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HANDLING MARKET IMPERFECTIONS IN A SPATIAL ECONOMY: A CGE APPROACH

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Abstract. The purpose of this paper was threefold. First, we presented a flexible analytical framework, based on sound and consistent economic theory and data, in order to assess the likely state/sectoral/income effects of policy changes in Brazil. This is the first fully operational interstate CGE model implemented for the Brazilian economy, based on previous work by the author and associates. Among the features embedded in this framework, modeling of scale economies and transportation costs provides an innovative way of dealing explicitly with theoretical issues related to integrated regional systems. Results seemed to reinforce the need to better specifying spatial interactions in interregional CGE models. Second, in order to illustrate the analytical capability of the CGE module, we presented a set of simulations, which evaluated the regional impacts of a decrease in transportation costs, in accordance with recent policy developments in Brazil. Rather than providing a critical evaluation of this debate, we intended to emphasize the likely structural impacts of such policies. Third, previous diagnostics suggested the need to make a more in-depth analysis of trade flows between the Brazilian states, potentially leading to generalizations regarding the type of trade involved, changes in its composition through time as the Brazilian economy develops, and the implications of these structural differences in the coordination and implementation of development policies. In order to address this issue we gave interregional trade its proper place by taking into account a fully specified interstate system of accounts specially developed for the purpose of calibrating the CGE model.

1. Introduction

The new economic geography has revisited the issues associated with applications of various competitive market structures to the spatial economy. The earlier admonitions of Isard (1959), to avoid the Anglo-Saxon biases imposed by the adoption of a space-less world in which all activity was assumed to be located on the head of a pin, provoked renewed interest in exploring location decision-making under alternative competitive regimes. However, it has only been through research in the last decade that has identified some important theoretical inconsistencies between competitive regimes conceptualized in a space-less and spatial economies. Some of these inconsistencies have found their way into applied and spatial computable general equilibrium models, especially those models involving interregional (intra-national) trade. Essentially, if space is homogeneous, with activities uniformly distributed, and a competitive market in operation, there will be no trade, with each point in space characterized by spatial autarchy. The theory has been modified to embrace increasing returns to scale and thus able to provide insights into the agglomeration of economic activity and returns to trade. The developments towards a core-periphery emerge as one of the dominant outcomes (see Fujita *et al.*, 1999; Fujita and Thisse, 2002).

However, even the new economic geography theory does not seem to be able to cover the notion of some intermediate form of space between homogeneous and non-homogenous that would essentially give rise to the Brazilian case. While appeal to core-periphery could be made, it seems that with high transportation costs, firms can exploit increasing returns to scale (IRTS) within less than complete national markets. The very size of São Paulo provides opportunities that could not be realized by similar firms in the located within the Northeast of Brazil; further, there exist certain asymmetries in competitive advantage. With improvements in transportation, the São Paulo firms, already further down the IRTS, possess a competitive advantage to further exploit scale economies with reductions in transportation costs, thereby exacerbating the welfare differentials between regions. One of the main reasons for their competitive advantage is their central position – not geographically, but in terms of the locus of productive activity or purchasing power (see Haddad and Azzoni, 2001).

The Brazilian case has been further complicated by a transportation infrastructure that until recently was regulated and biased towards investment in highways to the exclusion of water and railroad modes. Efficiency gains from investments appear not to have been considered from a broader perspective – such as enhancing interregional cohesion – but appear to have been oriented towards supporting increased exports. How are these investments to be estimated and can some method be found to simulate the effects of deregulation, through a process of increased competition that reduces spatial transfer costs?

This paper will begin with the exploration of computable general equilibrium models applied to multi-regional configurations of the Brazilian economy in a way that reflects some of the current market imperfections, some of which arise from historical investment decisions, some from Brazil's geography and some that reflect a combination of many factors including Brazil's recent decision to open its markets and to participate more actively in organizations like MERCOSUL and the proposed FTAA.

The remainder of the paper is organized in four sections and one Appendix. First, after this introduction, an overview of the CGE model to be used in the simulations (B-MARIA-27) is presented, focusing on its general features. Second, modeling issues associated with the treatment of non-constant returns and transportation costs are presented. As already mentioned, recent theoretical developments in New Economic Geography bring new challenges to regional scientists, in general, and interregional CGE modelers, in particular. Experimentation with the introduction of scale economies, market imperfections and transportation costs should provide innovative ways of dealing explicitly with theoretical issues related to integrated regional systems. An attempt to address these issues is then discussed in details. After that, the simulation experiment is designed and implemented, and the main results are discussed. Final remarks follow in an attempt to evaluate our findings and put them into perspective, considering their extension and limitations. Appendix A containing the full specification of the CGE core is also presented.

2. The B-MARIA-27 Model

In order to evaluate the short-run and ling-run effects of reductions in transportation costs, an interstate CGE model was developed and implemented (B-MARIA-27). The structure of the model represents a further development of the **B**razilian **M**ultisectoral **A**nd **R**egional/**I**nterregional **A**nalysis Model (B-MARIA), the first fully operational interregional

CGE model for Brazil.[1] Its theoretical structure departs from the MONASH-MRF Model (Peter *et al*., 1996), which represents one interregional framework in the ORANI suite of CGE models of the Australian economy. The interstate version of B-MARIA, used in this research, contains over 600,000 equations, and it is designed for forecasting and policy analysis. Agents' behavior is modeled at the regional level, accommodating variations in the structure of regional economies. The model recognizes the economies of 27 Brazilian states. Results are based on a bottom-up approach – national results are obtained from the aggregation of regional results. The model identifies 8 sectors in each state producing 8 commodities, one representative household in each state, regional governments and one Federal government, and a single foreign consumer who trades with each state. Special groups of equations define government finances, accumulation relations, and regional labor markets. The model is calibrated for 1996; a rather complete data set is available for 1996, which is the year of the last publication of the full national input-output tables that served as the basis for the estimation of the interstate input-output database (Haddad *et al*., 2002), facilitating the choice of the base year.

The mathematical structure of B-MARIA-27 is based on the MONASH-MRF Model for the Australian economy. It qualifies as a Johansen-type model in that the solutions are obtained by solving the system of linearized equations of the model. A typical result shows the percentage change in the set of endogenous variables, after a policy is carried out, compared to their values in the absence of such policy, in a given environment. The schematic presentation of Johansen solutions for such models is standard in the literature. More details can be found in Dixon *et al*. (1992), Harrison and Pearson (1994, 1996), and Dixon and Parmenter (1996).

2.1. General Features of B-MARIA-27

CGE Core Module

The basic structure of the CGE core module comprises three main blocks of equations determining demand and supply relations, and market clearing conditions. In addition, various regional and national aggregates, such as aggregate employment, aggregate price level, and balance of trade, are defined here. Nested production functions and household demand functions are employed; for production, firms are assumed to use fixed proportion combinations of intermediate inputs and primary factors are assumed in the first level while, in the second level, substitution is possible between domestically produced and imported intermediate inputs, on the one hand, and between capital, labor and land, on the other. At the third level, bundles of domestically produced inputs are formed as combinations of inputs from different regional sources. The modeling procedure adopted in B-MARIA uses a constant elasticity of substitution (CES) specification in the lower levels to combine goods from different sources.

The treatment of the household demand structure is based on a nested CES/linear expenditure system (LES) preference function. Demand equations are derived from a utility maximization problem, whose solution follows hierarchical steps. The structure of household demand follows a nesting pattern that enables different elasticities of substitution to be used. At the bottom level, substitution occurs across different domestic sources of supply. Utility derived from the

[1] The complete specification of the model is available in Haddad and Hewings (1997) and Haddad (1999).

consumption of domestic composite goods is maximized. In the subsequent upper-level, substitution occurs between domestic composite and imported goods.

Equations for other final demand for commodities include the specification of export demand and government demand. Exports face downward sloping demand curves, indicating a negative relationship with their prices in the world market. One feature presented in B-MARIA refers to the government demand for public goods. The nature of the input-output data enables the isolation of the consumption of public goods by both the federal and regional governments. However, productive activities carried out by the public sector cannot be isolated from those by the private sector. Thus, government entrepreneurial behavior is dictated by the same cost minimization assumptions adopted by the private sector.

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 is calibrated 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. Other definitions in the CGE core module include: tax rates, basic and purchase prices of commodities, tax revenues, margins, components of real and nominal GRP/GDP, regional and national price indices, money wage settings, factor prices, and employment aggregates.

Government Finance Module

The government finance module incorporates equations determining the gross regional product (GRP), expenditure and income side, for each region, through the decomposition and modeling of its components. The budget deficits of regional governments and the federal government are also determined here. Another important definition in this block of equations refers to the specification of the regional aggregate household consumption functions. They are defined as a function of household disposable income, which is disaggregated into its main sources of income, and the respective tax duties.

Capital Accumulation and Investment Module

Capital stock and investment relationships are defined in this module. When running the model in the comparative-static mode, there is no fixed relationship between capital and investment. The user decides the required relationship on the basis of the requirements of the specific simulation.[2]

Foreign Debt Accumulation Module

This module is based on the specification proposed in ORANI-F (Horridge *et al*., 1993), in which the nation's foreign debt is linearly related to accumulated balance-of-trade deficits. In summary, trade deficits are financed by increases in the external debt.

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[2] For example, it is typical in long-run comparative-static simulations to assume that the growth in capital and investment are equal (see Peter *et al*., 1996).

Labor Market and Regional Migration Module

In this module, regional population is defined through the interaction of demographic variables, including rural-urban and interstate migration. Links between regional population and regional labor supply are provided.

2.2. Structural Database

The CGE core database requires detailed sectoral and regional information about the Brazilian economy. National data (such as input-output tables, foreign trade, taxes, margins and tariffs) are available from the Brazilian Statistics Bureau (IBGE). At the regional level, a full set of state-level accounts were developed at FIPE-USP (Haddad *et al*., 2002). These two sets of information were put together in a balanced interstate absorption matrix. Previous work in this task has been successfully implemented in interregional CGE models for Brazil (e.g. Haddad, 1999; Domingues, 2002; Guilhoto *et al*., 2002).

2.3. Behavioral Parameters

Previous works with the B-MARIA framework have suggested that interregional substitution is the key mechanism that drives model's spatial results. In general, 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, of direct interest in our exercise, interregional trade flows should be incorporated in the model. Interregional input-output databases are required to calibrate the model, and regional trade elasticities play a crucial role in the adjustment process.

One data-related problem that modelers frequently face is the lack of such trade elasticities at the regional level. The pocket rule is to use international trade 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. In this sense, an extra effort was undertaken to estimate model-consistent regional trade elasticities for Brazil, to be used in the B-MARIA-27 Model.

Other key behavioral parameters were properly estimated; these include econometric estimates for scale economies; econometric estimates for export demand elasticities; as well as the econometric estimates for regional trade elasticities. Another key set of parameters, related to international trade elasticities, was borrowed from a recent study developed at IPEA, for manufacturing goods, and from model-consistent estimates in the EFES model for agricultural and services goods.

2.4. Closure

B-MARIA-27 contains 608,313 equations and 632,256 unknowns. Thus, to close the model, 23,943 variables have to be set exogenously. In order to capture the effects of lowering transportation costs, the simulations were carried out under standard short-run and long-run closures. A distinction between the two closures relates to the treatment of capital stocks encountered in the standard microeconomic approach to policy adjustments. In the short-run closure, capital stocks are held fixed, while, in the long-run, policy changes are allowed to affect capital stocks. In addition to the assumption of interindustry and interregional immobility of capital, the short-run closure would include fixed regional population and labor supply, fixed regional wage differentials, and fixed national real wage. Regional employment is driven by the assumptions on wage rates, which indirectly determine regional unemployment rates. On the demand side, investment expenditures are fixed exogenously – firms cannot reevaluate their investment decisions in the short-run. Household consumption follows household disposable income, and government consumption, at both regional and federal levels, is fixed (alternatively, the government deficit can be set exogenously, allowing government expenditures to change). Finally, since the model does not present any endogenous-growth-theory-type specification, technology variables are exogenous (Peter, 1997).

A long-run (steady-state) equilibrium closure is also used in which capital is mobile across regions and industries. Capital and investment are generally assumed to grow at the same rate. The main differences from the short-run are encountered in the labor market and the capital formation settings. In the first case, aggregate employment is determined by population growth, labor force participation rates, and the natural rate of unemployment. The distribution of the labor force across regions and sectors is fully determined endogenously. Labor is attracted to more competitive industries in more favored geographical areas. While in the same way, capital is oriented towards more attractive industries. This movement keeps rates of return at their initial levels.

3. Modeling Issues

3.1. Incorporation of Non-Constant Returns to Scale in Regional Production Functions for CGE Models

The basic structure of the CGE core module in B-MARIA (Haddad, 1999) comprises three main blocks of equations determining demand and supply relations, and market clearing conditions. In addition, various regional and national aggregates, such as aggregate employment, aggregate price level, and balance of trade, are defined here. Nested production functions and household demand functions are employed. For production, firms are assumed to use fixed proportion combinations of intermediate inputs and primary factors in the first level while, in the second level, substitution is possible between domestically produced and imported intermediate inputs, on the one hand, and between capital, labor and land, on the other. At the third level, bundles of domestically produced inputs are formed as combinations of inputs from different regional sources. The modeling procedure adopted in B-MARIA uses a constant elasticity of substitution (CES) specification in the lower levels to combine goods from different sources and primary factors. Given the property of standard CES functions, non-constant returns are ruled out.

However, one can modify assumptions on the parameters values in order to introduce non-constant returns to scale. In the CGE literature, there is an increasing concern about the role of functional forms. The parameter selection criteria used in most CGE models have been criticized on the grounds that the calibration approach leads to an over-reliance on non-flexible functional forms (McKitrick, 1998). Moreover, in the interregional context, an experimental approach has been advocated by Isard *et al*. (1998). The authors stimulate experimentation, arguing that the best approach [for the specification of the production subsystem] may turn out to be the simultaneous employment of several different production functions for a regional economy, each function representing a set of a few basic activities.

On the other hand, a conservative (tractability) approach is also supported by experienced modelers, narrowing the alternatives for exhaustive experimentation on functional forms. The main concern is about the possibilities of estimation/calibration and operationalization of (preferred) more flexible functional forms (Hertel and Tsigas, 1997).

This research adopts, as guiding principles for the use of more flexible functional forms, both the experimental and the conservative approaches. Changes in the production functions of the manufacturing sector in each one of the 27 Brazilian states is implemented in order to incorporate non-constant returns to scale, a fundamental assumption for the analysis of integrated interregional systems. We keep the hierarchy of the nested CES structure of production, which is very convenient for the purpose of calibration (Bröcker, 1998), but we modify the hypotheses on parameters values, leading to a more general form. This modeling trick allows for the introduction of non-constant returns to scale, by exploring local properties of the CES function. Care should be taken in order to keep local convexity properties of the functional forms to guarantee, from the theoretical point of view, existence of the equilibrium.

Schmutzler (1999) has pointed as one of the major contributions by the recent economic geography literature the formalization of a coherent analytical framework considering old concepts widely known by regional economists (e.g. centripetal and centrifugal forces, general equilibrium considerations and microfoundations). As increasing returns are crucial to the explanation of the agglomeration pattern, empirically verified, traditional Arrow-Debreu approaches would be unsuitable for issues of economic geography, because they rely on convex technology sets.[3]

The experimentation on scale effects undertaken in this paper, inspired by Whalley and Trela (1986), considers parameters that enable increasing returns to scale to be incorporated in an industry production function in any region through parametric scale economy effects. Changes in the production system are introduced only in the manufacturing sector, as data are available for the estimation of the relevant parameters. The proper estimation of such parameters provides point estimates for improved calibration, and standard errors to be further used in exercises of systematic sensitivity analysis (SSA). In the next section, we present the main modifications of the model specification. After that, we provide some comments on the estimation procedure, presenting the results.

3.1.1. The Modified CES Nested Structure of Production

[3] The applied models are usually associated with neoclassical assumptions of smooth monotonous convex functions and competitive market assumptions, which allow for a single equilibrium. Instead, one may however use model structures and functional specifications for which existence and uniqueness proofs are not available. (Dervis *et al*.,1982). In such cases, finding a solution becomes an empirical question.

Non-constant returns to scale are introduced in the group of equations associated with primary factor demands and prices within the nested structure of production. Only the manufacturing activities are contemplated with this change, as, following one of the guiding principles mentioned above, estimation of the relevant parameters was necessary. Due to data availability, other sectors maintain the standard nested production function with constant returns.

The equations in this group specify industry demands for labor, capital and land. They are derived under the assumption that industries choose their primary factor inputs to minimize primary factor costs subject to obtaining sufficient primary factor inputs to satisfy their technical requirements (nested CES function).[4] In the standard specification, it is assumed that there is no substitution between primary factors and other inputs, at the top of the nest; thus, industry *j*'s primary factor requirements are determined by its overall activity level, and by price-insensitive technology variables specifying the use of primary factors per unit of output. Here, the first modification is introduced. In the standard specification, demand for the primary factor composite can be thought to follow the more general specification, in levels, as shown below:

$$X1PRIM(j,q) = A1(j,q) * A1PRIM(j,q) * [\alpha(j,q)Z(j,q)]^{MRP(j,q)} \qquad (1)$$

where *X1PRIM(j,q)* is the demand for the primary factor composite by sector *j* in region *r*, *A1* and *A1PRIM* are technology variables, *Z(j,q)* is the level of activity of sector *j* in region *r*, $\alpha(j,q)$ is a technical input-output coefficient, and *MRP(j,q)* is a sector-regional specific parameter to returns to scale to primary factors, with $MRP(j,q) = 1$ indicating constant returns. Changing assumptions about *MRP(j,q)* enables the introduction of increasing returns to scale ($MRP(j,q) < 1$) and decreasing returns to scale ($MRP(j,q) > 1$). Whether or not non-constant returns operate becomes an empirical question. In the percentage-change form, equation (1) becomes equation (A4) in the Appendix.

Similarly, assumptions on the parameters of the CES can be modified to generate non-constant returns to specific primary factors. In the percentage-change form, the relevant equation is (A3). The key parameters, μ and α, remain to be estimated.

3.1.2. Parameters Estimation

As mentioned above, one of the guiding principles adopted for considering alternative functional forms is associated with the proper estimation of the relevant parameters of the new specification. Simpler versions of the modified equation (4), were then estimated for the manufacturing sector. The following basic specification was considered:

$$\ln(VA/\#\ firms) = \alpha + \beta \ln(GO/\#\ firms) \qquad (2)$$

where *VA/#firms* is the average value added by firm in a manufacturing sector, *GO/#firms* is the average gross output by firm in a manufacturing sector. The idea behind the use of averages by

[4] More precisely, in the standard specification, a nested Leontief/CES function is adopted. It can be shown, though, that the Leontief functional form represents a special case of the CES (see, for instance, Dixon *et al*., 1983).

firms is to introduce in the estimation process the concept of a representative agent, adopted in the interregional CGE model.

Equation (2) was estimated, for each state, using panel data for the years 1996 to 2001. Information on value added, gross output, number of employees, and number of firms for different manufacturing sectors in the 27 Brazilian states were obtained from the *Pesquisa Industrial Anual*, produced by the Brazilian National Statistics Office, IBGE, for six years. The number and type of manufacturing sectors included in each state's sample vary, as different levels of industrial complexity emerge. The software STATA 7 was used in the estimation process.

Regressions were estimated considering two different models: *fixed effects* (FE), and *random effects* (RE). A Hausman test (HT) for correlation between the error and the regressors was used to check for whether the random effects model was appropriate; the hypothesis that the parameters β and δ are equal to one (constant returns to scale) was tested through the *F*-test.

The results are presented in Table 1 with the numbers in parentheses indicating standard errors (columns FE and RE), and probability values (columns F-test and HT). Cells, for each state, that are circled, indicate the best method of estimation; shaded cells indicate that the coefficients are statistically different from one (non-constant returns), at 5%.

