4 Interregional Computable General Equilibrium Models♣

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4.1 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 contributed to its theoretical development. Thomas Malthus, David Ricardo and John Stuart Mill can be regarded as early expositors of general equilibrium theory while 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 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, and Starr, 2001)

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's (1960) work is also regarded as a benchmark in the literature of computable general equilibrium

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(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-five 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; Isard *et al*., 1998; Partridge and Rickman, 1998; and Haddad, 1999). 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 chapter, 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*., 2002),[1] and models whose regional setting considers national economies as regions in a multicountry framework. 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. Then, a bridge between theory and application is introduced through the discussion of social accounting matrices (SAM) as the basis for CGE modeling. Following that, some issues in regional and multiregional economic modeling are analyzed, with emphasis on those related to interregional CGE modeling; comparisons of regional CGE models are established based on published studies of operational models. Final remarks follow, providing a critical appraisal of the field and some directions for future research.

4.2 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).[2] The assumptions for the economy follow:

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

[2] "The recognition of the spatial element in the formation of a general equilibrium in a complex space-economy already dates back to early work of Lösch, Isard and

4.2.1 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).

4.2.2 Commodities

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

4.2.3 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.

4.2.4 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 $0 \le J^{(r)} \le J$ 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 $y^j = (0,...0, y_{1r},..., y_{Lr}, 0,...,0) \in IR^{LR}$.

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

4.2.5 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-

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Samuelson, but it reached a stage of maturity thanks to the new inroads made by Takayama" (van der Bergh *et al*. (1995), p. *v*)

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 $p=\left(p_{11},...,p_{L1},...,p_{1R},...,p_{LR}\right)$ constitute a Walrasian (or competitive) equilibrium if:

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

$p\cdot y^j \leq p\cdot y*^j$ 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 a 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 this 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 2R. Rewriting (i)-(iii) in

Definition 1 in functional form, and redefining the trade balance in each region for general flows, we have:

$$Y_{lr} = \sum_{j=1}^{J^{(r)}} y_{lr}^{j} = \varphi\left(p^{(r)}\right), \quad l = 1,...,L \quad r = 1,...,R \tag{4.1}$$

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*.

$$X_{lrs} = \sum_{i=1}^{I^{(s)}} x_{lrs}^{i} = \gamma\left(p, \omega^{(s)}, \theta^{(sr)}\right), \quad l = 1,...,L \quad r,s = 1,...,R \tag{4.2}$$

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*.

$$Y_{ls} = \sum_{r=1}^{R} X_{lsr} \quad l = 1,...,L \quad s = 1,...,R \tag{4.3}$$

$$b_r = \sum_{l=1}^{L} p_{lr} y_{lr} - \sum_{l=1}^{L}\sum_{s=1}^{R} p_{ls} x_{lsr}, \quad r = 1,...,R \tag{4.4}$$

Together with equations (4.1)-(4.4), the introduction of equation (4.5), determining the interregional aggregate price level – fixing arbitrarily the sum of prices to unity – is sufficient for finding a solution for the model.

$$\sum_{l=1}^{L}\sum_{s=1}^{R} p_{ls} = 1 \tag{4.5}$$

The interregional model consists of $LR^2 + 2LR + R + \left(R^2 + R\right)$ variables and $LR^2 + 2LR + R + \left(1\right)$ 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_r s. 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.[3] Secondly, 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

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[3] More appropriately, transportation services can be introduced to facilitate trade flows.

regional counterparts. Thirdly, 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. A wide range of possible extensions is one of the major attractiveness of general equilibrium models. 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 this sense, data availability provides a major constraint, and the role played by existing social accounting matrices is crucial. In the next section, the function of the SAM as the preferred database for CGE modeling is highlighted, and the process of scaffolding (Isard *et al*., 1998) discussed.

4.3 Social Accounting Matrices as the Basis for Modeling

The SAM synthesizes and calibrates the input data of CGE-type models, playing an important role in the general mechanics of their functioning (fig. 4.1). In our context, once the data in a particular country for a particular year have been organized in the form of a SAM, they present a static image, which can reveal much about the interregional system's economic structure (see King, 1990). However, in order to analyze how the economy works and to predict the effects of policy interventions, more is needed than just a static image. A model of the economy has to be created. In CGE modeling, the SAM satisfies the initial equilibrium condition required for the operation of the model. Given the initial solution, embedded in this database, counterfactual analysis can be carried out. In essence, what a typical simulation does is to depart from an equilibrium of the circular flow of income of the economy, depicted in the SAM, and reach another equilibrium – an updated version of the original SAM. Results are drawn from the comparison of the two equilibria.

