate households, **I**nvestors is the composite price of imports (PMS) plus retail sales tax	QMW QFM QGM QPM QIM	Quantity of composite imports (from all sources) of commodity *c* consumed in region *r* in aggregate and by **F**irms, **G**ov't., **P**rivate households, **I**nvestors	c,r, except domains for firms are c, a, r

(*continued*)

Trade

PCIF	***Bilateral cif import price*** is the *fob* export price plus bilateral *cif* charges for export of commodity *c* from source region *s* by destination region *d* (excludes import tariffs)	QXS	Quantity of bilateral import of commodity *c* from source region *s* by destination region *d*	c,s,d
PFOB	***Bilateral fob export price*** for export of commodity *c* from source region *s* to destination *d* is the producer sales price plus *s*'s bilateral export tax on sales from *s* to *d*	QXS	Quantity of bilateral export of commodity *c* from source region s to destination *d*	c,s,d
PMS	***Composite domestic price of composite import (basic)*** is the weighted sum of the bilateral domestic prices of commodity *c* from region s to region *d* where weights are cost shares of bilateral imports in total import value (includes import tariffs, excludes retail tax)	QMW QFM QGM QPM QIM	Quantity of composite import (from all sources) of *c* consumed in region *r* in aggregate and by **F**irms, **G**ov't., **P**rivate households, **I**nvestors	c,r

(*continued*)

Price variable	Definition	Quantity variable	Definition	Set domain
PMDS	***Bilateral domestic price of import (basic)*** is the bilateral *cif* import price (PCIF) on commodity *c* imported from source region *s* by destination region *d*, plus bilateral import tariff	QXS	Quantity of bilateral imports of commodity *c* imported from source region *s* by destination region *d*	c,s,d
PXW	***Composite world export price*** for total exports of commodity *c* from region *r* is the weighted sum of its bilateral *fob* export prices, where weights are bilateral value shares in *r*'s total exports of *c*	QXW	Aggregate quantity (to all destinations) of commodity *c* exported by region *r*	c,r
PMW	***Composite world import price*** for total imports of commodity *c* by region *r* is the share-weighted sum of its bilateral *cif* import prices (excludes tariffs) where weights are the bilateral value shares in *r*'s total imports of *c*	QMW	Aggregate quantity (from all sources) of commodity *c* imported by region *r*	c,r

(*continued*)

PXWCOM	***World price*** of the total quantity of world trade (QW) in commodity *c* is the weighted sum of all bilateral *fob* export prices of commodity *c* where weights are value shares of each bilateral flow in global trade of *c*	QXWCOM	Total quantity of world trade in commodity *c*	c
Factor endowments				
PE	***Composite net factor return (wage/rent)*** (excludes income tax) to aggregate supply of factor *e* in region *r,* where weights are value shares of after-tax earnings from each activity *a* in total earnings.	QE	Total quantity of endowment *e* in region *r*	e,r
PEB	***Basic price of factor endowment*** *e* purchased by activity *a* in region *r* (incl. income tax; excl. factor use tax)	QFE	Quantity of factor demand for endowment *e* in activity *a* in region *r*	e,a,r

(*continued*)

Price variable	Definition	Quantity variable	Definition	Set domain
PES	***Net factor income*** (excluding income tax) to factor *e* in activity *a* in region *r*	QES	Quantity of factor supply of endowment *e* to activity *a* in region *r*	e,a,r
PFE	***Price of factor endowment*** *e* purchased by activity *a* in region *r* (includes factor use taxes)	QFE	Quantity of factor demand for endowment *e* by activity *a* in region *r*	e,a,r

Notes:
1/ PCA equals PDS if each activity produces one commodity. If a commodity is made by more than one activity, PDS is a weighted sum of the supply prices, PCA, of *c* by all activities.
2/ PO equals PS if each activity produces one commodity. If an activity makes more than one commodity, PO is a weighted sum of the supply prices, PS, of all commodities made by the activity.

