The Quarterly Review of Economics and Finance
45 (2005) 476–496

The QUARTERLY REVIEW of ECONOMICS And FINANCE

Market imperfections in a spatial economy: some experimental results

Eduardo A. Haddad [a, b, *], Geoffrey J.D. Hewings [b]

[a] *FEA, University of São Paulo, Brazil*
[b] *Regional Economics Applications Laboratory, University of Illinois, Urbana, USA*

Accepted 6 December 2004
Available online 19 February 2005

Abstract

This paper offers some preliminary steps in the marriage of some of the theoretical foundations of the new economic geography with spatial computable general equilibrium models. Modeling the spatial economy of Brazil using the usual assumptions of CGE models makes little sense when one state, São Paulo, accounts for 40% of GDP and where transportation costs are high and accessibility low compared to European or North American standards. Hence, handling market imperfections becomes imperative as does the need to address internal spatial issues from the perspective of Brazil's increasing involvement with external markets such as MERCOSUL, EU, NAFTA. The paper builds on the B-MARIA-27, a multiregional CGE model of the Brazilian economy; non-constant returns and non-iceberg transportation costs are introduced and some simulation exercises carried out. The results, limited in this paper to short-run considerations, confirm the asymmetric impacts that transportation investment has on a spatial economy in which one state (São Paulo) is able to more fully exploit scale economies vis a vis the rest of Brazil. The analysis also reveals the importance of parameter estimation in handling imperfectly competitive markets.

Keywords: Economic geography; CGE model; Efficiency gains

* Corresponding author. Tel.: +55 11 3813 1444; fax: +55 11 3032 8334.
E-mail address: ehaddad@usp.br (E.A. Haddad).

1062-9769/$ – see front matter
doi:10.1016/j.qref.2004.12.016

1. Introduction

This paper reports on some experimental results derived from a multiregional computable general equilibrium model for the Brazilian economy. While it address some of the theoretical developments derived from the New Economic Geography, it provides some intermediate perspectives between a core-periphery model on the one hand and a perfectly competitive, homogeneous space model at the other extreme. In the Brazilian case, firms can exploit increasing returns to scale without serving a national market; in large part, market imperfections derive from transportation costs that essentially serve to segment markets. Further, the asymmetries in the distribution of productive activity, with the primacy of São Paulo, serve to strengthen existing competitive advantages.

This paper adds two new features to standard spatial CGE models; first, the system is integrated with a transportation network over which interregional commodities move. Secondly, firms in some regions are assumed to exploit increasing returns to scale. The impact of improvement in transportation costs thus has the impact of increasing the variety of goods and services shipped between regions, thus changing the spatial market structure and allowing some firms to enjoy even greater scale economies. The impacts on short-run welfare by region are examined.

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?

The remainder of the paper is organized in four sections. 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. In section three, modeling issues associated with the treatment of non-constant returns and transportation costs are presented. As already mentioned, recent theoretical developments in the 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 short-run simulation experiments are designed and implemented, and the main results are discussed in the following section. Final remarks follow in an attempt to evaluate our findings and put them into perspective, considering their extension and limitations.

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 Brazilian Multisectoral and Regional/Interregional Analysis Model (B-MARIA), the first fully operational interregional

CGE model for Brazil; full details of the model may be found in Haddad and Hewings (1997) and Haddad (1999) and will not be presented here. 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 eight sectors in each state producing eight 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 since a rather complete data set is available and it is also 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, Hewings, & Peter, 2002), facilitating the choice of the base year.

Previous analysis with the B-MARIA framework has suggested that interregional substitution is the key mechanism that drives the 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. Drawing on Bilgic, King, Lusby, and Schreiner (2002) findings about the importance of regional trade elasticities, a concerted effort was made to estimate these for Brazil rather than relying on other published (usually internationally based) trade elasticities.

As is usual with CGE models, the number of unknowns exceeded the number of equations; short- and long-run closure rules were adopted. 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 wages. 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). Further, technology variables are exogenous. While the model can be run with either short-run or long-run closures, only the results from the former simulations will be presented.[1]

[1] In the long-run (steady-state) equilibrium closure, 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: non-constant returns to scale and transportation networks

Two important changes were made to the B-MARIA model. The first attempted to develop a more flexible functional form for the manufacturing sector production function in each one of the 27 Brazilian states to incorporate non-constant returns to scale, a fundamental assumption for the analysis of integrated interregional systems. The hierarchy of a nested CES structure of production is retained, since it turn out to be very convenient for the purpose of calibration (Bröcker, 1998), the hypotheses on the parameters values are modified, 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 retain local convexity properties of the functional forms to guarantee, from the theoretical point of view, the existence of the equilibrium. 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).

