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INTERREGIONAL COMPUTABLE GENERAL EQUILIBRIUM MODELS: A SURVEY ON SPECIFICATION AND IMPLEMENTATION ISSUES

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Interregional Computable General Equilibrium Models: A Survey on Specification and Implementation Issues♣

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Abstract. Interregional computable general equilibrium modeling (ICGE) constitutes nowadays one of the main research frontiers in regional modeling. The main aspects related to its recent developments are discussed in this paper, based on the authors' experience in the field. The paper provides a survey on specification and implementation issues related to Walrasian-type ICGE models built for sub-national territories, using examples and gathering insights from different operational models presented in the literature.

1. Introduction

The theory of general equilibrium in economics has its origin in the work of the classical economists. The perception of its most important implication, that competitive markets can achieve an allocation of resources that is efficient in some sense, is present in Adam Smith's *The Wealth of Nations*, 1776. Although Leon Walras (1874) and Edgeworth (1881) are considered to be the precursors of the theory, as we know it today, many other authors are recognized to have given their contribution to its theoretical development. Thomas Malthus, David Ricardo and John Stuart Mill can be regarded as early expositors of general equilibrium theory. Stanley Jevons and Carl Menger also contributed to the development of important neoclassical elements present in the general equilibrium theory.

Modern theorists of general equilibrium did not emerge until the 1930's. The main issues examined related to the existence, uniqueness and stability of equilibrium, and comparative statics. The classic works by Debreu (1959) and Arrow and Hahn (1971) formalized the main results of the field and established general equilibrium as a

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recognized field in economics. [For an historical introduction to the development of general equilibrium analysis, see Arrow and Hahn (1971); for recent developments, see Eatwell *et al*. (1989).]

The general equilibrium approach treats the economy as a system of many interrelated markets in which the equilibrium of all variables must be determined simultaneously. Any perturbation of the economic environment can be evaluated by recomputing the new set of endogenous variables in the economy. This methodological feature of general equilibrium analysis attracted many researchers to develop its applied dimension. The desire to convert general equilibrium theory into a practical tool for the evaluation of economic policy motivated the construction of algorithms for computing solutions to numerically specified general equilibrium models. Scarf (1967, 1973) conceived the first description of a successful attempt to provide this link between theory and operational models. Johansen (1960) is also regarded as a benchmark in the literature of computable general equilibrium (CGE) modeling. His model for Norway is considered to be the first CGE model developed based on the premises of general equilibrium theory (Dixon and Parmenter, 1994).

In the last twenty years, stimulated by the work of Johansen and Scarf, a large number of computable general equilibrium models has been applied to a great variety of economic questions in different geographical areas [reviews are found in Dervis *et al*. (1982), Shoven and Whalley (1984), De Melo (1988)]. The broad spectrum of applications and theoretical issues envisaged by researchers in the area contributed to the substantial differences encountered in the CGE models around the world.

In this paper, attention is directed to Walrasian-type models built for sub-national territories. It precludes the analysis of Marshalian-type general equilibrium models (e.g. Israilevich *et al*., 1997; Haddad *et al*., 1998) and models whose regional setting

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considers national economies as regions in a multicountry framework.[3] Although such models provide interesting insights for issues related to interregional CGE modeling, which is the ultimate focus here, they are not considered.

In the next section, a stylized interregional general equilibrium model of a private ownership economy is formally introduced. The purpose is to show the essential structure of an interregional bottom-up CGE model, from a theoretical perspective. Following that, some issues in regional and multiregional economic modeling are analyzed, with emphasis on those related to CGE modeling; comparisons of regional CGE models are established based on published studies of operational models. Final remarks follow.

2. A Stylized Theoretical Interregional General Equilibrium Model

The purpose of this section is to show the essential structure of an interregional bottom-up CGE model, from a purely theoretical perspective. The starting point is the characterization of a private ownership economy. Results from general equilibrium theory are drawn from the literature (Mas-Colell *et al*., 1995; Varian, 1992; Eatwell *et al*., 1989); proofs are found elsewhere (Mas-Colell *et al*., 1995; Arrow and Hahn, 1971). The assumptions for the economy follow:

Regions

A.1. There are R regions, r = 1, ..., R, which exhaust the space of the economy. Economic interactions take place inside and outside the region (intraregional and interregional trade).

Commodities

[3] The Chicago Regional Econometric Input-Output Model (CREIM) incorporates the idea of the Marshallian equilibrium adjustment process (quantity adjustment process) to overcome the

A.2. There are L commodities, $l = 1, ..., L$, provided by R different sources. A list of quantities of all commodities are given by a vector in IR^{LR}.

Consumers

A.3. There are I consumers, $i = 1, ..., I$, spatially distributed in the R regions. In each region *r*, the population is given by $I^{(r)}$, so that $0 < I^{(r)} < I$ and $\sum_{r=1}^{R} I^{(r)} = I$.

A.4. Each consumer *i* is characterized by a convex consumption set $X^i \subset IR^{LR}$.

A.5. Consumers preferences are assumed to be rational (complete and transitive), continuous, convex, and locally nonsatiated.

Firms

A.6. There are J firms, $j = 1, ..., J$, spatially distributed in the R regions. In each region *r*, the number of firms is given by $J^{(r)}$, so that $0 \leq J^{(r)} \leq J$ and $\sum_{r=1}^{R} J^{(r)} = J$.

A.7. Each firm *j* is characterized by a production set $Y^j \subset IR^{LR}$. We impose a further restriction in Y^j, that the firms produce only regional commodities related to their specific location. Thus, if *j* is located in region *r*, *j*'s production of commodity *ls*, $s \neq r$, is zero. Production vectors available for each firm *j* in region *r* are denoted by $y^j = \left(0,...0, y_{1r}, \ldots, y_{Lr}, 0, \ldots, 0\right) \in IR^{LR}$.

A.8. Y^j is a closed, strictly convex set containing 0. Moreover, Y^j is bounded above.

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unavailability of regional prices of goods and services. As an input-output econometric model, a time series of regional prices would be necessary to estimate price-related parameters.

Endowments

A.9. Consumer i has an initial endowment vector of commodities $\omega^i \in X^i \subset IR^{LR}$ and a claim to a share $\theta^{ij} \in [0,1]$ of the profits of firm j, where $\sum_i \theta^{ij} = 1$ for every j.