Appendix C
Elasticity Parameters in the GTAP Model

Symbol	Definition	Parameter name
Supply elasticity parameters		
σ_a^{VA}	Factor substitution	ESUBVA
σ_a^{INT}	Intermediate input substitution	ESUBC
σ_a^{AGG}	Aggregate input substitution	ESUBT
σ_e^{F}	Factor transformation (mobility)	ETRAE
σ_a^{Q}	Commodity output transformation	ETRAQ
σ_c^{S}	Commodity sourcing substitution	ESUBQ
Demand elasticity parameters		
η_c	Income	INCAR
ε_c	Own-price	SUBPAR
$\sigma_{c,n}^{P}$	Commodity substitution	SUBPAR
σ_c^{D}	Import-domestic (Armington) substitution	ESUBD
σ_c^{M}	Import–import (Armington) substitution	ESUBM

Appendix D
Taxes in the GTAP Model

Tax name	Description	GTAP model notation – % change tax rate in experiment
Production tax	Tax on output of commodity *c* by production activity *a* in region *r*	$to_{c,a,r}$
Government domestic consumption tax	Tax on government consumption of domestically produced commodity *c* in region *r*	$tgd_{c,r}$
Government import consumption tax	Tax on government consumption of imported commodity *c* in region *r*	$tgm_{c,r}$
Uniform private household consumption tax	Uniform tax on private household consumption of all imported and domestic commodities in region *r*	$tpreg_{r}$
Private household domestic consumption tax	Tax on private household consumption of domestically produced commodity *c* in region *r*	$tpdall_{c,r}$
Private household import consumption tax	Tax on private household consumption of imported commodity *c* in region *r*	$tpmall_{c,r}$
Investment domestic consumption tax	Tax on investment consumption of domestically produced commodity *c* in region *r*	$tid_{c,r}$
Investment import consumption tax	Tax on investment consumption of imported commodity *c* in region *r*	$tim_{c,r}$
Intermediate domestic input use tax	Tax on use of domestically produced intermediate input *c* by activity *a* in region *r*	$tfd_{c,a,r}$
Intermediate import use tax	Tax on use of imported intermediate input *c* by activity *a* in region *r*	$tfm_{c,a,r}$

(*continued*)

(cont.)

Tax name	Description	GTAP model notation – % change tax rate in experiment
Factor endowment tax	Tax on use of factor endowment *e* by activity *a* in region *r*	$tfe_{e,a,r}$
Income tax	Income tax on factor endowment *e* employed in production activity *a* in region *r*	$tinc_{e,a,r}$
Uniform export tax	Tax on commodity *c* exported from region *r* to all destination region	$tx_{c,r}$
Export tax, bilateral	Tax on commodity *c* exported from source region *s* to destination region *d*	$txs_{c,s,d}$
Uniform import tariff	Uniform tariff on commodity *c* imported from all regions by region *r*	$tm_{c,r}$
Import tariff, bilateral	Tax on commodity *c* imported from source region *s* by destination region *d*	$tms_{c,s,d}$

Glossary

Accounting equation: *see* equation, accounting.

Activity is the domestic production of a good or service.

Ad valorem equivalent (AVE) is a tax that has the equivalent effects on market prices and quantities as a regulation.

Ad valorem tax is a tax levied as a percentage of value.

Agents include production activities, factors of production (e.g., labor and capital), household consumers, the government, investors, and the rest-of-world region, which supplies imports and demands exports.

Baseline scenario introduces projected growth in population, factor supplies, and/or real GDP and productivity.

Behavioral equation: *see* equation, behavioral.

Budget constraint is the amount of income received by a consumer that is then allocated to consumption, savings, and taxes.

Budget share is the value share of each good or service in total expenditure.

Calibration is a procedure that calculates quantities and normalized prices, and the shift and share parameters used in the production and utility functions in the CGE model so that the solution to model equations replicates the initial equilibrium as reported in the base data.

cif: *see* cost, insurance, freight.

Circular flow of income and spending describes transactions in an economy: Activities buy inputs and pay wages and capital rents to factors used in the production of goods and services. Activity payments to factors are the income earned by households and spent on goods and services, government taxes, and savings. Taxes and savings lead to government and investment demand. Activities respond to demand by buying inputs and hiring labor and capital.

Closure defines whether a variable is endogenous or exogenous.