The results, shown 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.

The second major change in the structure of B-MARIA was the formal inclusion of transportation margins to account for the real costs of moving goods from one region to another.

Fig. 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.[2] 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.

As already mentioned, the supply of the transportation sector meets margin and non-margin demands. In the former case, Fig. 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.

However, rather than modeling the interstate flows over a topological network, the flows were mapped onto a geo-coded transportation network model, enhancing the po-

[2] The Armington assumption is used here.

Table 1
Estimates of scale parameters

	β	Sample size
Acre	0.983 (0.074)	30
Amapá	*1.110 (0.053)*	*36*
Amazonas	0.952 (0.054)	120
Pará	0.987 (0.025)	114
Rondônia	*0.780 (0.071)*	*66*
Roraima	0.890 (0.142)	36
Tocantins	0.919 (0.055)	72
Alagoas	1.029 (0.042)	108
Bahia	0.979 (0.024)	132
Ceará	0.993 (0.037)	114
Maranhão	*1.135 (0.058)*	*96*
Paraíba	1.007 (0.031)	108
Pernambuco	0.060 (0.799)	120
Piauí	*0.890 (0.043)*	*84*
Rio Grande do Norte	1.049 (0.041)	90
Sergipe	*1.091 (0.030)*	*96*
Espírito Santo	0.974 (0.031)	108
Minas Gerais	*0.892 (0.023)*	*534*
Rio de Janeiro	1.032 (0.022)	498
São Paulo	*0.951 (0.008)*	*588*
Paraná	*0.956 (0.014)*	*528*
Santa Catarina	*0.965 (0.015)*	*402*
Rio Grande do Sul	*0.961 (0.013)*	*522*
Distrito Federal	0.887 (0.060)	96
Goiás	0.942 (0.036)	114
Mato Grosso	*0.818 (0.065)*	*114*
Mato Grosso do Sul	0.930 (0.039)	108
Brazil	*0.907 (0.012)*	*618*

tential of the framework in understanding the role of infrastructure on regional development. Hence, it would be possible now to 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 into 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.

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; it is assumed that trade within the state takes place on an abstract route between the capital and a point located at a distance equal to half the implicit radius related to the state area.[3] The transport model calculates the minimum interstate distances, considering the existing road network in 1997.

[3] Given the state area, we assume the state is a circle and calculate the implicit radius.