A.1 defines the regional setting of the model. A.2 suggests that the source of each commodity matters, and spatial heterogeneity is taken into account in the model. A.3-A.5 describes the consumers' characteristics: A.3 distributes the population across the regions so that in each region there is at least one consumer; A.4 and A.5 are technical assumptions. A.6-A.8 refer to the firms: A.6 is connected to the regional productive structure; A.7 says that the source of production is directly connected to the location of the firm where the commodity is produced, while A.8, again, is a technical assumption. Finally, A.9 outlines the initial distribution of wealth among consumers.

Definition 1. Given a private ownership economy specified by A1-A.9, an allocation (x*, y*) and a price vector $p = \left(p_{11}, \ldots, p_{L1}, \ldots, p_{1R}, \ldots, p_{LR}\right)$ constitute a Walrasian (or competitive) equilibrium if:

(i) For every j, y^{*j} maximizes profits in Y^j; that is,

$$p \cdot y^j \leq p \cdot y^{*j} \quad \text{for all } y^j \in Y^j$$

(ii) For every i, x^{*i} is a preference-maximizing choice in the budget set

$$\left\{ x^i \in X^i : p \cdot x^i \leq p \cdot \omega^i + \sum_j \theta^{ij} p \cdot y^{*j} \right\}$$

(iii) For every r, $\sum_{i=1}^{I^{(r)}} x^{*i} + \sum_{i=I^{(r)}+1}^{I} x^{*i} = \sum_{i=1}^{I} \omega_r^i + \sum_{j=1}^{J^{(r)}} y^{*j}$

Definition 1 is precisely what Walrasian general equilibrium models are about, the determination of equilibrium quantities and prices in a system of perfectly competitive markets and maximizing behavior by the agents. *(i)* defines the producer's supply of each regional commodity based on profit-maximizing behavior; *(ii)* states that each consumer's demand arises from utility maximization subject to budget constraint; *(iii)* is a market clearing equation, that equates aggregate demand for each regional commodity to its aggregate supply (including initial endowments of each commodity). The existence of a Walrasian equilibrium in our economy is assured by the set of assumptions above. We need an additional claim to pursue the main properties of a spatial general equilibrium model.

Claim. Given a private ownership economy specified by A1-A9. Let b_r be the trade balance of region *r*. Walrasian equilibrium implies that

(i) For every *r*, $b_r = \sum_{l=1}^{L} p_{lr} y^*_{lr} - \sum_{l=1}^{L}\sum_{s=1}^{R} p_{ls} x^*_{lsr}$

(ii) $\sum_{r=1}^{R} b_r = 0$

This claim is easily proved by contradiction. For sake of exposition, it is assumed from now on that consumers living in the same region are equal, and that the population in each region is known. In addition, the economic structure of each region is also known and firms within a region adopt the same technology. By using these assumptions, a representative agent approach can be used, implying a dramatic reduction in the size of the model. The number of equations and variables in the model are reduced proportionally from the order of (*I*+*J*) to 2*R*. Rewriting *(i)-(iii)* in *definition 1* in functional form, and redefining the trade balance in each region for general flows, we have:

$$Y_{lr} = \sum_{j=1}^{J^{(r)}} y^j_{lr} = \varphi\left(p^{(r)}\right), \quad l = 1,\dots,L \quad r = 1,\dots,R \qquad (1)$$

where Y_{lr} is the output of commodity *l* supplied by producers in region *r*, and $p^{(r)}$ is the price vector referring to the *L* commodities produced in region *r*.

$$X_{lrs} = \sum_{i=1}^{I^{(s)}} x_{lrs}^{i} = \gamma\left(p, \omega^{(s)}, \theta^{(sr)}\right), \quad l = 1,\ldots,L \quad r,s = 1,\ldots,R \tag{2}$$

where X_{lrs} is the demand by consumers in region *s* for commodity *l* produced in region *r*, *p* is the price vector which includes all *LR* commodities, and $\omega^{(s)}$ and $\theta^{(sr)}$ reflect the aggregated wealth of consumers in region *s*. In this case, $\omega^{(s)}$ is the vector of initial endowments of consumers in region *s*, and $\theta^{(sr)}$ is the claim to a share of profits of firms in each region, *r*, from consumers in region *s*.

$$Y_{ls} = \sum_{r=1}^{R} X_{lsr} \quad l = 1,\ldots,L \quad s = 1,\ldots,R \tag{3}$$

$$b_r = \sum_{l=1}^{L} p_{lr} y_{lr} - \sum_{l=1}^{L}\sum_{s=1}^{R} p_{ls} x_{lsr}, \quad r = 1,\ldots,R \tag{4}$$

Together with equations (1)-(4), the introduction of equation (5), determining the interregional aggregate price level – fixing arbitrarily the sum of prices to unity – is sufficient for finding a solution for the model.

$$\sum_{l=1}^{L}\sum_{s=1}^{R} p_{ls} = 1 \tag{5}$$

The interregional model consists of $LR^2 + 2LR + R + \left(R^2 + R\right)$ variables and $LR^2 + 2LR + R + (1)$ equations. The closure of the model requires $\left(R^2 + R - 1\right)$ variables to be determined exogenously. One suggestion is to set the $\theta^{(sr)}$s exogenously together with all but one of either the $\omega^{(s)}$s or the b_rs. Once the closure is determined, the equilibrium solution to the model is achieved when a vector of prices is found that clears the markets for all regional commodities [see also Naqvi and Peter, 1996].

The simple stylized model depicted above is rooted in established microeconomic concepts. Optimizing behavior of consumers and producers is explicitly specified, as well as the institutional environment (competitive markets). Thus, demand and supply functions are derived consistently with prevalent consumer and production theories.

Interesting insights for regional analysis can be gathered from the properties of this stylized model. First, regional interactions are captured through interregional trade. Interregional linkages have an important role in interregional CGE models, as it will become clearer as some modeling aspects are analyzed below. Second, the behavior of agents is specified in all regions, which characterizes the bottom-up approach in regional modeling. Outcomes for the economy as a whole are summations from their regional counterparts. Third, one can describe, *ex ante*, the regional economic structure of the economy, based – in the case of the stylized model – on the assumptions of the model. This is a somehow neglected issue in most of the CGE applications, but it is an important component for the understanding of such complex models.

More sophisticated theoretical general equilibrium systems are described in the literature. Incorporation of different features, such as factor markets, are very usual, but it would not add much to the discussion above, given the scope of our exposition. Open economy models with taxes and tariffs are presented in Shoven and Whalley (1992). Harris Jr. (1988) describes a dynamic spatial economic system without recontracting, that includes governments as separate decision-making units, allows for foreign trade, and allows the possibility of externalities and monopolistic power. A wide range of possible extensions is one of the major attractiveness of general equilibrium models. The examples cited above only give a light taste of it. Many issues might be addressed through the general equilibrium framework, and many researchers in both theoretical and applied analysis have been developing this feature. In the next section, some issues related to applied models focusing on regional economies are addressed.

