CHAPTER 5

Contribution of Computable General Equilibrium Modeling to Policy Formulation in Developing Countries

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Abstract

This chapter reviews the experience of computable general equilibrium (CGE) models from the perspective of how they have, or have not, influenced public policy in developing countries. The paper describes different classes of empirical models — from small, stylized to large, multisectoral applied models; from static equilibrium models to dynamic, perfect-foresight models — and identifies the characteristics of models best suited to address different policy problems in developing countries. The paper then discusses the different ways CGE models have been and are being used in policy formulation, the types of questions they have addressed, and the lessons learned from past experience. Finally, the paper suggests that, in light of the changing nature of policy making in developing countries, in the future CGE models should be used differently, moving from a purely technocratic exercise used by policy makers to providing an accessible empirical framework that can contribute to a widespread public debate.

Keywords

Computable general equilibrium modeling, economic development, policy modeling, computable general equilibrium in democracy

JEL classification codes

O2, F1, H2, Q1, Q5

5.1 INTRODUCTION

The first computable general equilibrium (CGE) model, developed for Norway by Leif Johansen (Johansen, 1960), was intended to be used for policy analysis and its descendants are still used by the Norwegian government today. Early applications of models of the US also focused on policy issues (in public finance, international trade and environmental policy; Shoven and Whalley, 1972, Jorgenson, 1984). In parallel, there has been an equally rich and varied tradition of applications to developing countries, starting from work with input-output and programming models, which were precursors to CGE

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models, and then CGE models.[1] These different strands of work, while initially focused on different policy issues, are all rooted in the same core of neoclassical general equilibrium theory.[2]

Many developing countries, starting with India, were initially engaged in central planning. CGE models, or their predecessor input-output and programming models, were appropriate instruments for evaluating the consistency of public investment programs and other policies with the plan's objectives.[3] As countries abandoned central planning and moved towards more market-based economies, with less direct government involvement in production and investment decisions, CGE models became even more appropriate, as they simulate the operation of market economies. Finally, inasmuch as developing countries are characterized by high levels of poverty and poverty reduction is a major goal of policy, a tool that captures the uses and sources of people's incomes (both of which are mediated through product and factor prices) is not just valuable – it is essential.

On the other hand, some observers were, and a few continue to be, skeptical about the application of CGE models to developing countries for the following reasons: (i) Developing countries are characterized by many institutional factors and rigidities (dual labor markets, thin capital markets, state-owned enterprises, controlled prices, etc.) so that a neoclassical, price-endogenous model, where agents optimize based on full information about prices and their own endowments, may not be the most suitable theoretical framework. (ii) These models require large amounts of data – across sectors and over time – in countries where even robust national accounts are a recent phenomenon. (iii) The domestic capacity to build, maintain and use CGE models was limited in most developing countries. Models built by scholars in developed countries might at best be ineffective and at worst be seen as yet another imposition from rich countries. To be sure, advances in developing countries over the past 30–40 years have allayed many of these concerns and CGE models are now widely used there as standard tools of policy analysis.

This chapter reviews the experience of applying CGE models to policy problems in developing countries. We focus on those cases where the use of models has made a contribution to policy formulation. We do not therefore look at the numerous applications that have shed light on development economics in general (Gunning and Keyzer, 1995; Robinson, 1989). In Section 5.2, we show how the above-mentioned tension between the need for a price-endogenous, general equilibrium model and some

1 See, e.g. Blitzer *et al.* (1975), Adelman and Robinson (1978), and Dervis *et al.* (1982).

2 While they shared the same underlying theory, the different strands of work initially used different approaches to solving the models empirically (see, e.g. Dixon and Parmenter, 1996). Today, solving even very large CGE models has become routine, so these differences do not concern those engaged in policy analysis with these models.

3 The theoretical evolution from programming models to general equilibrium models was a focus of academic work on general equilibrium analysis (see, e.g. Dorfman *et al.*, 1958).

of the features of developing countries — such as institutional rigidities and poor data — have led to particular types of CGE models being more commonly used to inform policy in developing countries. In Section 5.3, we review the main policy questions facing developing countries, and show how these models have been used to address them and the lessons learned from the experience. Section 5.4 draws the lessons learned and suggests future directions for enhancing the impact of CGE models on development policy.

5.2 TYPES OF CGE MODELS FOR DEVELOPMENT POLICY

5.2.1 Theory and empirical models

Models in general, and CGE models in particular, are used widely in economics. To understand their application to developing countries, it is useful to place CGE models along two continua: (i) analytic to applied and (ii) reduced form to deep structural.

"Analytic" refers to theoretical models that can be solved mathematically, while applied models are simulation models that are solved numerically because they are too complex to be solved analytically. "Stylized numerical models" are simulation models that stay as close as possible to their theoretical roots, are typically small and provide numerical solutions that can be used to explore the empirical implications of different theoretical mechanisms at work in the models. On the continuum, they lie between analytic and applied models. We will use the term "applied" to refer to empirical simulation models that attempt to incorporate institutional features of particular developing economies; they provide a more realistic representation of such economies than is typical of stylized models. These applied models tend to be larger and more complex than stylized models. In this continuum, "policy models" are simulation models that explicitly include policy instruments and capture the links between changes in those instruments and economic outcomes. In policy analysis, empirical policy models tend to be applied models, but, as we show below, there are many examples of stylized numerical models that incorporate policy instruments and have been used in policy debates.

In policy analysis, the credibility, applicability and realism of economic models are often subjects of debate. Simulation models have been criticized for being "black boxes" whose results are difficult or impossible to explain in terms of credible causal chains that are accessible to policy makers. The work program on the policy use of CGE models has involved, over a long period, both theoretical and empirical advances that have illuminated the black boxes. For example, the theoretical treatment of foreign trade in CGE models has been of particular concern, given the wide use of these models in the analysis of trade policy. The specification of traded goods as imperfect substitutes for domestically produced goods in the same commodity classification — the Armington insight — was viewed by some as an *ad hoc* empirical specification that was theoretically suspect.[4] Others criticized the theoretical role of exchange rates in CGE models, since a Walrasian general equilibrium model can only determine relative prices and there is no role for a "financial" exchange rate variable.[5] These theoretical debates spilled over into criticisms of the policy uses of CGE models and needed to be resolved to establish the validity of these models in policy analysis.