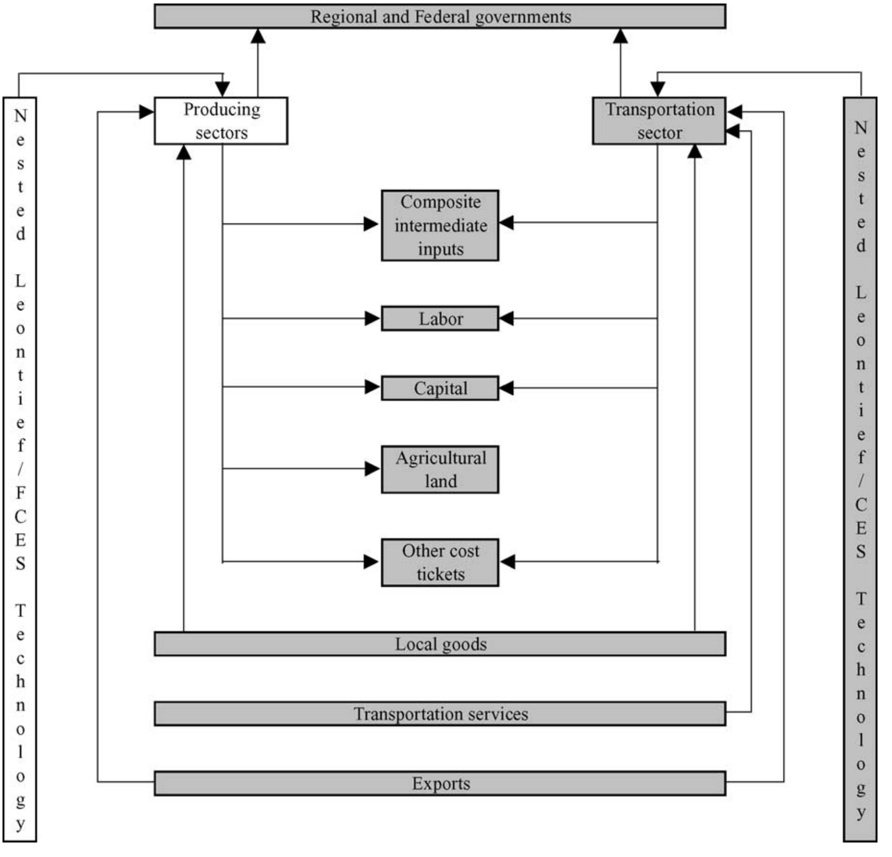

Fig. 1. Flowchart with regional production technology in B-MARIA: highlighting the transportation sector.

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. 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.

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

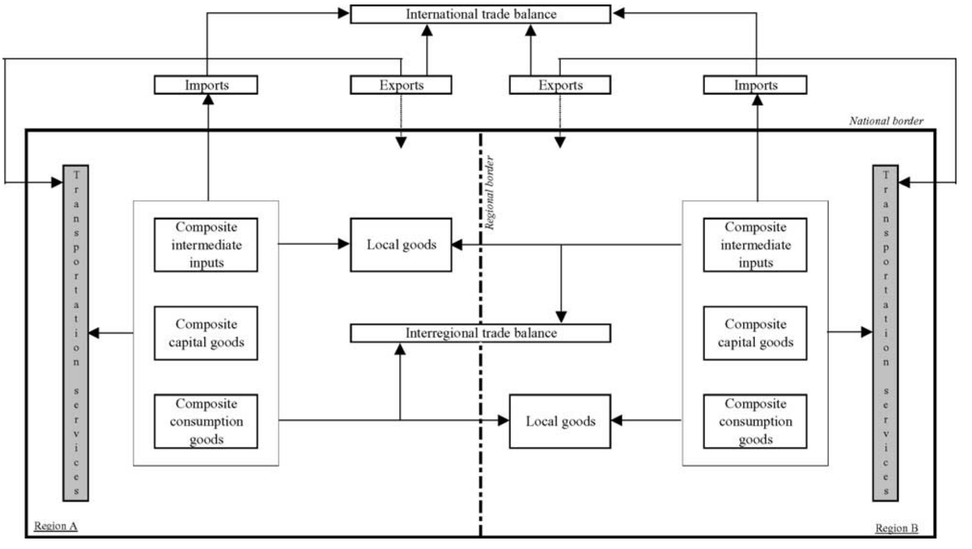

Fig. 2. The role of transportation services in B-MARIA: illustrative flowchart in a two-region integrated framework.

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 & Walters, 1978). The Hicksian measure of EV would consider computing the hypothetical change in income in prices of the post-shock equilibrium (Bröcker & 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 in Almeida (2003):

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

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 the 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:

$$\mathrm{REV}^r = \frac{\mathrm{EV}^r}{I^r} \tag{2}$$

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, Parmenter, Sutton, & Vincent, 1982).

4. The simulation phase

To capture the impacts of investments that involve any change in the structure of the transportation system, the model accommodates the changes through changes in the matrix of minimum interregional distances. Basically, improvements in transportation result in the "shrinking" of distance; the impacts can thus be traced, through changes in transportation margins on the production function by commodity and region. 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 *within* a national economy.

In the next 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%. Only the short-run simulations will be presented as a first step in the more extensive analysis that would be needed to assess potential efficiency gains in the transportation network associated with regulation issues, as discussed in the introduction.

How are the decreases in transportation costs entered into the model? 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.[4]

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 incomes generate 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 – that will require 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. Fig. 3 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

[4] Further extensions would include the specification of a distinction between shippers and carriers, with the latter choosing not only the routes between regions but also the mode of transportation used. For an example, see Sohn, Kim, Hewings, Lee, and Jang, (2003, 2004).