Results for equation (2), presented in Table 1, reveal evidence of increasing returns in the following states: Minas Gerais, São Paulo, Paraná, Rio Grande do Sul, and Santa Catarina, all located in the more developed Center-South of the country. Also, Rondônia (North), Piauí (Northeast), and Mato Grosso (Center-West) presented evidence of increasing returns. The poor, relatively isolated states of Amapá, Maranhão and Sergipe showed evidence of decreasing returns to scale. Other states did not show evidence of non-constant returns in the manufacturing sector.

<< Insert Table 1 here >>

3.2. Modeling of Transportation Costs

The set of equations that specify purchasers' prices in the B-MARIA model imposes zero pure profits in the *distribution* of commodities to different users. Prices paid for commodity *i* from region *s* in region *q* by each user equate to the sum of its basic value and the costs of the relevant taxes and margin-commodities.

The role of margin-commodities is to facilitate flows of commodities from points of production or points of entry to either domestic users or ports of exit. Margin-commodities, or, simply, margins, include transportation and trade services, which take account of transfer costs in a broad sense.[5] Margins on commodities used by industry, investors, and households are assumed to be produced at the point of consumption. Margins on exports are assumed to be produced at the point of production. The margin demand equations show that the demands for margins are proportional to the commodity flows with which the margins are associated; moreover, a

[5] Hereafter, transportation services and margins will be used interchangeably.

technical change component is also included in the specification in order to allow for changes in the implicit transportation rate. The general functional form used for the margin demand equations is presented below:

$$XMARG(i,s,q,r) = AMARG(i,s,q,r) * [\eta(i,s,q,r) * X(i,s,q,r)^{\theta(i,s,q,r)}] \qquad (3)$$

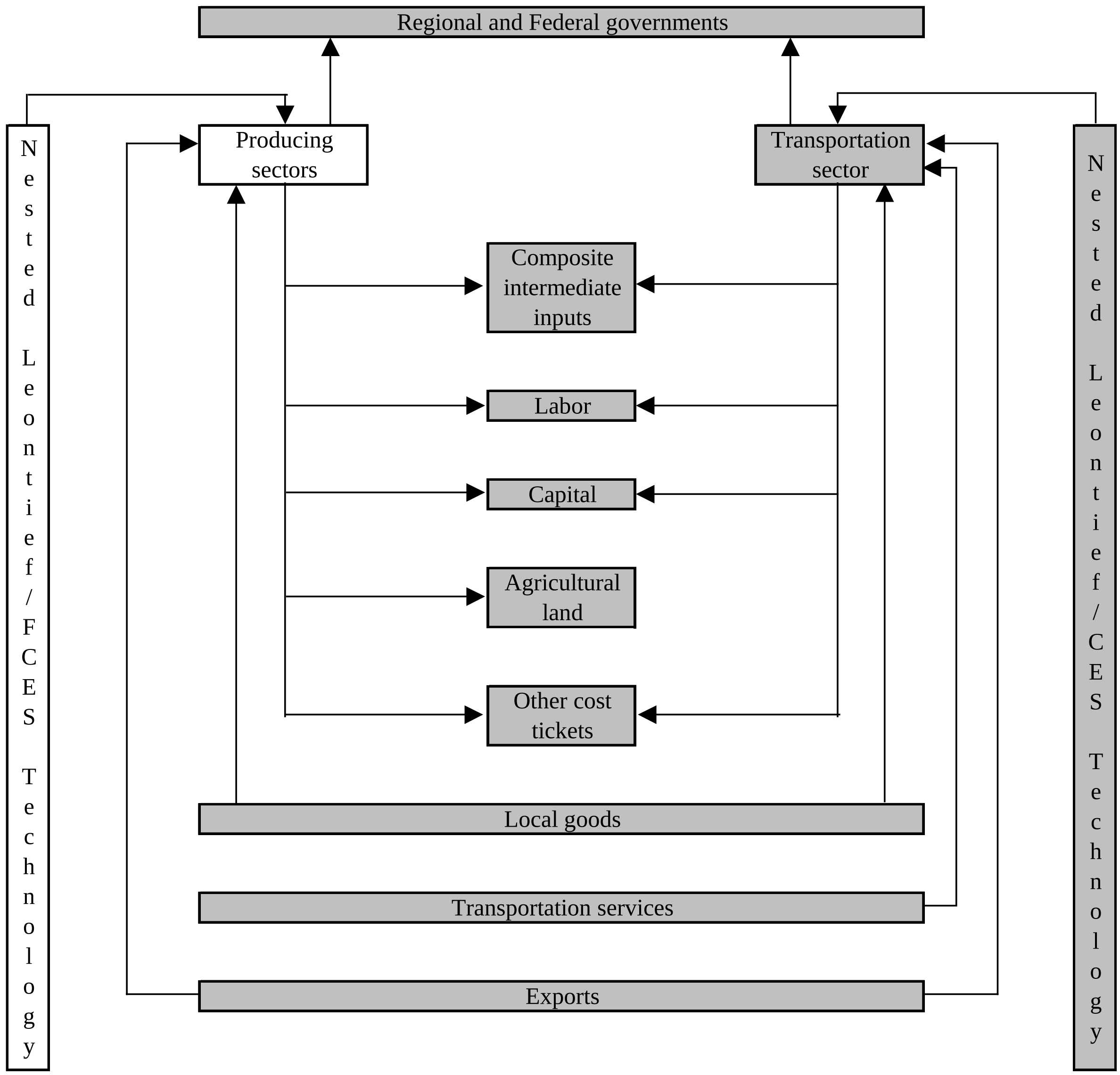
where *XMARG(i,s,q,r)* is the margin *r* on the flow of commodity *i*, produced in region *r* and consumed in region *q*; *AMARG(i,s,q,r)* is a technology variable related to commodity-specific origin-destination flows; $\eta(i,s,q,r)$ is the margin rate on specific basic flows; *X(i,s,q,r)* is the flow of commodity *i*, produced in region *r* and consumed in region *q*; and $\theta(i,s,q,r)$ is a parameter reflecting scale economies to (bulk) transportation. In the calibration of the model, $\theta(i,s,q,r)$ is set to one, for every flow.

In B-MARIA, transportation services (and trade services) are produced by a regional resource-demanding optimizing transportation (trade) 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. transportation 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). As will be shown, the model is 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.

Figure 1 highlights the production technology of a typical regional transport sector in B-MARIA in the broader regional technology. Regional transportation sectors are assumed to operate under constant returns to scale (nested Leontief/CES function), using as inputs composite intermediate goods – a bundle including similar inputs from different sources.[6] Locally supplied labor and capital are the primary factors used in the production process. Finally, the regional sector pays net taxes to Regional and Federal governments. The sectoral production serves both domestic and international markets.

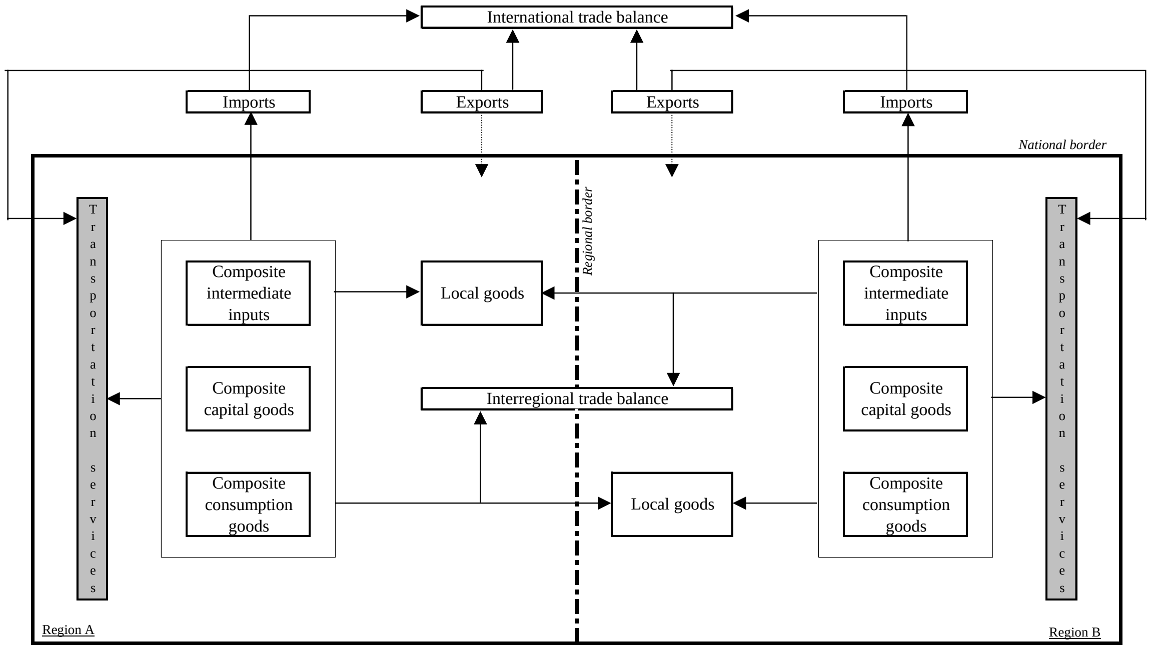
[6] The Armington assumption is used here.

Figure 1. Flowchart with Regional Production Technology in B-MARIA: Highlighting the Transportation Sector



As already mentioned, the supply of the transportation sector meets margin and non-margin demands. In the former case, Figure 2 illustrates the role of transportation services in the process of facilitating commodity flows. In a given consuming region, regionally produced transportation services provide the main mechanism to physically bring products (intermediate inputs, and capital and consumption goods) from different sources (local, other regions, other countries) to within the regional border. Also, foreign exporters use transportation services to take exports from the production site to the respective port of exit.

Figure 2. The Role of Transportation Services in B-MARIA: Illustrative Flowchart in a Two-Region Integrated Framework



The explicit modeling of transportation costs, based on origin-destination flows, which takes into account the spatial structure of the Brazilian economy, creates the capability of integrating the interstate CGE model with a geo-coded transportation network model, enhancing the potential of the framework in understanding the role of infrastructure on regional development. Two options for integration are available, using the linearized version of the model, in which equation (3) becomes[7]:

$$xm\arg(i,s,q,r) = am\arg(i,s,q,r) + \theta(i,s,q,r) * x(i,s,q,r) \quad (4)$$

Considering a fully specified geo-coded transportation network, one can simulate changes in the system, which might affect relative accessibility (e.g. road improvements, investments in new highways). A minimum distance matrix can be calculated *ex ante* and *ex post*, and mapped to the interregional CGE model. This mapping includes two stages, one associated with the calibration phase, and another with the simulation phase; both of them are discussed below.

3.2.1. Integration in the Calibration Phase

In the interstate CGE model, it is assumed that the *locus* of production and consumption in each state is located in the state capital. Thus, the relevant distances associated with the flows of commodities from points of production to points of consumption are limited to a matrix of distances between state capitals. Map 1 presents their location within the state borders. Moreover, in order to take into account intrastate transfer costs, it is assumed that trade within the state takes place on an abstract route between the capital and a point located at a distance

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[7] Equation (12) in the Appendix.

equal to half the implicit radius related to the state area.[8] The transport model calculates the minimum interstate distances, considering the existing road network in 1997. As Castro *et al*. (1999) observe, road transportation (i.e. truck) is responsible for the largest share of interstate trade in Brazil, accounting for well over 70% of the total value transported. In Brazil's North, however, fluvial transportation is particularly important, but the low quality of the services implies equivalent (high) logistic costs. Results for minimum distances are presented in Table 2.

<< Insert Map 1 here >>
<< Insert Table 2 here >>

The process of calibration of the B-MARIA model requires information on the transport and trade margins related to each commodity flow. Aggregated information for margins on intersectoral transactions, capital creation, household consumption, and exports are available at the national level. The problem remains to disaggregate this information considering previous spatial disaggregation of commodity flows in the generation of the interstate input-output accounts. Thus, given the available information – interstate/intrastate commodity flows, transport model, matrix of minimum interregional distances and national aggregates for specific margins, the strategy adopted considered the following steps:

1. In an attempt to capture scale effects in transportation – long-haul economies, a tariff function was used to calculate implicit logistic road transport costs in the interstate Brazilian system.[9] The function considered was estimated by Castro *et al*. (1999), for 1994, using freight cost data: $tariff = 0.25 * dist^{0.73}$, where *tariff* is the road transportation tariff; and *dist* refers to the distance between two points. This information was then combined with the matrix of minimum interstate distances to generate a matrix of tariffs evaluated for each path. Long-haul effects are clearly perceived in Figure 3, which plots tariffs for different distances within the relevant range for Brazilian interstate trade.

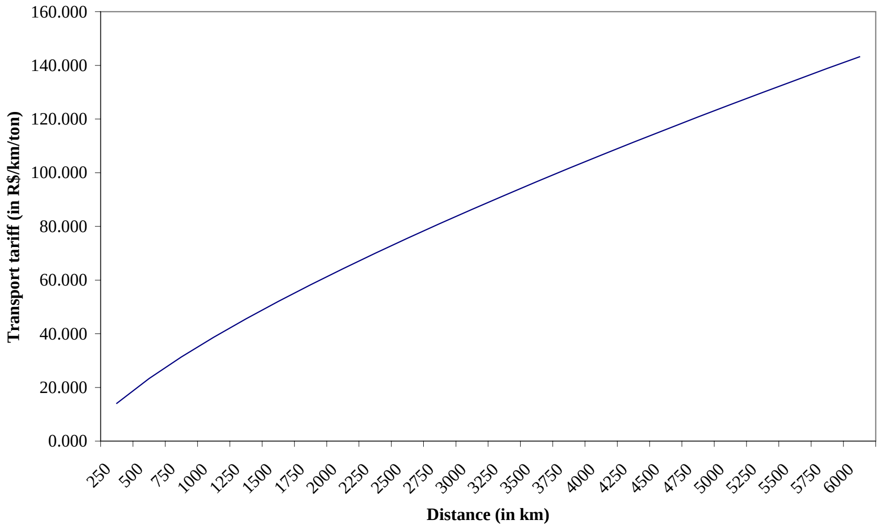
2. By using such transportation structure, one can capture not only the above-mentioned scale effects, but also relative transfer costs by different origin-destination pairs, which are to be used further on. With that in mind, an index of relative transportation cost was generated. The rows of the tariff matrix were normalized, providing information on differential transportation costs from a given state capital to other state capital, when compared to intrastate costs.

3. The estimates of the various commodity flows at basic values, embedded in the interstate input-output accounts, were then multiplied by the relevant indices from the normalized tariff matrix. This procedure provides the necessary information to generate a distribution matrix, which considers different spatial-destination weights for commodity flows originating in a given state.

[8] Given the state area, we assume the state is a circle and calculate the implicit radius.
[9] The general form of transport cost functions (…) is either linear or concave with distance. These reflect the usual empirical observations of the relationship between transport costs and haulage distance (McCann, 2001).

4. Finally, the distribution matrix was applied to national totals, considering disaggregated national information on margins by different users, maximizing the use of available information. Further balancing was necessary during the calibration of the model.

Figure 3. Estimated Logistic Road Transport Cost Function: (Castro *et al*., 1999)



In summary, the calibration strategy adopted here takes into account explicitly, for each origin-destination pair, key elements of the Brazilian integrated interstate economic system, namely: a) the type of trade involved (margins vary according to specific commodity flows); b) the transportation network (distance matters); and c) scale effects in transportation, in the form of long-haul economies. Moreover, the possibility of dealing explicitly with increasing returns to transportation is also introduced in the simulation phase, as discussed in the next section. The implicit average margin rates are presented below, for trade services, transportation services and total transfer services (Tables 3-5). Margin rates are calculated as a mark-up, considering the relation between margins and the respective basic flows.

<< Insert Table 3 here >>
<< Insert Table 4 here >>
<< Insert Table 5 here >>

3.2.2. Integration in the Simulation Phase

When running simulations with B-MARIA, one may want to consider changes in the physical transportation network. For instance, one may want to assess the spatial economic effects of an investment in a new highway, expenditures in road improvement, or even the adoption of a toll system, all of which will have direct impacts on transportation costs, either by reducing travel time or by directly increasing out-of-the pocket transfer payments. The challenge becomes one of finding ways to translate such policies into changes in the matrix of minimum interregional distances, mimicking potential reductions/increases in the distance between two or more points in space. Such a matrix serves as the basis for integrating the transport model to the interregional CGE model in the simulation phase.

One way to integrate both models, in a sequential path, requires the use of either the variable *amarg(i,s,q,r)* or the parameter $\theta(i,s,q,r)$, in equation (3), as linkage variables. Changes in the matrix of interregional distances are calculated in the transport model, so that an interface with the interregional CGE model is created.[10] As in the specification of the margin demand equations the variable distance is only implicitly portrayed in the parameter $\eta(i,s,q,r)$, one has to come up with ways in which the information generated by the transport model can be suitably incorporated. Specific transfer rates are present in the model, and changes in them can be easily associated with changes in the matrix of distances.

Let us consider, as an example, a two-region economy, consisted of regions A and B. Let us assume the minimum distance through the existing road network is 100km, on a highway that allows the maximum speed of 50 km/h. Thus, traveling 100 km between A and B takes 2 hours. Moreover, the transfer rate for the only commodity flow, from A to B, is 10%. If the government undertakes a project to improve the A-B link, so that, in the operational phase, maximum speed increases to 80 km/h, a change in the transfer rate due to a change in distance – in our example, travel time reduces to one hour and fifteen minutes (time reduction of 37.5%) – may be estimated, using a model-consistent transfer rate function. A new highway project may also be considered, and a more efficient road design may reduce distance between A and B to, say, 75 km. In this sense, if the new road speed limit is also 50 km/h, one can consider a shortening of distance of 25%. Other similar examples apply.

In the B-MARIA model, information on transfer (trade and transport) rates is available, and so is information on the relevant distances, enabling estimation of a model-consistent transportation cost function. With that in hand, changes in transfer rates can be estimated and incorporated in the interregional CGE model, as follows. Rearranging equation (3), we have:

$$\frac{XMARG(i,s,q,r)}{X(i,s,q,r)^{\theta(i,s,q,r)}} = AMARG(i,s,q,r) * \eta(i,s,q,r) \qquad (5)$$

with $\theta(i,s,q,r) = 1$ implying that the left-hand-side becomes the specific transfer (trade or transport) rate. A percentage change in the transfer rate can then be mapped into the technology variable, *AMARG(i,s,q,r)*. Thus, in percentage-change form, *amarg(i,s,q,r)* becomes the relevant linkage variable, as:

$$xm\arg(i,s,q,r) - x(i,s,q,r) = am\arg(i,s,q,r) \qquad (6)$$

The parameter $\theta(i,s,q,r)$ can also be used in the simulation phase, especially in sensitivity analysis experiments. Suppose, for instance, that scale effects to transportation appear for a given

[10] This procedure assumes one can translate time distance into Euclidean distance. Ideally, one should use a minimum *time* distance matrix to avoid shortcomings in the process mentioned above.

commodity flow, in a specific path. Changing assumptions on the values of $\theta(i,s,q,r)$ allows for addressing this issue in a proper way, instead of relying on hypotheses on the linkage variable, *AMARG(i,s,q,r)*. On this issue, Cukrowski and Fischer (2000), and Mansori (2003) have shown that these spatial implications are considered in the context of international trade, and therefore, increasing returns to transportation should be carefully considered.

3.3. The Household Demand System and Welfare Indicators

B-MARIA adopts the specification of household demand presented in the MONASH-MRF model (Peter *et al*., 1996). Consumption is specified via price and expenditure elasticities, which satisfy utility-maximizing conditions. Each representative regional household maximizes a Stone-Geary utility function subject to budget constraint.