The theoretical issues around the Armington specification and the role of the exchange rate in CGE models were sorted out through the development of a small theoretical model – the 1–2–3 model (one country, two activities, three commodities) – that captured the theoretical core of trade-focused CGE models.[6] The 1–2–3 model is an extension of the Salter–Swan "Australian" model, which distinguished a tradable and a non-tradable commodity, with the tradable price determined in the world market and the non-tradable price determined in the domestic market. In the Salter–Swan model, the real exchange rate is the relative price of the tradable to the non-tradable commodity.

Using the Armington insight, the 1–2–3 model specifies that a country produce two commodities, one for domestic consumption and one for exports, and also consumes a third commodity, an import, which is an imperfect substitute in consumption with the domestic good. The model extends Salter–Swan in specifying degrees of tradability. Both export and import commodities are "semi-tradable" – imperfect substitutes with domestically produced goods sold on the domestic market, as in trade-focused CGE models. The 1–2–3 model is simple enough to be solved analytically, so that all its properties can be shown algebraically (and graphically).[7]

The 1–2–3 model demonstrated that CGE models are theoretical generalizations of the Salter–Swan model and that the textbook neoclassical trade theory model, with all commodities specified as both tradable and perfect substitutes with domestically

4 Armington (1969) assumed imperfect substitutability of traded and non-traded goods in estimating import demand functions, and the approach was picked up by early CGE models. Deardorff (1984), in a survey for the *Handbook of International Trade*, described the use of this specification in CGE models as theoretically unsatisfactory but useful in empirical models, which would otherwise generate nonsensical results (e.g. extreme specialization).

5 See Whalley and Yeung (1984), who carefully avoided the term "exchange rate" when discussing the "parameter" that adjusted to clear the foreign trade balance constraint in trade-focused CGE models.

6 See de Melo and Robinson (1989), Devarajan and de Melo (1987), and Devarajan *et al*. (1990, 1993) for discussions of the 1–2–3 model. Thierfelder and Robinson (2003) extend the 1–2–3 model to include factor markets and describe the theoretical implications for the Stolper–Samuelson and Rybczynski Theorems, and the link between wages and changes in the trade balance.

7 The technique used to solve the 1–2–3 model analytically (and graphically) is to note that a CGE model can be written as a special constrained maximization problem, maximizing social welfare subject to constraints on available resources and the trade balance – the value in world prices of total imports cannot exceed the value of total exports plus any foreign transfers. The shadow prices from the solution to this maximization problem equal the solution market prices from a CGE model. The solution real exchange rate can be seen as the shadow price of the trade-balance constraint. The use of this theoretical approach to solve CGE models is described in Ginsburgh and Keyzer (2002), and its application in models where there is a trade-balance constraint (and perhaps other aggregate "macro" constraints) is described in Ginsburgh and Robinson (1984).

produced commodities, is a special case of this model. As in the Salter–Swan model, the exchange rate in the 1–2–3 model and CGE models is a theoretically well-defined relative price of aggregates of traded to non-traded commodities. It can be seen as a signal in commodity markets and is in no sense a financial variable, since the CGE model does not contain money, financial instruments or asset markets. Conceptually, it is close to the "real effective exchange rate" calculations published by the International Monetary Fund and others (Devarajan *et al.*, 1993).

The 1–2–3 model and CGE models based on this specification have a number of realistic empirical properties compared to models assuming perfect substitutability of traded and non-traded commodities.

- The model allows two-way trade (both exports and imports) in particular commodity classifications, which is realistic given the level of aggregation usually specified in empirical models; indeed, two-way trade is observed at very detailed levels of disaggregation of trade data.
- Changes in world prices, and the impact of changes in tariffs, are only partially transmitted to domestic prices, depending on both the degree of substitutability and trade shares; again, a realistic property.
- Changes in aggregate exports and imports are related to the real exchange rate, with a real depreciation associated with an increase in aggregate exports and a decrease in imports (with the amounts depending on elasticities).
- An increase in the trade balance (i.e. aggregate imports rising relative to exports due, for example, to an increase in foreign borrowing) will always lead to an appreciation of the real exchange rate – the model replicates the "Dutch Disease" effect specified in macro models. The trade balance is monotonically related to the real exchange rate.
- The powerful links between world markets, factor prices and the sectoral allocation of resources that are evident in models with all commodities tradable are damped in the 1–2–3 model (extended to include factor markets). In particular, the magnification effects shown in the Stolper–Samuelson theorem (wages) and Rybczynski theorem (factor allocation across sectors) now depend on substitution elasticities and trade shares, and are empirically much more realistic in CGE models (Thierfelder and Robinson, 2003). If imports are poor substitutes for domestic commodities, even the sign of the Stolper–Samuelson effect of changes in world prices on factor prices is reversed.

While it was developed to contribute to the theoretical debate, the 1–2–3 model has also been implemented as the core of stylized numerical models used to understand, and explain to policy makers, the results of larger applied models. Versions of the 1–2–3 model have been used to estimate the revenue implications of trade reforms (Devarajan *et al.*, 1999) and the degree of overvaluation of the CFA Franc (Communauté Financière Africaine) in the early 1990s (Devarajan, 1997). The use of theoretically well-specified, stylized numerical models to explain the results of larger, applied policy models has greatly reduced the "black box" criticism of CGE simulation models.

The second model continuum, "reduced form to deep structural," refers to the way in which economic theory is reflected in model structure. The term "reduced form" comes from econometrics, where such models include equations linking endogenous and exogenous variables, but where it is often impossible to "identify" the underlying structural model that gives rise to the reduced form equations. In effect, such models use economic theory to motivate the specification, but end up with estimated equations and parameters only loosely linked to the theory. At the other end of this continuum, "deep structural" models such as CGE models, explicitly specify the economic actors (e.g. households and producers), their motivation (e.g. utility and profit maximization), the markets across which they interact (e.g. commodity and factor markets) and the signals to which they respond (e.g. relative prices of commodities and factors). In addition, CGE models specify aggregate resource supplies (e.g. labor and capital) and market-clearing conditions (supply equals demand in all markets) whose satisfaction determines the equilibrium solution values for commodity and factor prices, as well as all quantities.

