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# Computable General Equilibrium Models: A Literature Review

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# RESUMO/ABSTRACT

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Applied general equilibrium models have become popular tools used on ongoing economic policy debates. In this paper we discuss at length the most proeminent features of applied general equilibrium models in a comprehensive and non-technical way, thus accessible to the reader interested in economic policy but with no prior formal exposure to economic modeling. We rationalize the increasing political demand for such models as policy analysis tools. We argue that applied general equilibrium models are best equipped to model regional economies.

Keywords: Regional Economic Modeling; CGE Models.
JEL Codes: R11; C68.

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# Computable General Equilibrium Models: A Literature Review*

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**Abstract**

Applied general equilibrium models have become popular tools used on ongoing economic policy debates. In this paper we discuss at length the most proeminent features of applied general equilibrium models in a comprehensive and non-technical way, thus accessible to the reader interested in economic policy but with no prior formal exposure to economic modeling. We rationalize the increasing political demand for such models as policy analysis tools. We argue that applied general equilibrium models are best equipped to model regional economies.

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# 1 Introduction

Policy makers and professionals alike are commonly interested in learning the direct and indirect effects of specific policy measures on economic outcomes. The ubiquitous existence of rich data sets, both at a macro and at a micro level, combined with abundant computing power, explains the increasing political demand for quantitative assessments of the economic impacts of actual or eventual policy choices.

Since the beginning of the 1980s Computable General Equilibrium (CGE) models have become increasingly popular tools to analyze the consequences of policy choices and the allocation of resources in developing as well as in developed economies. In fact, CGE models are used nowadays not only in universities and research institutions, but also by governments worldwide in policy formulation and debate.

In this paper, we provide an introduction to the essence of CGE models at an economically intuitive level, and, in the process, we rationalize the growing popularity of CGE models as policy analysis tools. In order to achieve this, we set ourselves out to motivate answers to the following questions:

1. Why do we need economic models?
2. Why do we need CGE models?
3. What are the building blocks of CGE models?
4. What are the weaknesses and the strengths of CGE models?
5. How do CGE models compare with other competing economic models?
6. How have CGE models been applied?
7. Where are CGE models headed?

As this paper aims a general audience interested in economic policy analysis, but not necessarily with prior formal exposure to economic modeling, the paper employs an intuitive, non-formal, approach to answer the questions above. The paper provides, thus, a comprehensive non-technical introduction to CGE models. However, we do refer to economic objects and concepts such as utility functions or neoclassical theory with little or no attached explanations whatsoever, so some basic economic understanding is assumed. We note that our primary interest lies in regional models. Hence, we focus on keys aspects of regional modeling and, therefore, answer to the questions above bearing in mind our end goal: to discuss the salient features of an applied regional general equilibrium model. We shall use the terms applied general equilibrium models and CGE models interchangeably. As there are many excellent surveys on CGE models, we borrow extensively from existing work and capitalize, thus, on the existing literature.

The paper is organized as follows. Section 2 discusses why we need economic models. Section 3 lays out basic desiderata of what constitutes a good economic model. Section 4 discusses the most prominent features of CGE models, including its building blocks and applications. Section 5 reviews some well-known criticisms of CGE models. Section 6 points out research directions and concludes.

## 2 The Need for Economic Models

First and foremost, it is instructive to motivate the need for economic models. Economic models are, in their essence, abstract representations of reality, build to promote our understanding of the different economic interrelationships at play in the real world.

Since policy choices affect economic outcomes and, concomitantly, our general well being, there is the need to anticipate the effects of such policy choices. As with other social sciences, experimentation is not, usually, a choice. Trial and error learning processes are just inviable since policy changes involve affecting human experiences. Hence, economic models act as laboratories where one learns the expected direct and indirect economic effects of specific policy choices. There is, thus, an obvious need for economic models.

Iqbal and Siddiqui (2001) motivate the need for economic models citing Rust (1997), who, in turn, states the need of an economic model as follows: "To have a complete understanding [of economic systems], we need to be able to calculate detailed implications and predictions of these abstract theories and determine whether the predictions of these models are consistent with what we observe in the real world. So we can not pretend to have a complete understanding of real economies until we can show that the detailed implications of our theories provide sufficiently accurate representations of the real world that we would take our models seriously for forecasting and policy analysis."

In the same line of reasoning, Iqbal and Siddiqui (2001) cite Shoven and Whalley (1992) who stated "...the virtue of using applied general equilibrium models is that, once constructed, they yield a facile tool for analyzing a wide range of possible policy changes. Such analysis generates results that either yield an initial null hypothesis, or challenge the prevailing view. It may be that subsequently the conclusions from the model are rejected as inappropriate; the assumptions may be considered unrealistic; errors may be unearthed, or other factors may undermine confidence in the results. But there will be a situation in which the modeler and those involved in the policy decision process will have gained new perspectives as a result of using the model." These new, formally educated, perspectives on the functioning of the economy, that follow from the modeling process, are invaluable to the policymaker.

