9

Conclusion: Frontiers in CGE Modeling

Computable general equilibrium (CGE) models are sometimes criticized for being "black boxes" in which everything is moving at once. 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 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, in their rich diversity in incomes, tastes, ages, and wealth, 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 more sophisticated and 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. On 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 households with mainly wage income.

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. (2004); and Verma and Hertel (2009, summarized in Text Box 9.1)].

Extensions of CGE models to describe diversity among producers are similar in many respects to the disaggregation of the representative household. One approach is to differentiate industries by adding additional industry accounts to the SAM, as in Block et al., 2006 and Diao, et al., 2008. For example, agricultural production of each commodity could be differentiated by region, so that the SAM has row and column activity accounts for two vegetable industries – one in the north and one in the south of the country, or perhaps one of the two vegetable industries uses irrigation and one does not. 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). Perhaps the state of Michigan will receive 10 percent of

Text Box 9.1. An Intertemporal Dynamic CGE Model of the United States
"***Trade Liberalization in General Equilibrium: Intertemporal and Inter-Industry Effects.***" (Goulder and Eichengreen (1989)).

What is the research question? Most CGE analyses of trade liberalization have studied its effects on trade in goods and services. How might trade liberalization impact the U.S. economy if its effects on the international flow of investment capital are also considered?

What is the CGE model innovation? The authors develop an intertemporal, dynamic CGE model of the United States and an aggregate, rest-of-world region. The model assumes forward-looking behavior by U.S. and foreign firms, who pursue investment strategies over time that maximize their current and future profits. Forward-looking U.S. and foreign households maximize their lifetime utility by deciding how much to save or consume in each period and how to allocate their savings to domestic or foreign investments. The model is first solved to produce a baseline, steady-state equilibrium. After the policy shock, the model solves for a time path of temporary equilibria that converge to a new steady-state equilibrium. In each period of the time path, supply and demand for goods and factors are equal, and savings equals investment, but capital returns can diverge across industries and portfolio returns can diverge between countries. Over time, firms adjust their investments, and households adjust their savings and portfolio choices, until capital and portfolio returns equalize in a new steady-state equilibrium.

What is the model experiment? The authors assume permanent, unilateral cuts of 50 percent in U.S. tariffs and voluntary export quotas.

What are the key findings? The welfare gain to the United States is larger when international capital flows are taken into account because inflows of foreign investment increase U.S. household consumption in the near term, although this lowers U.S. consumption in the long run because the foreign debt must be repaid.

the change in national U.S. 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.

Stochastic models are an 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 percent change in wheat productivity, which results in a 10 percent 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 due to 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 models. See for example, Block, et al.'s (2006) study of droughts and floods in Ethiopia, summarized in Text Box 5.2, and contrast it with Verma and Hertel's (2009) study of the effects of world food price volatility on caloric consumption in Bangladesh, summarized in Text Box 9.1.

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 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]

Broadly speaking, there are two 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 re-solved, 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 World Bank's multicountry Linkage model (van der Mennsbrugghe, 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) and the World Bank's

[1] See Devarajan and Go (1998) for an introduction to dynamic CGE models.

Text Box 9.2. 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 due to 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 microsimulation 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 reproduces 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.

MAMS model (Gottschalk, et al. 2009). Recursive dynamic models have also begun to assume an important role in the analysis of long-term global climate change. Recursive dynamic climate models include CIM-EARTH, an open CGE model available at www.CIM-earth.org (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 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 thirty year time path equals thirty 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 U.S. 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 – see Text Box 9.2), Jokisch and Kotlikoff (2005), Rutherford and Tarr (2003), and Diao, Somaru, and Roe (2001)].

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 whether we advance to the frontiers of CGE modeling, we are always trying to distill a simplified representation of a complex world.