3. Regional and Interregional Computable General Equilibrium Modeling

Regional economic models reveal systematic and quantitative representations of spatial economic systems. Different modeling approaches have been developed for understanding regional economies and interactions among them. Traditional methodological approaches include economic base methods, input-output analysis, gravity-type models, shift-share analysis, econometric models and programming models (Nijkamp *et al*., 1986). A large literature on the development of such models is available [e.g. Anselin and Madden (1990), Harrigan and McGregor (1988a), Hewings and Jensen (1986), Nijkamp *et al*. (1986), Bolton (1985)]. More recently, a new approach of regional modeling has been gaining the attention of regional scientists, and efforts have been being increasingly concentrated in order to develop its vast possibilities of addressing regional economic issues. Contrasts between traditional fixprice methods, such as input-output, and flexprice methods (e.g. CGE) appear in that relative prices play a central role in the latter as a means of allocating resources [see Batten and Westin (1988), and West (1995) for a comparison of fixprice and flexprice models]. CGE modeling constitutes nowadays the main research frontier in regional modeling[4]. The main aspects related to its recent developments are discussed below.

3.1. Regional Setting and Data Constraints

Many of the issues related to regional CGE modeling, as will be seen, are general issues of the broader field of regional modeling. In general, the construction of an

[4] Partridge e Rickman (1998) survey of the literature related to regional CGE modeling.

operational CGE model follows two basic steps: a) the specification of the model; and b) the calibration of the model, using input-output data and elasticities estimates. More general features of the model should be tackled at first. The choice of the regional setting is of major interest since it implies data availability and relevance of the policy simulations. On the one hand, data availability not only restricts enormously the regional aggregation of the model, but it also contributes to the proliferation of studies for a few regions for which consistent data are available. In the first case, researchers are constrained to define their object of study. Regions are almost always defined based on statistical divisions (Haddad, 1978, Adams and Dixon, 1995), which in most cases do not accompany the dynamism of changes in space. More comprehensive (Markusen, 1987) or economic-oriented (Boudeville, 1961) definitions of regions remain to be implemented, and, in the rare cases in which they have been, the method follows an *ad hoc* (dis)aggregation of statistical divisions data.

In the case of the examined regions, more in academic research and less in government studies, there seems to be an inclination among researchers to minimize their efforts in data collection by selecting the regional setting putting a heavy weight on data availability. Selection always falls on those regions for which government agencies have consistently estimated regional databases. In regional CGE modeling, this procedure can be justified on the grounds of the novelty of the field (data are used just to illustrate the new ideas). Harris Jr. (1988) suggests that for such models to be useful to policy makers, data effort is necessary. The point here is that those regions for which information exists have benefited from academic studies in a cumulative way.

Finally, the choice of a region embeds the policy simulations to be carried out. It is important to define the regional setting in accordance with the economic issues to be addressed. Model results should also encompass consistent estimates for the main variables of the region under consideration. Not only spatial limits should be carefully defined, but also the number of regions in the model and their interactions. Single-region and multiregional CGE models provide different perspectives of policy simulations. Single-region models, in most cases, adapt the structure of existing national models; feedback effects from the region are not considered. The regional economy is modeled in the same way as small open economies in the international trade literature: trade has an important role and the economy is assumed to be a price-taker. Examples of single-region CGE models are: Despotakis and Fisher (1988), Harrigan *et al*. (1992), Dixon *et al*. (1993), Koh *et al*. (1993). The alternatives to single-region models are multiregional models. They allow for interregional imbalances to be captured and are preferred to single-region models in the sense that regional interactions can be introduced. The discussion that follows focuses mainly on such models.

3.2. Bottom-Up and Top-Down Approaches

Closely related to the policy implementations and results is the specification of linkages between the national and regional economy. Two basic approaches are prevalent – top-down and bottom-up – and the choice between them usually reflect a trade-off between theoretical sophistication and data requirements (Liew, 1984b).

The top-down approach consists of the disaggregation of national results to regional levels, on an *ad hoc* basis. The disaggregation can proceed in different steps (e.g. country-state → state-county), enhancing a very fine level of regional divisions.[5] The desired adding-up property in a multi-step procedure is that, at each stage, the disaggregated projections have to be consistent with results at the immediately higher level (Adams and Dixon, 1995). The starting point of top-down models is economy-wide projections. The mapping to regional dimensions occurs without feedback from the regions. In this sense, effects of policies originating in the regions are precluded. In accordance with the lack of theoretical refinement in terms of modeling of behavior of regional agents, most top-downs CGE models are not as data demanding as bottom-up models.

Examples of CGE models that rely on a top-down approach in their analysis of regional questions include ORANI [Dixon *et al*. (1982)], and Horridge *et al*. (1995) and MONASH-RES (Parmenter and Welsh, 2000). In ORANI, an adaptation of the method proposed by Leontief *et al*. (1965) for regional disaggregation of national input-output outcomes is used. The method is very economical in its data demand, in the sense that the necessity of interregional trade flows is avoided. It consists of three stages: a) in the first stage, the ORANI model is run to obtain projections for different national aggregates; b) then, constant-regional-share assumptions are used to allocate economy-wide outputs of national goods to the regions; c) in the third stage, the condition that regional outputs of local goods equal regional demands is imposed. Thus, regional outcomes capture differences in the economic structures of the regions and the local multiplier effects. Consistency with the economy-wide ORANI results can be checked: by reaggregating the regional results, initial economy-wide results are reproduced. MONASH-RES combines a top-down regional equation system (similar to the method used in ORANI) with the MONASH dynamic model of Australia (Dixon *et al.*, 2000) to produce regional forecasts or policy analysis.

In the bottom-up approach, agents' behavior is modeled at the regional level. A fully interdependent system is specified in which national-regional feedback may occur in both directions. In this way, analysis of policies originating at the regional level is facilitated. The adding-up property is fully recognized, since national results are obtained from the aggregation of regional results. In order to make such highly sophisticated theoretical models operational, data requirements are very demanding. To start with, an interregional input-output data base is required, with full specification of interregional flows. Data also include interregional trade elasticities

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[5] Adams and Dixon (1995) report regionally disaggregated projections for 56 statistical divisions in Australia derived from national forecasts of the MONASH model.

and other regional variables, for which econometric estimates are rarely available in the literature.