With these continua in mind, CGE models can be seen as deep structural, empirical, market simulation models, with many examples along the continuum from stylized to applied and usually incorporating policy instruments explicitly. They have to be structural because understanding the mechanisms through which policies affect the economy is the whole purpose of the exercise. A reduced-form model, even if it forecasts the economy's aggregate variables accurately, is of little use for policy analysis, which requires explicit structural links between policy choices and economic outcomes. For policy debates and analysis, models tend to be at the applied end, incorporating institutional detail and commodity/factor disaggregation that adequately describe the economic environment and mechanisms by which policy instruments affect economic actors.

5.2.2 Types of equilibrium and domain of application

In addition to these continua, CGE models can be classified according to: (i) the nature of the equilibrium they embody and (ii) their domain of application. A standard static CGE model is a "neoclassical" Arrow—Debreu general equilibrium model in that it incorporates only flow equilibria in product and factor markets, and solves only for relative prices. The model contains no assets or money, and is static, with myopic agents who do not look beyond the current period in making decisions — or do not need to, if the static equilibrium can be viewed as a steady state. Walras, not Keynes, is the patron saint of CGE models. When these models incorporate financial assets, it is often in an *ad hoc* manner, departing from the neoclassical assumptions of the rest of the model.

Nevertheless, some of these departures are necessary to address the question at hand, and to incorporate characteristics of developing economies.[8]

There are two broad types of dynamic CGE models: dynamic recursive and forward-looking. Dynamic recursive models are the most commonly used in developing-country applications, with a two-step dynamic process: (i) a "within-period" static CGE model is solved, yielding a within-period set of equilibrium prices and quantities, and (ii) a "between-period" model is solved, specifying how parameters that are exogenous in the within-period model are updated between periods. Such updating may involve applying simple growth rates (e.g. labor force or total factor productivity growth) or specifying some kind of "adaptive expectations" (e.g. allocation of investment to sector of destination). While agents may adapt, there is no forward-looking equilibrium in such models (e.g. perfect foresight or rational expectations equilibrium). As we show in the case of Turkey's real exchange rate below, this admittedly imperfect way of incorporating changes over time can yield important insights for policy – especially when the alternative of a forward-looking dynamic model is not available or seems theoretically inappropriate in a particular applied setting.

There are many examples of forward-looking dynamic CGE models that essentially incorporate neoclassical growth theory.[9] These models tend to be highly stylized, but often include policy instruments and have been used to explore issues such as investment strategies or climate change where intertemporal resource allocation is salient. These models have not generally been influential in policy debates in developing countries, largely because of their stylized nature – they lack the granularity and specificity of applied models to particular country settings. Dynamic stochastic general equilibrium (DSGE) models, in cases where they include more than one sector, are close to this class of highly stylized, neoclassical dynamic CGE models.

Simulation models in general and CGE models in particular can also be characterized by their domain of applicability – the range of phenomena they incorporate. When considering the usefulness of a particular model in a particular application, it is important to judge whether the model adequately incorporates and simulates the features of an economy necessary for capturing the links under study. Model specifications that may be adequate for one purpose may be inappropriate for another. For example, many static CGE models specify simple utility functions such as Cobb–Douglas that assume unitary income elasticities of demand for all commodities. In a static model, where income does not change significantly, such an approximation may be adequate, but it is clearly

8 The issues of macro features of CGE models, and of integrating macro and CGE models, have been topics of active debate throughout the history of CGE models applied to developing countries. See Rattso (1982) and Robinson (1989, 1991, 2006) for surveys of these debates.

9 An excellent textbook treatment of empirical growth models is Roe *et al.* (2010).

inadequate for a dynamic model where incomes change over time, and Engel's law will come into play.[10]

The large number of CGE models used to analyze the implications of trade liberalization – a major policy issue in developing countries over the last two decades – is another example. Most of these models captured the changes in the intersectoral structure of demand and supply arising from trade reforms. They did not address the endogenous growth effects of lowering trade barriers, except in an *ad hoc* manner (e.g. by assuming an impact of lower tariffs on total factor productivity). These effects are better analyzed in dynamic models, although there is as yet no widespread agreement about the theoretical specification of such links. Even with a limited scope, as we illustrate with the case of India below, static CGE models have been influential in sharpening the debate on trade policy in developing countries.

The notion of domain of applicability is relevant to another model design characteristic: simplicity. There is a modeler's version of "Occam's Razor:" always use the simplest and smallest model that is adequate to the task.[11] In policy debates, this notion of model simplicity is especially important. As we discuss below, it is very important in policy debates to be able to explain model results in simple terms – avoiding the "black box" criticism discussed earlier. Models that are needlessly complex make it harder to trace and explain the causal chains between changes in policy instruments and economic outcomes. At the same time, policy makers are sometimes skeptical about models that leave out phenomena they consider important – even if, in the modeler's view, including them would make no difference to the model's results for particular policy issues.

There are many examples of CGE models linked to "auxiliary" models or relationships, which are used to trace the outcomes from the CGE model to other relevant variables. For example, the (Maquette for MDG Simulations) model at the World Bank consists of a core single-country, dynamic recursive CGE model which generates scenarios for: output, trade, employment, and income over time.[12] The model includes a set of auxiliary functions, mostly regression equations and elasticity relationships that determine the impact of the national economic changes on a set of the Millennium Development Goals (MDGs), which includes measures of poverty, nutrition status, and so on. The result is a linked set of models that are, however, viewed as a single integrated model. These extraneous relationships are not integral to the CGE model, but are linked to it in policy debates, and criticisms concerning the validity of these relationships spill

10 The assumption of unitary own-price elasticities of demand in a Cobb–Douglas utility function seems unrealistic, even in simple models.

11 Note that simplicity is not necessarily related to size. Large models may be driven by simple causal chains that are easy to explain, while small models may be theoretically very complex.

12 See Lofgren and Diaz-Bonilla (2012) and Lofgren *et al.* in Chapter 4 of this Handbook.

over to the CGE model. In this case, it would be useful in policy applications to separate the two strands of analysis in the discussion of results.