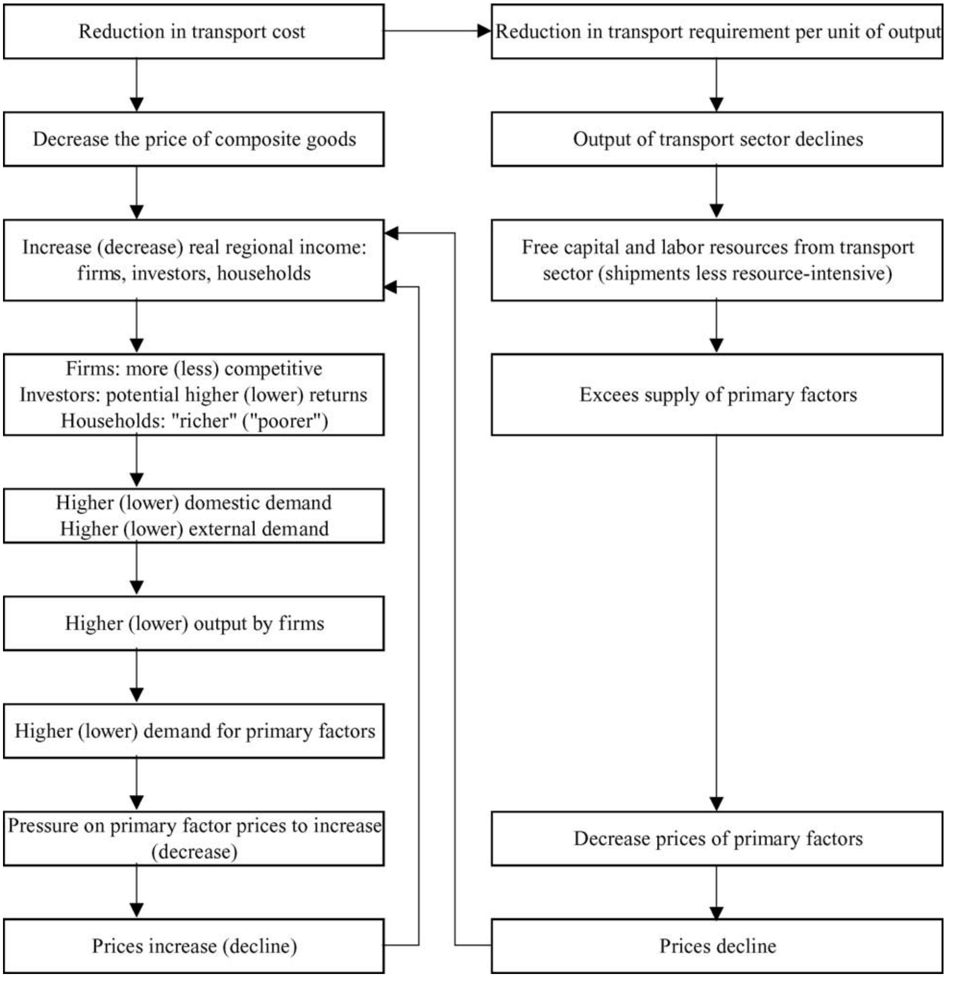

Fig. 3. Causal relationships in the simulation.

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 (*r*) and another importing (*s*), respectively. As transportation costs between the two regions go down, *r* will increase its penetration into *s*, producing more for *s*, as it will now be cheaper for agents in *s* to buy from *r*. A substitution effect operates in the sense that *s* will directly substitute output from *r* for either its own 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 on whether the direct and indirect substitution effects will prevail over the income effect.[5]

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 and would likely feature prominently for trade between regions within a nation.

5. Results

The presentation of the simulation results will focus on the short-run effects; the impacts on the longer-run changes (when, for example, capital and labor are free to move between regions) may be found. Attention will be directed to the relevant aggregate variables that help us understand the functioning mechanism of the model. 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.

Finally, in 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.

5.1. Basic results

Table 2 summarizes the results; gains in efficiency (real GDP growth) and welfare (equivalent variation) are positive. Table 3 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. The intuition here is that lower transport costs will result in a greater

[5] 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. However, in this paper, only short-run (essentially fixing capital) considerations are taken into account.