Alternatives to the theoretical appealing bottom-up and the data-saving top-down CGE models are available. In Higgs *et al*. (1988), a partially regionalized CGE model is used to drive a top-down regional equation system. Using the fact that in most national CGE models agents are defined at a sectorally disaggregated level, the authors propose a further sectoral disaggregation in which regional sectors are explicitly specified. Although this procedure ameliorates the model's ability to handle some regional shocks, analysis of region-wide shocks still requires the more demanding bottom-up approach.

A different hybrid approach is proposed by Liew (1995). In this model, national-regional interactions are restricted to strategic interactions over money creation between the central and regional governments. The CGE core of the model remains purely top-down in essence. Interactions that drive one of the components of final demand are deliberately taken as generating important feedback from the regions.

Comparisons of operational models using the different approaches show that the construction of bottom-up models does not always justify the extra effort involved. Liew (1984b) compares regional results of a change in tariffs from the ORANI model (top-down) with regional results from a model constructed adopting the bottom-up approach, an extension of ORANI involving, essentially, the application of the same approach to regional agents. He finds that the introduction of interstate commodity flows, under very restrictive assumptions (constant technology and sales patterns across states, uniformity of price and expenditure elasticities for each commodity across states) does not contribute significant insights beyond those drawn from the top-down procedure. However, this conclusion is not valid when the interest is on individual regional-industry results, which seems to be one of the most desirable results in interregional multisectoral models. Moreover, when less restrictive assumptions about interregional feedback are used (McGregor *et al*., 1996), some exogeneity assumptions may induce considerable bias in the measurement of regional variables.[6]

Defining an hypothetical input-output data base, Parmenter *et al*. (1985) use three skeletal models for performance comparison of three methods for regionalizing CGE models: top-down, bottom-up and hybrid. The hypothetical data base minimizes data differences, in the sense that the same economy-wide picture is depicted in the three models. This comparison allows only for national policies, given the restrictive features of the top-down and hybrid approaches. Although other dimensions of regional economies are not taken into account (for instance, regional commodity distinctions are minimal), results exhibit some illuminating differences.

3.3. Operational Models

Albeit the very heavy data requirement for bottom-up CGE models, they do not seem to have been neglected in favor of data-saving top-down model for the purpose of regional impact analysis. Regional CGEs based on the former approach have been developed in different contexts. Examples of operational interregional bottom-up CGE models are: Liew (1982, 1984a, 1984b), Ko (1985), Ko and Hewings (1986), Harrigan and McGregor (1988b), Morgan *et al*. (1989), Jones and Whalley (1988, 1989), Kraybill *et al*. (1992), Gazel (1994), McGregor *et al*. (1996), Naqvi and Peter (1996), Watanuki (1996), Madden and Pant (1998), Hirte (1998), Miyagi *et al.*, (1998) and Haddad (1999).

Two different models for the U.S. are reported in Morgan *et al*. (1989) and Kraybill *et al*. (1992). The latter analyzes regional and sectoral impacts of macroeconomic imbalances, focusing on the economy of Virginia. Seemingly aspatial national

[6] McGregor *et al*. (1996) compare a single-region version of a CGE model for Scotland with an interregional extension of it, in which the behavior of agents in the Rest of UK is explicitly modeled. In

policies – changes in the Federal government deficit, and in the international trade balance – are showed to be an important source of shifts in the geographic distribution of output and income. In a six region general equilibrium model for the U.S., Morgan *et al*. (1989) assess the potential long-run effects of tax policies on regional production patterns.

Jones and Whalley (1988, 1989) developed an interregional CGE model for the Canadian economy. The model is used for comparative statics, dealing with the evaluation of regional impacts of government policies. Applications of different variants of the model are reported in the literature and refer primarily to tax policies. Whalley and Trela (1986) exhaustively applied the model to a variety of policies elements within Confederation with regional impacts.

An interregional multicountry model was developed by Gazel (1994) on the premises of the skeletal version of a single-country CGE model developed at the U.S. International Trade Commission. The author expanded that model incorporating two different regional dimensions to it: firstly, the model was divided into three trading blocks (U.S., Canada and Rest of the World); secondly, the American economy was regionalized, being specified four regions.[7] The model was designed specifically for the analysis of the effects of the Free Trade Agreement (FTA) between U.S. and Canada. The impacts of the elimination of all tariff barriers between U.S. and Canada were measured and showed that Canada gains more than the U.S. in relative terms as the result of the FTA. However, gains are regionally concentrated and they are not proportional to regional income. These results provide a taste of interregional CGE models, showing their capability of capturing region-specific impacts in an integrated framework.

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this case, exogeneity of regional prices and quantities, in the former model, for the Rest of UK is considered.

[7] In an intermediary step, the American economy was divided into two regions.

AMOS (Harrigan *et al*., 1992) is a regional CGE model for the Scottish economy; its interregional version, AMOS-RUK, developed by McGregor *et al*. (1996), consists of two complete models of regions, each of which is very similar to AMOS. MONASH-MRF (Naqvi and Peter, 1996) is an interregional multisectoral model of the Australian economy. The model is fully documented: reports on the theoretical structure (Peter *et al*., 1996b), the implementation (Naqvi and Peter, 1995), the construction of the data base (Peter *et al*., 1996a), and application of the model (Peter, 1996) are available. FEDERAL (Madden and Pant, 1998) is also an interregional multisectoral model of the Australian economy, and contains a very detailed modeling of the finances of two tiers of government, with a range of explicitly modeled regional (state) and federal government taxes affecting the purchase price of commodities, and of regional incomes.

Hirte (1998) calculates welfare effects of regional income taxes by means of an interregional CGE model of the Germany economy. The model is an eleven-region model with two production sectors and two primary factors. Miyagi, Honbu, and Inoue (1998) make use of a nine-region interregional CGE model of the Japanese economy to explore issues related to the integration of spatial and economic concepts of transport in an equilibrium framework.

Examples of interregional CGE models for developing economies are presented in Ko (1985), Ko and Hewings (1986), Watanuki (1996), Harrigan and McGregor (1988b, 1989), Haddad (1999), Casimiro Filho *et al.* (2000). Ko (1985) and Ko and Hewings (1986) expanded the national model for Korea developed by Adelman and Robinson (1978) adopting a five-region bottom-up approach. The model is based on region-specific equations, comprising of five highly interdependent CGE models. Watanuki (1996) presents a model for Indonesia, in which the Indonesian economy is divided into two regions: Java (central and developed region), and the Outer Islands (peripheral and underdeveloped region). The stylized model for Malaysia described in Harrigan and McGregor (1988b, 1989) provides a very rich contribution in terms of modeling issues to be addressed in interregional CGEs. Haddad's model for Brazil simulates different strategies of economic development through the evaluation of the impacts of macroeconomic, structural and sectoral policies on the patterns of regional inequality and structural changes in the country. [8] Finally, Casimiro Filho *et al.* (2000) present a prototype interregional CGE model of the Brazilian economy, adopting a five-region bottom-up approach.