# 3 Model Design

Having established the need for economic models, we are, then, left with the following question: What is a good economic model? We answer this question bearing in mind that our main goal is to analyze economic policy, and not necessarily, say, short-term forecasting. This distinction is of the essence since analyzing economic policy implies that we should be able to uncover causal relationships, from economic policy instruments to economic outcomes, in an economically intuitive manner. However, if one is interested in forecasting per se, there are statistical models that may deliver acceptable forecasts, in a statistical sense, with no say whatsoever on the underlying economic mechanisms at play. To answer to the question of what is a good economic model we borrow extensively from Devarajan and Robinson (2002) who claim that for an economic model to be useful for policy analysis it should exhibit the following desirable characteristics:

1. **Policy Relevance.** The model should explicitly link values of policy instruments to economic outcomes of interest to policymakers.

2. **Transparency.** The links between policy instruments and economic outcomes should be traceable and easy to explain.

3. **Timeliness.** The model should be based on recent, relevant data, if it is to be used on ongoing policy debates.

4. **Estimation and Validation.** The model parameters must be validated for the domain of application of the model.

5. **Diversity of Approaches.** The model results should be validated by the results from other models or approaches, whenever possible.

**Policy Relevance and Transparency** These two criteria argue bluntly for using structural models. In structural models, some of the endogenous variables (that is, the variables explained within the model) are expressed as functions of some other endogenous variables. In contrast, in reduced-form models all endogenous variables are expressed as functions of exogenous variables (exogenous variables are variables explained outside the model, and, thus, taken as given by the modeler) and model parameters (that is, parameters that describe economic behavior which are also taken as given by the modeler) only, but not as a function of other endogenous variables. Hence, reduced-form models typically do not explicitly model the links between policy instruments and economic outcomes or, at best, they do it in a way that it is difficult, if not impossible, to identify the underlying structural relations. Therefore, it is quite difficult to trace out the links between policy instruments and economic outcomes when using reduced-form models. In short, reduced-form models are "black-boxes" whose results are hard to explain. As it will become clear in the following sections, one of the most prominent features of applied general equilibrium models is that they are the opposite of what one would regard as a "black box".

Policy analysis ought to go hand in hand with policy agenda and public debate. Therefore, policy analysis must focus on measures with which people relate to at a very familiar level, such as, say, regional employment and growth. Hence, policy analysis typically should not be confined to esoteric measures such as compensating variation or equivalent variation.

The transparency criteria argues for a very stylized model, since this modeling strategy facilitates the tracing out of causal economic links between the policy instruments and the economic outcomes of interest. However, policy relevance usually speaks for more institutional and sectoral detail, since policymakers are naturally interested in identifying at a quite disaggregated level the winners and losers of a given policy package. Thus, policy relevance promotes the employment of large, complex models. However, by construction, CGE models explicitly model economic behavior at the individual level. Therefore, it is only natural with

CGE models to have detail, complexity and intuition simultaneously. There is no obvious need to trade-off detail for ease of interpretation in CGE modeling.

**Timeliness** The model should be based on recent, relevant data, if it is to be used on ongoing policy choices. Quite naturally, for a model to be credible, it must employ up-to-date data. If one uses historical data to draw lessons, then one must also be capable of demonstrating that the structural form of the economy has not substantially changed, for the lessons drawn to be of any value.

**Estimation and Validation** The issue of validation of a policy model also argues, such as the transparency and the policy relevance criteria, for a structural model. The domain of applicability of a reduced-form econometric model must be contained within the historical range of the data used to estimate the model. The domain of applicability of a structural model depends on the applicability of the structural relations and on the stability of its parameters in the period of analysis.

In model validation, there is a trade-off between using a structural model, which requires estimation of a large number of structural parameters, and a reduced-form model with far fewer parameters.

Structural models are highly non-linear, unlike most of its predecessors which were often linear and easy to handle. However, and quite fortunately, the recent advances in computing methods have turned this feature of non-linearity almost a non-bidding constraint.

Structural models, in general, and CGE models, in particular, are based on data such as input-output tables which are not usually continuously available, but rather only for a few periods, with long gaps. In contrary, reduced-form models are usually much less demanding on the number of parameters that must be estimated.

However, some reduced-form (econometric) models require time-series data which, sometimes, are available for only a short period or not available at all. This is not necessarily the case of CGE models, where one needs to be confident about the validity of the available data, which may be available for one or a few recent years.

**Diversity of Approaches** An ultimate goal of constructing an economic model may be policy guidance. However, before leaping from policy simulations to policy implementations one must feel confident with one's model. In order to build up such confidence, it is convenient to assess our model predictions by confronting them with other approaches, whenever possible. Hence, it is often the case that researchers are interested in confronting results from different models.[1]

In summation, it follows from this scrutiny that, aside for those who care for short-term forecasting per se, if our interest is in economic policy guidance, the economic model should be a structural model. Given the appropriate data, CGE models are natural candidates to fulfill the desiderata above.

