# 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<br>(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<br>(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 | | |