3.4. Interregional Linkages

Interregional linkages play an important role in the functioning of interregional CGE models. These linkages are driven by trade relations (commodity flows) and factor mobility (capital and labor migration). In the first case, interregional trade flows should be incorporated in the model. Interregional input-output data bases are required to calibrate the model, and interregional trade elasticities play an important role. In the second case, labor mobility has received more attention from modelers.

In the CGE context, interregional feedback, when explicitly modeled, has proven to provide more refined results. The scale of feedback effects is also relevant. In the interregional CGE model for UK (McGregor *et al*., 1996), preclusion of feedback effects from the Rest of UK to Scotland in the model, albeit its modest scale, generates considerable long-run bias in the measurement of employment effects. In a CGE experiment for Indonesia (Watanuki, 1996), in which interregional trade and factor mobility are incorporated, it is shown that new investments in a less developed, dependent region (Outer Islands) benefit, through feedback effects, relatively more the more developed, more dynamic region (Java). Similar results were found using an interregional input-output model (Hulu and Hewings, 1993); however, when disaggregated results are considered, the CGE model provides more insights on the regional economies.

[8] The B-MARIA model has been applied to study short-run regional effects of new investments and technological upgrade in the Brazilian automobile industry (Haddad and Hewings, 1999) and issues related to trade liberalization and geographical shifts (Haddad and Azzoni, 2001).

The degree of interregional interaction of all markets includes different dimensions, as indicated above. One possible dimension of "openness" of regional economies is encompassed in the elasticities of substitution between similar commodities produced in different regions. A common assumption widely used in interregional CGE models, the Armington assumption, considers similar commodities produced in different regions as close substitutes, but unique goods (Armington, 1969). It allows for the incorporation of estimates of elasticities of substitution between domestically produced products and similar imported products, and between regionally produced products and similar products from other regions, suggesting nested multiple stage demand functions. Spencer (1988) points out that this assumption is extraordinarily convenient for [interregional] CGE work, since it admits the presence of cross-hauling in a standard neoclassical model and reduces concern about small changes having big effects on the pattern of trade and production (ruling out specialization in consumption). However, econometric estimates for such elasticities for interregional substitution are extremely rare, and modelers have often to extrapolate from estimates for their equivalent estimates for substitution between domestic and foreign commodities.

Factor mobility also plays an important role. Factors might be allowed to move intersectorally, interregionally, and internationally. Models vary in the treatment given to mobility of capital and labor. Capital is commonly assumed immobile in short-run simulations. In the long-run, capital movements are conventionally stimulated by rates-of-return differentials across sectors and regions, and productivity differentials. The basic stimulator of labor migration present in CGE models is regional wage differentials.

Differences in the treatment of labor mobility have been shown to have major impacts in model results (Harrigan and McGregor, 1988b). Simulations using AMOS-RUK (McGregor *et al*., 1996) confirmed, at the interregional level, the results achieved through experiments with AMOS (Harrigan *et al*., 1992) showing that specific treatment of labor markets heavily affects the properties of the system as a whole. Three aspects of regional labor markets were individually considered. First, the determination of wages was addressed through a variety of perspectives, including labor market closures with both aggregate and disaggregate regional labor markets, with different theoretical orientation (e.g. neoclassical, Keynesian). Second, net migration was assumed to respond to any induced changes in wages and unemployment in the regions. Finally, labor demand was consistently derived from firms' optimizing behavior. Empirical simulations in Morgan *et al*. (1989) include the extreme case of no labor mobility as well as the intermediate cases, through the imposition of different elasticity values of interregional migration response to real wage gap. Values used for interregional migration elasticity were set at 100 (perfect mobility), 0.1 (partial mobility), and 0 (immobility). Labor mobility was found to be an important determinant of regional growth, because less capital is attracted if the labor force cannot expand.

Some unconventional modeling attempts to include other variables affecting migration decision include Ko (1985), Ko and Hewings (1986), Jones and Whalley (1988, 1989), and Gazel (1994). In Ko (1985) and Ko and Hewings (1986), supply of labor is assumed to depend not only on the wage differentials across sectors and regions but also on adjusted differences in expected wages over some horizon plan, incorporating the Harris-Todaro hypothesis. In Jones and Whalley (1988, 1989), labor is assumed to be partially mobile across regions. This assumption is incorporated into the model through an ingenious mechanism. They assume that individuals in each region differ only by their intensity of locational preference, and then specify the utility function for any agent in any region as the maximum of two separate subutility functions. These functions represent the utility from consuming the same bundle of goods inside and outside the region, and, thus, it is possible to base an individual's choice of migrating on a trade-off between differences in income across regions and locational preference. Partial mobility of labor is justified against polar cases based on the latter's inability to capture appropriate welfare effects of policies pursued under Confederation. Individuals would either have no direct association with specific regions – in the case of perfect mobility of labor –, or not respond to policies on fiscally induced migration – in the case of interregional labor immobility. In Gazel (1994), labor mobility was given special attention. In a variant of the basic model – in which labor is immobile – labor was allowed to move following the utility-equalization-across-space hypothesis of open city models in urban economics. Labor supply in each region responds to wage and price differentials up to the point when utility is the same in all regions.