Following Horridge (1991), the Stone-Geary or Klein-Rubin per-household utility function, which has the Cobb-Douglas form, is given by:

$$U^r = \sum_i \frac{1}{Q^r}(X_{(i\bullet)}^{(3)r} - \gamma_{(i)}^r)^{\beta_{(i)}^r} \qquad i = i,...,g; r = 1,...,R \tag{7}$$
$$\sum_{\text{i}} \beta_i^r = 1$$

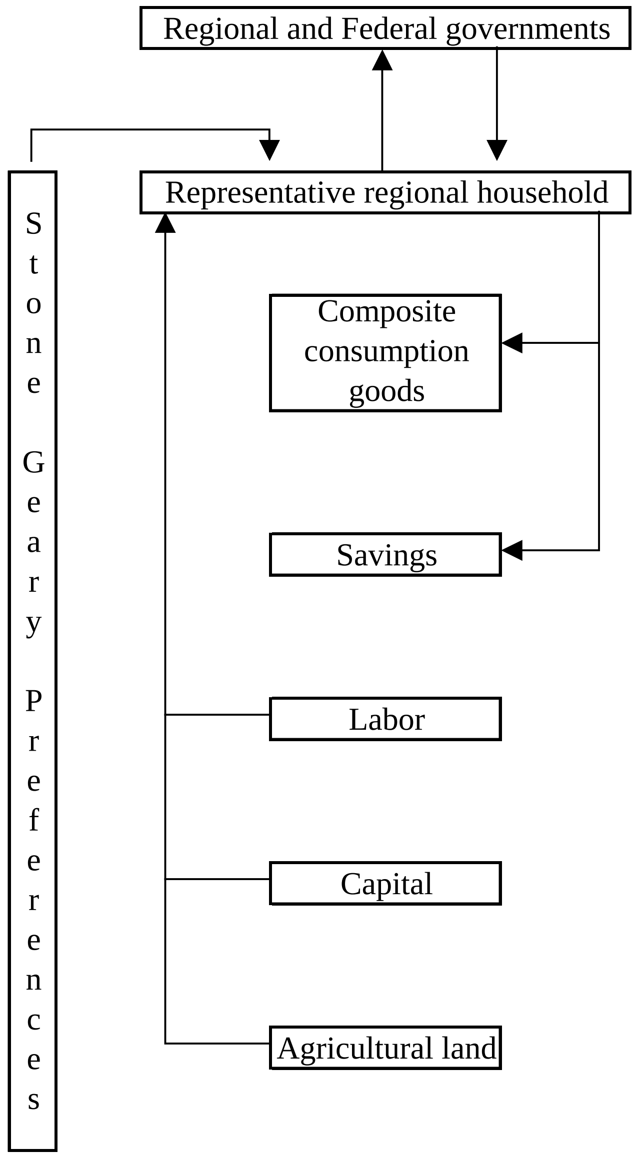
where $X_{(i\bullet)}^{(3)r}$ is the aggregate consumption of good *i* in region *r*, and $\gamma_{(i)}^r$ (subsistence quantity) and $\beta_{(i)}^r$ (marginal budget shares on total spending on luxuries) are vectors of parameters. As noted by Peter *et al*. (1996), a feature of the Stone-Geary utility function is that only the above-subsistence, or luxury, component affects the per-household utility.

It turns out that the resulting regional demand system implies that the amount spent on each above-subsistence quantity, $(X_{(i\bullet)}^{(3)r} - \gamma_{(i)}^r)$, is a constant share of the total amount spent on above-subsistence goods:

$$(X_{(i\bullet)}^{(3)r} - \gamma_{(i)}^r)P_{(k\bullet)}^{(3)r} = \beta_{(i)}^r \sum_k (X_{(k\bullet)}^{(3)r} - \gamma_{(k)}^r)P_{(k\bullet)}^{(3)r} \tag{8}$$

In the B-MARIA model, household preferences are described by a three-level utility function. Together with equation (8), source-specific demand functions, which are specified under the nested structure (Dixon and Rimmer, 2002), determine the composition of household composite good demands. Total household consumption is determined by regional household disposable income, whose definition includes the various components of income and expenditures for the representative households (Figure 4).

Figure 4. Flowchart with a Representative Regional Household in B-MARIA



3.3.1. Measures of welfare

The specification of the household demand system in the B-MARIA model allows the computation of measures of welfare. More specifically, one can calculate the equivalent variation (EV) associated with a policy change. The equivalent variation is the amount of money one would need to give to an individual, if an economic change did not happen, to make him as well off as if it did (Layard and Walters, 1978). The Hicksian measure of EV would consider computing the hypothetical change in income in prices of the post-shock equilibrium (Bröcker and Schneider, 2002). Alternatively, it can be measured as the *monetary change* of benchmark income the representative household would need in order to get a post-simulation utility under benchmark prices. More precisely, for homogenous linear utility functions, it can be written as (Almeida, 2003):

$$EV^r = \left(\frac{U^r(1) - U^r}{U^r} \right) I^r \qquad (9)$$

where $U^r(1)$ is the post-shock utility; U^r is the benchmark utility; and I^r is the benchmark household disposable income. Note that EV has the same sign as the direction of the change in welfare, i.e., for a welfare gain (loss) it is positive (negative). Aggregate (national) welfare can be assessed by simply summing up the regional EV^r over *r*.

Another informative welfare measure refers to the relative equivalent variation (REV). It is defined as the *percentage change* of benchmark income the representative household would need in order to get a post-simulation utility under benchmark prices (Bröcker, 1998). That is:

$$REV^r = \frac{EV^r}{I^r} \qquad (10)$$

3.3.1.1. Calibration

Calibration of the household demand system in B-MARIA requires benchmark values for each regional household's income and expenditure flows, which are derived from the SAM database, and estimates for the regional budget shares, $\beta^r_{(i)}$ (see Dixon *et al*., 1982).

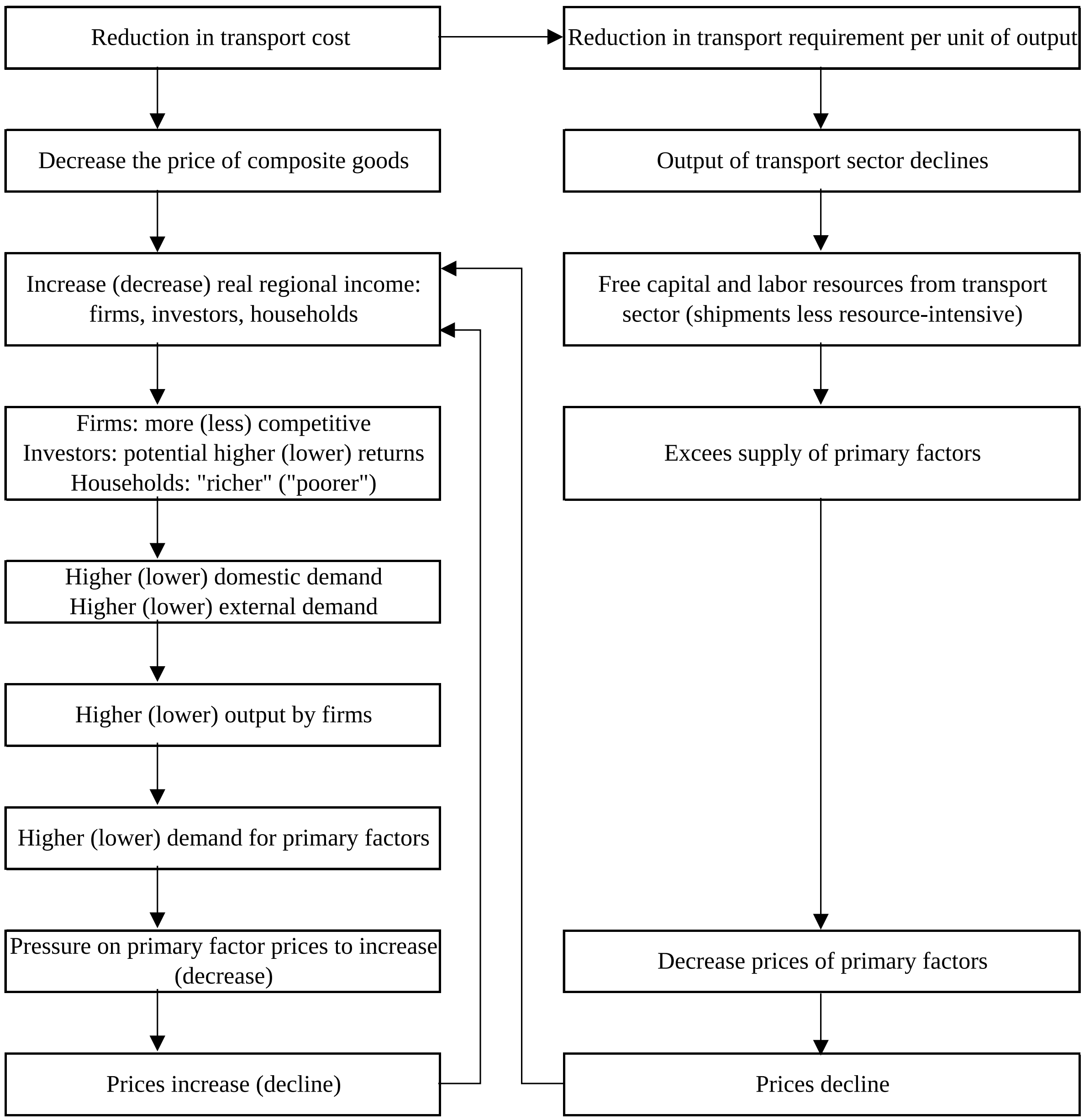
4. Simulations

In this section, the main results from the simulations are presented. The basic experiment consisted of the evaluation of an overall 1% reduction in transportation cost within the country. In other words, for every domestic origin-destination pairs, the usage of transportation margins is reduced by 1%. The simulations were carried out under two different economic environments: short-run and long-run. The idea behind this exercise is to assess potential efficiency gains in the transportation network associated with regulation issues, as discussed in the introduction.

4.1 Functioning Mechanism

In this sub-section, we present the main causal relationships underlying the simulation results. The simulation exercise considers an overall reduction in the transportation cost in the Brazilian interstate system. According to the model structure, this represents a margin-saving change, i.e. the use of transportation services per unit of output is reduced, implying a direct reduction in the output of the transportation sector. As shipments become less resource-intensive, labor and capital are freed generating excess supply of primary factors in the economic system. This creates a downward pressure on wages and capital rentals, which are passed on in the form of lower prices. A more comprehensive attempt would need to link this system with a model of the transportation shippers' market to explore the degree to which de-regulation would effect downward pressure of transportation costs and the extent to which these changes would or would not been uniform across commodities and interstate routes.

Figure 5. Causal Relationships in the Simulation



The reduction in transport cost decreases the price of composite commodities, with positive implications for real regional income: in this cost-competitiveness approach, firms become more competitive – as production costs go down (inputs are less costly); investors foresee potential higher returns – as the cost of producing capital also declines; and households increase their real income, envisaging higher consumption possibilities. Higher income generates higher domestic demand, while increases in the competitiveness of national products stimulates external demand. This creates room for increasing firms' output – directed for both domestic and international markets – which requires more inputs and primary factors. Increasing demand puts pressure on the factor markets for price increases, with a concomitant expectation that the prices of domestic goods would increase.

Second-order prices changes go in both directions – decrease and increase. The net effect is determined by the relative strength of the countervailing forces. Figure 5 summarizes the transmission mechanisms associated with major first-order and second-order effects in the adjustment process underlying the model's aggregate results.

As for the differential spatial effects, three major forces operate in the short-run – two price effects and one income effect – and the net result will heavily depend on the structure of the integrated interstate system. Regarding regional performance, two substitution mechanisms through price effects are relevant to understand the adjustment process. First, there is a direct substitution effect. Consider two trading regions, one exporting and another importing, *r* and *s*, respectively. As transportation costs between the two regions go down, *r* will increase its penetration in *s*, producing more for *s*, as it is now cheaper to buy from *r*. A substitution effect operates in the sense that *s* will directly substitute output from *r* for either regional output, or other regions' output (including foreign products).

Moreover, another substitution effect operates. In order to produce for *s*, *r* will buy inputs from other regions. As these inputs are now cheaper, due to reductions in transportation costs, region *r*, with better access to input sources, becomes more competitive, expanding its output. This is the indirect substitution effect.

However, a third countervailing force appears in the form of an income effect. With better accessibility, the demand for products from region *r* increases. The sources of higher demand for the region's output come from a substitution effect – prices of *r*'s output are now lower – and an income effect – real income increases. This put pressures on prices, and the net effect will depend whether the direct and indirect substitution effects will prevail over the income effect.

In the long-run, a fourth mechanism becomes relevant: the "re-location" effect. As factors are free to move between regions, new investment decisions define marginal re-location of activities, in the sense that the spatial distribution of capital stocks and the population changes. The main mechanism affecting regional performance is associated with capital creation. As transportation costs decreases, better access to non-local capital goods increases the rate of returns in the regions. At the same time this potentially benefits capital importing regions, it has a positive impact on the capital-good sectors in the producing regions.

Finally, regions might be adversely affected through re-orientation of trade flows (trade diversion), as relative accessibility changes in the system. Thus, overall gains in efficiency in the transportation sector are not necessarily accompanied by overall gains in welfare. This issue of trade diversion versus trade creation has been an important one in the international trade literature.

4.2. Results

The presentation of the simulation results is divided in four groups.

First, we present the basic results under the short-run and long-run closures, focusing on the relevant aggregate variables that help us understanding the functioning mechanism of the model, as described in the previous sub-section. Spatial effects considering changes in welfare and real GDP are also presented.

Secondly, we check the robustness of the results for the key parameters related to the simulation exercises, namely, regional trade elasticities, and parameters to scale economies. To reach this goal, systematic sensitivity analysis is carried out.

Thirdly, we take a closer look at the long-run results, as they seem to be more closely linked to expected outcomes of transportation policies. Scaffolding of the spatial results is considered in order to evaluate analytically important transportation links to optimize specific policy goals.

Fourthly, as an attempt to better understand the role of increasing returns in the spatial allocation of activities in an integrated interregional system, we adjust the parameter of scale economies in the São Paulo manufacturing sector with the idea to check whether, in the Brazilian case, with improvements in transportation, the São Paulo firms have a competitive advantage to further exploit scale economies with reductions in transportation costs, thereby exacerbating the welfare differentials between regions.

4.2.1. Basic Results

Table 6 summarizes the results of the two simulations. Gains in efficiency (real GDP growth) and welfare (equivalent variation) are positive, and magnified in the long-run. Table 7 presents the efficiency and welfare spatial effects. While in terms of efficiency, states in the Center-South seem to have a better performance, in terms of welfare, households in the less developed regions with better access to producing regions appear to be better-off.

Table 6. Aggregate Results (in percentage-change)

Activity level	*Short-run*	*Long-run*
Agriculture	0.0016	0.0020
Manufacturing	0.0030	0.0069
Utilities	0.0003	0.0074
Construction	-0.0002	0.0021
Trade	0.0002	0.0056
Financial institutions	0.0021	0.0127
Public administration	0.0004	0.0088
Transportation and other services	-0.0098	-0.0067
Total	-0.0015	0.0026
Prices		
Investment price index	-0.0172	-0.0212
Consumer price index	-0.0239	-0.0213
Exports price index	-0.0132	-0.0181
Regional government demand price index	-0.0240	-0.0138
Federal government demand price index	-0.0250	-0.0217
GDP price index, expenditure side	-0.0236	-0.0210
Primary factors		
Aggregate payments to capital	-0.0256	-0.0201
Aggregate payments to labor	-0.0279	-0.0165
Aggregate capital stock, rental weights	-	0.0018
Aggregate employment, wage bill weights	-0.0040	0.0039
Aggregate demand		
Real household consumption	0.0006	0.0082
Aggregate real investment expenditure	-	0.0049
Aggregate real regional government demand	-	0.0125
Aggregate real Federal government demand	-	0.0082
Export volume	0.0273	0.0025
Aggregate indicators		
Equivalent variation – total (change in $)	8.97	168.44
Real GDP	0.0031	0.0067

Table 7. Spatial Results

	Short-run			Long-run		
	EV	*REV*	*GDP*	*EV*	*REV*	*GDP*
Acre	0.46	0.062%	0.0059	1.30	0.176%	-0.1905
Amapá	0.41	0.043%	0.0101	4.77	0.507%	-0.0263
Amazonas	2.64	0.015%	0.0039	5.23	0.030%	0.0016
Pará	2.71	0.028%	0.0037	31.61	0.326%	-0.0271
Rondônia	0.64	0.025%	0.0034	0.85	0.033%	0.0350
Roraima	0.26	0.075%	0.0110	-0.36	-0.103%	0.2589
Tocantins	0.24	0.024%	0.0102	0.72	0.070%	0.0473
Alagoas	2.06	0.058%	0.0062	-5.28	-0.150%	0.1602
Bahia	5.56	0.020%	0.0043	13.54	0.048%	-0.0004
Ceará	3.09	0.028%	0.0052	-17.20	-0.157%	0.0520
Maranhão	2.55	0.054%	0.0082	1.83	0.039%	0.0330
Paraíba	1.76	0.033%	0.0049	24.17	0.450%	-0.1384
Pernambuco	5.54	0.033%	0.0055	52.41	0.309%	-0.0357
Piauí	0.71	0.029%	0.0079	-6.93	-0.284%	0.2080
Rio Grande do Norte	1.77	0.041%	0.0045	-0.07	-0.002%	0.0406
Sergipe	0.75	0.023%	0.0025	1.55	0.048%	0.0296
Espírito Santo	-0.35	-0.003%	0.0030	3.42	0.030%	-0.0018
Minas Gerais	5.33	0.009%	0.0054	124.06	0.214%	-0.0383
Rio de Janeiro	-1.86	-0.002%	0.0019	-6.94	-0.008%	0.0113
São Paulo	-21.51	-0.008%	0.0026	-110.54	-0.041%	0.0185
Paraná	1.93	0.005%	0.0020	1.07	0.003%	0.0116
Santa Catarina	-0.99	-0.004%	0.0023	-8.41	-0.035%	0.0119
Rio Grande do Sul	0.69	0.001%	0.0032	52.68	0.092%	-0.0183
Distrito Federal	-3.79	-0.012%	0.0015	17.12	0.056%	0.0065
Goiás	0.29	0.003%	0.0030	-1.41	-0.016%	0.0305
Mato Grosso	-1.11	-0.015%	0.0035	-11.89	-0.161%	0.0387
Mato Grosso do Sul	-0.80	-0.010%	0.0018	1.12	0.014%	0.0063
Brazil	8.97	0.001%	0.0031	168.44	0.024%	0.0067

EV measured in 1996 R$ millions; REV measured in % of benchmark disposable income; GDP measured as a percentage-change in real terms.

4.2.2. Systematic Sensitivity Analysis[11]

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

[11] The discussion below draws on Domingues *et al*. (2003).

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 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 the B-MARIA-27 model, one set of regional trade elasticities in the Armington demand structure determines the substitution possibilities between goods from different domestic sources. Smaller trade elasticities imply less substitution among regional sources in the model. The change in the results will depend on the interaction of the transportation cost cuts, price responses and these elasticities. Table 8 shows the default values in the aggregation used in this paper. Data from the balanced interstate SAM were extracted to estimate implicit regional trade elasticities, to be used in the calibration of the model. This procedure guarantees data consistency between the SAM database and the estimated parameters. Moreover, it is now possible to provide point and standard error estimates for such key parameters. However, the model-consistent information is not free from the structural constraints imposed during the process of building the SAM; on the other hand, without this information, proper estimation would not be possible. The second group of sensitivity analyses was carried out in the scale economies parameters, μ.