Compensated demand curve implies that the government compensates consumers dollar for dollar for their tariff expenditure. This compensation assumption allows all quantity changes due to a tax to be attributed to the substitution effect (which is the excess burden) because the compensation cancels any income effects of the tax.

Complements are inputs or consumption goods that are used together, so that a rise in the price of one input or good causes demand for the other to fall.

Composite import is an aggregation of imports across bilateral sources of supply.

Composite price is a weighted sum of the prices of items in a composite quantity, where the weights are the items' cost shares in the value of the composite quantity.

Composite quantity is an aggregation of like items. It can be an aggregation of a commodity, composed of domestically produced and imported varieties or imports from multiple sources. It can be an aggregation of factors of production. It can be a composite production good, composed of varieties produced for domestic and export sales.

Computable general equilibrium (CGE) model describes an economy as a whole and the interactions among its parts. It is solved to find the set of prices at which quantities of supply and demand are in equilibrium in all markets.

Constant elasticity of substitution (CES) or constant elasticity of transformation (CET) is a function in which the elasticity of substitution is the same for any ratio of inputs and at any level of output. In a CES function, a rise in an input's price reduces its quantity share in total output; in a CET function, a rise in an input's price increases its quantity share in total output.

Consumer price is the price paid by consumers. It is the domestic producer price plus sales tax, or bilateral *cif* import price plus import tariff and sales tax.

Consumer price of imports is the *cif* import price plus import tariffs.

Cost-insurance-freight (*cif*) is the value of an import, including the cost of the good, plus the insurance and freight services used in its international transport.

Deadweight loss is the loss in producer and consumer surplus that is not recouped elsewhere in the economy.

Depreciation is that portion of investment spending that replaces worn-out capital stock.

Deterministic CGE model provides unique solution values for each variable, given model equations, parameters, and base data.

Diagonal make matrix describe a production structure in which each production activity makes a single commodity and each commodity is made by one production activity.

Direct burden is the amount of tax paid to the government.

Direct cost of a regulation is the deadweight efficiency loss in a market due to its regulation.

Direct tax is a tax that is levied on factors or individuals and whose burden cannot be passed on to other agents.

Downstream industries are the production activities that use the output of other, "upstream" industries as intermediate inputs into their production process.

Dutch Disease describes the deindustrialization of an economy when an increase in the world price of a natural resource export price leads to an expansion of the booming resource sector, higher incomes and spending, and real exchange rate appreciation.

Dynamic CGE model describes a country's long-run growth path, with capital accumulation and productivity growth.

Effective factor endowment is the quantity of a factor adjusted for its productivity level.

Effective factor price is the wage or rental paid per unit of effective labor or capital.

Effective import price is the price paid per unit of effective import quantity.

Effective import quantity is the export quantity shipped by the exporter minus its iceberg trade costs (the quantity of itself used up in its transport).

Elasticity is an exogenous parameter in a CGE model that describes the responsiveness of supply or demand to a change in prices or income.

Elasticity, aggregate input substitution for production activity a describes the percent change in the ratio of the value-added bundle to the intermediate input bundle in the final product, given a percent change in their inverse price ratio, holding the quantity of final output constant.

Elasticity, commodity output transformation describes the percent change in the quantity of one output to the other output, given a percent change in the inverse ratio of their sales prices, holding the total quantity of output constant.

Elasticity, commodity sourcing substitution describes the percent change in the quantity ratios (market shares) of suppliers of the same commodity given a percent change in the ratios of their supply prices, holding the total quantity supplied constant.

Elasticity, commodity substitution in consumption between commodities *c* and z describes the percent change in the quantity ratios in a given consumer basket, relative to a percent change in their inverse price ratio, for a given level of utility.

Elasticity, export demand for commodity *c* describes the percent change in a country's world market share given a percent change in the ratio of the average global price to its *fob* export price.

Elasticity, export transformation for production activity *a* describes the percent change in the quantity ratio of exports to domestic sales given a percent change in the ratio of the domestic sales price to the *fob* world export price, holding the quantity of output of *c* constant.

Elasticity, factor transformation or mobility for factor *e* describes the percent change in an production activity's quantity share in total employment of a factor given a percent change in the ratio of the economy-wide average factor price to the industry's wage or rent, holding national supply of the factor constant.