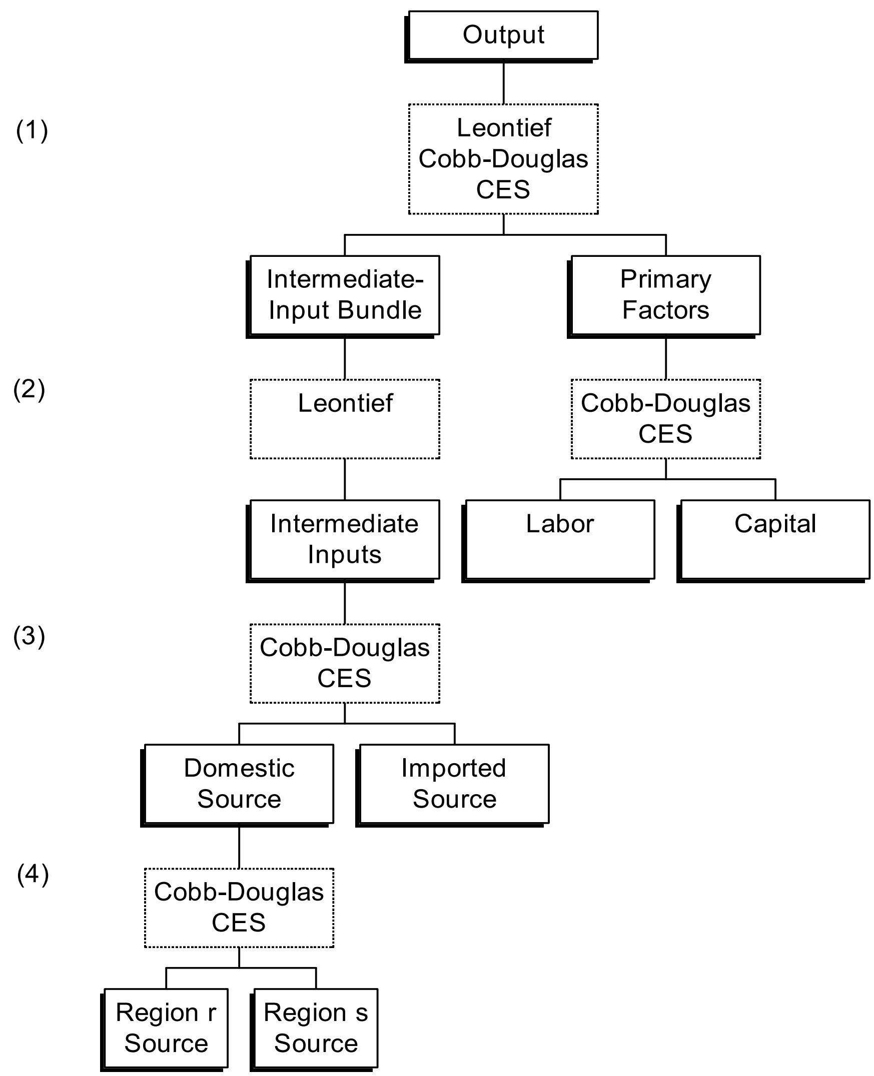
3.5. Theoretical Specification

In the elaboration of a CGE model, different blocks of equations have to be specified. The basic structure comprises three blocks of equations determining demand and supply relations, and market clear conditions. In the stylized model depicted in the last section, it implies the algebraic specification of the demand functions, φ, and the supply functions, γ. Production technology and structure of household demand determine these functional forms, and, in interregional models, they are commonly based on multilevel structures, which enable a great number of substitution possibilities. Models that have been produced so far share common features in such nesting structures.

Figure 1 illustrates the basic variations of production technology encountered in most models. Dotted-lined boxes represent standard functional forms used at each stage. Two broad categories of inputs are recognized: intermediate inputs and primary factors. Producers in each regional industry choose inputs requirements per unit of output through optimizing behavior (e.g. cost minimization). Constraints are given by the nested production technology. In the first level, primary factors and an intermediate-input bundle are combined, either assuming fixed proportions (Leontief) or some degree of substitution between them (Cobb-Douglas or CES). The use of

CES production functions at the top level of the production structure dominates modeling procedures. Fixed proportion combinations of intermediate inputs are assumed in the second level, on one side, and substitution between capital and labor, on the other side. The third level involves substitution between domestically produced and imported intermediate inputs. At the fourth level, bundles of domestically produced inputs are formed as combinations of inputs from different regional sources.

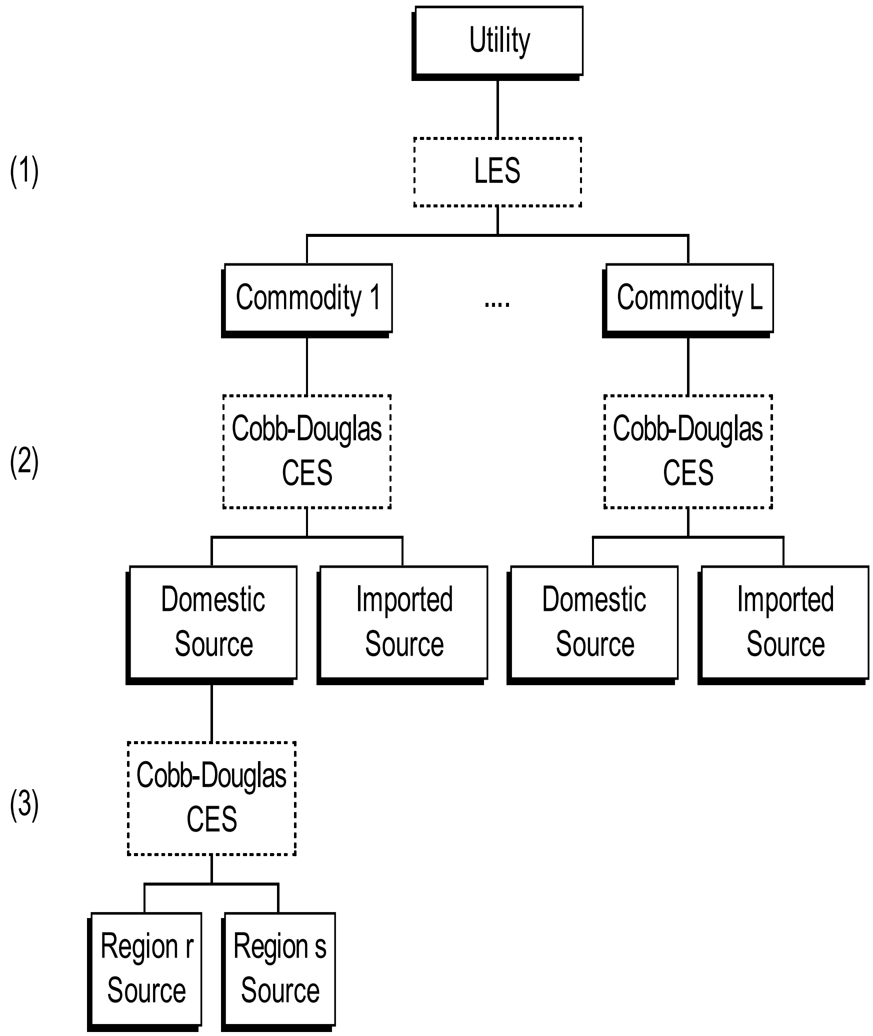
Figure 1. Standard Nesting Structures of Regional Production Technology in Interregional CGE Models



Standard modeling procedures use either Cobb-Douglas or constant elasticity of substitution (CES) functions in the lower levels to combine goods from different sources. More flexible functional forms have been rarely attempted in regional models, due to data availability. One exception in regional CGE modeling is the model developed by Despotakis and Fisher (1988) for California. In that model, a generalized Leontief specification is adopted. Dixon *et al*. (1982) propose the use of constant ratios of elasticities of substitution, homothetic (CRESH) functions, a generalization of CES which allows for elasticities of substitution between different pairs of inputs to differ. However, the estimation procedure was not satisfactory, leading the authors to adopt CES estimates.