In short, simplification should be strategic. As Einstein reportedly said: "Everything should be made as simple as possible, but no simpler."

5.2.3 Estimation and validation

Model estimation and validation are difficult issues for CGE simulation models. For a macro-econometric simultaneous equation model; estimation, validation and definition of the domain of applicability are all done simultaneously. Estimation of parameters and validation are done together by finding parameter values that minimize a "goodness-of-fit" distance function between the forecast values of endogenous variables and historical data. The better is the goodness of fit, the more "valid" is the model.[13] The domain of values of the historical data and the range of values of the endogenous variables define the domain of applicability of the estimated model. Using such a model to "forecast" endogenous variables for values of exogenous variables outside the domain of the historical data used to estimate the model is not statistically justified and is problematic. Validation of an econometric model for such forecasting requires information about the validity of the structural relations in the model outside of historical experience.

For deep structural CGE models of developing countries, parameter estimation and model validation are separate exercises. Typically, there are two kinds of parameters to be estimated for the various production and cost functions and expenditure equations – shares and elasticities. The shares can be estimated with confidence from data in the social accounting matrix (SAM), which is assumed to represent an equilibrium solution of the model in the base year. The various elasticities of substitution in production and demand are more difficult to estimate, since there are rarely adequate time-series data to support estimation by standard econometric methods. However, there are often scattered econometric studies from which estimates can be drawn. The specification of the deep structural model allows for a Bayesian approach, using priors for elasticities based on theoretical and empirical information about the nature of the underlying production, cost and expenditure functions. Defining the domain of applicability of the CGE model also relies on a Bayesian analysis of the specification and parameters of the deep structural model. Economic theory provides information about the validity of the relationships and related econometric studies provide information about potential parameter values, which together define the domain of applicability of the model. Given the lack of data to support standard econometric analysis, validation also often

[13] When feasible (e.g. with lots of data), good econometric practice is to estimate the model with one set of data and then use a separate data set to validate the model, using the estimated parameters from the first set in forecasting the endogenous variables in the second set.

involves sensitivity analysis to determine if the model results are robust over its domain of application. In an environment of poor data, as in many developing countries, this sensitivity analysis for model validation becomes increasingly important.

5.2.4 Modes of policy analysis

In policy analysis, CGE models have typically been used to explore different "scenarios" where policies are changed and then the model is solved to see how the changes affect the economy. The model is used as a simulation laboratory for doing controlled experiments, which are designed to explore the empirical importance of the links between policy changes and economic outcomes. The scenarios are not necessarily designed to be realistic in the sense that they are "likely" to occur. Rather, they are meant to inform policy makers about the relative strength of potential impacts of policy changes. Nor are they designed to provide "forecasts" since the variables being held constant in order to isolate important causal chains are unlikely to be constant in the real world. As illustrated in the case of a carbon tax in South Africa, it is common when exploring and comparing the distortionary impact of different tax regimes to design scenarios where tax rates are changed, but total government revenue is held constant. This assumption provides a control – a benchmark – to facilitate comparison across different tax instruments. However, it is not a realistic assumption if the goal is to provide a forecast of the impact of a proposed change in tax regime in a particular institutional setting.

In principle, a good, deep structural simulation model can be used for forecasting as well as for scenario analysis. The challenges, however, are different between the approaches. Scenarios are generally designed to isolate and quantify the importance of different causal chains linking policy changes and economic outcomes. Forecasting requires designing composite scenarios where realistic changes in all exogenous parameters and variables need to be specified and implemented simultaneously in the model, which will then be solved for the forecast of all endogenous variables. The accuracy and hence validity of the forecasted endogenous variables is conditioned on the accuracy of the forecast of all the exogenous variables and parameters.

For the purposes of policy analysis, scenario analysis is generally more relevant than forecasting – policy makers are interested in the potential impacts of the choices they are considering. In making decisions about policy choices, scenario analysis that focuses on controlled experiments to explore the links between policies and outcomes provides the relevant framework for analysis.

In scenario analysis, we distinguish four different "modes" of analysis with CGE models in empirical applications: (i) timeless comparative statics, (ii) dated comparative statics, (iii) timeless dynamics and finally (iv) dated dynamics. Dated comparative statics and dated dynamics can be seen as two forms of "projection" analysis.

In timeless comparative statics, a model calibrated for a particular year is "shocked" by changing various exogenous variables or parameters (often policy parameters) and the results are compared with the base-year solution (which is an equilibrium solution calibrated to replicate the base-year data). The analysis answers counterfactual questions of the form: "What would the economy have looked like in the base year given the particular shocks under consideration?" Since the analysis often focuses on the impact of particular policy changes, there is no attempt to generate composite experiments that incorporate changes in all the exogenous variables and parameters that changed (or are projected to change) over some actual period, historical or in the future. The results are thus "timeless" in the sense that they are not designed to reflect actual changes over a given period. They represent "what if" counterfactual experiments tied to the base year of the analysis.

Most policy analysis with CGE models has been conducted in this timeless-static mode. Work in this mode generates *ex ante* information about the empirical importance of different shocks and also is used to uncover important synergistic effects arising from simultaneous changes in a variety of policies. To test the quality of these results using *ex post* historical data is difficult because a fair test requires somehow "removing" from the actual data the impact of everything that happened *except* the particular shocks considered in the timeless-static analysis. In this case, validation cannot be done by comparing with historical data, but must be done by evaluating the appropriateness of the theoretical structure of the model and the quality of the estimated parameters of the structural relationships, given the domain of applicability of the model. This kind of validation typically employs a lot of sensitivity analysis to determine how robust the results are, given reasonable variations in parameter values and model specification (Devarajan and Robinson, 2005).

The second mode of analysis – dated comparative statics – involves solving a CGE model for a year some periods away from the base year of the model, incorporating in the solution actual changes in many exogenous variables and parameters for which there are data. This approach is a form of "projection" in which a comparative statics experiment is designed to incorporate changes (historical or projected) in important exogenous variables and parameters. The distinction between "timeless" and "dated" is the identification of the model solution with a particular year. In this mode, for a historical period, a fair test of the quality of the model is to compare the model solution with actual data from the terminal solution year. The validity of the model results is reflected in some measure of correctness of fit between the solution values of endogenous variables and actual data. These results, of course, are conditional on the values of the exogenous variables.