<<Insert Table 8 here >>

The transportation cost reduction experiments discussed above are employed using the Gaussian Quadrature approach to establish confidence intervals for the main results. The range for the elasticities was set to +/- one standard error estimate around the default value, with independent, symmetric, triangular distributions for the two parameters.

Tables 9-16 summarize the sensitivity of GDP and welfare results in each Brazilian state for the ranges in the two individual sets of parameters. The lower bound and the upper bound columns represent the 90% confidence intervals for the estimates, constructed using Chebyshev’s inequality.

We observe that, in general, state results are relatively more robust in the short-run rather than in the long-run, and also more robust to scale economies parameters rather than to regional trade elasticities. Overall, the state simulation results can be considered robust to both sets of parameters. In some cases, however, qualitative changes can be observed for the SSA of the trade elasticities: in the long-run, direction of welfare in Rio Grande do Norte, Rio de Janeiro, Paraná, Santa Catarina, and Goiás is inconclusive; direction of GDP growth in the states of Amazonas, Bahia, Pernambuco, Espírito Santo, and Goiás is also inconclusive.

Table 9. Systematic Sensitivity Analysis – Trade Elasticities Short-run Welfare Changes (R$ millions)

	Lower bound	*Upper bound*
Acre	0.46	0.46
Amapá	0.41	0.41
Amazonas	2.62	2.65
Pará	2.69	2.73
Rondônia	0.63	0.65
Roraima	0.26	0.26
Tocantins	0.24	0.25
Alagoas	2.05	2.06
Bahia	5.53	5.58
Ceará	3.08	3.11
Maranhão	2.54	2.56
Paraíba	1.75	1.76
Pernambuco	5.53	5.55
Piauí	0.71	0.71
Rio Grande do Norte	1.77	1.79
Sergipe	0.74	0.75
Espírito Santo	-0.37	-0.33
Minas Gerais	5.28	5.38
Rio de Janeiro	-1.97	-1.76
São Paulo	-21.59	-21.44
Paraná	1.91	1.95
Santa Catarina	-1.00	-0.98
Rio Grande do Sul	0.65	0.72
Distrito Federal	-3.82	-3.75
Goiás	0.27	0.31
Mato Grosso	-1.11	-1.10
Mato Grosso do Sul	-0.81	-0.79
Brazil	8.81	9.14

Table 10. Systematic Sensitivity Analysis – Trade Elasticities Short-run GDP Changes (percentage change)

	Lower bound	*Upper bound*
Acre	0.0058	0.0059
Amapá	0.0101	0.0101
Amazonas	0.0039	0.0039
Pará	0.0037	0.0038
Rondônia	0.0033	0.0034
Roraima	0.0110	0.0110
Tocantins	0.0099	0.0105
Alagoas	0.0062	0.0062
Bahia	0.0043	0.0043
Ceará	0.0052	0.0052
Maranhão	0.0081	0.0082
Paraíba	0.0049	0.0049
Pernambuco	0.0055	0.0055
Piauí	0.0078	0.0079
Rio Grande do Norte	0.0044	0.0045
Sergipe	0.0025	0.0025
Espírito Santo	0.0029	0.0030
Minas Gerais	0.0054	0.0055
Rio de Janeiro	0.0019	0.0019
São Paulo	0.0026	0.0026
Paraná	0.0020	0.0020
Santa Catarina	0.0023	0.0023
Rio Grande do Sul	0.0031	0.0032
Distrito Federal	0.0014	0.0016
Goiás	0.0029	0.0030
Mato Grosso	0.0035	0.0036
Mato Grosso do Sul	0.0018	0.0018
Brazil	0.0031	0.0031

Table 11. Systematic Sensitivity Analysis – Trade Elasticities Long-run Welfare Changes (R$ millions)

	Lower bound	*Upper bound*
Acre	1.27	1.33
Amapá	4.44	5.08
Amazonas	1.32	8.97
Pará	27.34	35.93
Rondônia	0.72	0.96
Roraima	-0.42	-0.29
Tocantins	0.55	0.88
Alagoas	-7.62	-3.18
Bahia	12.53	14.53
Ceará	-26.91	-8.25
Maranhão	0.65	2.97
Paraíba	13.49	35.80
Pernambuco	18.41	90.43
Piauí	-8.91	-4.93
Rio Grande do Norte	-1.34	1.14
Sergipe	0.85	2.30
Espírito Santo	2.22	4.55
Minas Gerais	116.15	131.44
Rio de Janeiro	-19.70	5.04
São Paulo	-216.62	-9.27
Paraná	-4.37	7.14
Santa Catarina	-24.58	6.27
Rio Grande do Sul	51.27	54.07
Distrito Federal	13.41	21.05
Goiás	-5.42	2.54
Mato Grosso	-13.63	-10.28
Mato Grosso do Sul	0.06	2.14
Brazil	87.42	246.09

Table 12. Systematic Sensitivity Analysis – Trade Elasticities Long-run GDP Changes (percentage change)

	Lower bound	*Upper bound*
Acre	-0.1973	-0.1830
Amapá	-0.0281	-0.0241
Amazonas	-0.0024	0.0057
Pará	-0.0338	-0.0205
Rondônia	0.0304	0.0395
Roraima	0.2475	0.2708
Tocantins	0.0445	0.0506
Alagoas	0.1300	0.1945
Bahia	-0.0008	0.0000
Ceará	0.0277	0.0775
Maranhão	0.0281	0.0380
Paraíba	-0.2228	-0.0609
Pernambuco	-0.0757	0.0001
Piauí	0.1824	0.2327
Rio Grande do Norte	0.0399	0.0412
Sergipe	0.0122	0.0456
Espírito Santo	-0.0046	0.0011
Minas Gerais	-0.0402	-0.0362
Rio de Janeiro	0.0090	0.0138
São Paulo	0.0092	0.0283
Paraná	0.0091	0.0137
Santa Catarina	0.0010	0.0240
Rio Grande do Sul	-0.0190	-0.0176
Distrito Federal	0.0050	0.0080
Goiás	-0.0031	0.0645
Mato Grosso	0.0354	0.0421
Mato Grosso do Sul	0.0012	0.0116
Brazil	0.0045	0.0091

Table 13. Systematic Sensitivity Analysis – Scale Economies Parameters Short-run Welfare Changes (R$ millions)

	Lower bound	*Upper bound*
Acre	0.46	0.46
Amapá	0.41	0.41
Amazonas	2.64	2.64
Pará	2.71	2.71
Rondônia	0.64	0.64
Roraima	0.26	0.26
Tocantins	0.24	0.24
Alagoas	2.06	2.06
Bahia	5.56	5.56
Ceará	3.09	3.10
Maranhão	2.55	2.55
Paraíba	1.75	1.76
Pernambuco	5.54	5.54
Piauí	0.71	0.71
Rio Grande do Norte	1.77	1.78
Sergipe	0.75	0.75
Espírito Santo	-0.35	-0.35
Minas Gerais	5.32	5.34
Rio de Janeiro	-1.87	-1.86
São Paulo	-21.54	-21.49
Paraná	1.92	1.93
Santa Catarina	-0.99	-0.98
Rio Grande do Sul	0.68	0.69
Distrito Federal	-3.79	-3.78
Goiás	0.29	0.29
Mato Grosso	-1.11	-1.10
Mato Grosso do Sul	-0.80	-0.80
Brazil	8.94	9.00

Table 14. Systematic Sensitivity Analysis – Scale Economies Parameters Short-run GDP Changes (percentage change)

	Lower bound	*Upper bound*
Acre	0.0059	0.0059
Amapá	0.0101	0.0101
Amazonas	0.0039	0.0039
Pará	0.0037	0.0037
Rondônia	0.0033	0.0034
Roraima	0.0110	0.0110
Tocantins	0.0102	0.0102
Alagoas	0.0062	0.0062
Bahia	0.0043	0.0043
Ceará	0.0052	0.0052
Maranhão	0.0081	0.0083
Paraíba	0.0049	0.0049
Pernambuco	0.0055	0.0055
Piauí	0.0078	0.0079
Rio Grande do Norte	0.0045	0.0045
Sergipe	0.0025	0.0025
Espírito Santo	0.0030	0.0030
Minas Gerais	0.0054	0.0055
Rio de Janeiro	0.0019	0.0019
São Paulo	0.0026	0.0026
Paraná	0.0020	0.0020
Santa Catarina	0.0023	0.0023
Rio Grande do Sul	0.0031	0.0032
Distrito Federal	0.0015	0.0015
Goiás	0.0030	0.0030
Mato Grosso	0.0035	0.0036
Mato Grosso do Sul	0.0018	0.0018
Brazil	0.0031	0.0031

Table 15. Systematic Sensitivity Analysis – Scale Economies Parameters Long-run Welfare Changes (R$ millions)

	Lower bound	*Upper bound*
Acre	1.30	1.31
Amapá	4.47	5.08
Amazonas	5.00	5.47
Pará	31.41	31.83
Rondônia	0.81	0.89
Roraima	-0.36	-0.35
Tocantins	0.71	0.73
Alagoas	-5.38	-5.18
Bahia	13.44	13.65
Ceará	-17.62	-16.77
Maranhão	1.79	1.88
Paraíba	23.93	24.40
Pernambuco	51.54	53.26
Piauí	-7.63	-6.24
Rio Grande do Norte	-0.11	-0.03
Sergipe	1.45	1.65
Espírito Santo	3.37	3.49
Minas Gerais	122.40	125.71
Rio de Janeiro	-7.75	-6.17
São Paulo	-118.26	-102.31
Paraná	0.23	1.92
Santa Catarina	-9.59	-7.21
Rio Grande do Sul	51.80	53.57
Distrito Federal	16.83	17.39
Goiás	-1.57	-1.25
Mato Grosso	-13.55	-10.28
Mato Grosso do Sul	1.03	1.22
Brazil	162.24	175.05

Table 16. Systematic Sensitivity Analysis – Scale Economies Parameters Long-run GDP Changes (percentage change)

	Lower bound	*Upper bound*
Acre	-0.1940	-0.1870
Amapá	-0.0295	-0.0231
Amazonas	0.0012	0.0019
Pará	-0.0274	-0.0268
Rondônia	0.0340	0.0360
Roraima	0.2574	0.2603
Tocantins	0.0464	0.0483
Alagoas	0.1582	0.1622
Bahia	-0.0005	-0.0004
Ceará	0.0511	0.0528
Maranhão	0.0323	0.0336
Paraíba	-0.1402	-0.1366
Pernambuco	-0.0366	-0.0348
Piauí	0.1916	0.2247
Rio Grande do Norte	0.0403	0.0409
Sergipe	0.0284	0.0307
Espírito Santo	-0.0020	-0.0017
Minas Gerais	-0.0388	-0.0378
Rio de Janeiro	0.0111	0.0116
São Paulo	0.0178	0.0192
Paraná	0.0108	0.0124
Santa Catarina	0.0112	0.0127
Rio Grande do Sul	-0.0187	-0.0180
Distrito Federal	0.0064	0.0066
Goiás	0.0275	0.0337
Mato Grosso	0.0345	0.0431
Mato Grosso do Sul	0.0059	0.0066
Brazil	0.0066	0.0069

4.2.3. Analytically Important Trasnportation Link

Ii has been argued that, 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 "black-box syndrome". However, some important points should be addressed 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 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.[12]

In order to address this issue, in the context of our long-run simulation, we proceeded with a thorough decomposition of the results considering the role played by the various shocks. In other words, we explicitly considered the role played by each transportation link – 27x27 in total – in generating the model's results.[13] For each transportation link, we calculated its contribution to the total outcome, considering different dimensions of regional policy. Impacts on regional efficiency and welfare were considered. We looked at the effects on regional efficiency, through the differential impacts on GDP growth for the five Brazilian macro regions (North, Northeast, Southeast, South and Center-West), and for the country as a whole (systemic efficiency). Moreover, we considered the differential impacts on regional welfare, looking at the specific macro regional results, and also at total national welfare.

Tables 17-22 present the results for the different policy targets. Transportation links between and within macro regions are explicitly considered, and the estimates of their contributions to the specific policy outcome are presented.

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

[13] We were able to consider the two-way dimension of a transportation link between to regions, i.e. the way "in" and the way "out".

Table 17. Short-Run Regional and Total Welfare Effects: Decomposition of equivalent variation (EV) according to origin-destination pairs of transportation cost reductions (-1%)

North

Origin \ Destination	N	NE	SE	S	CO	Total
N	2.92	-0.03	-0.12	-0.01	0.00	*2.75*
NE	0.72	-0.40	-0.16	-0.02	-0.01	*0.13*
SE	6.50	-0.61	-1.65	-0.29	-0.26	*3.68*
S	1.55	-0.16	-0.29	-0.36	-0.07	*0.66*
CW	0.37	-0.02	-0.11	-0.01	-0.10	*0.14*
Total	*12.06*	*-1.21*	*-2.34*	*-0.70*	*-0.45*	*7.36*

South

Origin \ Destination	N	NE	SE	S	CW	Total
N	-0.33	-0.08	-0.25	0.27	0.00	*-0.39*
NE	-0.08	-1.20	-0.35	0.49	-0.03	*-1.17*
SE	-0.72	-1.85	-3.98	5.93	-0.64	*-1.26*
S	-0.15	-0.49	-0.70	6.35	-0.12	*4.88*
CW	-0.04	-0.05	-0.28	0.16	-0.23	*-0.43*
Total	*-1.32*	*-3.66*	*-5.58*	*13.21*	*-1.02*	*1.63*

Northeast

Origin \ Destination	N	NE	SE	S	CW	Total
N	-0.48	0.77	-0.59	-0.06	-0.02	*-0.37*
NE	-0.12	13.55	-0.75	-0.10	-0.06	*12.52*
SE	-0.99	20.78	-7.53	-1.22	-1.18	*9.86*
S	-0.20	5.55	-1.35	-1.38	-0.33	*2.28*
CW	-0.05	0.53	-0.51	-0.03	-0.44	*-0.50*
Total	*-1.84*	*41.18*	*-10.74*	*-2.79*	*-2.02*	*23.79*

Center-west

Origin \ Destination	N	NE	SE	S	CW	Total
N	-0.23	-0.05	-0.26	-0.03	0.04	*-0.54*
NE	-0.06	-0.83	-0.32	-0.05	0.10	*-1.16*
SE	-0.49	-1.28	-3.21	-0.60	2.13	*-3.45*
S	-0.10	-0.34	-0.56	-0.48	0.66	*-0.83*
CW	-0.02	-0.03	-0.20	-0.02	0.85	*0.58*
Total	*-0.90*	*-2.54*	*-4.57*	*-1.18*	*3.79*	*-5.40*

Southeast

Origin \ Destination	N	NE	SE	S	CW	Total
N	-1.42	-0.29	0.44	-0.16	-0.04	*-1.46*
NE	-0.34	-4.44	0.66	-0.28	-0.14	*-4.53*
SE	-2.91	-6.80	10.37	-3.39	-2.88	*-5.62*
S	-0.57	-1.82	1.40	-3.99	-0.80	*-5.78*
CW	-0.13	-0.17	0.49	-0.09	-1.09	*-1.01*
Total	*-5.37*	*-13.52*	*13.35*	*-7.91*	*-4.95*	*-18.40*

Brazil

Origin \ Destination	N	NE	SE	S	CW	Total
N	0.46	0.32	-0.79	0.02	-0.02	*-0.01*
NE	0.13	6.68	-0.93	0.03	-0.13	*5.78*
SE	1.39	10.24	-6.01	0.42	-2.83	*3.21*
S	0.53	2.73	-1.52	0.14	-0.67	*1.21*
CW	0.13	0.26	-0.62	0.01	-1.00	*-1.22*
Total	*2.63*	*20.24*	*-9.87*	*0.63*	*-4.65*	*8.97*

Table 18. Short-Run Regional and Total Welfare Effects: Decomposition of relative equivalent variation (REV) according to origin-destination pairs of transportation cost reductions (-1%)

North

Origin		*Destination* N	NE	SE	S	CO	Total
	N	0.009%	0.000%	0.000%	0.000%	0.000%	*0.008%*
	NE	0.002%	-0.001%	0.000%	0.000%	0.000%	*0.000%*
	SE	0.020%	-0.002%	-0.005%	-0.001%	-0.001%	*0.011%*
	S	0.005%	-0.001%	-0.001%	-0.001%	0.000%	*0.002%*
	CW	0.001%	0.000%	0.000%	0.000%	0.000%	*0.000%*
	Total	*0.037%*	*-0.004%*	*-0.007%*	*-0.002%*	*-0.001%*	*0.022%*

South

Origin		*Destination* N	NE	SE	S	CW	Total
	N	0.000%	0.000%	0.000%	0.000%	0.000%	*0.000%*
	NE	0.000%	-0.001%	0.000%	0.000%	0.000%	*-0.001%*
	SE	-0.001%	-0.002%	-0.003%	0.005%	-0.001%	*-0.001%*
	S	0.000%	0.000%	-0.001%	0.005%	0.000%	*0.004%*
	CW	0.000%	0.000%	0.000%	0.000%	0.000%	*0.000%*
	Total	*-0.001%*	*-0.003%*	*-0.005%*	*0.011%*	*-0.001%*	*0.001%*

Northeast

Origin		*Destination* N	NE	SE	S	CW	Total
	N	-0.001%	0.001%	-0.001%	0.000%	0.000%	*0.000%*
	NE	0.000%	0.017%	-0.001%	0.000%	0.000%	*0.016%*
	SE	-0.001%	0.026%	-0.009%	-0.002%	-0.001%	*0.012%*
	S	0.000%	0.007%	-0.002%	-0.002%	0.000%	*0.003%*
	CW	0.000%	0.001%	-0.001%	0.000%	-0.001%	*-0.001%*
	Total	*-0.002%*	*0.052%*	*-0.013%*	*-0.004%*	*-0.003%*	*0.030%*

Center-west

Origin		*Destination* N	NE	SE	S	CW	Total
	N	0.000%	0.000%	0.000%	0.000%	0.000%	*-0.001%*
	NE	0.000%	-0.002%	-0.001%	0.000%	0.000%	*-0.002%*
	SE	-0.001%	-0.002%	-0.006%	-0.001%	0.004%	*-0.006%*
	S	0.000%	-0.001%	-0.001%	-0.001%	0.001%	*-0.002%*
	CW	0.000%	0.000%	0.000%	0.000%	0.002%	*0.001%*
	Total	*-0.002%*	*-0.005%*	*-0.008%*	*-0.002%*	*0.007%*	*-0.010%*

Southeast

Origin		*Destination* N	NE	SE	S	CW	Total
	N	0.000%	0.000%	0.000%	0.000%	0.000%	*0.000%*
	NE	0.000%	-0.001%	0.000%	0.000%	0.000%	*-0.001%*
	SE	-0.001%	-0.002%	0.002%	-0.001%	-0.001%	*-0.001%*
	S	0.000%	0.000%	0.000%	-0.001%	0.000%	*-0.001%*
	CW	0.000%	0.000%	0.000%	0.000%	0.000%	*0.000%*
	Total	*-0.001%*	*-0.003%*	*0.003%*	*-0.002%*	*-0.001%*	*-0.004%*

Brazil

Origin		*Destination* N	NE	SE	S	CW	Total
	N	0.000%	0.000%	0.000%	0.000%	0.000%	*0.000%*
	NE	0.000%	0.001%	0.000%	0.000%	0.000%	*0.001%*
	SE	0.000%	0.001%	-0.001%	0.000%	0.000%	*0.000%*
	S	0.000%	0.000%	0.000%	0.000%	0.000%	*0.000%*
	CW	0.000%	0.000%	0.000%	0.000%	0.000%	*0.000%*
	Total	*0.000%*	*0.003%*	*-0.001%*	*0.000%*	*-0.001%*	*0.001%*