Table 2
Short-run aggregate results (in percentage-change)

Activity level	% Change
Agriculture	0.0016
Manufacturing	0.0030
Utilities	0.0003
Construction	−0.0002
Trade	0.0002
Financial institutions	0.0021
Public administration	0.0004
Transportation and other services	−0.0098
Total	−0.0015
Prices	
Investment price index	−0.0172
Consumer price index	−0.0239
Exports price index	−0.0132
Regional government demand price index	−0.0240
Federal government demand price index	−0.0250
GDP price index, expenditure side	−0.0236
Primary factors	
Aggregate payments to capital	−0.0256
Aggregate payments to labor	−0.0279
Aggregate capital stock, rental weights	–
Aggregate employment, wage bill weights	−0.0040
Aggregate demand	
Real household consumption	0.0006
Aggregate real investment expenditure	–
Aggregate real regional government demand	–
Aggregate real Federal government demand	–
Export volume	0.0273
Aggregate indicators	
Equivalent variation—total (change in $)	8.97
Real GDP	0.0031

volume of goods being available at lower prices in the less developed regions; regional welfare would also be enhanced by the expectation that a greater variety of goods and services will now be made available in those regions.

Consider the findings for the Southeast and South states; Minas Gerais, Espírito Santo, Paraná, and Rio Grande do Sul gain while São Paulo, Rio de Janeiro and Santa Catarina lose. Since the impacts feature short-run solutions, the intuition here is that for São Paulo, supply is relatively inelastic. Consumer in this state now face more competition from consumers in other states since the effects of decreases in transportation costs serve to expand the geographical scope of the market that could potentially be served by São Paulo. This increase in demand is met by higher prices in São Paulo, leading to a negative equivalent variation. Minas Gerais, on the other hand, is a primary producer of intermediate rather than final products and thus expansion of consumer demand will lead to increases in demand for intermediates, yielding, on balance a positive short run outcome.

Table 3
Spatial results

		Short-run		
		EV	REV (%)	GDP
North	Acre	0.46	0.062	0.0059
	Amapá	0.41	0.043	0.0101
	Amazonas	2.64	0.015	0.0039
	Pará	2.71	0.028	0.0037
	Rondônia	0.64	0.025	0.0034
	Roraima	0.26	0.075	0.0110
	Tocantins	0.24	0.024	0.0102
Northeast	Alagoas	2.06	0.058	0.0062
	Bahia	5.56	0.020	0.0043
	Ceará	3.09	0.028	0.0052
	Maranhão	2.55	0.054	0.0082
	Paraíba	1.76	0.033	0.0049
	Pernambuco	5.54	0.033	0.0055
	Piauí	0.71	0.029	0.0079
	Rio Grande do Norte	1.77	0.041	0.0045
	Sergipe	0.75	0.023	0.0025
Southeast	Espírito Santo	−0.35	−0.003	0.0030
	Minas Gerais	5.33	0.009	0.0054
	Rio de Janeiro	−1.86	−0.002	0.0019
	São Paulo	−21.51	−0.008	0.0026
South	Paraná	1.93	0.005	0.0020
	Santa Catarina	−0.99	−0.004	0.0023
	Rio Grande do Sul	0.69	0.001	0.0032
	Distrito Federal	−3.79	−0.012	0.0015
Center-West	Goiás	0.29	0.003	0.0030
	Mato Grosso	−1.11	−0.015	0.0035
	Mato Grosso do Sul	−0.80	−0.010	0.0018
	Brazil	8.97	0.001	0.0031

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

5.2. Systematic sensitivity analysis

How sensitive are the results to parameter specification? CGE models have been frequently criticized for resting on weak empirical foundations.[6] 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

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

CGE models, arguing that the calibration approach leads to an over-reliance on non-flexible functional forms.

Although most CGE modelers recognize that accurate parameters values are very important, it is not easy to find empirical estimates of key parameters, such as substitution elasticities, in the literature. Most of the models take up estimates "found in the literature" or even "best guesstimates" (Deardorff & Stern, 1986). Thus, if there is 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 & Preckel, 1997; Domingues, Haddad, & Hewings, 2003) 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.

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 4 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.

Table 4
Trade elasticities in the B-MARIA-27 model

	International	Regional
Agriculture	0.343	1.570
Manufacturing	1.278	2.079
Utilities	0.011	1.159
Construction	0.002	0.002
Trade	0.694	0.001
Financial institutions	0.137	1.385
Public administration	0.070	0.001
Transportation and other services	1.465	0.001

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.