A judgment about the validity or quality of a dated-static model also depends on the intended domain of applicability of the model. A model with many exogenous variables is hard to compare with a more ambitious model that seeks to endogenize more effects. If almost everything is exogenous, a projection conditional on known values of all the exogenous variables should do very well. A model with more endogeneity has more variables to compare with historical values, which raises the bar on validation tests.

An early example of a model used in dated-static mode is the analysis of the causes of the Turkish foreign exchange crisis in the late 1970s by Dervis and Robinson (1982).[14] The model was calibrated using data for 1972 and then used to generate a dated-static "historical run" experiment for a year during the crisis, 1977. Exogenous variables in the simulation included the nominal exchange rate, aggregate price level, levels of foreign borrowing and remittances, degree of import rationing, and world prices of oil and other important commodities. Model validation was done by comparing the dated-static run with actual data for various endogenous macro aggregates in 1977. A series of experiments was then done to decompose the "sources" of the crisis, removing the shocks one by one by setting particular exogenous variables (domestic price level, world prices of major imports, foreign borrowing and remittances) one at a time to their 1972 levels and then solving them for the equilibrium exchange rate. The results indicated that about half, but only half, of the gap between the equilibrium real exchange rate and the actual rate – the measure of the degree of the foreign exchange "crisis" – was due to the Turkish policy decision not to adjust the nominal exchange rate given the rise in domestic prices. The rest of the gap was due, in declining degree, to the oil price rise, loss of foreign remittances and other world price rises. The results were of policy interest because the International Monetary Fund was arguing at the time that the major problem was that the Turks had failed to devalue to adjust the nominal exchange rate for differential changes in world and domestic price levels – a serious underestimate and misunderstanding of the drivers at work.

A more recent example is Kehoe *et al.* (1995), which tests a CGE model of Spain by comparing forecast values of a number of endogenous variables with actual data for a dated comparative simulation one year after the base year of the model. That article was narrow in focus, looking only at changes in tax rates in one year. They created a partial dated-static run where they fixed a few exogenous variables to their actual values in the next year after the base. Running the model for only one year undoubtedly helped, since, as they note, "… this time horizon is short enough to justify ignoring secular trends and the inter-sectoral impact of changes in the growth rate." They concluded that the results validated the model, which seems a reasonable conclusion for the domain of applicability of exploring the impact of changes in tax rates.

Kehoe (2005) used his Spanish exercise as an example to criticize various CGE models used in the North American Free Trade Area (NAFTA) debate in the US because the modelers did not do a similar validation exercise, comparing their model results with what happened 5 years after NAFTA was implemented. Given the low bar

14 The analysis is also described in Dervis *et al*. (1982, Chapter 10). There are many examples of analyses by Peter Dixon and numerous coauthors using the ORANI/MONASH CGE model in dated-static mode.

that Kehoe, Polo and Sancho set for themselves, this criticism of NAFTA modelers seems especially inappropriate. The NAFTA models were all used in comparative static mode, and the period after NAFTA came into effect was characterized by a financial crisis, deep devaluation and recession in Mexico, a recession and recovery in the US, and changes in world markets — none of which were relevant to NAFTA or a concern in the policy debate. Evaluations of the NAFTA models after the fact indicated that they correctly estimated the relevant impacts of NAFTA for the policy debate at the time and were consistent with other impact studies at various levels of aggregation and detail.[15]

Some examples of timeless-dynamic models include the work with steady-state, balanced-growth, dynamic CGE models (Devarajan and Go, 1998; Diao *et al.*, 1998. Roe *et al.*, 2010). Dawkins *et al.* (2001) discuss the problems of calibrating this type of model, using as an example a real business cycle model. The calibration cannot refer to "dated" information for specific years, but they sought to specify their model "so that its steady-state properties were consistent with long-term trend data for the US."

Finally, a dated-dynamic model refers to particular years and must be calibrated for those years (Jorgenson and co-authors in Jorgenson, 1998). These models incorporate both a steady-state, balanced growth path and an adjustment path to get from the model's (benchmark) base year to the steady-state path. In principle, these models can be tested against actual historical data. Some of these papers have explicitly discussed the problems of calibrating this type of dated-dynamic model.

In sum, CGE models used for policy formulation in developing countries range along the continuum from stylized to applied numerical simulation models. They are deep structural models specifying agent behavior in product and factor markets, and attempt to capture the salient structural relationships in developing countries that are relevant for the policy problem at hand. Their estimation and validation tends to be Bayesian in spirit, drawing on information from many sources, and involving a combination of calibration and estimation of certain parameters where feasible; sensitivity analysis is widely used as a substitute for classic econometric validation. With some exceptions, these models are either timeless or dated comparative static models, although dynamic models are beginning to see more use in policy discussions.

5.3 CGE MODELS AND POLICY FORMULATION

Broadly speaking, the CGE models characterized in the previous section have been used in policy analysis in four main ways:

- *Measurement.* Many — although not all — policy questions require some quantitative measurement. By how much should an exchange rate be devalued? How much extra

[15] See Devarajan and Robinson (2005) for a review of the use of CGE models in the NAFTA debate.

revenue will a tax reform generate? How will world trade patterns change if a global trade agreement is signed? These are questions that require a consistent analytical framework (i.e. a model) for their answer. As we show below, CGE models have often proved useful in providing estimates of the magnitudes involved. Even if the estimates have been crude, they have been obtained in a transparent manner, with the assumptions and parameters lending themselves to sensitivity analysis.