Each cell in a SAM (see fig. 4.2), which is a transaction, can be thought of as the outcome of an underlying optimization problem of the relevant institution(s). We can represent the flow in the cell as:

$$t_{ij} = t(p, q; V, \theta)$$

where p and q are respectively vectors of relative prices (for goods and factors) and quantities. The vector V is a vector of exogenous factors and θ is a vector of parameters defining the relevant functional form. A CGE model is simply a formalization of this general representation of each flow, considering the sectoral and macroeconomic balance constraints defined in the SAM (totals). CGE models differ in the way we define the structure of the t_{ij}'s.[4]

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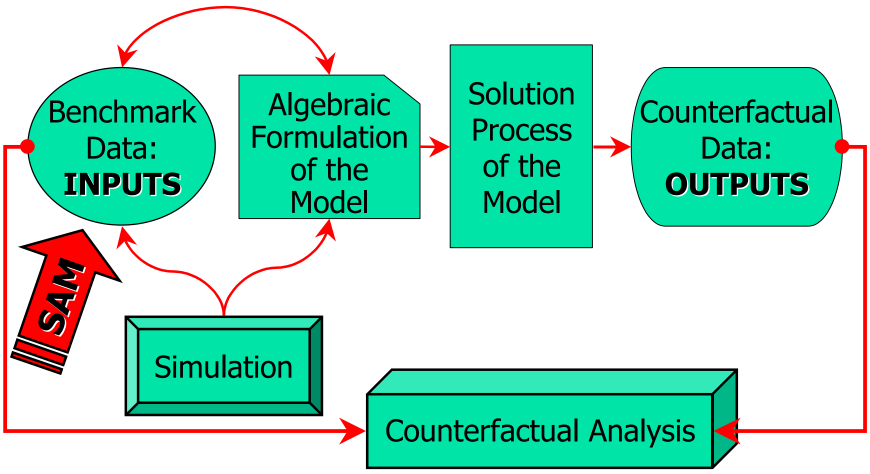
[4] For a given SAM.



Source: Emini (2002)

Fig. 4.1 The SAM's *Locus* in the General Mechanics of CGE Modeling

Expenditures / Revenues		Sequence Numbers of Accounts by Columns *(j=1,…,k,…n)*					Totals
		1	….	k	….	n	
Sequence Numbers of Accounts by Rows *(i=1,…,k,…,n)*	1	$t_{1,1}$		$t_{1,k}$		$t_{1,n}$	$\sum_{j=1}^{n} t_{1,j}$
	….						
	k	$t_{k,1}$		$t_{k,k}$		$t_{k,n}$	$\sum_{j=1}^{n} t_{k,j}$
	….						
	n	$t_{n,1}$		$t_{n,k}$		$t_{n,n}$	$\sum_{j=1}^{n} t_{n,j}$
Totals		$\sum_{i=1}^{n} t_{i,1}$		$\sum_{i=1}^{n} t_{i,k}$		$\sum_{i=1}^{n} t_{i,n}$	

Source: Emini (2002)

Fig. 4.2 Schematic Representation of a SAM

3.1 Scaffolding

A possible definition of the SAM is of a system of disaggregated data, consistent and comprehensive, that captures the existing interdependence within the economy (flow of income). To better understand the spatial interaction within an integrated interregional system, Isard *et al*. (1998) call the attention for the need of a proper scaffolding of a core SAM. The basic idea is to incorporate all the relevant flows associated with the insertion of a region within the national *and* the global economy. Thus, a richly specified flow of income in an interregional multi-country framework is advocated. The relevant institutions should be explicitly modeled, and, whenever data availability allows, a link between a real SAM and a financial SAM should be incorporated. This "ideal" framework would enhance the analytical capability of interregional CGE models, but data availability for a real economy still remains an impediment. We will return to this issue when discussing some of the data problems associated with the implementation of CGE models.

In the next section, some issues related to applied models focusing on regional economies are addressed. Features of specification and implementation will be highlighted, considering the state-of-the-art in interregional CGE modeling.

4.4 The State-of-the-art: Common Features, Common Issues

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; and Bolton, 1985). More recently, a new approach to 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 one of the main research frontiers in regional modeling. The main aspects related to its recent developments are discussed below.

4.4.1 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 operational CGE model follows two basic steps: a) the specification of the model; and b) the calibration of the model, using SAM 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 so, the method follows an *ad hoc* (dis)aggregation of statistical divisions data. More recently, the issue associated with the relevant spatial unit, and the sensitivity of the models' results to the chosen spatial aggregation, started to concern researchers in the field.