Table 19. Long-Run Regional and Total Welfare Effects: Decomposition of equivalent variation (EV) according to origin-destination pairs of transportation cost reductions (-1%)

North

		Destination					
		N	**NE**	**SE**	**S**	**CO**	**Total**
Origin	**N**	12.89	-0.20	0.43	-0.24	0.13	*13.02*
	NE	4.40	-1.31	0.14	-0.43	0.15	*2.96*
	SE	30.42	-1.78	-3.92	-5.22	3.52	*23.02*
	S	8.05	-1.08	-0.44	-5.09	1.67	*3.11*
	CW	1.62	-0.13	-0.34	-0.14	1.00	*2.00*
	Total	*57.38*	*-4.49*	*-4.13*	*-11.13*	*6.48*	*44.11*

South

		Destination					
		N	**NE**	**SE**	**S**	**CW**	**Total**
Origin	**N**	-0.12	0.21	-1.67	1.55	-0.09	*-0.13*
	NE	-1.02	6.98	-2.17	2.80	-0.24	*6.35*
	SE	-4.02	9.81	-16.60	33.72	-6.37	*16.55*
	S	-2.27	2.22	-4.19	31.31	-2.28	*24.79*
	CW	-0.57	0.20	-1.95	0.92	-0.79	*-2.19*
	Total	*-8.00*	*19.42*	*-26.58*	*70.30*	*-9.76*	*45.38*

Northeast

		Destination					
		N	**NE**	**SE**	**S**	**CW**	**Total**
Origin	**N**	-1.51	1.44	0.53	-0.17	-0.27	*0.02*
	NE	0.24	20.06	1.00	-0.30	0.01	*21.01*
	SE	1.43	29.56	10.70	-3.69	-0.05	*37.95*
	S	1.37	10.31	2.45	-8.96	-1.88	*3.29*
	CW	0.27	0.99	1.27	-0.09	-0.69	*1.75*
	Total	*1.80*	*62.35*	*15.96*	*-13.21*	*-2.88*	*64.02*

Center-west

		Destination					
		N	**NE**	**SE**	**S**	**CW**	**Total**
Origin	**N**	1.11	-0.04	-0.01	0.01	-0.74	*0.33*
	NE	0.48	-1.44	0.07	0.02	0.24	*-0.63*
	SE	3.44	-2.15	0.62	0.29	4.95	*7.15*
	S	1.20	-0.44	0.27	0.50	-4.14	*-2.61*
	CW	0.25	-0.03	0.19	0.01	0.29	*0.71*
	Total	*6.47*	*-4.10*	*1.14*	*0.83*	*0.59*	*4.94*

Southeast

		Destination					
		N	**NE**	**SE**	**S**	**CW**	**Total**
Origin	**N**	-20.99	-0.33	10.31	-1.06	3.33	*-8.73*
	NE	-8.85	13.21	8.15	-1.91	0.92	*11.52*
	SE	-60.35	22.51	34.45	-22.86	19.76	*-6.49*
	S	-16.76	1.26	5.59	-10.90	26.56	*5.75*
	CW	-3.09	-0.08	-1.15	-0.64	12.98	*8.02*
	Total	*-110.04*	*36.58*	*57.35*	*-37.37*	*63.55*	*10.07*

Brazil

		Destination					
		N	**NE**	**SE**	**S**	**CW**	**Total**
Origin	**N**	-8.62	1.08	9.60	0.10	2.35	*4.51*
	NE	-4.75	37.50	7.20	0.18	1.09	*41.21*
	SE	-29.08	57.96	25.25	2.24	21.80	*78.18*
	S	-8.42	12.28	3.68	6.86	19.94	*34.33*
	CW	-1.51	0.94	-1.99	0.05	12.80	*10.28*
	Total	*-52.39*	*109.76*	*43.74*	*9.42*	*57.98*	*168.51*

Table 20. Long-Run Regional and Total Welfare Effects: Decomposition of relative equivalent variation (REV) according to origin-destination pairs of transportation cost reductions (-1%)

North

Origin	Destination: N	NE	SE	S	CO	Total
N	0.039%	-0.001%	0.001%	-0.001%	0.000%	*0.040%*
NE	0.013%	-0.004%	0.000%	-0.001%	0.000%	*0.009%*
SE	0.093%	-0.005%	-0.012%	-0.016%	0.011%	*0.070%*
S	0.025%	-0.003%	-0.001%	-0.016%	0.005%	*0.009%*
CW	0.005%	0.000%	-0.001%	0.000%	0.003%	*0.006%*
Total	*0.175%*	*-0.014%*	*-0.013%*	*-0.034%*	*0.020%*	*0.135%*

South

Origin	Destination: N	NE	SE	S	CW	Total
N	0.000%	0.000%	-0.001%	0.001%	0.000%	*0.000%*
NE	-0.001%	0.006%	-0.002%	0.002%	0.000%	*0.005%*
SE	-0.003%	0.008%	-0.014%	0.029%	-0.005%	*0.014%*
S	-0.002%	0.002%	-0.004%	0.027%	-0.002%	*0.021%*
CW	0.000%	0.000%	-0.002%	0.001%	-0.001%	*-0.002%*
Total	*-0.007%*	*0.017%*	*-0.023%*	*0.060%*	*-0.008%*	*0.039%*

Northeast

Origin	Destination: N	NE	SE	S	CW	Total
N	-0.002%	0.002%	0.001%	0.000%	0.000%	*0.000%*
NE	0.000%	0.025%	0.001%	0.000%	0.000%	*0.026%*
SE	0.002%	0.037%	0.013%	-0.005%	0.000%	*0.048%*
S	0.002%	0.013%	0.003%	-0.011%	-0.002%	*0.004%*
CW	0.000%	0.001%	0.002%	0.000%	-0.001%	*0.002%*
Total	*0.002%*	*0.078%*	*0.020%*	*-0.017%*	*-0.004%*	*0.080%*

Center-west

Origin	Destination: N	NE	SE	S	CW	Total
N	0.002%	0.000%	0.000%	0.000%	-0.001%	*0.001%*
NE	0.001%	-0.003%	0.000%	0.000%	0.000%	*-0.001%*
SE	0.006%	-0.004%	0.001%	0.001%	0.009%	*0.013%*
S	0.002%	-0.001%	0.000%	0.001%	-0.008%	*-0.005%*
CW	0.000%	0.000%	0.000%	0.000%	0.001%	*0.001%*
Total	*0.012%*	*-0.007%*	*0.002%*	*0.002%*	*0.001%*	*0.009%*

Southeast

Origin	Destination: N	NE	SE	S	CW	Total
N	-0.005%	0.000%	0.002%	0.000%	0.001%	*-0.002%*
NE	-0.002%	0.003%	0.002%	0.000%	0.000%	*0.003%*
SE	-0.014%	0.005%	0.008%	-0.005%	0.005%	*-0.002%*
S	-0.004%	0.000%	0.001%	-0.003%	0.006%	*0.001%*
CW	-0.001%	0.000%	0.000%	0.000%	0.003%	*0.002%*
Total	*-0.026%*	*0.009%*	*0.014%*	*-0.009%*	*0.015%*	*0.002%*

Brazil

Origin	Destination: N	NE	SE	S	CW	Total
N	-0.001%	0.000%	0.001%	0.000%	0.000%	*0.001%*
NE	-0.001%	0.005%	0.001%	0.000%	0.000%	*0.006%*
SE	-0.004%	0.008%	0.004%	0.000%	0.003%	*0.011%*
S	-0.001%	0.002%	0.001%	0.001%	0.003%	*0.005%*
CW	0.000%	0.000%	0.000%	0.000%	0.002%	*0.001%*
Total	*-0.007%*	*0.016%*	*0.006%*	*0.001%*	*0.008%*	*0.024%*

Table 21. Short-Run Regional and Total GDP Effects: Decomposition of GDP according to origin-destination pairs of transportation cost reductions (-1%)

North

Origin \ Destination	N	NE	SE	S	CO	Total
N	0.0010	0.0000	0.0000	0.0000	0.0000	*0.0010*
NE	0.0002	0.0000	0.0000	0.0000	0.0000	*0.0003*
SE	0.0021	0.0000	0.0001	0.0000	0.0000	*0.0023*
S	0.0005	0.0000	0.0000	0.0000	0.0000	*0.0005*
CW	0.0001	0.0000	0.0000	0.0000	0.0000	*0.0001*
Total	*0.0039*	*0.0001*	*0.0001*	*0.0000*	*0.0000*	*0.0042*

South

Origin \ Destination	N	NE	SE	S	CW	Total
N	0.0000	0.0000	0.0000	0.0000	0.0000	*0.0001*
NE	0.0000	0.0000	0.0000	0.0001	0.0000	*0.0002*
SE	0.0000	0.0001	0.0003	0.0009	0.0000	*0.0013*
S	0.0000	0.0000	0.0000	0.0009	0.0000	*0.0010*
CW	0.0000	0.0000	0.0000	0.0000	0.0000	*0.0001*
Total	*0.0001*	*0.0001*	*0.0004*	*0.0019*	*0.0001*	*0.0026*

Northeast

Origin \ Destination	N	NE	SE	S	CW	Total
N	0.0000	0.0001	0.0000	0.0000	0.0000	*0.0001*
NE	0.0000	0.0014	0.0000	0.0000	0.0000	*0.0015*
SE	0.0001	0.0021	0.0003	0.0000	0.0001	*0.0026*
S	0.0000	0.0006	0.0001	0.0001	0.0000	*0.0007*
CW	0.0000	0.0001	0.0000	0.0000	0.0000	*0.0001*
Total	*0.0001*	*0.0043*	*0.0004*	*0.0001*	*0.0001*	*0.0050*

Center-west

Origin \ Destination	N	NE	SE	S	CW	Total
N	0.0000	0.0000	0.0000	0.0000	0.0000	*0.0000*
NE	0.0000	0.0000	0.0000	0.0000	0.0001	*0.0000*
SE	0.0000	0.0000	0.0000	0.0000	0.0013	*0.0013*
S	0.0000	0.0000	0.0000	0.0001	0.0004	*0.0005*
CW	0.0000	0.0000	0.0000	0.0000	0.0005	*0.0005*
Total	*0.0000*	*0.0000*	*0.0000*	*0.0000*	*0.0023*	*0.0023*

Southeast

Origin \ Destination	N	NE	SE	S	CW	Total
N	0.0000	0.0000	0.0002	0.0000	0.0000	*0.0002*
NE	0.0000	0.0001	0.0002	0.0000	0.0000	*0.0002*
SE	0.0000	0.0001	0.0018	0.0000	0.0000	*0.0019*
S	0.0000	0.0000	0.0003	0.0000	0.0000	*0.0004*
CW	0.0000	0.0000	0.0001	0.0000	0.0000	*0.0001*
Total	*0.0001*	*0.0002*	*0.0025*	*0.0001*	*0.0001*	*0.0029*

Brazil

Origin \ Destination	N	NE	SE	S	CW	Total
N	0.0001	0.0000	0.0001	0.0000	0.0000	*0.0002*
NE	0.0000	0.0002	0.0001	0.0000	0.0000	*0.0004*
SE	0.0001	0.0003	0.0012	0.0002	0.0001	*0.0019*
S	0.0000	0.0001	0.0002	0.0002	0.0000	*0.0005*
CW	0.0000	0.0000	0.0001	0.0000	0.0000	*0.0001*
Total	*0.0003*	*0.0006*	*0.0016*	*0.0004*	*0.0002*	*0.0031*

Table 22. Long-Run Regional and Total GDP Effects: Decomposition of GDP according to origin-destination pairs of transportation cost reductions (-1%)

North

		Destination					
		N	**NE**	**SE**	**S**	**CO**	**Total**
Origin	**N**	-0.0051	0.0001	-0.0001	0.0001	0.0000	*-0.0048*
	NE	-0.0015	0.0007	0.0001	0.0002	0.0000	*-0.0004*
	SE	-0.0092	0.0012	0.0036	0.0027	-0.0006	*-0.0024*
	S	-0.0011	0.0007	0.0005	0.0026	0.0001	*0.0028*
	CW	-0.0002	0.0001	0.0003	0.0001	-0.0002	*0.0000*
	Total	*-0.0171*	*0.0028*	*0.0043*	*0.0058*	*-0.0007*	*-0.0049*

South

		Destination					
		N	**NE**	**SE**	**S**	**CW**	**Total**
Origin	**N**	-0.0001	0.0000	0.0006	-0.0002	0.0001	*0.0002*
	NE	0.0001	-0.0015	0.0007	-0.0004	0.0000	*-0.0011*
	SE	0.0002	-0.0024	0.0054	-0.0053	0.0014	*-0.0006*
	S	0.0002	-0.0005	0.0012	-0.0030	0.0009	*-0.0012*
	CW	0.0001	0.0000	0.0005	-0.0001	0.0003	*0.0007*
	Total	*0.0004*	*-0.0045*	*0.0085*	*-0.0091*	*0.0027*	*-0.0020*

Northeast

		Destination					
		N	**NE**	**SE**	**S**	**CW**	**Total**
Origin	**N**	0.0003	0.0001	0.0000	0.0000	0.0001	*0.0005*
	NE	-0.0001	0.0044	-0.0002	0.0000	0.0000	*0.0041*
	SE	-0.0009	0.0073	-0.0038	0.0005	-0.0001	*0.0029*
	S	-0.0005	0.0011	-0.0007	0.0022	0.0005	*0.0026*
	CW	-0.0001	0.0001	-0.0004	0.0000	0.0001	*-0.0003*
	Total	*-0.0014*	*0.0130*	*-0.0052*	*0.0028*	*0.0005*	*0.0098*

Center-west

		Destination					
		N	**NE**	**SE**	**S**	**CW**	**Total**
Origin	**N**	-0.0019	0.0000	0.0006	0.0000	0.0008	*-0.0006*
	NE	-0.0007	0.0009	0.0005	-0.0001	0.0005	*0.0012*
	SE	-0.0052	0.0010	0.0026	-0.0007	0.0099	*0.0076*
	S	-0.0015	0.0001	0.0006	-0.0003	0.0070	*0.0058*
	CW	-0.0003	0.0000	0.0001	0.0000	0.0052	*0.0049*
	Total	*-0.0097*	*0.0020*	*0.0043*	*-0.0011*	*0.0234*	*0.0189*

Southeast

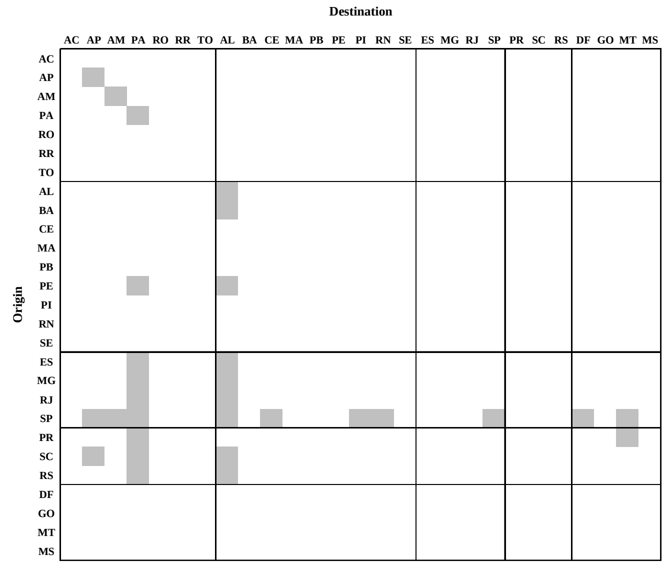
		Destination					
		N	**NE**	**SE**	**S**	**CW**	**Total**
Origin	**N**	0.0010	0.0000	0.0000	0.0001	-0.0002	*0.0010*
	NE	0.0003	-0.0005	0.0002	0.0002	-0.0001	*0.0001*
	SE	0.0024	-0.0010	0.0038	0.0022	-0.0016	*0.0059*
	S	0.0005	0.0001	0.0007	0.0017	-0.0014	*0.0015*
	CW	0.0001	0.0000	0.0003	0.0001	-0.0007	*-0.0002*
	Total	*0.0044*	*-0.0014*	*0.0050*	*0.0042*	*-0.0039*	*0.0083*

Brazil

		Destination					
		N	**NE**	**SE**	**S**	**CW**	**Total**
Origin	**N**	0.0002	0.0000	0.0002	0.0000	0.0000	*0.0004*
	NE	0.0001	0.0000	0.0003	0.0000	0.0000	*0.0004*
	SE	0.0006	-0.0001	0.0031	0.0006	-0.0001	*0.0041*
	S	0.0002	0.0001	0.0006	0.0008	-0.0002	*0.0015*
	CW	0.0000	0.0000	0.0003	0.0000	-0.0001	*0.0003*
	Total	*0.0011*	*0.0001*	*0.0044*	*0.0015*	*-0.0004*	*0.0067*

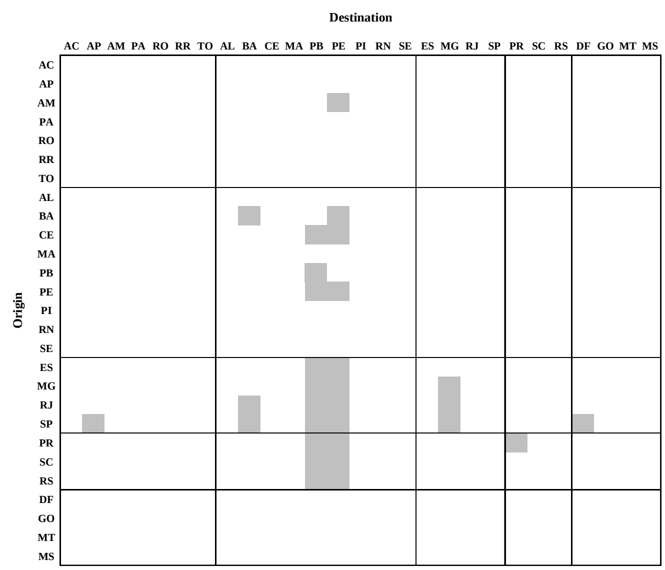
To obtain a finer perspective on the analytically most important transportation links for optimizing a given policy target (regional/national efficiency/welfare), we further decomposed the results into state-to-state links. Key links for each policy strategy (regional/national GDP growth and welfare) are presented in Figures 6-17.