# 4 CGE Models

## 4.1 Prominent Features

In this section, we highlight prominent features of CGE models, bearing in mind that we are mainly interested in modeling regional economies.

**Microeconomic Principles** As stated in Rege (2003), general equilibrium models possess a rigorous structure derived from sound microeconomic optimization theory. This feature leads to results with a clear structural or theoretical interpretation.

**General Equilibrium Nature** Households and markets are modeled in an extensive way, and not in a partial setting. This is important because it builds complex interactions between the different economic agents into the model. These interactions must be considered as indirect effects usually work in important and, sometimes, counter-intuitive ways. Such general equilibrium nature naturally evokes the underpinnings of Walrasian general equilibrium (see Varian 1992). As lucidly exposed by Wing (2004) Walrasian general equilibrium has in its cornerstone the following accounting rules:

- Conservation of product: "... reflects the physical principle of material balance that the quantity of a factor with which households are endowed, or of a commodity that is produced by firms, must be completely absorbed by the firms or households (respectively) in the rest of the economy."

[1] West (1995) provides an extensive account of a comparison between different models at the regional level.

- Conservation of value: "...reflects the accounting principle of budgetary balance that for each activity in the economy the value of expenditures must be balanced by the value of incomes."

These accounting rules are usually depicted in the form of the popular circular flows.

**Detail and Disaggregation** Considerable detail is devoted to individual behavior. Agents - households, firms, governments, .... - and markets - commodities, factors of production, ... - are modeled in an explicit way with as much detail as desired. CGE models are well known for treating with great detail issues such as, say, tax structure, production structures, and so on. Acknowledging detail is a requirement for policy guidance, which cannot make ado with aggregation and simplification. As a result, CGE models are best equipped to model regional economies in the sense that any good regional model should consider regional specificities.

## 4.2 Building Blocks and Essence

The main building blocks are the agents and the markets that one needs to specify in the model in order to capture all the key causal chains in the economy. The agents' set comprises, usually, households, firms, governments and institutions, whereas the markets's set entails factors of production, commodities, and, less often, financial assets.

Agents' behavior follows strictly from microeconomic principles, with explicit modeling of objective functions, control variables, expectations rules and functional forms.

Markets operate according to institutional features and regulatory constraints. Market structure is modeled following Industrial Organization models of both perfect and imperfect competition.

The environment is either static, partial-dynamic (recursive) or fully dynamic, in the sense that one may have long or infinitely lived agents who care about the future and whose problems are related over time. This is particularly important for matters such as capital accumulation. Rege (2003) provides an interesting discussion of how CGE models treat time.

The general equilibrium nature of these models is their most distinguishing feature and, concomitantly, explains their increasing popularity, over partial equilibrium models. General equilibrium models explicitly model all key aspects of a given economy, in contrast with partial equilibrium models which take as given important aspects of the economy. In fact, if a policy instrument is used to achieve a change in an economic target variable, other economic variables than the target variable will be affected. The resulting final economic outcomes may well differ substantially from the intention of policy makers and the direct effects predicted by partial equilibrium models.

A CGE model may be defined as the fundamental macroeconomic general equilibrium links among incomes of various groups, the pattern of demand, the balance of payments and a multisector production structure.[2] In addition, a CGE model incorporates a set of behavioral equations describing the optimizing economic behavior of the agents identified in the model and the technological, endowment and institutional constraints that these agents face.

Devarajan and Robinson (2002) distinguish between stylized and applied CGE models. Stylized models stay as close as possible to theory in order to isolate the empirical importance of a link that theory suggests as potentially important. As the name indicates, stylized models are not constructed with the intention of being realistic, since they are designed to address a particular causal mechanism.

CGE models are aggregate representations of the economy and are based on the flow equilibrium in product and factor markets in real as well as in nominal terms. Opposite to input-output models, both quantities and relative prices are endogenous, while consumption is no longer exogenous but linked to income. The general equilibrium approach, in contrast with partial equilibrium approaches which analyze the different sectors separately under ceteris paribus assumptions, intends to model all links within the economy that represent a transaction of money or goods. The analysis is usually based on comparative numerical static analysis.

[2] The model is in general equilibrium because a set of prices exists such that all excess demands for commodities and services, in nominal and in real terms, are zero. That is, the model is in general equilibrium when the Walras' Law is valid and the equilibrium price vector is not equal to the zero price vector. In mathematical terms: $p.z(p) = 0$ and $z(p^*) = 0$, with $z$ equal to the excess demand function, $p$ equal to the price-vector and $p^*$ equal to the equilibrium price vector. See Varian (1992) for an extensive discussion on Walras' Law and General Equilibrium Theory, rooted on the seminal work by Debreu (1954, 1959).