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 could be justified on the grounds of the novelty of the field (data are used just to illustrate the new ideas). Nowadays, though, given its way towards maturity, Harris Jr. (1988)'s suggestion – that for such models to be useful to policy makers, data effort is necessary – becomes more and more critical. In this sense, 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 should spatial limits 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 to the nation 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.

4.2 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, often on an *ad hoc* basis. The disaggregation can proceed in different steps (e.g. country-state → state-municipality), 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-down 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)), Horridge *et al*. (1995), MONASH-RES (Parmenter and Welsh, 2000), and Haddad and Azzoni (2001). 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 demands, 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 model of Australia (Dixon *et al.*, 2000) to produce regional forecasts or policy analysis. The ORANI and the MONASH-RES top-down approaches were successfully implemented in Brazil by Haddad and Azzoni (2001), and Haddad and Domingues (2003), respectively.

In the bottom-up approach, agents' behavior is modeled at the regional level. A fully interdependent system is specified in which national-regional feedbacks 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/SAM database is required, with full specification of interregional flows. Data also include interregional trade elasticities 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.

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

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. Liew 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 feedbacks 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 database, 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 database 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.

4.4.3 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 databases 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), for instance, 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

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

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 into the impacts on regional economies. Haddad and Hewings (1999) provide an interesting exercise considering the regional effects of sectoral policies. In their paper, the regional impacts of the new investments in the automobile industry in Brazil are evaluated through the use of an interregional CGE model. The simulation results for the short-run show that: a) the employment effects of the labor-saving technology in the automobile industry are positive for the economy as a whole; and b) even though investments in the less developed region (Northeast) are more beneficial to the improvement of regional imbalances in the country, in terms of efficiency, investments in the richer Center-South generate higher national economic growth.

The role of interregional trade in sub-national economies needs to be further highlighted. Regional interactions need to be studied to gain a better understanding of how regional economies are affected, in international markets and domestic ones, since for the smaller economies, in particular, the performance of the more developed regions is crucial. The usual view of spatial interaction, which considers the region *vis-à-vis* the rest of the world, conceals two properties that are fundamental for understanding an interregional system, namely feedback and hierarchy. Interregional trade can generate potential for propagating feedback effects which could well be quantitatively more important than those generated by international trade. Nonetheless, the impact of feedback effects will partly be determined by the hierarchical structure of the economy's regional system.

Previous diagnostics suggests the need to make a more in-depth analysis of trade flows between sub-national spaces, potentially leading to generalizations regarding the type of trade involved, changes in its composition through time as the economy develops, and the implications of these structural differences in the coordination and implementation of development policies (Anderson and Hewings, 1999; Haddad *et al*., 2002). In order to address this issue, interregional CGE models should attempt to give interregional trade its proper place by taking into account a fully specified interregional system of accounts specially developed for the purpose of calibrating the models.

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 often have to extrapolate from estimates for their equivalent parameters 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). Secondly, 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), the 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.

4.4.4 Production and Consumption Systems

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 section 4.2, 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.

Fig. 4.3 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 – less restrictive than Leontief or Cobb-Douglas – 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.

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 of the exceptions 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) proposed 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.

One of the main limitations of the standard assumptions about the production system adopted in CGE models is that they fail to recognize market imperfections. This problem is usually confronted by using *ad hoc* formulae to introduce scale economies and non-competitive behavior. Some experimentation in the interregional framework is already documented in Whalley and Trela (1986), where increasing returns to scale were introduced, and Bröcker (1998a) who explored monopolistic competition with increasing returns and free entry.