Figure 6. Long-Run Analytically Important Transportation Links Based on Regional Welfare*: North



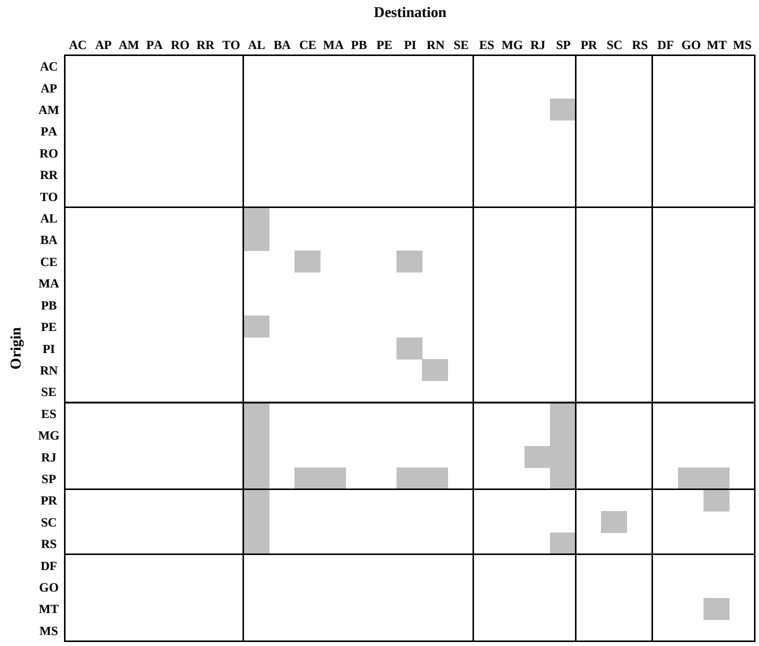
* Indicator of regional welfare: equivalent variation in the North region

Figure 7. Long-Run Analytically Important Transportation Links Based on Regional Welfare*: Northeast



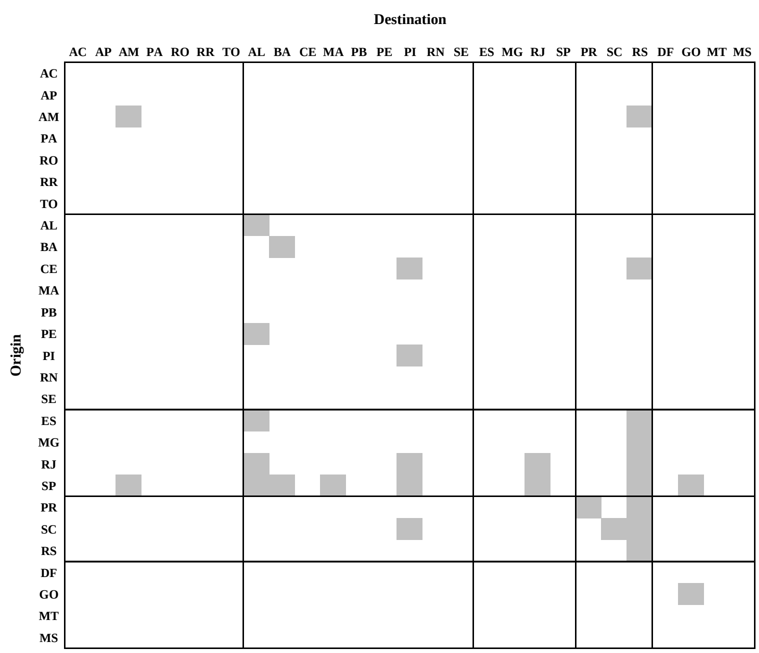
* Indicator of regional welfare: equivalent variation in the Northeast region

Figure 8. Long-Run Analytically Important Transportation Links Based on Regional Welfare*: Southeast



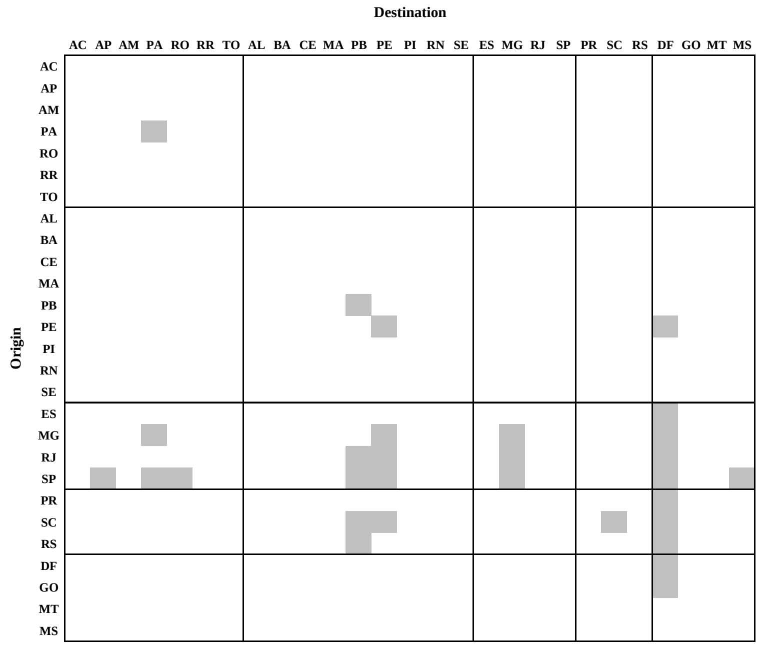
* Indicator of regional welfare: equivalent variation in the Southeast region

Figure 9. Long-Run Analytically Important Transportation Links Based on Regional Welfare*: South



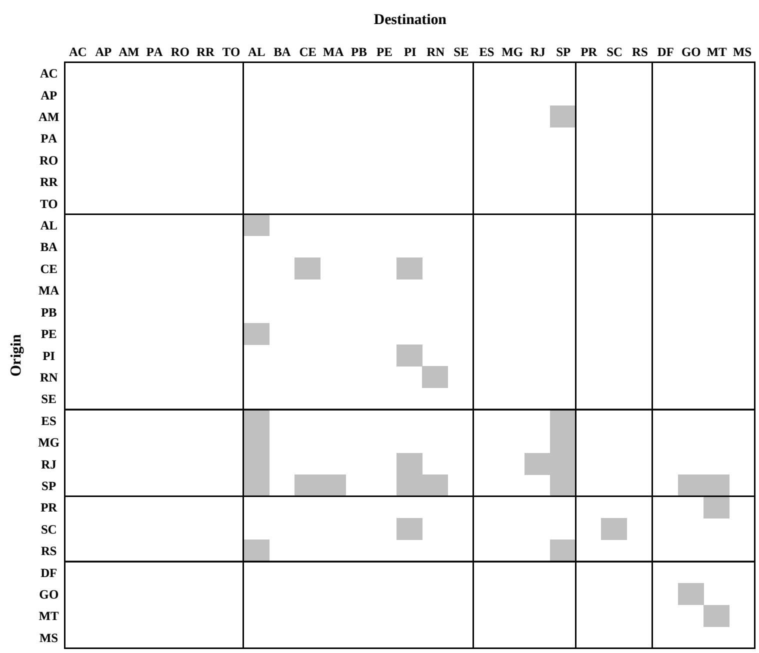
* Indicator of regional welfare: equivalent variation in the South region

Figure 10. Long-Run Analytically Important Transportation Links Based on Regional Welfare*: Center-West



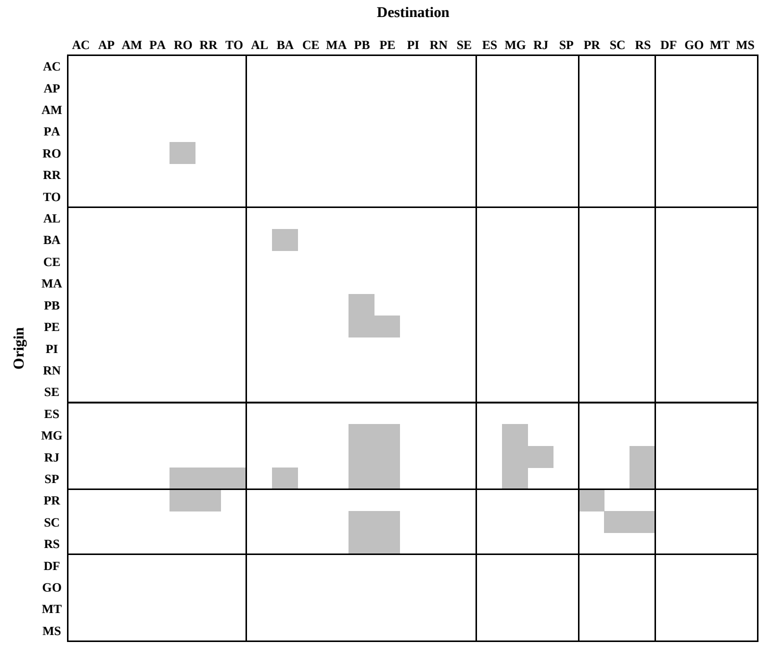
* Indicator of regional welfare: equivalent variation in the Center-West region

Figure 11. Long-Run Analytically Important Transportation Links Based on National Welfare*: Brazil



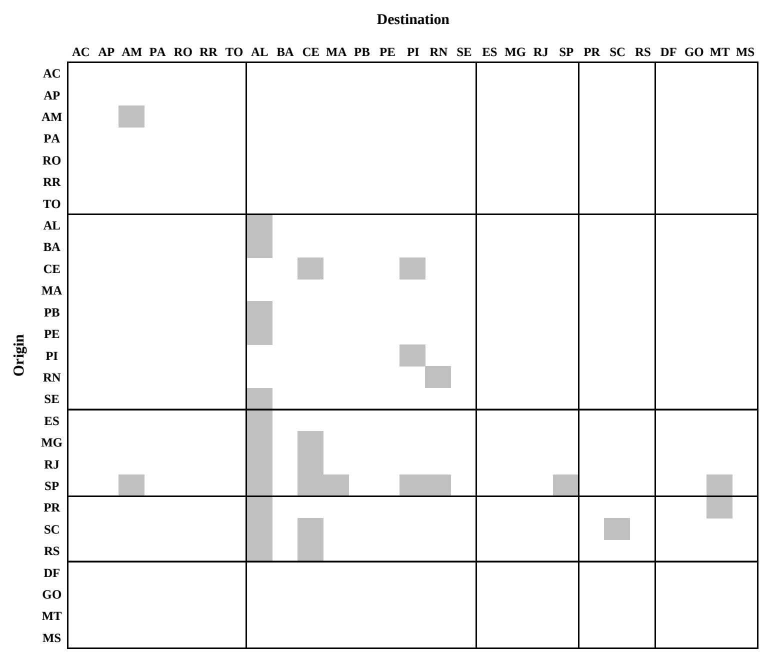
* Indicator of regional welfare: national equivalent variation

Figure 12. Long-Run Analytically Important Transportation Links Based on Regional Efficiency*: North



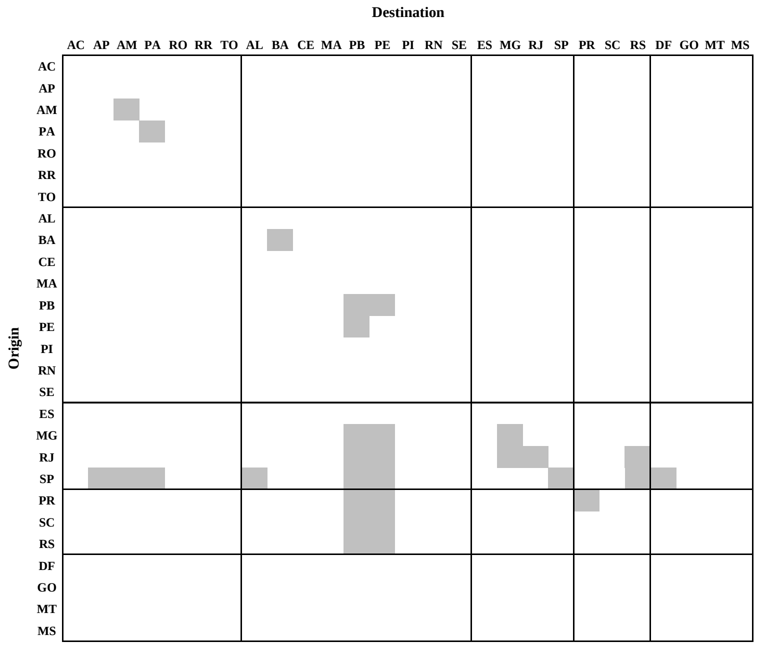
* Indicator of regional efficiency: GDP growth in the North region

Figure 13. Long-Run Analytically Important Transportation Links Based on Regional Efficiency*: Northeast



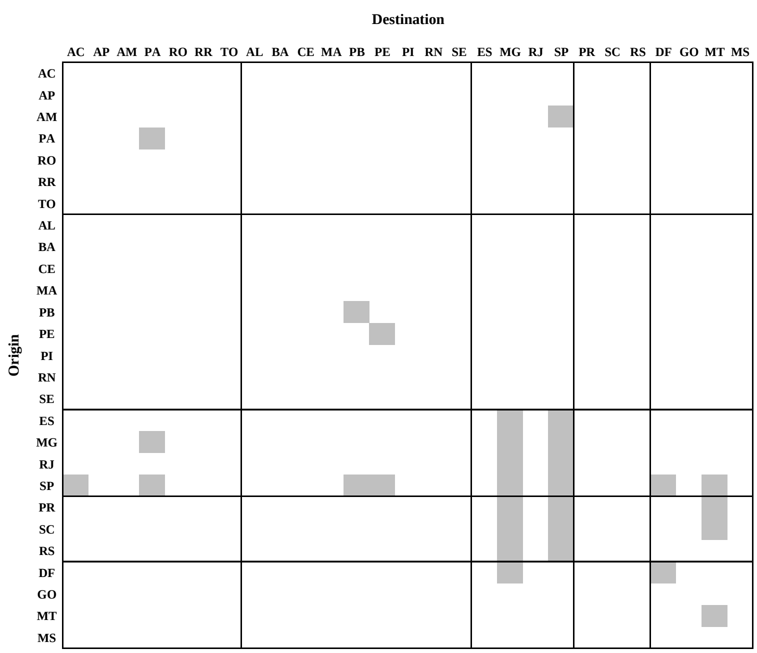
* Indicator of regional efficiency: GDP growth in the Northeast region

Figure 14. Long-Run Analytically Important Transportation Links Based on Regional Efficiency*: Southeast



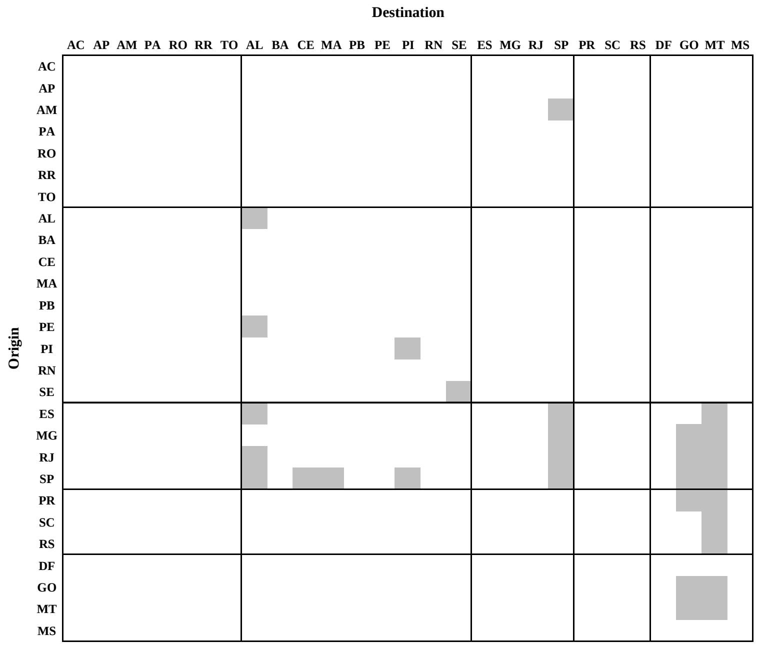
* Indicator of regional efficiency: GDP growth in the Southeast region

Figure 15. Long-Run Analytically Important Transportation Links Based on Regional Efficiency*: South



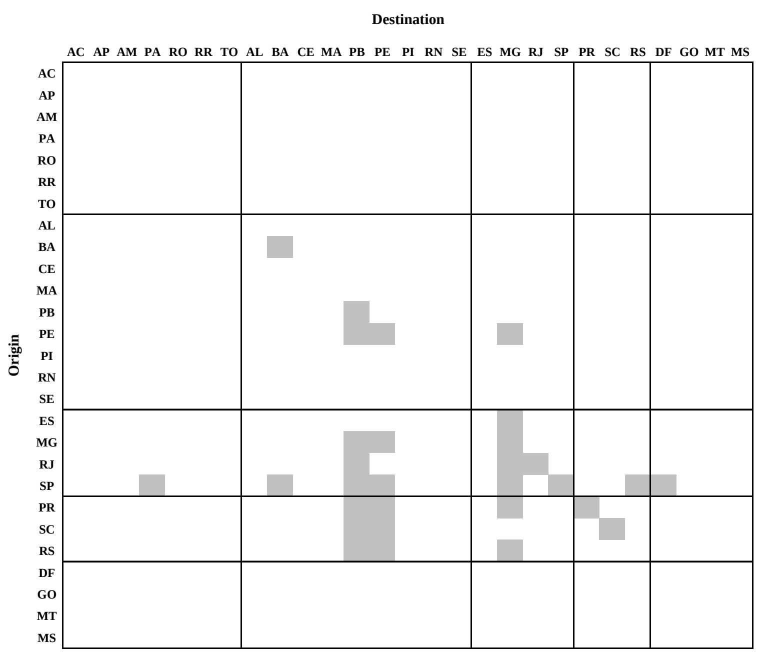
* Indicator of regional efficiency: GDP growth in the South region

Figure 16. Long-Run Analytically Important Transportation Links Based on Regional Efficiency*: Center-West



* Indicator of regional efficiency: GDP growth in the Center-West region

Figure 17. Long-Run Analytically Important Transportation Links Based on Systemic Efficiency*: Brazil



* Indicator of systemic efficiency: national GDP growth

4.2.4. The Role of Increasing Returns

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,*[14] 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.

Qualitative sensitivity analysis is carried out in this sub-section in order to grasp a better understanding on the role played by the introduction of non-constant returns to scale in the modeling framework. More specifically, the goal here is to assess the role played by increasing returns in the manufacturing sector in the state of São Paulo, the richest, most industrialized state in Brazil and for which there is evidence that it is the focal point of agglomeration economies in the country. For instance, a crude indicator using the PIA data set mentioned above shows that, while São Paulo's average annual share in manufacturing value added in the period 1996-2001 was 47.3%, the state's average annual share in total manufacturing labor was 39.9%.

Theoretical results from the new economic geography literature suggest that there is a fundamental trade-off between transportation costs and increasing returns. If this is the case, in a core-periphery interregional system, the core region, which hosts the increasing-return sector, can potentially further benefit from improvements in the transportation sector by exploiting scale economies. We check this result using the B-MARIA model with a special set of values for the scale economies parameters; we assume constant returns in every sector in every state. The only exception is the manufacturing sector in the state of São Paulo, for which we consider an interval in the IRTS curve, ranging from high increasing returns ($\mu = 0.5$) to decreasing returns to scale ($\mu = 1.5$), i.e., $\mu \in [0.5, 1.5]$ in the manufacturing sector. A series of simulations is run for various vales of μ in the assumed interval. Results are presented in the Figures 18-23. Theoretical results are confirmed in the empirical experimentation with B-MARIA-27. As it becomes clear from the results for both São Paulo's GDP and welfare, the further down the IRTS curve, the better the state's performance in terms of GDP growth and welfare.

[14] 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.