The treatment of household demand structure, depicted in Figure 2, is also standard in most of the interregional CGEs. It is based on nested Cobb-Douglas (or CES)/linear expenditure system (LES) preference functions. Demand equations are derived from an utility maximization problem, whose solution follows hierarchical steps. It resembles the utility tree and multiple-stage budgeting problem analyzed in Deaton and Muellbauer (1980), in which separable preferences enable stepwise choices according to different group levels of commodities. In the interregional context, group dimensions refer to regional sources of commodities. The structure of household demand follows a nesting pattern which enables different elasticities of substitution to be used. At the bottom level, substitution occurs across different regional domestic sources of supply. Utility derived from the consumption of domestic composite goods is maximized. In the subsequent upper level, substitution occurs between domestic composite and imported goods.

Figure 2. Standard Nesting Structure of Regional Household Demand in Interregional CGE models



The generalized use of Leontief, Cobb-Douglas and CES specifications in the production side of regional CGE models, and LES in the household demand side is partly explained by the structural properties of such functions [see Dixon *et al*. (1983) for a detailed theoretical analysis]. These functional forms have been conveniently used in empirical applications. Their low requirements for parameters determination is the main attractiveness for modelers, specially when calibration of large-scale models is to take place (Koh *et al*., 1993).

3.6. Calibration

The calibration of regional CGE models, i.e., the assignment of values to the relevant parameters and coefficients of the model, is a very demanding process. It consists of fitting the model specification to a consistently adjusted basic data set for the economy for a single year. This procedure determines the parameters values of the model for a benchmark equilibrium. [Shoven and Whalley (1992), Koh *et al*. (1993) and (Partridge e Rickman, 1998)) discuss the calibration procedure of CGE models.] Interregional input-output tables provide the various production and consumption estimates. Specification of exogenous elasticities values is also needed.

Interregional commodity flows data are seldom available. It has been common practice in regional CGE modeling to use nonsurvey techniques to estimate them, which might incorporate bias in the model estimates. Gravity type models (Leontief and Strout, 1963), contingency table method (Batten, 1982), and a combination of Round's method (Round, 1978, 1983) and *ad hoc* splits of rows and columns of national tables based on extraneous regional shares (Hulu and Hewings, 1993) are examples of techniques utilized. In Gazel (1994), great attention was given to the estimation of the interregional trade matrix. The method developed by Hulu and Hewings (1993) was adopted, and sensitivity analysis for the interregional trade flows data was carried out in which a 10% increase in imports was assumed. Remarkable differences were noted for labor and capital incomes, but not for the aggregated income.[9]

Even though consistent non-survey techniques for the estimation of interregional trade flows are available, the quality of regional data has always been a problem. A validation test was carried out in Ko (1985), showing that results for the national

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[9] The choice of input-output data for regional models is an important issue in regional modeling. A recent paper by Israilevich *et al*. (1996) reveals that differently constructed input-output tables would have a significant effect on the results of a regional econometric model, both in forecast and impact analyses.

aggregates are far better than those for regional variables. The improvement of the regional results would involve the availability of better data.

Bias in the estimates of the MONASH-MRF model (Naqvi and Peter, 1996) is compromised by the estimation procedure of the interregional input-output. The spatial disaggregation of the national input-output table relied on *ad hoc* column and row splits based on regional shares. The use of other non-survey techniques that carry the theoretical background essential to a more reliable construction of regional input-output tables under limited information, widely available in the literature, should be considered [see Round (1978, 1983), Hulu and Hewings (1993)].

Another data-related problem that modelers frequently face is the lack of trade elasticities at the regional level. The pocket rule is to use international trade elasticities as benchmarks for “best guess” procedures. Other elasticities are commonly borrowed from econometric studies; in this case, more reliable estimates are available. Sensitivity analysis for key parameters are sometimes performed, providing a more reliable range of model results.

3.7. Closure

The selection of the set of exogenous variables determines many features of the use of the model. Closure reflects the theoretical orientation and the type of simulation of the experiment being undertaken. In regional models, specifically, they define the settings that will determine the interactions among regional markets. McGregor *et al*. (1996) consider a range of alternatives on wage determination by using different labor market closures. In the neoclassical closure, regional wage adjusts so as to continuously clear the region’s labor market, while in the Keynesian closure, nominal wages are fixed. It is shown that, by alternating closures representing contrasting macroeconimc visions of a regional economic system, the direction and scale of the interregional transmission of disturbances are affected.

The determination of regional investment in Peter *et al*. (1996b) is specified by different closures, implying distinct experiments: short-run and long-run comparative statics, and forecasting. In short-run experiments, capital stocks in regional industries and national aggregate investment are exogenously determined; aggregate investment is distributed among the regional industries on the basis of relative rates of return. In long-run comparative statics experiments, it is assumed that the aggregate capital stock adjusts to preserve an exogenously determined economy-wide rate of return. Further, it is assumed that the allocation of capital across regional industries adjusts to satisfy exogenously specified relationships between relative rates of return and relative capital growth; industries' demands for investment goods are determined by exogenously specified investment/capital ratios. Finally, in forecasting experiments, regional industry demand for investment is determined by an assumption on the rate of growth of industry capital stock and an accumulation relation linking capital stock and investment between the forecast year and the year immediately following the forecast year. Forecasting closure demands that changes in all exogenous variables over the simulation period be taken into account. In general, this information has to be taken from extraneous sources. Time is also taken into consideration in historical closures, which might be utilized to update the input-output data base. A policy or deviation closure has been applied by Adams *et al.* (2000) in an interregional CGE model for Australia to analyze environmental issues, MMRF-Green. Policy analysis involves the comparison of two alternative sequences of solutions, one generated without the policy change, the other with the policy change in place. The first sequence is called basecase projection and is used as a control path from which deviations are measured in assessing the effects of the policy shock. The policy simulation generates deviations from the corresponding forecast simulation in response to the exogenously imposed shocks.