Elasticity, factor substitution for production activity *a* describes the percent change in the quantity ratio of a factor to total factor inputs given a percent change in the inverse ratio of the factor's price relative to the prices of other factors, holding the quantity value-added bundle constant.

Elasticity, domestic-import substitution (Armington) for commodity *c* describes the percent change in the quantity ratio of imported to domestic varieties given a percent change in their inverse price ratio, holding the quantity of consumption of *c* constant.

Elasticity, import-import substitution (Armington) for commodity *c* describes the percent change in the quantity ratio of imports from partner *s* and partner *z* given a percent change in their inverse price ratio, holding the quantity of imports of *c* constant.

Elasticity, income for commodity *c* describes the percent change in quantity demanded given a percent change in income.

Elasticity, intermediate input substitution for production activity *a* describes the percent change in the quantity ratios of intermediate inputs given a percentage change in the inverse ratio of input prices, holding the quantity of composite inputs constant.

Elasticity, own price for commodity *c* describes the percent change in quantity demanded given a percent change in its price.

Elasticity, price transmission measures the percent change in one price given a percent change in another price.

Endogenous variable has a value that is determined as the solution of a model equation.

Equation, accounting is used to define variables as sums or products of other variables, such as a retail price is the sum of the wholesale price plus the retail sales tax.

Equation, behavioral describes the economic behavior of producers or consumers based on microeconomic theory.

Equation, identity defines a variable as a mathematical function (sum, product, etc.) of other variables. It describes an accounting relationship or imposes a market-clearing constraint. Closure rules specify which variable adjusts to maintain the constraint.

Equilibrium occurs when the quantities of supply and demand are in balance at some set of prices.

Equivalent variation: *see* welfare, equivalent variation.

Excess burden is the loss in economic efficiency when producers and consumers change the quantities that they produce or consume to avoid a tax.

Exchange rate, nominal measures the rate at which currencies are exchanged for one another.

Exchange rate, real measures the relative prices of traded to non-traded goods.

Exogenous parameters in a CGE model are tax and tariff rates, elasticities of supply and demand, and the calibrated shift and share coefficients used in supply-and-demand equations.

Exogenous variable is a variable whose value is fixed at its initial level and does not change when model equations are solved.

Externality is the negative or positive spillover effect of an economic transaction between two parties, which is not reflected in market prices.

Factor of production is a primary productive resource, such as land, labor, or capital, that is combined with intermediate inputs to produce goods and services.

Factor endowments are the stocks of labor, capital, and other primary factors that constitute the productive resource base of an economy.

Factor endowment, effective is the stock of a factor that takes into account both the quantity and the efficiency of a factor.

Factor, fully mobile moves across production activities within a country in response to changes in relative wages and rents, until wages and rents are equalized.

Factor intensity is measured by the relative size of factors' input-output coefficients. The comparison of coefficients can be made across factors within a production activity, or by comparing a factor's coefficient across industries or countries. An activity is intensive in a factor if the coefficient for that factor is higher than for other factors, higher for that factor compared to other activities, or higher for that factor compared to the same activity in other countries.

Factor mobility describes the ease with which labor, capital, and other factors can move to new employment within a country when wages and rents differ across production activities.

Factor, partially mobile is a factor for which transition costs are important enough to discourage it from changing its employment unless pay differences across industries are sufficient.

Factor price is the wage or rent paid to a factor by the production activity that employs it.

Factor price, effective is the wage or rent paid per unit of effective factor quantity.

Factor productivity describes the level of output per unit of factor input.

Factor, sector-specific (immobile) does not move from the production activity in which it is originally employed, regardless of differences in relative wages or rents across production activities.

Factor unemployment describes factors that are not employed by any production activity and are not counted as part of the productive capacity of an economy.

Factors, complementary describe factors for which an increase (decrease) in the use of one factor in the production process requires an increase (decrease) in use of the other.

Factors, substitute describe factors that can replace one another in the production of a good or service.

Final demand is the demand for goods and services in their end-use; they are not further combined or processed into other goods and services. Private households, government, and investors are components of final demand.

fob: *see* free-on-board.