- *Directions of change.* Sometimes, it is the direction rather than the magnitude of the change that is salient to the policy debate. For instance, while increased public spending will (absent a tax increase and/or Keynesian multiplier effects) raise the fiscal deficit, if that spending is on productive infrastructure that, in turn, raises the economy's growth rate, then the fiscal deficit as a share of GDP may go down over time. Likewise, if a carbon tax shifts the production mix of the economy towards heavily-taxed goods (and away from subsidized goods), then the net welfare effect may be positive. To demonstrate that these are realistic possibilities, one needs a general equilibrium framework; CGE models are one way of quantifying that framework, even though it is the direction of change that is of ultimate interest. Often CGE models are used to determine the magnitude of the crucial parameters on which the particular direction of change will depend. The simple 1–2–3 model, for instance, shows that whether the real exchange rate appreciates or depreciates in the wake of an import price shock depends on whether the elasticity of substitution between domestic and imported goods is greater or less than one (Devarajan *et al.*, 1990).
- *Evidence to nourish the public debate.* In general, policies are not decided by a single number, much less a direction of change, arising out of a CGE model simulation. Rather, they are decided by there being a domestic political consensus. And that consensus is more likely to be sustained if it is the result of an open and evidence-based debate. CGE models can contribute evidence to a debate, where evidence is also provided by other types of models as well as other sources of information. For instance, debates over whether trade liberalization lowers workers' wages – a critical debate to determine future trade reforms – can be informed by CGE model simulations. The results of these simulations can be compared with those coming from partial equilibrium models and other techniques. In addition, as we will see below, CGE models have contributed evidence to debates that would otherwise have been politically charged (e.g. black unemployment in South Africa).
- *Comparative analysis across countries.* Policy makers are often influenced not by analysis of their own country, but by the experience of other countries. CGE models have provided a way of distilling the experience of, say, tax reform in many countries, by casting it in a common analytical framework, so that differences can be analyzed in detail. The large number of studies analyzing trade liberalization's effect is

a case in point. Another is the study by Mitra (1994) of adjustment in oil-importing countries.

5.3.1 Policy formulation in practice

All four of the above channels through which CGE models are used in policy have seen their application in developing countries. The areas of application fall under nine categories.

5.3.1.1 Adjustment to external shocks

Starting in the late 1970s, these models were used to underpin the many structural adjustment programs of countries such as Turkey, Indonesia and Thailand. In some cases — Turkey is a good example — CGE models were useful in estimating the real exchange rate depreciation necessary to accommodate a simultaneous oil price increase and a shock to workers' remittances (Dervis *et al.*, 1982). A similar modeling exercise estimated the overvaluation of the CFA Franc in the early 1990s (Devarajan, 1997), which was important for the decision to devalue the CFA Franc in 1994. A recent example was the policy debate in Ethiopia about the need to devalue the currency in the face of external shocks and domestic inflation that had led to import rationing (Dorosh *et al.*, 2011). The article, which started as a discussion paper in 2009, alerted the authorities to the undesirable implications of using import rationing to manage the overvalued exchange rate.

5.3.1.2 Trade reform

Most of the adjustment programs of this era involved a reduction in trade protection, especially tariffs. The reforms were resisted for a variety of reasons, one of which was the potential loss in tariff revenues. A series of CGE models of various countries estimated the loss in revenues from trade reform, concluding for the most part that it was smaller than originally thought, because of increases in the tax base. A particularly important application was Go and Mitra's (Go and Mitra, 1999) study of India — a country that even in the late 1980s had not reformed its tariffs. Their study showed that the effects of trade liberalization could be quite beneficial to the country, since the growth effects of cheaper intermediate goods outweighed any negative consequences of lower protection. The study fed into policy makers' thinking on the eve of India's 1991 trade liberalization. Subsequent work by Chadha *et al.* (1999) validates the Go—Mitra *ex ante* analysis, while showing that the gains may be even greater because of scale effects. A similar analysis of China's accession to the World Trade Organization (WTO) both quantified the gains and allayed concerns about the impacts on poverty and inequality (Bhattasali *et al.*, 2004).

In addition to revenue losses, the other problem with trade reform is that there are winners and losers. CGE models are ideally designed to identify these groups, since they can capture the impact of price and wage changes on people's sources and uses of income. Not surprisingly, therefore, there is a long tradition of CGE models being used to inform the debate about trade reform in developing countries, starting with Australia, which spent the 1940s to the 1970s arguing that it was "a developing country that happened to be rich."[16] The debate in Australia was underpinned by the ORANI model – one of the earliest CGE models used for trade policy analysis (Dixon *et al*., 1977, 1982). In describing Australia's early trade reform, Gary Banks (Banks, 2010), the chairman of the Productivity Commission, said:

> *A novel feature was the development of analytical tools to estimate relative (net) assistance levels across industries, and the impacts of protection not just on consumers but also on domestic (user) industries. As a result, the farmers and miners came to appreciate that, contrary to the accepted myth of "protection all around," a tax on imports was actually a tax on (their) exports. They accordingly became a countervailing political force for reform.*

5.3.1.3 Public finance

In addition to trade policy, another area where CGE models have played an important role in public policy is, not surprisingly, public finance (Shoven and Whalley, 1972). On the tax side, general equilibrium tax incidence analysis was used to dispel the notion that increasing energy taxes (or, equivalently, lowering energy subsidies) was regressive in the Philippines (Devarajan and Hossein, 1998), a finding that contributed to the government's decision to raise energy taxes during an election year. In a novel application, Dabla-Norris and Feltenstein (2005) used a CGE model to simulate the effects of tax evasion on the macroeconomy in Pakistan – a country where this was a major policy issue. On the expenditure side, a few papers examined whether government infrastructure expenditure crowds out private investment and exports, or crowds them "in" by lowering the costs of production. Feltenstein and Ha (1999) showed, in the case of Mexico, that the latter effect is unlikely to exceed the former. The pressure that increased infrastructure spending puts on the interest rate and inflation greatly reduces any benefits from higher infrastructure stocks. Similarly, Feltenstein and Ball (2001) looked at the general equilibrium effects of government bailouts of insolvent banks in Bangladesh. Their model was operational at the Bangladesh Ministry of Finance for several years.

CGE models have been used extensively in developing countries to explore the implications of adopting a value-added tax (VAT). A good example is Mozambique, where CGE model analysis was part of an extensive work program concerning the economic impacts of adopting a VAT system, and the problems of implementing and administering the new tax system. Tarp and Arndt (2009) describe the overall work program and Arndt *et al*. (2009) describe the CGE application. The model was adapted

[16] Will Martin, personal correspondence.

to incorporate in detail the European-style destination VAT system in Mozambique, with exempt sectors, zero-rated sectors and a complicated rebate system. The analysis focused on problems of applying the VAT and noted that, in some cases, it operated more like a tariff than a VAT, since it was easy to tax imports, but difficult to tax domestic producers of the same products.