## 4.3 Steps in Applied CGE Modeling

In this section we present a number of steps usually undertaken in applied CGE modeling exercises, following Bayar (2005). We find this exercise instructive as it highlights the tasks at hand and, concomitantly, it guides us in our discussion of the weaknesses and strengths of CGE models below.

1. Specify dimensions of the model and choose key causal relations. In this step, one answers the following questions: How many different types of agents to consider? Which goods and factors are produced and employed in production? How many regions and countries are there? Which markets are active? As stated above, the model should feature all key causal relations in the economy.

2. Choose functional forms. To make the model operational one needs to go from general algebraic representations or formulae to specific functional forms. In this step, it is important to skillfully balance analytical convenience and adherence to reality.

3. Construct consistent data set. The data must go hand in hand with theory. For instance, one should specify the set of factors according to the data available.

4. Calibration and econometric estimation. The key causal relations captured by the model must be traced back to real data. The model should be able to replicate real case scenarios.

5. Counter-factual experiments, scenario and impact analysis. This step amounts to putting the model to work.

6. Regular updating. As new data become available, one should update all the previous steps. This is important because one must prove that there are no structural breaks or, to be more general, the model is being applied within its domain of applicability: where the causal relations and their functional and numerical structures are valid (on this, see below the section on criticisms).

## 4.4 Applications of CGE Models

In this section we discuss the main applications of applied general equilibrium models. After a first look at the literature from an historical perspective, we then discuss how the literature has evolved according to key aspects of applied general equilibrium modeling, namely, production structures, consumer behavior, exports and imports, regional governments, imperfect competition and increasing returns to scale, and, finally, dynamics.

**Applications: A Brief Literature Survey** The range of issues on which CGE models have been applied is quite wide and growing. The spectrum of applications of CGE models includes international trade, public finance, agriculture, transportation, welfare, environment and income distribution. There are many excellent surveys of the literature. For the sake of preserving space, we focus here only on the seminal works and regional modeling works.[3]

CGE models are, in their essence, the modern version of Walras' model of the competitive economy. Johansen (1960) is usually referred to as the first main attempt to use a large CGE model to study a real economy. Shoven and Whalley (1972), Whalley (1975, 1977), Shoven (1976), and Miller and Spencer (1977) are found among the earliest followers of the seminal work by Johansen.

As discussed in Wing (2004), CGE models have been used in areas as diverse as fiscal, social policy and development planning (e.g., Pereira 1993, Perry et al 2001, Gunning and Keyzer 1995, Ballard et al 1985, Ballard and Goulder 1985, Bandara 1991, Bayar 1993, Dewatripont et al 1991, Goulder and Summers 1989), international trade and factor mobility (e.g., Martins and Winters 1996, Harrison et al 1997, Bovenberg and Goulder 1989), and increasingly, environmental regulation (e.g., Jorgenson and Wilcoxen 1990, Weyant 1999, Bovenberg and Goulder 1996, Goulder 1992, Prost and Van Regemorter 1990). In fact, several authors have recently applied CGE models to study the implications of introducing tax or subsidy distortions that aim to reduce dioxide carbon emissions (see Wing 2004 for an excellent, easy to read introduction to this subject).

In the 1980s, many applied general equilibrium models were built for the United States, Canada and the United Kingdom and for several developing countries. However, widespread applications of regional CGE models are more recent.

One of the main reasons to this late development of regional applied general equilibrium models is the poverty of the data available at the regional level. Indeed, applied general equilibrium models require a considerable number of extremely detailed data: sectoral production, intersectoral exchanges, commercial flows, distribution of income, private

[3] We thank Ali Bayar for his extensive contribution to this section.

consumption, investments, public expenditures and taxes, just to list a few pieces of data usually required by modern applied general equilibrium models. These data are sometimes difficult to gather even at a national level, but the problem becomes even worse at a regional level.

Moreover, other complications emerge when one moves from the national level to the regional level, such as, for example, the greater openness of the regional economy to the external world. Being a more open economy has an important influence on interregional mobility of labor and capital but also on differentiation of the regional products with respect to the other areas and on interregional commercial flows. These differences with the national models accentuate the difficulties in transposing the national results into the regional models (for example, estimates of certain parameters of elasticity) and thus suggest divergences of structure between national and regional general equilibrium models.