Free-on-board (fob) is the value of the export good, including export taxes but excluding the trade margin costs (c*if)* costs paid by the importer.

Gross complement: Two goods are gross complements if a decline in the price of one good causes the quantity demanded of the second good to rise.

Gross Domestic Product (GDP) from the expenditure side reports the allocation of national income across four categories of spending: private consumption (C), investment demand (I), government demand (G), and net exports (E−M).

Gross Domestic Product (GDP) from the income side reports the sources of total national income from the wages and rents earned by factors of production, taxes on economic activity, and depreciation.

Gross investment is the combined spending on replacement of depreciated capital plus investment in new equipment and machinery.

Gross substitute: Two goods are gross substitutes if a decline in the price of one good causes the quantity demanded of the second good to fall.

Gross output of a production activity is the sum of value-added plus the cost of intermediate inputs. It is the market value of industry output and reported as the sum total of the activity column in the SAM.

Hecksher-Ohlin theorem posits that countries will export goods that are intensive in the factors of production that are in relatively abundant supply, and import goods that are intensive in the factors of production that are in relatively scarce supply.

Homothetic utility function assumes an income elasticity of demand of one so that the percentage change in quantity demanded is the same as the percentage change in income.

Iceberg trade cost is the portion of the traded good that is used up, or "melted away," in its transport from the exporter to the importer.

Identity equation: *see* equation, identity.

Immobile factor (sector-specific) is a factor that remains fixed in its original sector of employment.

Import (Armington) aggregation function describes how imported and domestic varieties are combined to produce a composite commodity.

Independent goods or factors are items for which demand does not change when the prices of other goods or factors change.

Indifference curve describes all possible combinations of commodities that yield the same level of utility or satisfaction to the consumer.

Indirect costs of a regulation are (1) changes in total production of externalities that result from changes in industry size and composition, (2) second-best efficiency effects, and (3) terms of trade.

Inferior good is a good for which demand declines as income grows.

Input-output coefficient describes the ratio of an intermediate or factor input per unit of output.

Input-output coefficient matrix displays the input-output coefficients of all inputs in every production activity. The matrix shows how industries are linked through their demand for intermediate inputs.

Intermediate input is a good that is combined with other inputs and factors to produce a final product.

Intermediate input intensity is measured by the relative size of intermediate input-output coefficients. The comparison of coefficients can be made across intermediate inputs within a production activity, or by comparing an input's coefficient across industries or countries. An activity is intensive in an intermediate input if its input-output coefficient for that input is higher than for other intermediate inputs, higher for that input compared to other production activities, or higher for that input compared to the same activity in other countries.

Isocost describes all combinations of inputs that can be purchased for the same cost.

Isoquant describes all technologically feasible combinations of inputs that can be used to produce the same level of output.

Isorevenue line shows all combinations of outputs that generate the same amount of revenue for the producer.

Large country's world prices for its imports and exports are influenced by its export and import quantities.

Law of Demand states that demand for a good will rise (fall) when its price falls (rises).

Leontief fixed-proportions production function assumes that all inputs must be used in fixed proportions to output.

Long run is a post-shock adjustment period that is sufficiently long that factors are fully mobile across production activities, and factor endowments and factor productivity may change.

Luxury good has an income elasticity of demand that is greater than 1.

Macro-micro model provides the endogenous, macroeconomic results from a CGE model (the macro model) as the exogenous inputs into a microeconomic model with large numbers of households or production activities.

Marginal product is the addition to output from an additional unit of an input, holding other inputs constant.

Marginal rate of substitution is the rate at which the consumer is willing to trade off a unit of one good for one unit of the other good.

Marginal rate of transformation is the rate at which producers can substitute production for exports with production for the domestic market in a given level of output, or the rate at which workers can transform from employment in one industry to employment in another industry in a given size of labor force.

Marginal utility is the addition to utility or consumer satisfaction from an additional unit of consumption.

Marginal welfare burden is the change in national welfare due to a very small – marginal – change in an existing tax.

Market-clearing constraint equation ensures that the model solves for a set of prices at which quantities supplied and demanded are equal.

