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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 of model that we will be studying is a *Computable General Equilibrium (CGE)* model. It is an “economywide” 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 and hiring workers and capital equipment. The income generated from sales of firms’ output ultimately accrues to households, who spend it on goods and services, taxes and saving. Tax revenue and savings lead to government and investor spending. The combined demand by private households, government, and investors is met by firms who, to complete the *circular flow of income and*

Table 1.1. *Bicycle Industry Model*

Model Equations Type	General Notation	Numerical Function
Supply equation:	$Q_s = G(P_i, P)$	$Q_s = -4P_i + 2P$
Demand equation:	$Q_d = F(P, Y)$	$Q_d = 2Y - 2P$
Market clearing constraint:	$Q_s = Q_d = Q$	
Endogenous Variables		
Q = Quantity of bikes		
P = Price of bikes		
Exogenous Variables		
P _i = Prices of inputs (e.g., tires, steel)		
Y = Income		

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, Q_s , is related to the prices of bicycle inputs, P_i , such as rubber tires, and the market price of bicycles, P . With this general functional notation, we know only that there is a causal relationship among the variables, but not its size or whether it is 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, Q_d , 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, $Q = Q_s = Q_d$; the equilibrium quantity of bicycles supplied and demanded must be equal.

The three equations describing the bicycle industry model, expressed in general functional notation, are listed in Table 1.1. The model has two *exogenous* variables: input prices, P_i , and consumer income, Y . Their values are determined by forces outside the model, and we take them as given. The model has two *endogenous* variables: the equilibrium quantity, Q , and the price, P , of bicycles. Their values will be determined as solutions to our model’s equations.

Using our bicycle industry model with general functional 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, P_i , 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: $Q_d = 2Y - 2P$, 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 price of bicycles. Perhaps we also estimate this linear supply function for bicycle supply: $Q_s = -4P_i + 2P$. We now have a quantitative model that describes both supply and demand and is capable of yielding numerical solutions.

If we are now given values for our exogenous variables, Y and P_i , we can solve our model to find the initial, market-clearing values for the two endogenous values, P and Q . If, for example, we know that the value of Y is ten and P_i is four, then we can substitute these values into our equations and solve for the market clearing quantity of 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 P_i . 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 to 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 \$4.”

What Is a Computable General Equilibrium Model?

A CGE model is a system of equations that describe 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 “ $GNP = C + I + G + E - M$.” 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 economywide 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 re-solves 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 since 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 U.S. tariff, you are likely to argue that it will lower the price of the import, leading to an increase in the quantity demanded of imports and a decrease in the quantity demanded for the domestic, import-competing variety. However, policy makers 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 U. S. economy in 2004. In this case, the utility functions incorporate data on U.S. consumer preferences in 2004. The production function for each industry is based on U.S. firms’ technology – inputs and production levels – in 2004. 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 allow 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 NAFTA, emissions control programs, and the agreement to allow China’s WTO membership. 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 change 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 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 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 investors use savings to buy capital investment goods for use in future production activities. The combined demand

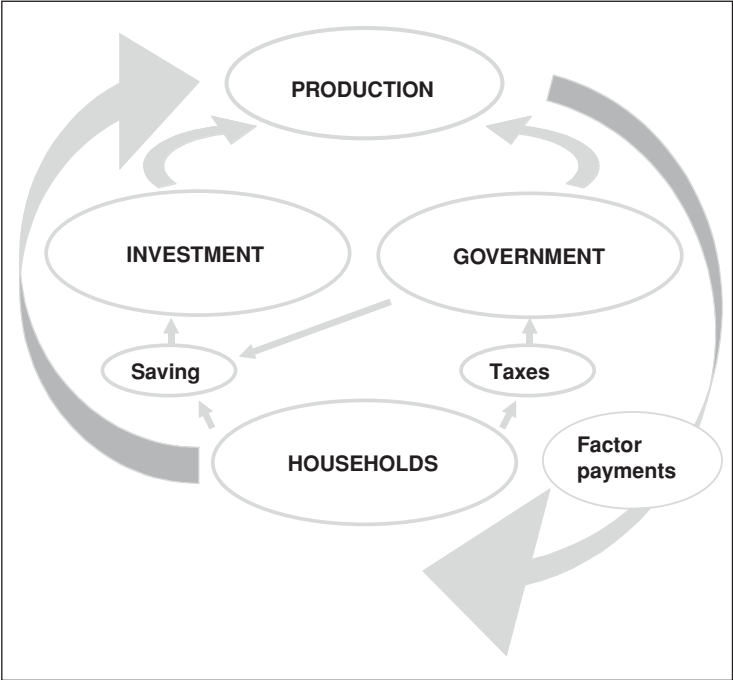


Figure 1.1. The circular flow of income and spending in a national economy

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 in 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, like the bicycle industry, or of one type of economic agent, such as 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 number of hours 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 aggregate supply of goods and services equals aggregate demand, all workers and the capital stock are employed, and national or global savings equals investment.

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 supply is again equal to demand 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 traverse the table. This is an important point to keep in mind as you use a 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 multicountry 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 the industries in which they are employed in response to changes in wages and capital rents, but too short for long-run changes in factor productivity or capital stock accumulation to take place.

We consider both single and multicountry CGE models in the following chapters. **Single-country** models describe one country in detail, with a simple treatment of its export and import markets. **Multicountry** 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 multicountry models are linked to each other through trade and sometimes through capital flows.

No one CGE model can have 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 in 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 Two. Other commands present the economic equations of the model. These are typically organized into blocks related to:

- 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 8.

CGE Model Database

A CGE model’s database describes the circular flow of income and spending in a national economy during a specific time period, usually a year, such as 2004. The database 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.

Of course, the database does not report every individual transaction that takes place in an economy during a year, such as your purchase of shoes last month. CGE model databases must aggregate or sum up economic activity into a tractable number of transactions. 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 food, manufactures, and services.

Every researcher must decide how to aggregate economic activity in his or her database, balancing the need for detail, for example on specific industries

Text Box 1.1. The GTAP Global Database
“Chapter 1: Introduction.” (Hertel and Walmsley, 2008)

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. These data include input-output tables, bilateral trade flows, transport costs, tax and tariff information, and all other data that comprise the Social Accounting Matrices (SAMs) used in CGE models. Version 7.0 of the GTAP database, released in 2008, describes 113 countries or regions and fifty seven commodities in a 2004 base year. The GTAP global database is regularly updated every three to four years and is reliant on broad participation by a network of database users who donate data.

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 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, three-sector, three-factor database for 2004 for the United States and an aggregated rest-of-world region, to use for demonstration throughout this book. The three sectors are agriculture, manufacturing, and services; and the three factors of production are land, labor, and capital.

The 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, which is written in general functional notation. 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.

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