Among the first regional general equilibrium models we find Norrie and Percy (1983), who analyzed Canadian regions, Kimbell and Harrison (1984), who studied California, and Liew (1984), who focused on Australian regions. This research was also enriched and stimulated by other contributions, for example, Hertel (1985), Hertel and Mount (1985), who studied the State of New York, and Jones, Whalley and Wigle (1985), who looked at Canadian regions, as well. Concomitantly with the recent development of this modeling approach at the regional level one finds a very fast proliferation of applied regional studies, mainly in the United States, Canada and in Australia and a diffusion of this approach to European regions (Italy, Germany and United Kingdom) and even to certain developing countries (Brazil and Malaysia). For the United States, we can cite Berck, Robinson and Goldman (1991), Waters et al (1997), Berck et al (1996), Buckley (1992), Despotakis and Fisher (1998), Hoffman et al (1996), Kilkenny (1993a, 1998), Koh et al (1993), Kraybill et al (1992), Li and Rose (1995), Morgan et al (1989), Morgan, Mutti and Rickman (1996), Rickman (1992), Schreiner et al (1999). For Canada we can quote Jones and Whalley (1989, 1990), Whalley and Trela (1986), Lemelin et al (1993), Gazel (1996), Gazel et al (1995), Wigle (1992); for Australia, we may cite, among others, Liew (1984) and Peter et al (1996). Conrad and Schroder (1993) and Hirte (1998) built models for German regions. Harrigan et al (1991; 1992; 1996), initially, McGregor, Swales and Yin (1995, 1996), thereafter, built a model for Scotland and D'Antonio et al (1988) built a model for Italian regions.

Harrigan and McGregor (1989), Ko (1985), Ko and Hewings (1986), Watanuki (1996), Ando et al (1997) and Haddad (1999) focused on developing countries (Malaysia, Korea, China, Indonesia and Brazil). Nowadays, applied general equilibrium models have become ubiquitous, in the sense that they have been routinely employed in regional studies devoted to both developed and developing regions.

As a corollary of the vigorous research devoted to applied regional general equilibrium models, we find several literature review essays. Among these we highlight the work by Lemelin (1994) and Partridge and Rickman (1998), as widely cited articles.

**Production Structures** In general, regional general equilibrium models assume a demand for intermediate goods based on a Leontief technology (i.e. the assumption of complementarity between intermediate inputs, based on the input/output matrix). Regional and imported inputs are, usually, supposed to be imperfect substitutes. The substitution between regional and imported inputs is generally specified by means of a function THESE (or Constant Elasticity of Substitution) in reference to the Armington assumption (Armington, 1969)[4] and often employed by regional general equilibrium models.

Concerning factors of production, substitution between factors of production is often ensured by Cobb-Douglas functions (CD) or THESE functions specified with constant returns to scale. Very often, an overlapping structure ("nested") on several levels is adopted to show substitution between different factors of production (for example, energy is often modelled like a factor of production with multiple components such as electricity, oil, natural gas, ...) and to overcome the limitations of the Cobb-Douglas functions and THESE functions on a level which impose, for the first, unit elasticities of substitution, and for the second the same elasticity of substitution between each pair of factors.

In the vast majority of regional models, production functions consider both intermediate goods and factors of production. Labor and capital are universally specified in regional general equilibrium models as factors of production. Several studies also consider as a factor of production natural resources, such as agricultural surfaces or energy production for better taking account of specificities of an area and/or a sector. The following table highlights how some regional studies have dealt with production structures.

**Table 1: Regional Studies and Production Functions**

[4] The well known Armington Assumption suggests the use of a function THESE to represent imperfect substitutability between domestic and imported goods.

| Regional Studies | Regions | Production Functions |
|---|---|---|
| Berck, Robinson and Goldman (1991) | San Joaquin Valley USA | CD w/ multi-level IO |
| Berck et al (1996) | California USA | THESE w/ multi-level IO |
| Buckley (1992) | 3 regions - USA | CD w/ multi-level IO |
| Condrad and Schroder (1993) | Baden-Wurtemberg (Germany) | THESE w/ multi-level IO |
| Despotakis and Fisher (1988) | California USA | Generalized Leontief |
| Gazel (1996) | 4 regions - USA and Canada | THESE w/ multi-level IO |
| Gazel, Hewings and Sonis (1995) | 4 regions - USA and Canada | THESE w/ multi-level IO |
| Haddad (1999) | 3 regions - Brazil | THESE w/ multi-level IO |
| Harrigan and McGregor (1989) | 2 regions - Malaysia | THESE w/ multi-level IO |
| Harrigan et al (1991; 1992) | Scotland and UK | THESE w/ multi-level IO |
| Hertel and Mount (1985) | New York State USA | Multi-level translog |
| Hirte (1998) | 10 regions - Germany | THESE w/ multi-level IO |
| Hoffman et al (1996) | California USA | THESE/IO/CD |
| Jones and Walley (1989, 1990) | 6 regions - Canada | THESE w/ multi-level IO |
| Jones, Walley and Wigle (1985) | 2 regions - Canada | THESE w/ multi-level IO |
| Kilkenny (1998) | USA | CD/IO/THESE |
| Kimbell and Harrison (1984) | California USA | THESE |
| Koh, Schreiner and Shin (1993) | Oklahoma USA | CD w/ multi-level IO |
| Li and Rose (1995) | Pennsylvania USA | Generalized Leontief |
| Liew (1984) | 6 regions - Australia | THESE w/ multi-level IO |
| McGregor, Swales and Yin (1995) | Scotland and UK | THESE w/ multi-level IO |
| McGregor, Swales and Yin (1996) | Scotland and UK | THESE w/ multi-level IO |
| Morgan, Mutti and Partridge (1989) | 6 regions - USA | Differential linear with CRS |
| Morgan, Mutti and Rickman (1996) | 6 regions - USA | THESE w/ multi-level IO |
| Peter et al (1996) | 8 regions - Australia | THESE w/ multi-level IO |
| Rickman (1992) | USA (some regions) | THESE w/ multi-level IO |
| Scheiner et al (1999) | Oklahoma USA | CD/THESE/IO |
| Walley and Trela (1986) | 6 regions - Canada | THESE w/ multi-level IO |
| Wigle (1992) | 6 regions - Canada and USA | THESE |