Medium run is a post-shock adjustment period sufficiently long that factors are fully mobile across production activities, but too short for long-run changes in factor accumulation or productivity to take place.

Model closure is the modeler's decision as to which variables are exogenous and which are endogenous.

Multi-country model contains two or more countries (or regions) whose economies and economic behavior are described in detail and which are linked through trade and, sometimes, capital and labor flows.

Multiregion input-output (MRIO) table describes international trade by end-user so that production activities' imports of intermediates from industries along the supply chain can be identified.

Necessity good has an income elasticity of demand that is less than 1.

Nested production function: *see* production function, nested.

Net investment is gross investment minus investment spending that replaces depreciated capital equipment. It is the net increase in the capital stock.

Net substitute: Two goods are net substitutes if a decline (rise) in the price of X relative to Y causes an increase (decrease) in the quantity ratio of X to Y, holding output or utility constant.

Non-diagonal make matrix describes a production structure in which more than one production activity makes a single commodity and/or each commodity is made by more than one production activity.

Nonhomothetic utility function assumes the income elasticity of demand does not equal one so that the percentage change in quantity demanded changes by less than (the income elasticity is less than 1) or more than (the income elasticity exceeds 1) the percentage change in income.

Nontariff measure (NTM) is a policy measure other than an import tariff that can potentially have an economic effect on international trade in goods by changing the quantities traded, their prices, or both.

Normal good has a positive income elasticity of demand. Demand for a normal good increases when income rises.

Normalized price is used to interpret value data as price and quantity data. If the price of a good is described as $1 then the value data can be interpreted as the quantity per $1.

Numeraire is a price that is fixed at its base value and serves as the standard of value against which all other prices in the model can be measured.

Outcome-based regulation allows producers to choose the least-cost means of achieving the regulatory goal.

Output effect on input demand is the change in demand for all inputs by the same proportion as the change in output, holding input price ratios constant.

Output effect of a regulation is the reduction in production of the externality that occurs when compliance costs lead to higher output prices and lower consumer demand and production.

Parameters in a CGE model include elasticity parameters, calibrated shift and share parameters used in production and consumption functions, and calculated tax rates.

Partial equilibrium model is a system of mathematical equations that describe the economic motives and behaviors in the market for one good, or for one type of economic agent, such as consumers, holding prices and quantities in the rest of the economy constant.

Preferential trade agreement reduces trade barriers among pact members but maintains barriers against nonmembers.

Price transmission describes the percentage change in a domestic price given a percentage change in another price.

Primary factor inputs: *see* factor.

Process-based regulation requires an industry to purchase a specific input or technology, or practice a mandated technique.

Product transformation curve plots all possible combinations of two goods that can be produced with a given quantity of productive resources.

Production function defines the technology, or physical production process, by which intermediate inputs are transformed by machinery and workers into a product.

Production function, nested separates the production process into smaller production processes that are "nested" within the larger process of producing the final product. Each nest has its own production function.

Quasi-homothetic preferences describe fixed minimum consumption requirements and homothetic preferences for discretionary consumption goods.

Rational expectations describe producers and consumers who anticipate and take into account prices and income in all time periods as they make their current decisions.

Real consumption measure of welfare: *see* welfare, real consumption.

Real exchange rate: *see* exchange rate, real.

Regional household is a macroeconomic account used in some CGE models that aggregates total national income from factor earnings and taxes, and allocates the income to private consumption, government, and savings.

Regulation is a "command and control" approach in which the government directly mandates certain behavior and enforces it with undesirable outcomes.

Rent (economic) from an NTM is measured by the price wedge between the domestic and world prices multiplied by the quantity produced or traded.

Rules of origin are the criteria used to define the national identity of a product based on the origin of its inputs. The rules impose compliance costs and lead to inefficiencies in production and consumption.

Rybczynki theorem posits that an increase in the quantity of one factor will lead to an absolute increase in the production of the good that uses that factor intensively, and an absolute decrease in production of the good that does not use it intensively, holding world prices constant.

Second-best is the most efficient outcome attainable if there is an existing distortion in another market due to a tax, a market failure, or other type of economic constraint.

Sector-specific factor: *see* immobile factor.