Table 5 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 to scale economies parameters rather than to regional trade elasticities. Overall, the state simulation results can be considered robust to both sets of parameters.

5.3. *Analytically important transportation links*

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 (1989), 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.[7]

To accomplish this task, the role played by each transportation link – 27 × 27 in total – in generating the model's results were evaluated.[8] 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 coun-

[7] See Domingues et al. (2003).

[8] 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 5
Systematic sensitivity analysis

	Trade elasticities				Scale economies parameter	
	Welfare changes (R$ million)		GDP changes (%)		GDP changes (%)	
	Lower bound	Upper bound	Lower bound	Upper bound	Lower bound	Upper bound
Acre	0.46	0.46	0.0058	0.0059	0.0059	0.0059
Amapá	0.41	0.41	0.0101	0.0101	0.0101	0.0101
Amazonas	2.62	2.65	0.0039	0.0039	0.0039	0.0039
Pará	2.69	2.73	0.0037	0.0038	0.0037	0.0037
Rondônia	0.63	0.65	0.0033	0.0034	0.0033	0.0034
Roraima	0.26	0.26	0.0110	0.0110	0.0110	0.0110
Tocantins	0.24	0.25	0.0099	0.0105	0.0102	0.0102
Alagoas	2.05	2.06	0.0062	0.0062	0.0062	0.0062
Bahia	5.53	5.58	0.0043	0.0043	0.0043	0.0043
Ceará	3.08	3.11	0.0052	0.0052	0.0052	0.0052
Maranhão	2.54	2.56	0.0081	0.0082	0.0081	0.0083
Paraíba	1.75	1.76	0.0049	0.0049	0.0049	0.0049
Pernambuco	5.53	5.55	0.0055	0.0055	0.0055	0.0055
Piauí	0.71	0.71	0.0078	0.0079	0.0078	0.0079
Rio Grande do Norte	1.77	1.79	0.0044	0.0045	0.0045	0.0045
Sergipe	0.74	0.75	0.0025	0.0025	0.0025	0.0025
Espírito Santo	−0.37	−0.33	0.0029	0.0030	0.0030	0.0030
Minas Gerais	5.28	5.38	0.0054	0.0055	0.0054	0.0055
Rio de Janeiro	−1.97	−1.76	0.0019	0.0019	0.0019	0.0019
São Paulo	−21.59	−21.44	0.0026	0.0026	0.0026	0.0026
Paraná	1.91	1.95	0.0020	0.0020	0.0020	0.0020
Santa Catarina	−1.00	−0.98	0.0023	0.0023	0.0023	0.0023
Rio Grande do Sul	0.65	0.72	0.0031	0.0032	0.0031	0.0032
Distrito Federal	−3.82	−3.75	0.0014	0.0016	0.0015	0.0015
Goiás	0.27	0.31	0.0029	0.0030	0.0030	0.0030
Mato Grosso	−1.11	−1.10	0.0035	0.0036	0.0035	0.0036
Mato Grosso do Sul	−0.81	−0.79	0.0018	0.0018	0.0018	0.0018
Brazil	8.81	9.14	0.0031	0.0031	0.0031	0.0031

try 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.

Table 6 presents the results for the welfare effects. Transportation links between and within macro regions are explicitly considered, and the estimates of their contributions to the specific policy outcome are presented. Focus attention, first on the entries in Table 6 that reveal the welfare effects. The overall national impact shown in Table 2 (R$ 8.97 million) is now decomposed into region-to-region links. For the North region, there is a positive intra-regional impact (2.92) from a transportation cost reduction in this region. Essentially, the transportation cost decrease lowers delivered prices to consumers who respond by purchasing more of the goods and services produced in the North region states. Further, consumers in this region are now able to purchase a greater number of goods and services produced in the Southeast, yielding to an increase of 6.50. A simi-

Table 6
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*

lar pattern may be found for the Northeast; here the intra-regional effect (13.55) and the Southeast–Northeast trade flow (20.78) are larger than comparable linkages for the North region. The gains in the South region for similar linkages lie between these two while those for the Center-West are smaller. For the Southeast region, the largest effect is the intra-regional gain—the impacts for those states within that region that gain offset the losses in other states.

5.4. *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*,[9] 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 share in manufacturing value added in the period 1996–2001 was 47.3%, the state's 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-returns 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

[9] 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.