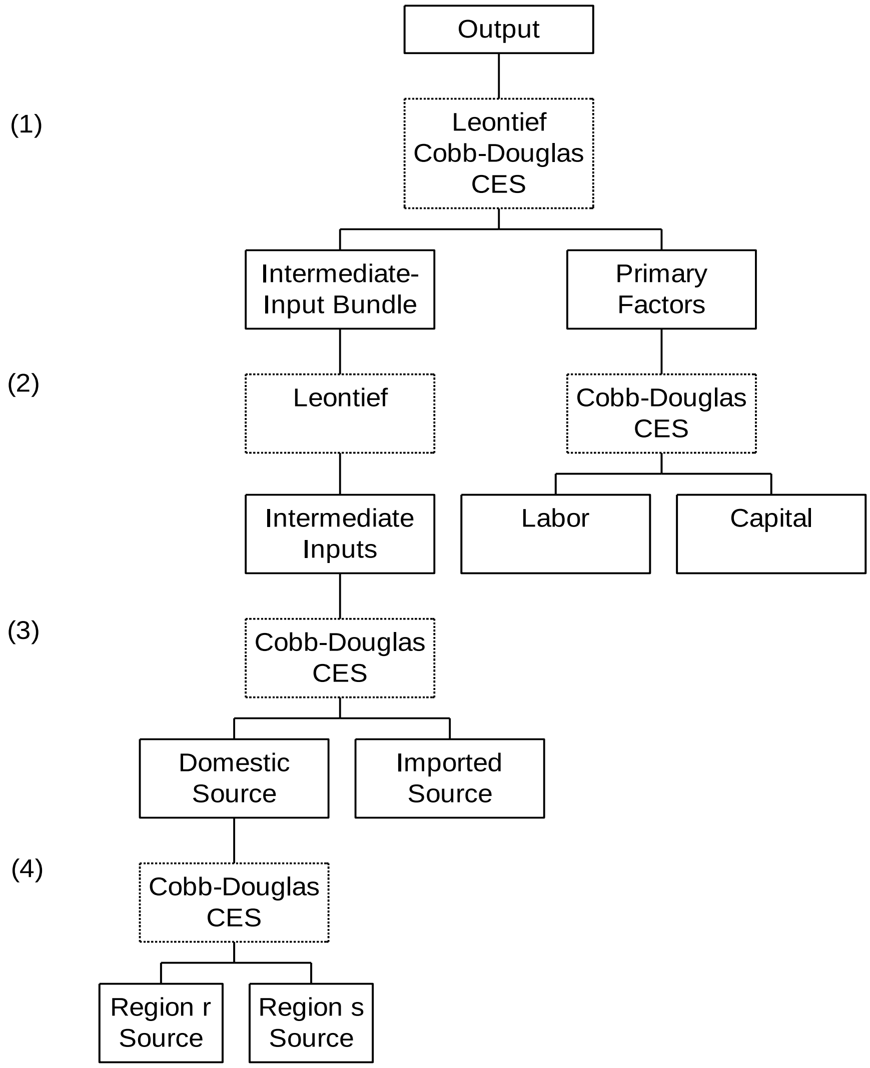

Fig. 4.3 Standard Nesting Structures of Regional Production Technology in Interregional CGE Models

The treatment of household demand structure, depicted in fig 4.4, 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 a 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.[7]