The degree of factor mobility plays an important part in the specification of a regional applied general equilibrium model and differs from one model to another. In general, factor mobility increases with the span of the period of analysis, so it is quite common to find fixed factor supplies, at least in the short term. With imperfect factor mobility, productivity wedges across regions may persist over time and, concomitantly, factor returns may also not be equal across regions as factor returns are linked in some sense to factor productivities.

To specify the "closing" of the regional labor market, the majority of the models use the neoclassical assumption:[5] wages are endogenous and flexible so wages adjust in order to equate labor demand and labor supply; nevertheless, more and more regional models incorporate Keynesian features: wages (prices) are fixed at predetermined exogenous levels and there may be factor underutilization (unemployment). See Ginsburgh et al 1986 for an example of a general equilibrium model with wage rigidities. The following table shows how different models have dealt with factor mobility and labor market closure.

**Table 2: Regional Studies, Factor Mobility and Labor Market Closure**

[5]Intutively, prices are flexible and adjust in order to clear the market in the sense that demand equals suply and, thus, there is no factor underutilization.

| **Regional Studies** | **Inputs** | **Closure**[6] |
|---|---|---|
| Berck, Robinson and Goldman (1991) | K, L, M, R, water; K, L fixed | Endogenous wages |
| Berck et al (1996) | K, L, M; L flexible | Endogenous wages |
| Buckley (1992) | K, L, M; K, L fixed | Endogenous wages |
| Condrad and Schroder (1993) | K, L, M, E; K, L fixed | Exogenous wages |
| Despotakis and Fisher (1998) | K, L, M, E; K, L fixed | Endogenous wages |
| Gazel (1996) | K, L; K fixed, L free | Endogenous wages |
| Gazel, Hewings and Sonis (1995) | K, L; K, L fixed | Endogenous wages |
| Haddad (1999) | K, L, M; K, L fixed | Wage differentials |
| Harrigan and McGregor (1989) | K, L, M; K fixed, L free | Several cases |
| Harrigan et al (1991; 1992) | K, L, M; K fixed, L free | Several cases |
| Hertel and Mount (1985) | K, L, M, E; K fixed, L free | Exogenous wage bill |
| Hoffman et al (1996) | K, L, M; Several cases | Several cases |
| Jones and Walley (1989, 1990) | K, L, M, R; K, L free | Endogenous wages |
| Kimbell and Harrison (1984) | K, L, M; K free, L fixed | Endogenous wages |
| Koh, Schreiner and Shin (1993) | K, L, M, R; L free | Several cases |
| Li and Rose (1995) | K, L, M, E; K, L fixed | Several cases |
| Liew (1984) | K, L, M, R; L fixed | Endogenous wages |
| McGregor, Swales and Yin (1995) | K, L, M; Several cases | Several cases |
| McGregor, Swales and Yin (1996) | K, L, M; Several cases | Several cases |
| Morgan, Mutti and Partridge (1989) | K, L, R; K, L free | Endogenous wages |
| Morgan, Mutti and Rickman (1996) | K, L, R; K, L free | Endogenous wages |
| Peter et al (1996) | K, L, M; K fixed, L free | Several cases |
| Rickman (1992) | K, L, R; K fixed, L free | Several cases |
| Scheiner et al (1999) | K, L, R, M; K fixed, L free | Endogenous wages |
| Walley and Trela (1986) | K, L, R; K, L free | Endogenous wages |

**Abbreviations:** K: capital; L: labor; M: intermediate goods; E: energy; R: natural resources (surfaces).

[6] Endogenous wages means that wages are flexible and calculated in order to clear the labour market ensuring, thus, that there does not exist involuntary unemployment in equilibrium. When wages are exogenous then involuntary unemployment may arise in equilibrium.