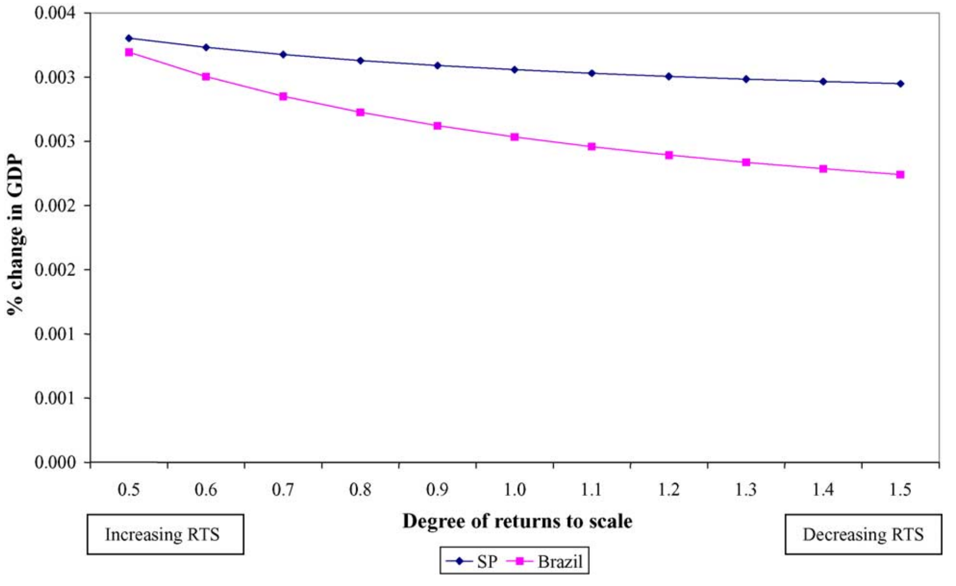

Fig. 4. Short-run effects on national and state GDP [efficiency gains].

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 Figs. 4 and 5. 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.

The results reveal that, in general, the Rest of Brazil has more to gain from increasing returns to scale than São Paulo; further, the variation in welfare effects are smaller (Fig. 5) than for efficiency effects (Fig. 4). While it would be premature to draw general conclusions form this single case study, it may turn out that transportation costs variations generate more impact on the spatial economy than scale economies in the short run, when supply constraints are stronger. However, it should be noted that transportation costs are often a relatively smaller component of total costs, so while percentage changes might be large, they need to be considered in the context of total input costs. Secondly, while the underlying input–output table assumes no scale economies, the production structure implicit in the Leontief system obviously includes a density function of production technologies that are in some sense averaged. For some sectors, the realization of scale economies may be more modest in that these sectors may contain a greater proportion of establishments that use more modern techniques and thus produce more efficiently. Unfortunately, these are empirical questions that cannot be answered without information on establishment level production functions.

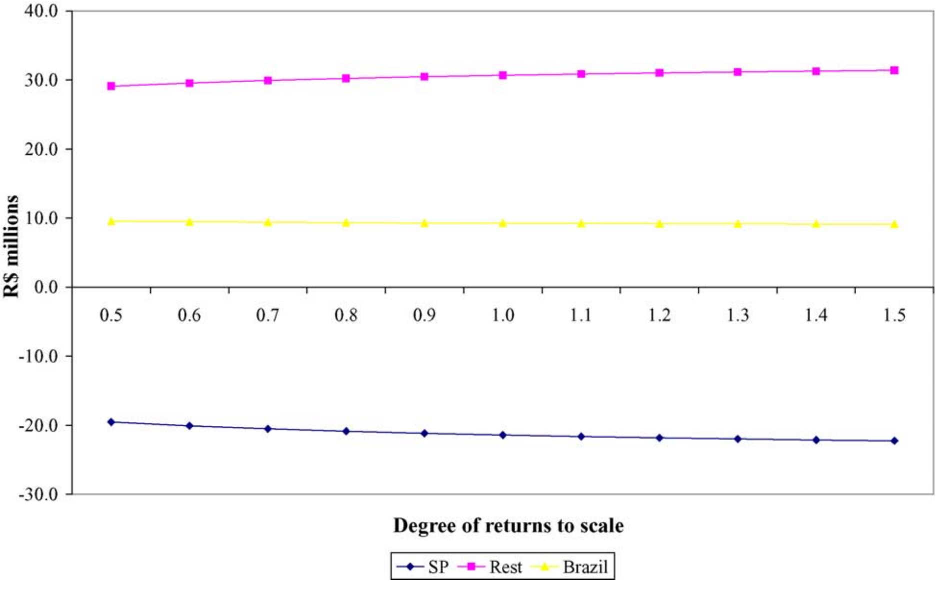

Fig. 5. Short-run effects on national and state welfare [welfare gains].