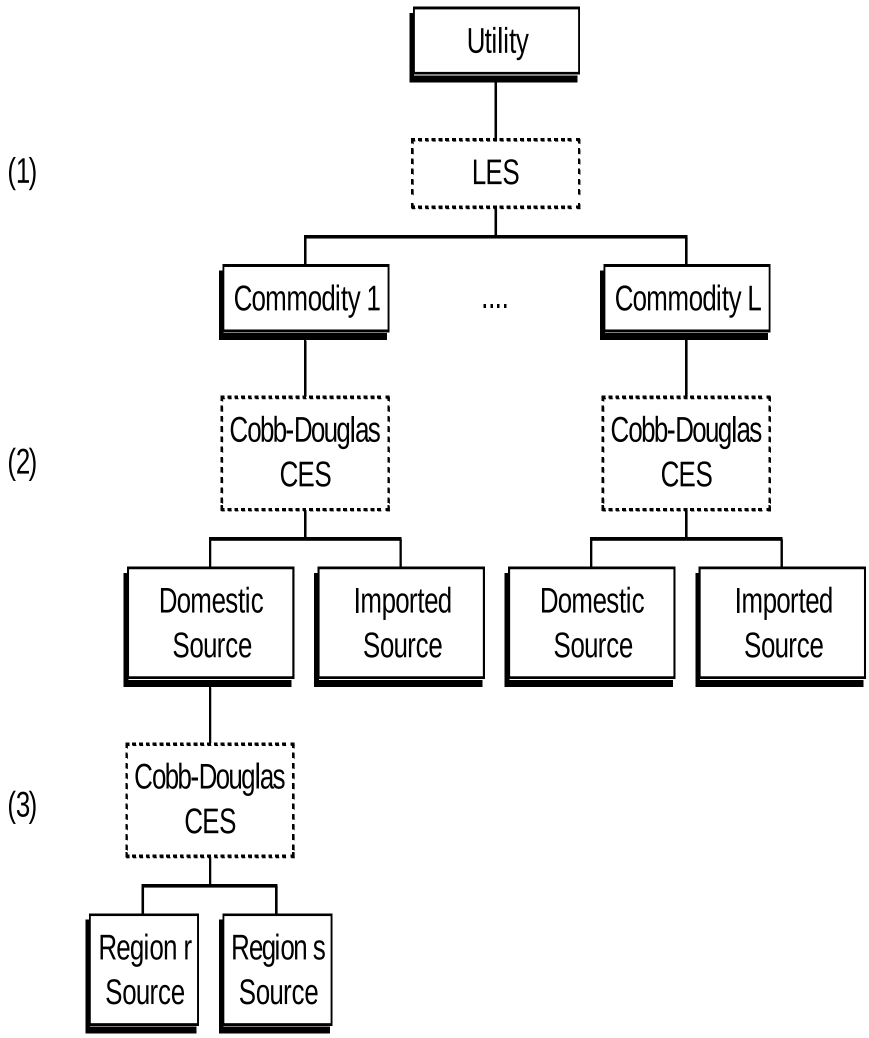

Fig. 4.4 Standard Nesting Structure of Regional Household Demand in Interregional CGE models

[7] It is also common to use a full-CES nested structure based on other nesting operations, which try to categorize consumption goods in a more systematic way (e.g. luxury and non-luxury; food and housing; grains and vegetables).

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 modest requirements for parameters determination is the main attractiveness for modelers, especially when calibration of large-scale models is to take place (Koh *et al*., 1993).

4.4.5 Transportation Services

The imbedding of spatial flows in the economic environment, especially those related to interregional trade linkages, usually should go along with the specification of transportation services. Given the existing interregional CGE studies with transportation, one can classify the ways in which transportation costs are explicitly introduced into three groups, all of them considering the fact that transportation is a resource-demanding activity. This basic assumption is essential if one intends to properly model an interregional CGE framework, invalidating the model's results if not considered (see Isard *et al*., 1998)

First, it is possible to specify transportation technology by adopting the iceberg transportation cost hypothesis, based on Samuelson (1952). It is assumed that a certain percentage of the transported commodity itself is used up during transportation. Analytically, one possible way to introduce iceberg costs is to consider the transport rate $\eta^i > 0$ to be the share of commodity *i* lost per unit of distance and z_{rs} the distance from *r* to *s*; then, the amount arriving in *s*, if one unit of output *i* is sent from *r* to *s*, is $\exp(-\eta^i z_{rs})$, which is less than unity, if z_{rs} is positive (Bröcker, 1998). To calibrate it, it is assumed that the transport rates η^i for each sector are know in form of data on transportation cost per unit of distance as percentages of the respective commodity values. The z_{rs}s provide potentially the linkage variables for the integration with a geo-coded transportation model. Models using this transportation technology framework include Bröcker (1998ab, 2002), Kilkenny (1998), and Hu (2002).

Secondly, one can assume transport services to be produced by a special optimizing transport sector. A fully specified PPF has to be introduced for the transportation sector, which produces goods consumed directly by users and consumed to facilitate trade, i.e. transport services are used to ship commodities from the point of production to the point of consumption. The explicit modeling of such transportation services, and the costs of moving products based on origin-destination pairs, represents a major theoretical advance (Isard *et al*., 1998), although it makes the model structure rather complicated in practice (Bröcker, 1998b). The model can be calibrated by taking into account the specific transportation structure cost of each commodity flow, providing spatial price differentiation, which indirectly addresses the issue related to regional transportation infrastructure efficiency. In this sense, space plays a major role. Examples can be found in Haddad (1999), and Haddad and Hewings (2001).

Finally, a third approach to introduce transportation into CGE models consists of the development of a satellite module for the transportation system. The transportation subsystem is usually exogenously modeled, generating transportation inputs that feed the production functions in the CGE model. In this case, there is no micro-foundation behind the satellite model, as is the case of the behavioral equations in the interregional CGE core. Roson (1994) and Kim and Hewings (2003, 2004) provide some examples of this approach.

4.4.6 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 and Rickman, 1998 discuss extensively the calibration procedure of CGE models). Interregional input-output/SAM databases provide the various production and consumption estimates. Specification of exogenous elasticities values will also be needed.

Interregional commodity flows data are seldom available. It has been common practice in regional CGE modeling to use non-survey 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.[8]

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 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; and Hulu and Hewings, 1993).