5.3.1.4 Poverty

The purpose of trade and public finance reforms in developing countries is to accelerate growth, to reduce poverty and enhance human capital. Some CGE models have looked at poverty and human capital directly. Robillard *et al.* (2008) used a micro—macro model to simulate the impact of the Asian financial crisis on poverty in Indonesia, as well as to compare different policy responses. Their analysis helped shape the government's response to subsequent crises. Likewise, Devarajan and Go's (Devarajan and Go, 2003) 123PRSP model was a simple framework to underpin Poverty Reduction Strategy Papers. Among other things, it showed that, in Zambia, a negative copper price shock could have regressive consequences — even though the poor do not earn their income from copper. These papers contributed to a stronger push for safety-net programs in the wake of a negative terms-of-trade shock.

5.3.1.5 Agriculture

A series of agriculture-focused, micro-macro CGE models were developed at the International Food Policy Research Institute (IFPRI) to explore the impact of different agricultural development strategies on growth and poverty in a number of African countries. These models were designed to explore the Comprehensive Africa Agriculture Development Program (CAADP) funded by AID in consultation with the governments of the countries involved. The approach linked top-down microsimulation models based on household survey data with economy-wide CGE models with detailed specification of agricultural sectors. The work explored the differential impact on the poverty of different agricultural investment programs (Breisinger, *et al.*, 2009; Diao *et al.*, 2012).

Related CGE models of countries across the world have examined the extent and impact of "policy bias" against agriculture in overall development programs, using CGE models to provide general equilibrium measures of such bias; see Jensen *et al.* (2010). This work demonstrated that policy bias against agriculture had largely disappeared by the late 1990s. In addition, the work showed that partial equilibrium measures often overstated the bias, because they assumed domestic and foreign goods were perfect substitutes — a point made earlier by Devarajan and Sussangkarn (1992). This body of work has been part of the movement to rationalize policies relating to the agriculture sector (see, e.g. Anderson, 2010).

5.3.1.6 Human development

Turning to human development, the MAMS class of models, discussed above, looks at various determinants of poverty and the MDGs in poor countries. In Ghana, for instance, the application showed that, when account is taken of the interdependence of the MDGs (progress on the water and sanitation goal contribute to the health goals, for instance), the incremental costs of reaching all the MDGs were much smaller than previously envisioned (Bogetic *et al.*, 2008) — a finding that made a meeting among donors and the government go much more smoothly. Sussangkarn (1995) — a CGE modeler who also served as Minister of Finance — used a combined CGE and demographic model to examine the impact of an accelerated education strategy on labor market outcomes in Thailand.[17] He showed that even an ambitious education strategy would not have a significant impact on the skills of the labor force — except with a long lag. Instead, Thailand started emphasizing the upgrading of skills of the existing labor force.

5.3.1.7 Labor markets

Another area of growing interest is labor markets and CGE models have contributed to the public debate in several countries. Go *et al.* (2010) examined the impact on employment of a proposed wage subsidy in South Africa. They showed that the impact is likely to be very small (alternatively, the fiscal costs could be very large) because of rigidities in South Africa's labor market. The model results served as background for the Finance Minister's budget speech and subsequently for a modification of the original wage subsidy proposal. Sussangkarn (1996) took on the sensitive issue of Thailand's migrant workers (largely from Myanmar). He showed that, because these workers' presence potentially expands total economic output, even though low-educated Thais might be hurt, there are ways to compensate them with transfers so that society as a whole benefits. The simulations helped defuse a potentially tense situation.

5.3.1.8 International trade agreements

Beyond the single-country CGE models described up to now, there are a number of multicountry models that have had significant policy influence since they have been designed around particular international agreements, such as the Uruguay Round in multilateral trade reform. Some of the first models in this tradition calculated the welfare gains from multilateral trade liberalization (Goldin *et al.*, 1993). These estimates underpinned the arguments that Organization for Economic Cooperation and Development (OECD) agricultural subsidies were hurting developing countries — to the tune of $300 billion, about 6 times foreign aid. Likewise, Hertel *et al.* (2009) created a stir when they showed that the Doha Development Round had omitted those policy

[17] Another CGE modeler who served as Minister of Finance was Jaime Serra-Puche in Mexico.

reforms that would do most to reduce poverty. They described the existing policies as "transferring money from poor farmers in poor countries to rich farmers in rich countries."

5.3.1.9 Climate change

Finally, in keeping with greater general interest on the subject, CGE modelers have been looking at climate change recently. In Africa's first application of carbon taxation to mitigate climate change, Devarajan *et al.* (2010) examine the welfare and distributional consequences of taxes on carbon and on carbon-intensive goods and services such as coal or transport in South Africa. They show that the welfare effects are driven by the interaction with other distortions in the economy rather than the carbon tax itself. For instance, a simulation with all the labor market distortions removed results in a negligible cost of carbon taxation. Coincidentally, the carbon tax rate in the base-case scenario of the South Africa model was very close to that used in the Government's position paper, which, in turn, is being implemented now.

On adaptation to climate change, there are now examples using CGE models to analyze the effects of climate variability on agriculture and the overall economy in a few countries (see Bangladesh: Yu *et al.*, 2010; Ethiopia: Arndt *et al.*, 2011a; Mozambique: Arndt *et al.*, 2011b). The projects on Ethiopia and Mozambique were done in consultation with the governments, and have been part of the climate change policy discussion in both countries.

5.3.2 Lessons learned

The examples presented above of the use of CGE models in policy discussions reflect both the potential as well as some of the pitfalls of this particular technique.[18] For instance, when a numerical estimate is called for (as in the case of real exchange rate overvaluation), a CGE model is both the appropriate tool as well as a convenient one for generating that estimate. However, in other cases, one wonders whether the fact that the estimate came from a CGE model gives a false sense of precision. This might be the case for the MAMS application in Ghana, where the estimate of foreign aid required to reach the MDGs depended not on the CGE model itself but on the auxiliary equations added to the model to capture the interactions among water and health outcomes. The CGE model was not necessary to obtain the estimate, but the fact that the estimates were part of an integrated CGE/MDG model gave the estimate a sense of accuracy that was not justified from the CGE work alone – in a chain of analysis, accuracy depends heavily on the weakest link.