Figure 18. Short-run Effects on National and State GDP

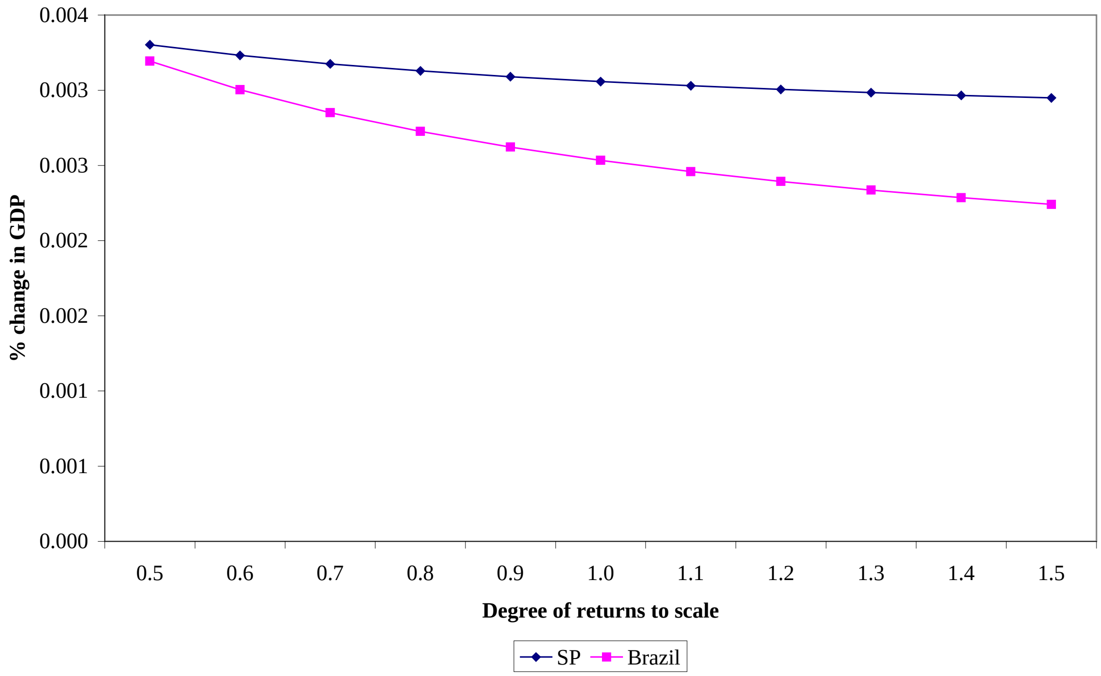


Figure 19. Long-run Effects on National and State GDP

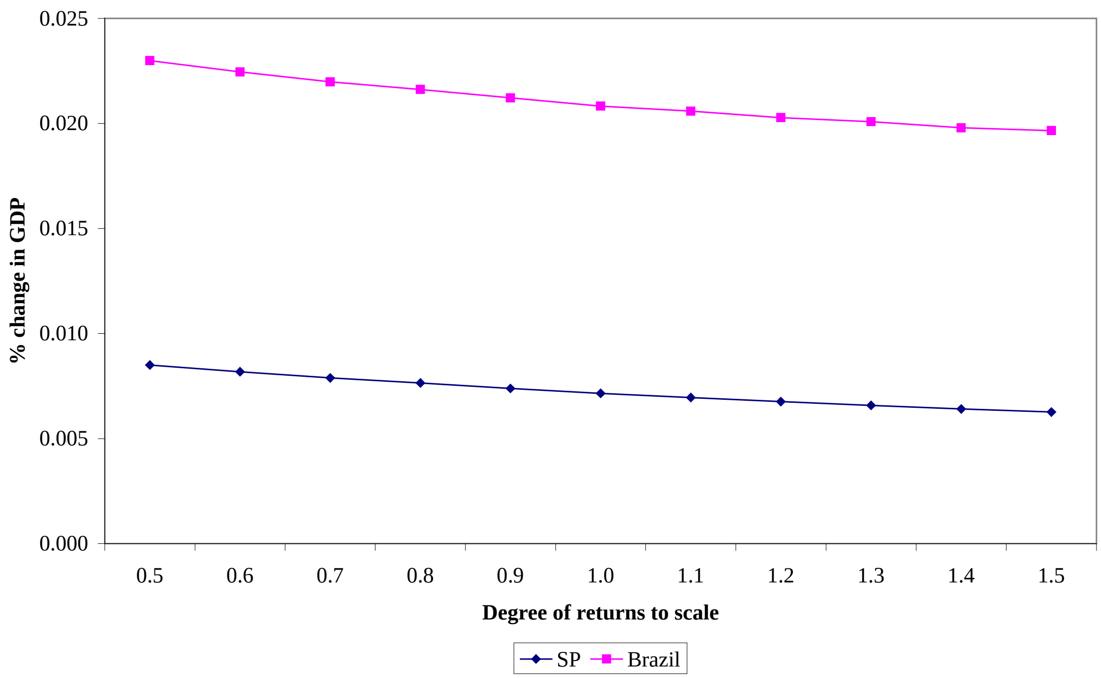


Figure 20. Short-run Effects on National and State Welfare

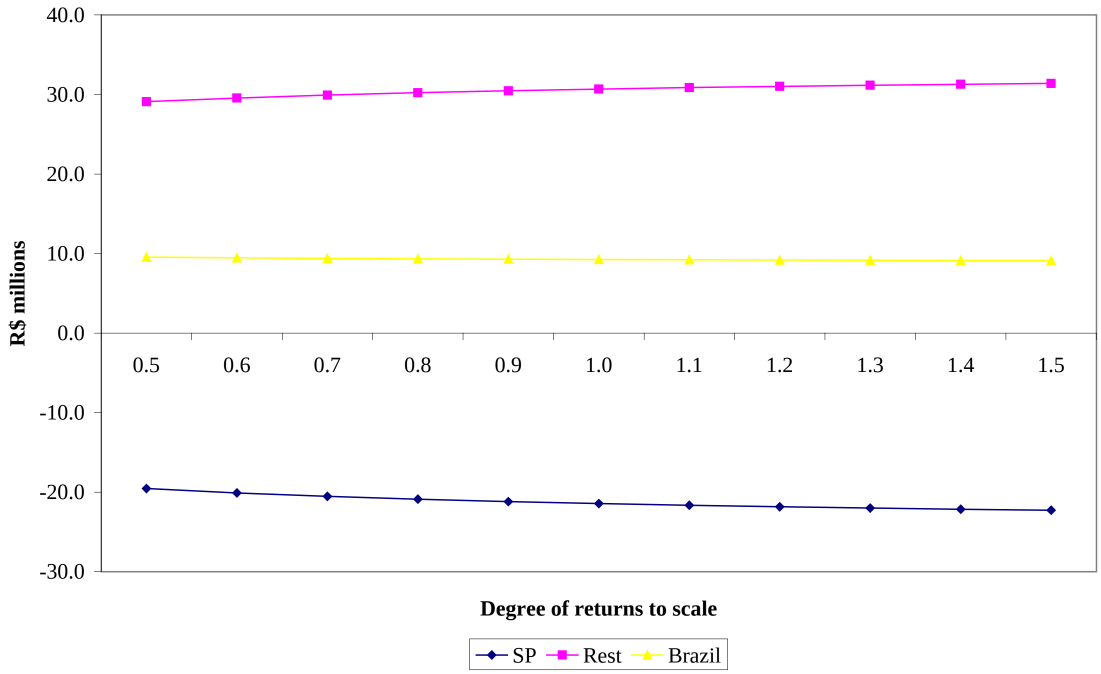


Figure 21. Long-run Effects on National and State Welfare

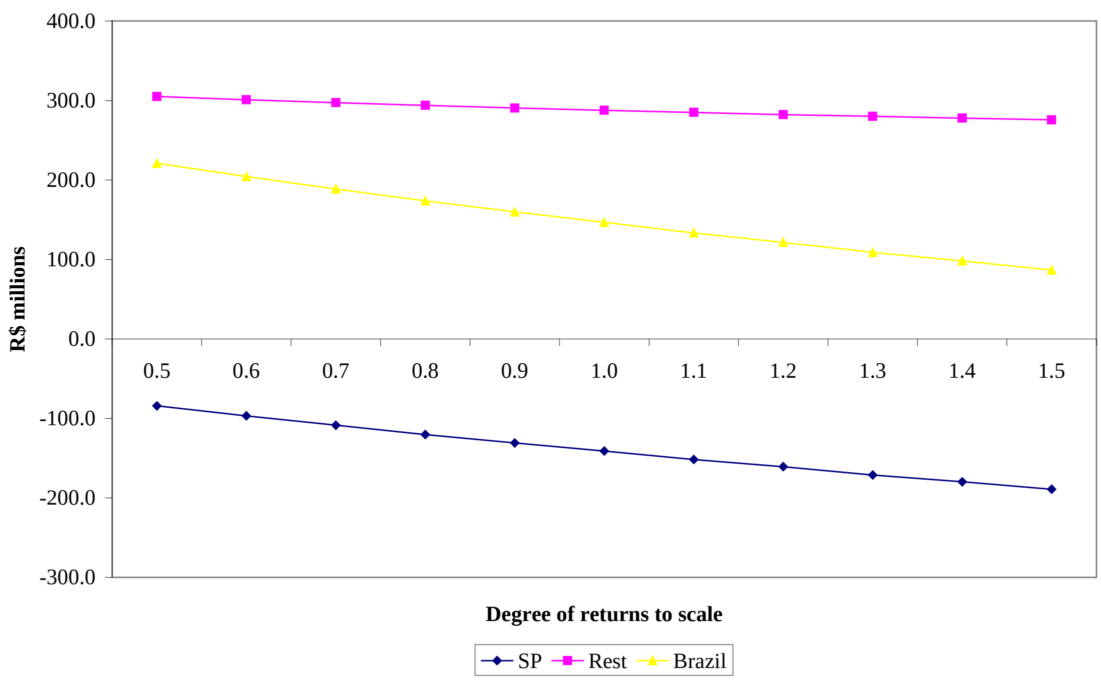


Figure 22. Short-run and Long-run National GDP Effects

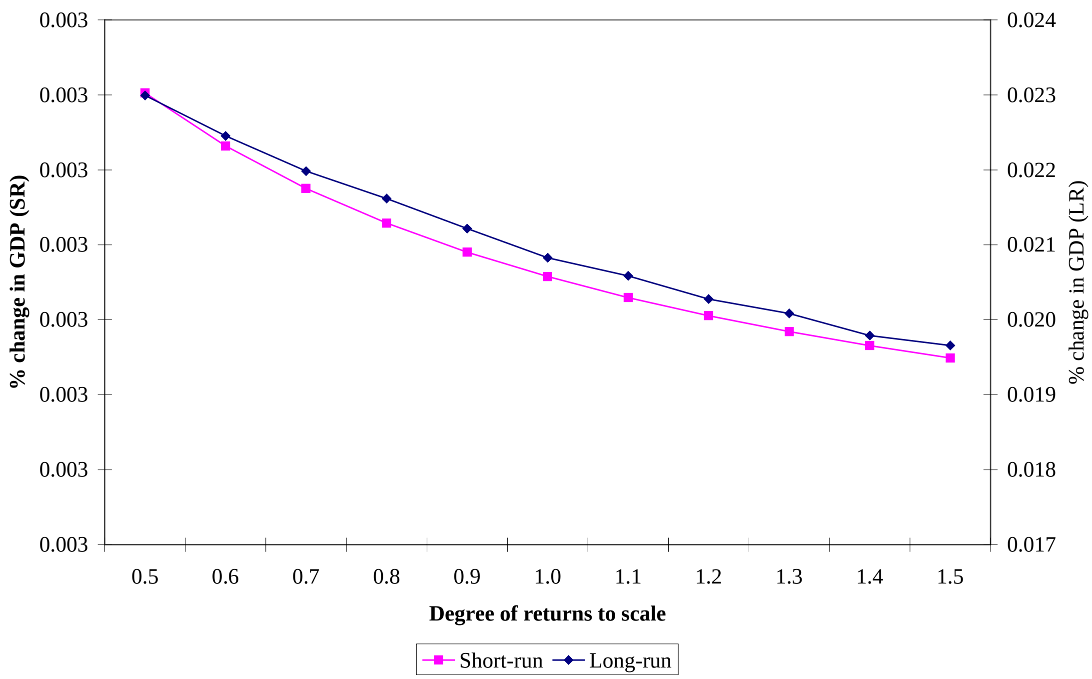
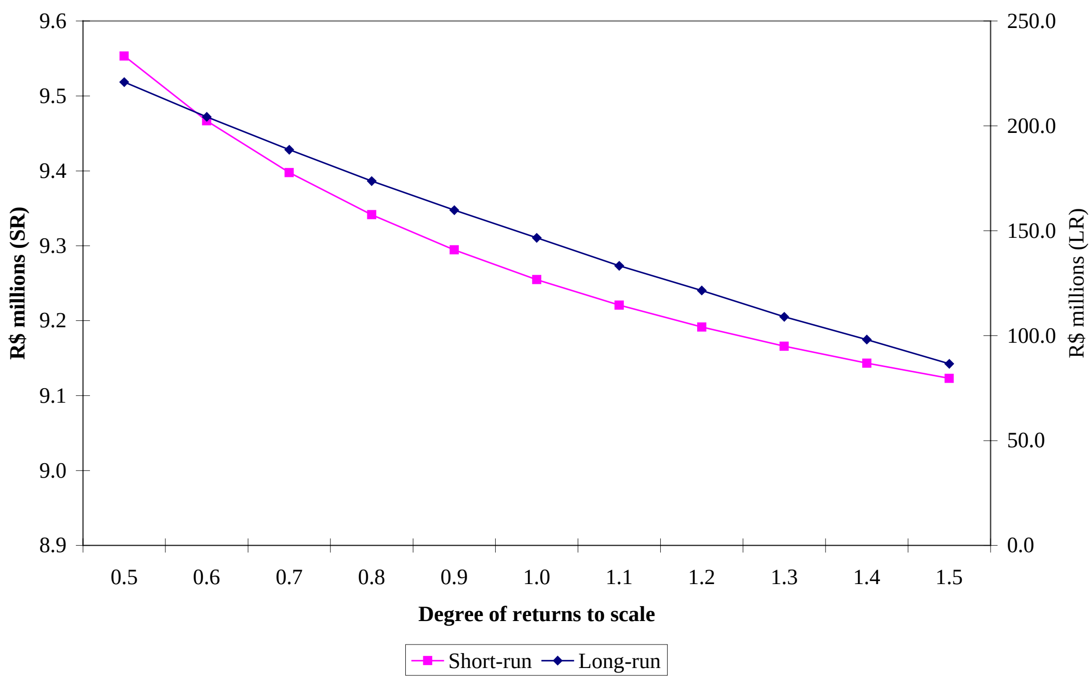


Figure 23. Short-run and Long-run National Welfare Effects



5. Final Remarks

This paper begins an exploration of the Brazilian economy using a multiregional computable general equilibrium model that is in the process of being unfettered from the reins of the perfectly competitive modeling paradigm. The process is on-going and difficult; attempts to handle non constant returns to scale, agglomeration and core-periphery phenomena, imperfect competition, and transportation costs present enormous challenges. Put together, the analysis becomes even more intractable. Further, there is the issue of parameter estimation and sensitivity; some of the analysis is this paper suggests that this area remains contentious.

However, the results provided are encouraging in the sense that the issues, while difficult, are not insurmountable. The challenges to competitive equilibrium in the spatial economy presented by the New Economic Geography remain largely untested. The present paper offers one approach to a goal of narrowing the gap between theory and empirical application. The Brazilian economy, sharing features of both developed and developing countries, presents a further challenge; the non-uniformity of the spatial distribution of resources and population, the glaring disparities in welfare across states and the presence of a hegemonic economy, in São Paulo, that renders traditional CGE modeling of limited value.

The results reveal that it is possible to handle increasing returns to scale, to address issues of asymmetric impacts of transportation investment and to approach the problems of more flexible functional forms, uncertainties about data and parameter estimates in ways that are tractable and theoretically defensible. The paper offers the perspective that there is a need, perhaps, to pause and take stock of the current state of the art in CGE modeling for multiregional (spatial) economies and to pursue further some of the lines of inquiry initiated by this work.

References

Almeida, E. S. (2003). MINAS-SPACE: A Spatial Applied General Equilibrium Model for Planning and Analysis of Transportation Policies in Minas Gerais. Ph.D. Dissertation, Departamento de Economia/IPE, Universidade de São Paulo, São Paulo (in Portuguese).

Arndt, C. (1996). An Introduction to Systematic Sensitivity Analysis via Gaussian Quadrature. GTAP Technical Paper No. 2 . West Lafayette, Indiana, Center for Global Trade Analysis, Purdue University.

Bilgic, A., King, S., Lusby, A. and Schreiner, D. F. (2002). Estimates of U.S. Regional Commodity Trade Elasticities. *Journal of Regional Analysis and Policy*, 32(2).

Bröcker, J. (1998). Operational Coputable General Equilibrium Modeling. *Annals of Regional Science*, 32: 367-387.

Castro, N., Carris, L. and Rodrigues, B. (1999). Custos de Transporte e a Estrutura Comercial do Comércio Interestadual Brasileiro. Paper presente at the *VI Seminário de Acompanhamento do Nêmesis*, December 06-07, IPEA, Rio de Janeiro.

Cukrowski, J. and Fischer, M. M. (2000). Theory of Comparative Advantage: Do Transportation Costs Matter? *Journal of Regional Science*, 40(2): 311-322.

Deardorff, A. V. and R. M. Stern. 1986. *The Michigan Model of World Production and Trade*. Cambridge: The MIT Press.

Dervis, K. J., De Melo, J. and Robinson, S.(1982). *General Equilibrium Models For Development Policy.* A World Bank Research Publication. Cambridge University Press, Cambridge.

DeVuyst, E. A. and Preckel, P. V. (1997). Sensitivity Analysis Revisited: A Quadrature-Based Approach. *Journal of Policy Modeling*, 19(2): 175-185.

Dixon, P. B., Bowles, S. and Kendrick, D. (1983). *Teoría Microeconómica: notas y problemas.* Barcelona, Editorial Hispano Europea.

Dixon, P. B., Parmenter, B. R., Powell, A. A. and Wilcoxen, P. J. (1992). *Notes And Problems In Applied General Equilibrium Economics.* Advanced Textbooks in Economics 32, Eds. C. J. Bliss and M. D. Intriligator, North-Holland, Amsterdam.

Dixon, P. B. and Rimmer, M. T. (2002). Forecasting and Policy Analysis with a Dynamic CGE Model of Australia. In *Using Dynamic General Equilibrium Models for Policy Analysis*, Harrison , G. W., Jensen, S. E. H., Pedersen, L. H.and Rutherford, T. F. (eds.). Amsterdan, Elsevier.

Dixon, P. B., Parmenter, B. R., Sutton, J. and Vincent, D. P. (1982). *ORANI: A Multisectoral Model Of The Australian Economy.* North-Holland, Amsterdam.

Domingues, E. P. (2002). Regional and Sectoral Dimensions of FTAA. Ph.D. Dissertation, Departamento de Economia/IPE, Universidade de São Paulo, São Paulo (in Portuguese).

Domingues, E. P., Haddad, E. A. and Hewings, G. J. D. (2003). “Sensitivity Analysis in Applied General Equilibrium Models: an Empirical Assessment for MERCOSUR Free Trade Areas Agreements.” Discussion Paper 04-T-4, Regional Economics Applications Laboratory, University of Illinois, Urbana.

Fujita, M., P. Krugman and A.J. Venables (1999) *The Spatial Economy: Cities, Regions and International Trade*, Cambridge, MIT Press.

Fujita, M. and J-F. Thisse (2002), *Economics of Agglomeration*. Cambridge, University Press.

Haddad, E. A. *Regional inequality and structural changes: lessons from the Brazilian experience.* Aldershot, Ashgate, 1999.

Haddad E.A. and C. R. Azzoni (2001) “Trade Liberalization and Location: Geographical Shifts in the Brazilian Economic Structure.” In J.J.M. Guilhoto and G.J.D. Hewings (eds), *Structure and Structural Chcnage in the Brazilian Economy*. Aldershot, Ashgate

Haddad, E. A., Hewings, G. J. D. and Peter, M. (2002). Input-Output Systems in Regional and Interregional CGE Modeling. In: Hewings, G. J. D., Sonis, M. and Boyce, D. (eds.). Trade, Networks and Hierarchies. Berlin, Springer-Verlag.

Hansen, L. P. and J. J. Heckman (1996). The Empirical Foundations of Calibration. *The Journal of Economic Perspectives* 10 (1): 87-104.

Harrison, W. J., Pearson, K. R. and Powell, A. A. (1994). Multiregional And Intertemporal AGE Modelling Via GEMPACK. *Preliminary Working Paper no. IP-66*, IMPACT Project, Monash University, Clayton, September.

Hertel, T. W. E. and Tsigas, M. (1997). Structure of GTAP. In *Global Trade Analysis: modeling and applications*, T. W. Hertel (ed.), Cambridge University Press.

Isard, W. (1959). *Location and the Space Economy*, Cambridge, MIT Press.