Another data-related problem that modelers frequently face is the lack of trade elasticities at the regional level. The rule-of-thumb is to use international trade

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[8] The choice of input-output data for regional models is an important issue in regional modeling. A 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, a Marshallian-type CGE model, both in forecast and impact analyses.

elasticities as benchmarks for "best guess" procedures. However, a recent study by Bilgic *et al*. (2002) tends to refute the hypothesis that international trade elasticities are lower bound for regional trade elasticities for comparable goods, an assumption widely accepted by CGE modelers. Their estimates of regional trade elasticities for the U.S. economy challenged the prevailing view and called the attention of modelers for proper estimation of key parameters. Other elasticities are commonly borrowed from econometric studies; in this case, more reliable estimates are available. Sensitivity analysis for key parameters is sometimes performed, providing a more reliable range of model results (see the next section).

4.4.7 Sensitivity Analysis[9]

CGE models have been frequently criticized for resting on weak empirical foundations. While Hansen and Heckman (1996) argue that the flexibility of the general equilibrium paradigm is a virtue hard to reject and provides a rich apparatus for interpreting and processing data, it can be considered as being empirically irrelevant because it imposes no testable restrictions on market data. McKitrick (1998) has also criticized the parameter selection criteria used in most CGE models, arguing that the calibration approach leads to an over-reliance on non-flexible functional forms.

Although most CGE modelers recognize that accurate parameters values are very important, it is not easy to find empirical estimates of key parameters, such as substitution elasticities, in the literature. Most of the models take up estimates "found in the literature" or even "best guesstimates" (Deardorff and Stern, 1986). Thus, if there is a considerable uncertainty surrounding the "right" parameters, and these are key elements in the CGE results, a consistent procedure in their evaluation is imperative. The problem in CGE models is compounded by the presence of a variety of parameters, some estimated with known probability distributions, others with no known distributions combined with input-output/SAM data that are provided as point estimates (see Haddad *et al*., 2002).

If a consistent econometric estimation for key parameters in a CGE model study is not possible, the effort should be directed to tests of the uncertainty surrounding these parameters in terms of their impact on the model. Robustness tests are an important step in enhancing the acceptance of the model results in applied economics. The assumptions embodied in CGE models come from general equilibrium theory. However, one set of assumptions, the values of model parameters are natural candidates for sensitivity analysis. Wigle (1991) has discussed alternative approaches for evaluating model sensitivity to parameter values, while DeVuyst and Preckel (1997) have proposed a quadrature-based approach to evaluate robustness of CGE models results, and demonstrated how it could be used for an applied policy model.

The Gaussian Quadrature (GQ) approach (Arndt, 1996; DeVuyst and Preckel, 1997) was proposed to evaluate CGE model results' sensitivity to parameters and exogenous shocks. This approach views key exogenous variables (shocks or parameters) as random variables with associated distributions. Due to the randomness in the exogenous variables, the endogenous results are also random; the GQ approach produces estimates of the mean and standard deviations of the endogenous model

[9] This section draws on Domingues *et al*. (2003).

results, thus providing an approximation of the true distribution associated with the results. The accuracy of the procedure depends on the model, the aggregation and the simulations employed. Simulations and tests with the Global Trade Analysis Project (GTAP) model, a large-scale model, have shown that the estimates of mean and standard deviations are quite accurate (Arndt and Hertel, 1997).

In interregional CGE modeling, another possible way to overcome the scarcity of estimates of regional key parameters is to estimate policy results based on different qualitative sets of values for the behavioral parameters and structural coefficients (Haddad *et al*., 2002). Through the judgment of the modeler, a range of alternative combinations reflecting differential structural hypotheses for the regional economies can be used to achieve a range of results for a policy simulation. This method, 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 through the use of possible structural scenarios. As data deficiency has always been a big concern in regional modeling, one that will not be overcome in the near future, this method tries to adjust the model for possible parameter misspecification. 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. Qualitative and systematic sensitivity analysis should be used on a regular basis in interregional CGE modeling in order to avoid, paradoxically, speculative conclusions over policy outcomes.

4.4.8 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 macroeconomic 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

[10] The term "qualitative sensitivity analysis" is used as opposed to "quantitative sensitivity analysis", which is the 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.

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 database. A policy or deviation closure has been applied by Adams *et al.* (2000) in an interregional CGE model for Australia, MMRF-Green, to analyze environmental issues. 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 the base case 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 be 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.