**Consumer Behavior** Cobb-Douglas (CD) and THESE functions are generally used to represent consumer utility but the homotheticity of these functions restricts consumption goods income elasticities to one. In addition, CD functions imply zero cross-price elasticities. To avoid these elasticity restrictions, several studies employ the more general, non-homothetic, "linear system of the expenditures" (Linear Expenditure System or LSE). Another method generally used to allow for various elasticities of substitution between the various sets of consumer goods is to use a nested structure of consumption. Import and domestically produced consumption goods are generally perceived as imperfect substitutes, following the well known Armington assumption.

**Exports and Imports** With regard to exports, the functions THESE of imports act as the source of request for exports in multi-regional models. In the mono-regional models, the goods produced in the area are often supposed to be delivered either to the local markets or to the external markets, the choice being made with the same assumption as for the imported goods, according to a constant elasticity of substitution, namely "constant elasticity of transformation" (Constant Elasticity of Transformation or CET). Nevertheless, certain models simply assume a constant elasticity of exports with respect to prices.

With regard to imports, regional general equilibrium models typically follow the Armington assumption to take account of imperfect substitution between the regional domestic goods and the imported goods.

**Regional Governments** In some regional general equilibrium models the regional government is lumped together with the federal government and treated as exogenous. However, some regional general equilibrium models do treat the regional government as a separate entity from the federal government, but take both of them as exogenous nonetheless.

The most complex treatments of the regional government are found without surprise in the studies which focus on regional budget policies. In these studies, the expenditure of the regional government is related to regional household incomes and, in some of them, the regional government is regarded as a sector of production which requires inputs. Some models allow for interactions between regional and federal taxes.

**Imperfect Competition and Increasing Returns to Scale** Most applied regional general equilibrium models assume, for the sake of convenience, perfectly competitive markets, with firms acting as price takers in both factor and commodities markets, under constant returns to scale production structures. Given the importance of imperfect competition in certain sectors, several authors moved away from the perfect competition paradigm and integrated imperfect competition aspects in their regional models, following the industrial organization (IO) and game theory literatures. For instance, Hertel (1985) and Hertel and Mount (1985) consider oligopolistic behavior in some sectors; Kilkenny (1993b, 1998) and Whalley and Trela (1986) model certain manufacturing sectors following monopolistic competition IO models; Mello and Tarr (1992) use duality theory to incorporate imperfect competition into some goods markets, namely, cars, iron and steel; finally, Tembo, Vargas and Schreiner (1999) consider the factor market for wood as a monopsony. Vargas et al 1999 present a regional CGE model where with monopsony markets in the forest products industry in the US state of Oklahoma. Some authors also deviated from the traditional perfect competition with constant returns to scale benchmark models by assuming increasing returns to scale in their production structures and imperfect competition (see Harris 1984).

**Dynamics** The simplest applied general equilibrium models are static in the sense that time is omitted from the analysis. Intuitively, all agents solve a one-shot problem. Clearly, this modeling strategy is inadequate to study a vast array of economic problems such as investment or capital accumulation. Savings and investment decisions, to name a few, are some of the economic problems which must be dealt with in a dynamic setting, that is, where time is explicitly treated in the analysis. Dynamic models are either recursive or fully-dynamic, with the latter being more complicated than the former. In recursive settings, the agents problems are typically related pair-wise over time, meaning that today's problem affects tomorrow's problem only. In fully-dynamic settings, all periods are related to one another simultaneously. Time dynamics are important if one is interested in the transition path from one equilibrium state of the economy to another. Comparative static analysis cares only about comparing one equilibrium against some other equilibrium. This is possible to analyze within a static framework. However, transitional dynamics, or how the economy actually moves from one equilibrium to another may be quite important to have a quantitative feeling of the welfare implications of a given policy package. Who gains and who loses from a given policy change? The answer to this question may depend on the time frame. Hence, welfare analyses are much more interesting when undertaken in a fully dynamic setting. See Rege (2003, Ch. 2) for an interesting discussion on this topic.

**Applications: A Tentative Classification** The regional general equilibrium models listed here were used in many fields. Any given classification scheme of such applications will, inevitably, be somewhat arbitrary. We can classify them in four important topics:

1. Topic 1: To study the direct and indirect economic effects of exogenous changes in final demands (say, government demand);
2. Topic 2: To evaluate trade or federal budget policies;
3. Topic 3: To evaluate regional budget policies;
4. Topic 4: To evaluate certain specific policies, such as agricultural, transportation and environmental.

The following table lists some applications classified according to the above structure.