One important issue raised when one moves to the interregional context refers to the macroeconomic closure of such systems. It becomes more complicated when compared to single-region models, in which the small-economy assumption holds, implying the exogeneity of prices and demands from the rest of the economy, as well as interest and exchange rates. Regional prices and quantities are taken care of in the bottom-up approach, but a more precise specification of interest rate and exchange rates still remains to de defined. In AMOS-RUK (McGregor *et al*., 1996), this issue is extensively discussed, but a solution for the treatment of nationwide prices seems to await further work.

3.8. Solution Method

A final remark on model specification and implementation refers to the solution method. Not so long ago, computational costs were always cited as a huge constraint in CGE modeling. The inclusion of a regional dimension to sectorally disaggregated CGE models increases the size of the system dramatically. Interregional models increase in size with the square of the number of regions. Some sacrifice in terms of sectoral aggregation and/or the range of intersectoral relationships to be included in interregional models was usually advocated and almost always necessary (Parmenter, 1983). Nowadays, computational costs do not play such a crucial role anymore. The recent developments in the computer industry allied to the development of software designed specifically for implementing and solving general and partial equilibrium models (e.g., GEMPACK, GAMS) reduced the limits of model sizes to memory requirements.

Solution methods adopted for regional CGE models fall into the same two broad classes as those for general CGEs: modifications of the Scarf algorithm, and the Johansen procedure for linearized models. One of the first modifications of the Scarf solution for regional models was discussed in Kimbell and Harrison (1984). The Johansen procedure is widely used in the Australian tradition, in the work by Dixon, Liew, Parmenter, and Peter, among others. Harrison *et al*. (1994) describe the implementation of Johansen-type multiregional models via GEMPACK. Special features of the software facilitate the work of model builders, increasing the flexibility of their models. Systematic sensitivity analysis can also be easily implemented in GEMPACK, by means of a Gaussian Quadrature approach (Arndt, 1996; DeVuyst and Preckel, 1997), in order to evaluate model results' sensitivity to parameters and exogenous shocks.

4. Final Remarks

The development of regional and interregional CGE modeling has experienced, in the last ten years, an upsurge in interest. Different models have been built for different regions of the world. Research groups, located especially in Australia and Canada, and individual researchers contributed to these developments through the specification and implementation of a variety of alternative models. However, much effort is still needed in the field. Issues such as the integration of disaggregated regional labor markets, the incorporation of financial markets, and different institutional frameworks including imperfect competition are examples of important theoretical issues to be operationally addressed in future work.

The use of CGE models in the regional context should be appealing for policy makers. Data availability has always been of great concern to regional scientists, and regional econometric models often encounter severe problems in their specification and implementation. First, reliable time-series data for sufficiently long periods are not available at the regional level, and, when available, the data often present inconsistencies which affect econometric estimation procedures. Second, regional structural changes appear to be very dynamic, which call for different structural models, thereby reducing the time span available for hypothesis testing with a selected econometric model (see De Melo, 1988). However, CGE models are not without their limitations – especially their limited ability to handle dynamics. Hence, they should be viewed as complement to existing models rather than as replacement.

Based on our experience with the interregional CGE model for the Brazilian economy (Haddad, 1997; Haddad and Hewings, 1997, 1998abc; Haddad and Hewings, 1999; Haddad and Azzoni, 2001), many of the issues discussed above have been tackled. B-MARIA is the first fully operational interregional CGE model for Brazil, containing three regions and forty sectors, which makes it a relatively detailed interregional CGE model. The model is used to analyze regional imbalances and structural changes in the Brazilian economy emphasizing the role of backwash and spread effects, which are qualitatively described in the regional development literature as the mechanisms driving regional (in)equity (e.g. Myrdal, 1957, Hirschman, 1958). The results are driven by price effects and the operation of internal and external multipliers in the regional economies.

The interregional input-output table used in the calibration of the model is derived from published regional tables, which are integrated in an interregional system consistent with the national tables. The estimation of the interregional trade flows is based on the method proposed by Hulu and Hewings (1993) and benefits from the existence of aggregate regional trade estimates. It is shown that a deep understanding of the relations presented in the benchmark data base facilitates the analysis of the model's results.

In many instances, the way the input-output data are compiled enables theoretical innovations in the specification of the models. The availability of key information for the calibration of specific coefficients motivates experiments with the structure of the model. For instance, the nature of the input-output data base used in the Brazilian model (B-MARIA) enabled the isolation of the consumption of public goods by both the Federal and regional governments, which encouraged the experimental specification of the government demand for public goods.

Another instance in which data availability induced theoretical experimentation in B-MARIA relates to the group of equations defining the government accounts. The existence of a previously developed data base for regional government accounts (Dinsmoor and Haddad, 1996) accommodated a common budget structure which enhanced the disaggregation and specification of the revenue and expenditure components of government accounts. However, in most cases, experiments with different structures of the model did not pay the extra modeling effort. In the Brazilian model, the existence of a group of equations, theoretically specified, that contains accumulation relations to facilitate forecasting with the model, does not produce reliable results. Unavailability of consistent time series at the regional level for Brazil precludes this specification to be operationalized.

A unique feature of B-MARIA is the explicit modeling of the transportation services and the costs of moving products based on origin-destination pairs. The model was calibrated taking into account the specific transportation structure cost of each commodity flow, providing spatial price differentiation, which indirectly addressed the issue related to regional transportation infrastructure efficiency.

One way to overcome the scarcity of estimates of regional trade elasticities (and any other key parameter), suggested here, is to estimate policy results based on different qualitative sets of values for the parameters. Starting with international trade estimates, if available, the calibration should be based on the specific characteristics of each commodity. The characteristics of each sector have to be considered individually and the commodities can, thus, be grouped. Through the judgment of the modeler, a range of alternative combinations reflecting differential technological hypothesis for the regional economies can be used to achieve a range of results for a policy simulation. This method, hereafter called *qualitative or structural sensitivity analysis*[10], provides a "confidence interval" to policy makers, and incorporates an extra component to the model's results which contributes to increased robustness

[10] The term "qualitative sensitivity analysis" is used as opposed to "quantitative sensitivity analysis", which is the common practice adopted by modelers to define confidence intervals for the simulations' results. Usually, the parameters are allowed to deviate over a range centered in the initial assigned values, or to present small increases/decrease in one direction, which does not address the likely cases of structural misspecifications.

through the use of possible structural scenarios. As data deficiency has always been a big concern in regional modeling, one which will not be overcome in the near future, this method tries to adjust the model for possible parameter mispecification. Qualitative, and systematic, sensitivity analysis should be used on a regular basis in regional CGE modeling in order to avoid, paradoxically, speculative conclusions over policy outcomes. If the modeler knows enough about the functioning of the particular national and regional economies, the model achieves a greater degree of accuracy when such procedure is adopted.

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