Isard, W., Azis, I. J., Drennan, M. P., Miller, R. E., Saltzman, S. and Thorbecke, E. (1998). *Methods of Interregional and Regional Analysis*, Ashgate.

Mansori, K. F. (2003). The Geographic Effects of Trade Liberalization with Increasing Returns in Transportation. *Journal of Regional Science*, 43(2): 249-268.

McCann, P. (2001). *Urban and Regional Economics*. Oxford University Press.

McKitrick, R. R. (1998). The Econometric Critique of Computable General Equilibrium Modeling: the role of functional forms. *Economic Modelling* 15 (4): 543-573.

Peter, M. W., Horridge, M., Meagher, G. A., Naqvi, F. and Parmenter, B. R. (1996). The Theoretical Structure Of MONASH-MRF. *Preliminary Working Paper no. OP-85*, IMPACT Project, Monash University, Clayton, April.

Schmutzler, A. (1999). The New Economic Geography. *Journal of Economic Surveys*, 13(4): 357-379.

Whalley, J. and Trela, I. (1986). *Regional Aspects of Confederation*. Vol. 68 for the Royal Commission on the Economic Union and Development Prospects for Canada. University of Toronto Press, Toronto.

Wigle, R. (1991). The Pagan-Shannon Approximation: unconditional systematic sensitivity in minutes. *Empirical Economics*, 16: 35-49.

Appendix A

The functional forms of the main groups of equations of the interstate CGE core are presented in this Appendix together with the definition of the main groups of variables, parameters and coefficients.

The notational convention uses uppercase letters to represent the levels of the variables and lowercase for their percentage-change representation. Superscripts *(u)*, *u = 0, 1j, 2j, 3, 4, 5, 6*, refer, respectively, to output *(0)* and to the six different regional-specific users of the products identified in the model: producers in sector *j (1j)*, investors in sector *j (2j)*, households *(3)*, purchasers of exports *(4)*, regional governments *(5)* and the Federal government *(6)*; the second superscript identifies the domestic region where the user is located. Inputs are identified by two subscripts: the first takes the values *1, ..., g*, for commodities, *g + 1*, for primary factors, and *g + 2*, for "other costs" (basically, taxes and subsidies on production); the second subscript identifies the source of the input, being it from domestic region *b (1b)* or imported *(2)*, or coming from labor *(1)*, capital *(2)* or land *(3)*. The symbol (•) is employed to indicate a sum over an index.

Equations

(A1) Substitution between products from different regional domestic sources

$$x_{(i(1b))}^{(u)r} = x_{(i(1\bullet))}^{(u)r} - \sigma_{(i)}^{(u)r}\,(p_{(i(1b))}^{(u)r} - \sum_{l \in S^*} (V(i,1l,(u),r)/V(i,1\bullet,(u),r)(p_{(i(1l))}^{(u)r}))$$

$$i = 1,...,g;\; b = 1,...,q;\; (u) = 3 \text{ and } (kj) \text{ for } k = 1 \text{ and } 2 \text{ and } j = 1,...,h; r = 1,...,R$$

(A2) Substitution between domestic and imported products

$$x_{(is)}^{(u)r} = x_{(i\bullet)}^{(u)r} - \sigma_{(i)}^{(u)r}\,(p_{(is)}^{(u)r} - \sum_{l=1\bullet,2} (V(i,l,(u),r)/V(i,\bullet,(u),r)(p_{(il)}^{(u)r}))$$

$$i = 1,...,g;\; s = 1\bullet \text{ and } 2;\; (u) = 3 \text{ and } (kj) \text{ for } k = 1 \text{ e } 2 \text{ and } j = 1,...,h; r = 1,...,R$$

(A3) Substitution between labor, capital and land

$$x_{(g+1,s)}^{(1j)r} - a_{(g+1,s)}^{(1j)r} = \alpha_{(g+1,s)}^{(1j)r} x_{(g+1\bullet)}^{(1j)r} - \sigma_{(g+1)}^{(1j)r}\{p_{(g+1,s)}^{(1j)r} + a_{(g+1,s)}^{(1j)r} - \sum_{l=1,2,3} (V(g+1,l,(1j),r)/V(g+1,\bullet,(1j),r))(p_{(g+1,l)}^{(1j)r} + a_{(g+1,l)}^{(1j)r})\}$$

$$j = 1,...,h;\; s = 1, 2 \text{ and } 3; r = 1,...,R$$

(A4) Intermediate and investment demands for composites commodities and primary factors

$$x_{(i\bullet)}^{(u)r} = \mu_{(i\bullet)}^{(u)r} z^{(u)r} + a_{(i)}^{(u)r}$$

$$u = (kj) \text{ for } k = 1, 2 \text{ and } j = 1,...,h$$

$$\text{if } u = (1j) \text{ then } i = 1,...,g+2$$

$$\text{if } u = (2j) \text{ then } i = 1,...,g;$$

$$r = 1,...,R$$

(A5) Household demands for composite commodities

$$V(i,\bullet,(3),r)(p_{(i\bullet)}^{(3)r}+x_{(i\bullet)}^{(3)r})=$$
$$\gamma_{(i)}^{r}P_{(i\bullet)}^{(3)r}Q^{r}(p_{(i\bullet)}^{(3)r}+x_{(i\bullet)}^{(3)r})+\beta_{(i)}^{r}(C^{r}-\sum_{j\in G}\gamma_{(j)}^{r}P_{(i\bullet)}^{(3)r}Q^{r}(p_{(i\bullet)}^{(3)r}+x_{(i\bullet)}^{(3)r}))$$
$$i=1,\ldots,g;\ r=1,\ldots,R$$

(A6) Composition of output by industries

$$x_{(i1)}^{(0j)r}=z^{(1j)r}+\sigma^{(0j)r}(p_{(i1)}^{(0)r}-\sum_{t\in G}(Y(t,j,r)/Y(\bullet,j,r))p_{(t1)}^{(0)r})$$

$$j=1,\ldots,h;\ \ \mathrm{i}=1,\ldots,\mathrm{g};\ r=1,\ldots,R$$

(A7) Indirect tax rates

$$t(\tau,i,s,(u)r)=f_{(\tau)}+f_{(\tau i)}+f_{(\tau i)}^{(u)}+f_{(\tau i)}^{(u)r},\quad i=1,\ldots,g;\ \ s=1b,2 \text{ for } b=1,\ldots,q;\ \tau=1,\ldots,t$$
$$(u)=(3),(4),(5),(6) \text{ and } (kj) \text{ for } k=1,2;\ j=1,\ldots,h$$
$$r=1,\ldots,R$$

(A8) Purchasers' prices related to basic prices, margins (transportation costs) and taxes

$$V(i,s,(u),r)p_{(is)}^{(u)r}=(B(i,s,(u),r)+\sum_{\tau\in T}T(\tau,i,s,(u),r))(p_{(is)}^{(0)}+t(\tau,i,s,u,r))$$
$$+\sum_{m\in G}M(m,i,s,(u),r)p_{(m1)}^{(0)r},$$
$$i=1,\ldots,g;\ (u)=(3),(4),(5),(6)$$
$$\text{and } (kj) \text{ for } k=1,2 \text{ and } j=1,\ldots,h;\ s=1b,2 \text{ for } b=1,\ldots,q$$
$$r=1,\ldots,R$$

(A9) Foreign demands (exports) for domestic goods

$$(x_{(is)}^{(4)r}-fq_{(is)}^{(4)r})=\eta_{(is)}^{r}(p_{(is)}^{(4)r}-e-fp_{(is)}^{(4)r}),\qquad i=1,\ldots,g;\ s=1b,2 \text{ for } b=1,\ldots,q;\ r=1,\ldots,R$$

(A10) Regional government demands

$$x_{(is)}^{(5)r}=x_{(\bullet\bullet)}^{(3)r}+f_{(is)}^{(5)r}+f^{(5)r}+f^{(5)}\qquad i=1,\ldots,g;\ s=1b,2 \text{ for } b=1,\ldots,q;\ \mathrm{r}=1,\ldots,\mathrm{R}$$

(A11) Regional government demands

$$x_{(is)}^{(6)r}=x_{(\bullet\bullet)}^{(3)\bullet}+f_{(is)}^{(6)r}+f^{(6)r}+f^{(6)}\qquad i=1,\ldots,g;\ s=1b,2 \text{ for } b=1,\ldots,q;\ \mathrm{r}=1,\ldots,\mathrm{R}$$

(A12) Margins demands for domestic goods

$$x_{(m1)}^{(is)(u)r}=\theta_{(is)}^{(u)r}x_{(is)}^{(u)r}+a_{(m1)}^{(is)(u)r}$$
$$m,i=1,\ldots,g;$$
$$(u)=(3),(4b) \text{ for } b=1,\ldots,r,(5) \text{ and } (kj) \text{ for } k=1,2;$$
$$j=1,\ldots,h;\ s=1b,2 \text{ for } b=1,\ldots,r;$$
$$r=1,\ldots,R$$

(A13) Demand equals supply for regional domestic commodities

$$\sum_{j\in H} Y(l,j,r)x_{(l1)}^{(0j)r} = \sum_{u\in U} B(l,1,(u),r)x_{(l1)}^{(u)r} + \sum_{i\in G}\sum_{s\in S}\sum_{u\in U} M(l,i,s,(u),r)x_{(l1)}^{(is)(u)r} \qquad l=1,...,g;\ r=1,...,R$$

(A14) Regional industry revenue equals industry costs

$$\sum_{l\in G} Y(l,j,r)(p_{(l1)}^{(0)r} + a_{(l1)}^{(0)r}) = \sum_{l\in G^*}\sum_{s\in S} V(l,s,(1j),r)(p_{(ls)}^{(1j)r}), \quad j=1,...,h;\ r=1,...,R$$

(A15) Basic price of imported commodities

$$p_{(i(2))}^{(0)} = p_{(i(2))}^{(w)} - e + t_{(i(2))}^{(0)}, \qquad i=1,...,g$$

(A16) Cost of constructing units of capital for regional industries

$$V(\bullet,\bullet,(2j),r)(p_{(k)}^{(1j)r} - a_{(k)}^{(1j)r}) = \sum_{i\in G}\sum_{s\in S} V(i,s,(2j),r)(p_{(is)}^{(2j)r} + a_{(is)}^{(2j)r}), \quad j=1,...,h;\ r=1,...,R$$

(A17) Investment behavior

$$z^{(2j)r} = x_{(g+1,2)}^{(1j)r} + 100 f_{(k)}^{(2j)r}, \qquad j=1,...,h;\ r=1,...,R$$

(A18) Capital stock in period T+1 – comparative statics

$$x_{(g+1,2)}^{(1j)r}(1) = x_{(g+1,2)}^{(1j)r} \qquad j=1,...,h;\ r=1,...,R$$

(A19) Definition of rates of return to capital

$$r_{(j)}^{r} = Q_{(j)}^{r}(p_{(g+1,2)}^{(1j)r} - p_{(k)}^{(1j)r}), \qquad j=1,...,h;\ r=1,...,R$$

(A20) Relation between capital growth and rates of return

$$r_{(j)}^{r} - \omega = \varepsilon_{(j)}^{r}(x_{(g+1,2)}^{(1j)r} - x_{(g+1,2)}^{(\bullet)r}) + f_{(k)}^{r}, \qquad j=1,...,h;\ r=1,...,R$$

Other definitions in the CGE core include: revenue from indirect taxes, import volume of commodities, components of regional/national GDP, regional/national price indices, wage settings, definitions of factor prices, and employment aggregates.

Variables

Variable	Index ranges	Description

$x_{(is)}^{(u)r}$	(u) = (3), (4), (5), (6) and
	(kj) for k = 1, 2 and j = 1,…,h;
	if (u) = (1j) then i = 1,…,g + 2;
	if (u) ≠ (1j) then i = 1,…,g;
	s = 1b, 2 for b = 1,…,q; and i = 1,…,g and
	s = 1, 2, 3 for i = g+1
	r = 1,…,R
		Demand by user (u) in region r for good or primary factor (is)

$p_{(is)}^{(u)r}$	(u) = (3), (4), (5), (6) and
	(kj) for k = 1, 2 and j = 1,…,h;
	if (u) = (1j) then i = 1,…,g + 2;
	if (u) ≠ (1j) then i = 1,…,g;
	s = 1b, 2 for b = 1,…,q; and i = 1,…,g and
	s = 1, 2, 3 for i = g+1
	r = 1,…,R
		Price paid by user (u) in region r for good or primary factor (is)

$x_{(i\bullet)}^{(u)r}$	**(u) = (3) and (kj) for k = 1, 2 and j = 1, …,h.**
	if (u) = (1j) then i = 1, …,g + 1;
	if (u) ≠ (1j) then i = 1, …,g
	r = 1,…,R
		Demand for composite good or primary factor i by user (u) in region r

$a_{(g+1,s)}^{(1j)r}$	j = 1, …,h and s = 1, 2, 3 r = 1,…,R	Primary factor saving technological change in region r
$a_{(i)}^{(u)r}$	i = 1,...,g, (u) = (3) and (kj) for k = 1, 2 and j = 1,..., h r = 1,…,R	Technical change related to the use of good i by user (u) in region r
C^r		Total expenditure by regional household in region r
Q^r		Number of households
$z^{(u)r}$	(u) = (kj) for k = 1, 2 and j = 1, …,h r = 1,…,R	Activity levels: current production and investment by industry in region r
$fq_{(is)}^{(4)r}$	i = 1, …,g; s = 1b, 2 for b = 1, …,q r = 1,…,R	Shift (quantity) in foreign demand curves for regional exports
$fp_{(is)}^{(4)r}$	i = 1, …,g; s = 1b, 2 for b = 1, …,q r = 1,…,R	Shift (price) in foreign demand curves for regional exports
e		Exchange rate
$x_{(m1)}^{(is)(u)r}$	m, i = 1,…,g; s = 1b, 2 for b = 1,…,q (u) = (3), (4), (5), (6) and (kj) for k = 1, 2 and j = 1, …,h r = 1,…,R	Demand for commodity (m1) to be used as a margin to facilitate the flow of (is) to (u) in region r
$a_{(m1)}^{(is)(u)r}$	m, i = 1,…,g; s = 1b, 2 for b = 1,…,q (u) = (3), (4), (5), (6) and	Technical change related to the demand for commodity (m1) to be used as a margin to

Variable	Index ranges	Description
	(kj) for k = 1, 2 and j = 1, …,h r = 1,…,R	facilitate the flow of (is) to (u) in region r
$x_{(i1)}^{(0j)r}$	i = 1,…,g; j = 1,…,h r = 1,...,R	Output of domestic good i by industry j
$p_{(is)}^{(0)r}$	i = 1,…,g; s = 1b, 2 for b = 1,…,q r = 1,...,R	Basic price of good i in region r from source s
$p_{(i(2))}^{(w)}$	i = 1,…,g	USD c.i.f. price of imported commodity i
$t_{(i(2))}^{(0)}$	i = 1,…,g	Power of the tariff on imports of i
$t(\tau, i, s, (u)r)$	i = 1,…,g; τ = 1,…,t; s = 1b, 2 for b = 1,…,q (u) = (3), (4), (5), (6) and (kj) for k = 1, 2 and j = 1,…,h r = 1,...,R	Power of the tax τ on sales of commodity (is) to user (u) in region r
$f_{(k)}^{(2j)r}$	j = 1,…,h r = 1,...,R	Regional-industry-specific capital shift terms
$f_{(k)}^{r}$	r = 1,...,R	Capital shift term in region r
$x_{(g+1,2)}^{(1j)r}(1)$	j = 1,…, h r = 1,...,R	Capital stock in industry j in region r at the end of the year, i.e., capital stock available for use in the next year
$p_{(k)}^{(1j)r}$	j = 1,…, h r = 1,...,R	Cost of constructing a unit of capital for industry j in region r
$f_{(\tau)}$	τ = 1,…,t	Shift term allowing uniform percentage changes in the power of tax τ
$f_{(\tau i)}$	τ = 1,…,t; i = 1, …,g	Shift term allowing uniform percentage changes in the power of tax τ on commodity i
$f_{(\tau i)}^{(u)}$	τ = 1,…,t; (u) = (3), (4), (5), (6) and (kj) for k = 1, 2 and j = 1, …, h	Shift term allowing uniform percentage changes in the power of tax τ of commodity i on user (u)
$f_{(\tau i)}^{(u)r}$	τ = 1,…,t; (u) = (3), (4), (5), (6) and (kj) for k = 1, 2 and j = 1, …, h r = 1,…,R	Shift term allowing uniform percentage changes in the power of tax τ of commodity i on user (u) in region r
$f_{(is)}^{(5)r}$	i = 1, …,g; s = 1b, 2 for b = 1,…,q r = 1,…,R	Commodity and source-specific shift term for regional government expenditures in region r
$f^{(5)r}$	r = 1,…,R	Shift term for regional government expenditures in region r
$f^{(5)}$		Shift term for regional government expenditures

Variable	Index ranges	Description
$f_{(is)}^{(6)r}$	i = 1, …,g; s = 1b, 2 for b = 1,…,q r = 1,…,R	Commodity and source-specific shift term for Federal government expenditures in region r
$f^{(6)r}$	r = 1,…,R	Shift term for Federal government expenditures in region r
$f^{(6)}$		Shift term for Federal government expenditures
ω		Overall rate of return on capital (short-run)
$r_{(j)}^{r}$	j = 1,...,h r = 1,…,R	Regional-industry-specific rate of return

Parameters, Coefficients and Sets

Symbol	Description
$\sigma_{(i)}^{(u)r}$	Parameter: elasticity of substitution between alternative sources of commodity or factor i for user (u) in region r
$\sigma^{(0j)r}$	Parameter: elasticity of transformation between outputs of different commodities in industry j in region r
$\alpha_{(g+1,s)}^{(1j)r}$	Parameter: returns to scale to individual primary factors in industry j in region r
$\beta_{(i)}^{r}$	Parameter: marginal budget shares in linear expenditure system for commodity i in region r
$\gamma_{(i)}^{r}$	Parameter: subsistence parameter in linear expenditure system for commodity i in region r
$\varepsilon_{(j)}^{r}$	Parameter: sensitivity of capital growth to rates of return of industry j in region r
$\eta_{(is)}^{r}$	Parameter: foreign elasticity of demand for commodity i from region r
$\theta_{(is)}^{(u)r}$	Parameter: scale economies to transportation of commodity (i) produced in region r shipped to user (u) in region r
$\mu_{(i\bullet)}^{(u)r}$	Parameter: returns to scale to primary factors (i = g+1 and u = 1j); otherwise, $\mu_{(i\bullet)}^{(u)r}=1$
$B(i,s,(u),r)$	Input-output flow: basic value of (is) used by (u) in region r
$M(m,i,s,(u),r$	Input-output flow: basic value of domestic good m used as a margin to facilitate the flow of (is) to (u) in region r
$T(\tau,i,s,(u),r)$	Input-output flow: collection of tax τ on the sale of (is) to (u) in region r
$V(i,s,(u),r)$	Input-output flow: purchasers' value of good or factor i from source s used by user (u) in region r
$Y(i,j,r)$	Input-output flow: basic value of output of domestic good i by industry j from region r
$Q_{(j)}^{r}$	Coefficient: ratio, gross to net rate of return
G	Set: {1,2, …, g}, g is the number of composite goods
G*	Set: {1,2, …, g+1}, g+1 is the number of composite goods and primary factors
H	Set: {1,2, …, h}, h is the number of industries
U	Set: {(3), (4), (5), (6), (k j) for k = 1, 2 and j = 1, …, h}
U*	Set: {(3), (k j) for k = 1, 2 and j = 1, …, h}
S	Set: {1, 2, …, r+1}, r+1 is the number of regions (including foreign)
S*	Set: {1, 2, …,r}, r is the number of domestic regions
T	Set: {1, …, t}, t is the number of indirect taxes