6. 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 ongoing and difficult; attempts to handle non-constant returns to scale, agglomeration and core-periphery phenomena, imperfect competition, 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 in this paper suggests that this area remains contentious. However, these steps will be necessary if CGE models are to achieve credibility in their ability to mimic changes in regulation and to provide policy makers with some reasonable degree of confidence in the measurement of outcomes generated by strategic, spatially targeted investment strategies, especially those focused on transportation networks.

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). Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana.

Bilgic, A., King, S., Lusby, A., & Schreiner, D. F. (2002). Estimates of U.S. regional commodity trade elasticities. *Journal of Regional Analysis and Policy*, *32*(2).

Bröcker, J. (1998). Operational computable general equilibrium modeling. *Annals of Regional Science*, *32*, 367–387.

Bröcker, J., & Schneider, M. (2002). How does economic development in eastern Europe affect Austria's regions? A multiregional general equilibrium framework. *Journal of Regional Science*, *42*(2), 257–285.

Cukrowski, J., & Fischer, M. M. (2000). Theory of comparative advantage: Do transportation costs matter? *Journal of Regional Science*, *40*(2), 311–322.

Deardorff, A. V., & Stern, R. M. (1986). *The michigan model of world production and trade*. Cambridge: The MIT Press.

DeVuyst, E. A., & Preckel, P. V. (1997). Sensitivity analysis revisited: A quadrature-based approach. *Journal of Policy Modeling*, *19*(2), 175–185.

Dixon, P. B., Parmenter, B. R., Sutton, J., & Vincent, D. P. (1982). *ORANI: A multisectoral model of the Australian economy*. Amsterdam: North-Holland.

Domingues, E. P., Haddad, E. A., & 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.

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

Haddad, E. A., & Hewings, G. J. D. (1997, November). *The theoretical specification of B-MARIA* (*Discussion Paper REAL 97-T-5*). Regional Economics Applications Laboratory University of Illinois at Urbana-Champaign.

Haddad, E. A., Hewings, G. J. D., & Peter, M. (2002). Input–output systems in regional and interregional CGE modeling. In G. J. D. Hewings, M. Sonis, & D. Boyce (Eds.), *Trade, networks and hierarchies*. Berlin: Springer-Verlag.

Hansen, L. P., & Heckman, J. J. (1996). The empirical foundations of calibration. *The Journal of Economic Perspectives*, *10*(1), 87–104.

Layard, P. R. G., & Walters, A. A. (1978). *Microeconomic Theory*. McGraw-Hill.

Mansori, K. F. (2003). The geographic effects of trade liberalization with increasing returns in transportation. *Journal of Regional Science*, *43*(2), 249–268.

McKitrick, R. R. (1998). The econometric critique of computable general equilibrium modeling: The role of functional forms. *Economic Modelling*, *15*(4), 543–573.

Sohn, J., Kim, T. J., Hewings, G. J. D., Lee, J. S., & Jang, S.-G. (2003). Retrofit priority of transport network links under an earthquake. *Journal of Urban Planning and Development*, *129*, 195–210.

Sohn, J., Hewings, G. J. D., Kim, T. J., Lee, J. S., & Jang, S.-G. (2004). Analysis of economic impacts of an earthquake on a transportation network. In Y. Okuyama & S. Chang (Eds.), *Modeling spatial and economic impacts of disasters*. Heidelberg: Springer.

Sonis, M., & Hewings, G. J. D. (1989). Error and sensitivity input-output analysis: A new approach. In R. E. Miller, K. R. Polenske, & A. Z. Rose (Eds.), *Frontiers of input-output analysis*. New York: Oxford University Press.

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

Wigle, R. (1991). The Pagan–Shannon approximation: Unconditional systematic sensitivity in minutes. *Empirical Economics*, *16*, 35–49.