**Table 3: Regional Studies - Some Applications**

| Regional Studies | Topic |
|---|---|
| Berck, Robinson and Goldman (1991) | 4 |
| Berck et al (1996) | 3 |
| Buckley (1992) | 4 |
| Condrad and Schroder (1993) | 4 |
| Despotakis and Fisher (1998) | 1, 4 |
| Gazel (1996) | 2 |
| Gazel, Hewings and Sonis (1995) | 2 |
| Haddad (1999) | 2, 4 |
| Harrigan and McGregor (1989) | 1 |
| Harrigan et al (1991; 1992) | 1 |
| Hertel and Mount (1985) | 4 |
| Hoffman et al (1996) | 1, 2 |
| Jones and Walley (1989, 1990) | 1, 2, 3 |
| Kimbell and Harrison (1984) | 3 |
| Koh, Schreiner and Shin (1993) | 1 |
| Li and Rose (1995) | 4 |
| Liew (1984) | 2 |
| McGregor, Swales and Yin (1995) | 4 |
| McGregor, Swales and Yin (1996) | 4 |
| Morgan, Mutti and Partridge (1989) | 3 |
| Morgan, Mutti and Rickman (1996) | 3 |
| Peter et al (1996) | 4 |
| Rickman (1992) | 3 |
| Scheiner et al (1999) | 4 |
| Walley and Trela (1986) | 2, 4 |

# 5 Comments on CGE Models

In this section we discuss weaknesses and strengths of applied general equilibrium models as well as where are these models headed.

According to Iqbal and Siddiqui (2001), despite the fact that applied general equilibrium models have raised the level of sophistication of the policy debate, applied general equilibrium models are subject to criticism on many counts. A CGE model embodies three types of information: analytical, functional and numerical. The analytical structure is the theoretical support where one identifies the variables of interest and postulates their causal relations. The functional structure is the algebraic representation of the analytical structure necessary to make the model operational. Finally, the numerical structure consists of the coefficients in the equations considered in the model. The criticism is mainly directed towards the functional and numerical structures of the calibrated or applied CGE model.

- **Quality of Data:** The quality of the model is heavily dependent on the quality of the data of the chosen benchmark period, say, without lost of generality, a given year. This benchmark year is perceived as a good representation of the deep or structural key causal relations in the economy. Any given year will reflect a series of anomalous events which, in turn, undermines generalizations. In this sense, regular updating is important to asses eventual structural breaks or the importance of erratic events.

- **Choice of Parameters:** In CGE models, some parameters are taken from empirical studies, some are chosen arbitrarily and some are calibrated, in the sense that they are picked in a way that forces the model to replicate the data of a chosen benchmark year. Several authors offer the following criticisms to such practices. In order to model production structures one typically has to quantify elasticities. If one borrows elasticities from empirical studies devoted to other regions or time periods, one may be using information from sectors with different statistical classifications or technologies, which, in addition, may be obsolete. As with any calibration exercise, there is no way to formally test the validity of the parameters calibrated, since by construction they guarantee that the model replicates the benchmark data.

- **Choice of Functional Forms:** Most CGE models assume first order functional forms which are easy to handle but embody unwelcome elasticity restrictions. However, and as several authors show, it is possible to avoid such restrictions by assuming more flexible functional forms and, consequently, the models can represent all the relevant own and cross price elasticities derived from an arbitrary utility or profit function, without imposing prior constraints.

- **Calibration of the Model:** Calibrating a CGE model to a given benchmark year may be problematic as the benchmark year may not accurately represent the natural state of the economy or it may not provide enough data.

- **Static CGE Model:** Static CGE models can address questions of what happens to an economy as it moves from one state of exogenous conditions to another, that is, comparative static analysis. By design, however, comparative static analysis omits the time path of response of the economy, which may be important for welfare analysis and, of course, for forecasting. Moreover, in static models some intertemporal problems such as consumption and saving are modeled in an arbitrary way, without formal optimization or guidance from theory. Hence, in a setting short of fully dynamic, the economy may move along a non-optimal path. In order to avoid non-optimal paths, fully dynamics must be considered and great care should be devoted to the role of expectations.

- **Sensitivity of Results:** Results are sensitive to inputs such as key elasticities. Hence, it is instructive to learn how results vary as one allows these key elasticities to vary according to guidance from empirical econometric studies.

# 6 Concluding Remarks

Applied CGE models are nowadays the most popular modeling approach to regional phenomena. This is hardly surprising when one realizes that applied CGE models allow for a great deal of detail and complexity of institutional features and of regional specificities and are theoretically coherent. Since its origins in the 1960s, applied CGE models have come a long way. However, there is still an ongoing widespread research effort that continuously brings more realistic models into the forefront practice. The research agenda includes the following topics and challenges:

- Interactions between regions;

- Disintegration of the labor market;

- Imperfect competition and increasing returns to scale;

- Dynamic aspects of the economies;
- More flexible functional forms;
- In addition to calibration, to use econometric estimates whenever possible;
- Consider financial assets;
- Consider transportation costs;
- Consider household heterogeneity;
- Consider alternative macro closure rules.

The current research agenda and the recent successes will, certainly, reinforce the popularity of applied CGE models and the political demand for their use as policy guidance tools in the near future. However, it is possible that in some regions, poor data make theory ahead of measurement.

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