Sensitivity analysis is a check on the robustness of model results to alternative values of elasticity parameters or sizes of shocks.

Sets are the domains over which parameters, variables, and equations are defined.

Shadow price measured by an endogenous tax rate is the marginal cost of compliance with a regulation.

Share parameter is a calibrated parameter that describes a share, such as a factor share in value added, or imported and domestic shares in consumption.

Shift parameter is a calibrated parameter in the production function that describes the level of input productivity.

Short-run equilibrium describes a post-shock adjustment period that is short enough that at least one factor of production, usually capital, remains immobile, and no long-term changes in factor endowments or productivity occur.

Single-country model describes only one country in detail and summarizes the rest-of-world economy as import demand and export supply functions.

Small country's world prices for its imports and exports are determined by world price levels and are independent of its export and import quantities.

Social Accounting Matrix is a square matrix whose columns and rows describe transactions among buyers and sellers in the circular flow of income and spending in an economy in a time period.

Static model describes an economy's equilibria before and after a shock, holding factor supplies constant, and does not depict the adjustment path.

Stochastic CGE model accounts for randomness in the economy and solves for the mean values and probability distributions of the endogenous variables.

Stolper-Samuelson theorem posits that an increase in the world price of a good leads to a rise in the price of the factor used intensively in its production, and a decline in the price of the other factor.

Structure refers to the shares in economic activity, including industrial composition of output, the commodity composition of demand and trade, and shares of each factor in employment and earnings.

Structure table uses the microeconomic data in the SAM to describe the economy in terms of shares (e.g., shares of each commodity in households' consumption).

Substitute goods or factors are items for which the producer or consumer is willing to trade off more of one for less of the other as their relative prices change.

Substitution effect is the change in the ratio of inputs in production or in consumption as relative prices change, at constant output or utility levels.

Tax, ad valorem is levied as a percentage of the value of goods or services.

Tax, direct is levied on factors or individuals; its direct burden cannot be shifted to other agents.

Tax, export is levied on exports.

Tax, factor use is levied on producers based on their employment of factors of production.

Tax incidence describes how the direct burden of indirect taxes is shared among buyers and sellers after prices and quantities adjust.

Tax, income is a direct tax paid by factors or households on the basis of income earned.

Tax, indirect is levied on the production or purchase of goods or factors; its direct burden can be shifted from the entity that pays the tax onto someone else through a change in price of the good or factor.

Tax, lump sum is a fixed tax liability that does not depend on income, wealth, or level of consumption or production.

Tax, production is levied on producers based on their output.

Tax, sales is levied on purchases of goods and services used as intermediate inputs or in final demand.

Tax, specific is levied per quantity unit.

Technology tree: *see* nested production function.

Terms of trade is the ratio of the world (*fob*) price of a country's export good(s) relative to the *cif* price of its import good(s).

Total factor productivity (TFP) is the output level per unit of aggregate factor input.

Trade creation is the shift in the quantity of production within a preferential trade area from a high-cost producer to lower-cost members, plus the expansion of the quantity of consumption as prices within the union fall.

Trade diversion is the shift in the quantity of imports from lower-cost countries outside of a preferential trade agreement to higher-cost producers within the trade pact.

Trade efficiency is a measure of the use of resources used in the transport of goods from the exporting country to the importing country.

Trade margins are the insurance plus freight charges incurred when goods are shipped by air, sea, or overland from the exporting country to the importing country.

Upstream industries are the production activities that produce goods that are used as intermediate inputs into other, "downstream" industries.

Utility function describes how commodities can be combined, according to the tastes and preferences of consumers, to generate consumer utility or satisfaction.

Value added includes factor input costs and tax payments by activities in the production of goods and services.

Value-added production function describes the stage of the production process in which producers choose the most efficient ratios of factors in a given value-added bundle.

Welfare, equivalent variation is a money-metric measure of the value to the consumer of the price changes due to a shock. It is calculated as the difference in income required to achieve the new versus the initial levels of utility when goods are valued at base year prices.

Welfare, real consumption is a money-metric measure of the value to the consumer of the price changes due to a shock. It is calculated as the difference in income required to buy the new basket of goods versus the initial basket of goods when both baskets are valued at base year prices.

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