[18] For an excellent discussion of these issues, see McDougall (1993).

The cases where the CGE model was used to show directions of change also fall into two categories. The first are those cases where the CGE model was the appropriate framework, such as for instance, tax incidence or tax evasion. A multisector, multi-household, price-endogenous model is what is needed. In other cases, however, the direction of change depends mainly on the additional equations, such as the work on fiscal effects of infrastructure spending. Whether public infrastructure spending crowds-in or crowds-out private investment will depend on the importance of public infrastructure stock in the private production function. However, this is a parameter that is outside the CGE model. Nevertheless, here too the analyst can undertake sensitivity analysis and identify the critical value of the parameter that will reverse the result. In fact, this technique is one of the advantages of using a CGE model to underpin the discussion.

As the examples above show, CGE models have also contributed evidence to an ongoing policy debate. The case of trade liberalization in India is illustrative. There was a vigorous and often ideological debate on the topic throughout the 1980s. The Go and Mitra study did not enter the "big debate" of whether or not India should liberalize. Rather, they attempted to contribute evidence to a component of the debate, i.e. the impact of trade liberalization on revenues. Since their study used a CGE model, their results also shed light on the bigger debate. Whereas some of the rhetoric at the time was bemoaning the fact that existing industries will die, the Go–Mitra study showed that, on the contrary, some industries would do quite well because intermediate goods would now be cheaper. Likewise, the Sussangkarn study on migrant workers rigorously portrayed the output-enhancing effects of these workers and presented a dispassionate analysis on a charged topic.

However, here, too, there are cases where it may appear as if the main contribution was not directly associated with the CGE model, but a closer examination reveals that it was. For example, Hertel's result that most of the poverty-reducing measures had not been included in the Doha Round was driven by the profile of tariff and subsidy cuts, which were exogenous to the model. Yet it required model simulations to show that what was left out of the Doha Round was more poverty friendly than what was included. These results – especially as they created a stir at the WTO in Geneva – were more credible since they were based on a coherent analytical framework.

Where multiple CGE models and complementary detailed micro analysis (based on different models) have provided the same result, as was the case with the distributional effects of trade liberalization, the power of these models becomes evident – a point made with respect to the NAFTA debate by Devarajan and Robinson (2005). Not only are CGE models the right model to capture the salient mechanisms in the economy, but the fact that they stem from a rigorous analytical framework (e.g. the models satisfy Walras' law and are homogenous of degree zero in prices) increases the chances that the consistency of the results is saying something about the economy and not just a fluke. The statement about trade liberalization in Australia captures this phenomenon very well. To be sure, disagreement among model results can also be instructive, because they help identify differences among underlying assumptions and data (also noted by Devarajan and Robinson, 2005).

Finally, there is the question of whether the CGE model should be embedded in a government institution, as were the Bangladesh and South Africa models, or built and maintained independently, as were most of the other cases presented here. The Australian experience, which is noteworthy for its long-standing and continuous presence, is discussed in Dixon (2008). The argument for embedding in a government institution is that there will be greater ownership, and hence acceptance, of the model results, and that the analysis is more likely to be focused and timely – crucial matters in policy debates. On the other hand, their very presence in government might constrain the questions the model could ask (think of the work on tax evasio/n in Pakistan), not to mention the answers. The resolution is clearly a question of judgment and will depend on country circumstances. The typical pattern seems to be that models are developed outside government, but then adopted and used by government agencies as well as advisers and consultants to government. This may also be a moot question, given the direction that policy making in developing countries is going – a point to which we now turn.

5.4 CONCLUSIONS

After examining different classes of CGE models, this survey has identified the policy questions that these models can be designed to answer, the way in which the models are used to answer the questions and how such a process works out in practice. We showed how CGE models have been used in practice to inform policy making in developing countries. Looking ahead, it is apparent that policy making in developing countries is rapidly changing. With the rise of democracy and, in some cases, multiparty democracy, decisions are no longer made by an elite group of technocrats. Rather, policy is made with a view towards what the voters think. It is of course natural for politicians to think in terms of their electorate. However, it is a lesson often forgotten in CGE modeling circles, where recommendations are derived from model results without reflecting on the incentives facing politicians, who are the decision makers. The use of models to identify winners and losers arising from policy choices is often more important than more general welfare analysis.

The implication of this way of looking at policy making is that the process of using CGE models should also be changing. Rather than building and running models to serve the technocrats (who, in the past, would take the model results and interpret them to the omnipotent decision maker), modelers should be using their simulations to contribute evidence to the public debate. In turn, this statement means that the choice of questions should follow from those being debated. While this is already the case for many exercises, a clearer link between model design and use, and the burning questions of the day, would greatly enhance the models' impact.

In addition, if the goal is to contribute evidence to the public debate, the models must be publicly available and accessible by all sides of the debate. This would apply whether the model is in the government or outside.

Furthermore, the model results should be communicated in such a way that the participants in that debate — ordinary voters — can absorb them. Not only should the results be rigorously examined, but they should be presented so that average citizens can connect with them. For example, instead of presenting the incidence of taxation as a table of numbers, they could be presented as the story of five families (one in each quintile) and what the tax change means to them. The results should also be communicated by more than the standard medium of a paper or book, which is likely to be read by only a tiny fraction of the voting population. With two-thirds or more of the developing-country population having cell phones, CGE model results could be transmitted to people living in remote areas — provided we have a way of translating model results into SMS messages. To be sure, there is a danger that in such a situation the loudest voice receives the greatest credence, even if it is not correct. This is why it is particularly important that model results be scrutinized by experts — the equivalent of peer review in scholarly journals. However, the danger that modelers will be satisfied with just publishing results in journals rather than trying to get maximum impact is also significant. Either way, the model's results should be broadcast to the general public, allowing the debate to decide whether this particular set of simulations, or analysis from a completely different model, or even no model at all, plays the pivotal role in influencing the policy decisions.

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