4.4.9 Intertemporal Analysis

The few attempts at incorporating intertemporal analysis in interregional CGE models is closely related to closure issues. The common approach is based on a standard mechanism of capital accumulation; next period's stock of capital is determined by current period's depreciated stock of capital and investment expenditure. What drives investment expenditure becomes the major mechanism of intertemporal transmission in such recursive models; closure rules may vary in order to capture specific aspects of agents' investment decisions.[11] The common feature is to give model results a "temporal" dimension, but with very poor dynamics involved. Little attention is given to proper specification of other possible mechanisms of dynamics, which play an important in the dynamics of interregional systems (e.g. labor market and population dynamics, consumption dynamics, financing dynamics).

Forward-looking models have some limitations, which modelers do not always take into account. Interregional CGE models have the capability of capturing effects

[11] Recent examples include Kim and Kim (2002, 2003), and Giesecke (2002).

associated with the static impact-effect question, i.e., given the structure of the economy, what-if questions can be addressed in a comparative-static framework. Short run and long run considerations differ in the way the equilibrating mechanisms are set through the closures specified. Structural changes are captured *only* through the evaluation of a re-allocation of resources. The dynamic time-path question, sometimes mistakenly assumed to be endogenously incorporated by modelers, brings along long-term considerations. In this case, interesting issues associated with technology, learning, externalities and political economy are in the core of the debate of structural changes. However, interregional CGE models fail to capture them, as they are not built to do so.

4.4.10 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) basically 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 facilitates~~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.

4.4.11 Operational Models

Notwithstanding the very heavy data requirements for bottom-up CGE models, they do not seem to have been neglected in favor of data-saving top-down models 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), Bröcker (1998a), Madden and Pant (1998), Hirte (1998), Miyagi *et al.*, (1998), Haddad (1999), Giesecke (2002), Kim and Kim (2002, 2003), and Groenewold *et al*. (2003).[12]

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 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: first, the model was divided into three trading blocks (U.S., Canada and Rest of the World); secondly, the American economy was regionalized, into four regions.[13] 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. Moreover, efforts on scaffolding the SAM, in Isard's proposed way, are to be noticed.

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.[14] 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

[12] The list is not intended to be exhaustive.

[13] In an intermediate step, the American economy was divided into two regions.

[14] The most recent development of MONASH-MRF is the so-called MONASH-GREEN (Adams *et al*., 2000), which incorporates an environment component to its predecessor.

(state) and federal government taxes affecting the purchase price of commodities, and of regional incomes.

Bröcker (1998a) provides some experimentation with different market structures. A spatial CGE is developed for a large number of European regions in order to evaluate the impacts of transport cost reductions. It is shown that benefits from new transport capacities under conditions of imperfect competition might differ from those under perfect competition, the reason being that substitution effects, income effects and competition effects can lead to expansion or contraction in those sectors showing comparatively high excess of price over marginal cost.

Hirte (1998) calculates welfare effects of regional income taxes by means of an interregional CGE model of the Germany economy. The model considers eleven regions containing two production sectors and two primary factors. Miyagi *et al*. (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), Kim and Kim (2002, 2003), Domingues (2002), and Almeida (2003). 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.[15]

Kim and Kim (2002, 2003) present a standard intertemporal multiregional CGE model for Korea for the analysis of regional development strategies in the country. Special attention is given to the distributional effects of such polices and the trade-off between regional equity and regional growth. Equity issues are examined not only across regions but also across representative households classified in ten income groups.

In Domingues (2002), an interregional CGE model is used to analyze the short-run and long-run regional and sectoral effects of trade liberalization in a FTAA agreement. The model provides a description of the Brazilian inter-regional economic system, separated in two regions, São Paulo and Rest of Brazil. One of its innovations is a full specification of foreign trade in both regions, capturing the complete structure of trade flows linking the two Brazilian regions and FTAA markets – an important step towards

[15] 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).

a proper scaffolding in an interregional multi-country context. In this way, adequate tariff liberalization simulations can be implemented.

Almeida (2003) develops a spatial CGE model to be used in the planning and the analysis of transportation policies in the Brazilian state of Minas Gerais (MINAS-SPACE), following Bröcker's parsimonious approach (Bröcker, 1998b). Two counterfactual experiments are developed: a generalized decrease of transportation costs due to a reduction in distance; and a decrease of transportation costs due to a reduction in freight for all commodities. The main findings witness an asymmetrical distribution of the spatial economic effects of these experiments and show that policies that improve the transportation conditions have the effect of provoking welfare gains, increasing the economic efficiency and diminishing regional disparities in the Brazilian state of Minas Gerais.

4.5 The Road Ahead: Challenges and New Directions

In the last ten years, the development of regional and interregional CGE modeling has experienced an upsurge in interest. Different models have been built for different regions of the world. Research groups, located especially in Australia, Brazil, Canada, Scotland and U.S., 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.

Recent theoretical developments in New Economic Geography bring new challenges to regional scientists, in general, and interregional CGE modelers, in particular.[16] Experimentation with the introduction of scale economies and market imperfections should provide innovative ways of dealing explicitly with theoretical issues related to integrated regional systems.

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. Secondly, 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.

In this sense, modeling integration becomes a major goal to pursue. Some of the shortcomings of interregional CGE models might be suppressed by inserting a core CGE in a broader modeling framework. Isard's vision of integrated modeling, which

[16] See, for instance, Fujita *et al*. (1999) and Fujita and Thisse (2002).

anticipated the proposals reported in Isard and Anselin (1982), provided a road map for the development of more sophisticated analysis of spatial economics systems (Hewings, 1986; Hewings *et al*. 2004). Given their many virtues, if adequately addressed, interregional CGE models are the main candidates for the core subsystem in a fully integrated system.

Methodological advances should be pursued to reach the planners. Spatial infrastructure and spatial socio-economic phenomena are key elements that shape and help better understanding economic spaces. Examples to tackle some of these issues are given below.

First, a framework, incorporating the explicit modeling of transportation costs, based on origin-destination flows, which takes into account the spatial structure of the study economy, creates the capability of integrating the interregional CGE model with a geo-coded transportation network model, enhancing the potential of the integrated system in understanding the role of infrastructure on regional development. Initial attempts to link a transportation network model with an interregional CGE model are documented in Kim and Hewings (2003, 2004), with appealing results for regional planners. However, proper linkages that connect models need to be reconsidered, providing a fertile research area.

Secondly, if one is interested in income distribution analysis (relative poverty), a "pure macro" CGE multi-agent model is sufficient. However, to analyze absolute poverty, a link with a survey is essential. As the households' responses to economy-wide changes vary across sectors and regions – the growth process is not uniform spatially – the redistribution mechanism will not be homogenous. Increasing focus on welfare, poverty and income distribution calls for strengthened links between macro and household level analysis, so that linkage of macro data and household surveys will contribute to the design of more effective poverty reduction policies and programs.[17] In this regard, to analyze absolute poverty, or other socio-economic phenomena, a link with household survey is essential. The way this link is operational becomes a major research question, including the possibility of adopting spatial micro-simulation techniques.

Appropriate use of interregional CGE models has not always been the norm. As Hertel (1999) notices, consumers of CGE results are initially happy to simply "get the numbers." Rationalized by the "black box syndrome," rigorous analysis of CGE results is not often undertaken: the large number of simultaneous interactions often leaves the user wondering where to jump in and start the analysis. However, given the relatively standard structure of CGE models, it is possible to come up with general approaches and techniques for facilitating analysis of model outcomes.

Also, given the intrinsic uncertainty in the shock magnitudes and parameter values, sensitivity tests are an important next step in the more formal evaluation of the robustness of (interregional) CGE analysis and the fight against the "syndrome". However, some important points should be addressed in the future in order to have a better understanding of the sensitivity of the models' results. In similar fashion to the fields of influence approach for input-output models developed by Sonis and Hewings (1992), attention needs to be directed to the most important synergetic interactions in a CGE model. It is important to try to assemble information on the parameters, shocks

[17] See Agénor *et al*. (2000).

and database flows, for example, that are the *analytically* most important in generating the model outcomes, in order to direct efforts to a more detailed investigation.[18]

A final remark concerns further the "black box syndrome" (interregional) CGE models suffer. As seen, CGE models are explicitly structural and, thus, do not find identification problems commonly associated with econometric models. This characteristic forces modelers to be explicit about the behavioral assumptions adopted for the relevant agents (e.g. consumers, producers, government). Moreover, CGE models demand data consistency for defining the initial equilibrium. In other words, what one sees is what one gets. However, even for experienced modelers, with the information provided in studies that use CGE models as the basic analytical tool, it is very hard to consider the major mechanisms that drive models' results. Without access to a comprehensive documentation of the model, which is not available in a 20-30-page article, due to understandable reasons, replication of simulations is never possible. One way of overcome this difficulty and give a major step towards opening existing "black boxes" is to treat operational models as public goods for the interested community, comprised basically of modelers and users of CGE-based policy studies. The successful experiences with ORANI/MONASH and GTAP should be used as references for research groups of interregional CGE modelers.

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[18] See Domingues *et al*. (2003).

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