Sensitivity Analysis in Computable General Equilibrium Models: An Application for the Regional Effects of the Free Trade Area of the Americas (FTAA)*

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Abstract

The goal of this paper is to explore an applied tool for sensitivity analysis in computable general equilibrium models (CGE). An interregional CGE model is used to assess the impacts of the Free Trade Area of the Americas (FTAA) on Brazilian regions. As interregional substitution and factor mobility can be the key mechanisms that drive the model results, one should take closer attention to the estimated regional trade elasticities. Since information for proper estimation is rarely available, qualitative sensitivity analysis should be designed and used together with systematic quantitative sensitivity analysis. The sensitivity of results to parameters is evaluated in such a way that we can assess the robustness of results to different levels of elasticities of substitution.

Keywords: Sensitivity Analysis, Computable General Equilibrium, Regional Models, FTAA.

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1. Introduction

The framework of applied economic models can be classified based on three major characteristics, as proposed by Mckitrick (1998): analytical, functional and numerical. The analytical framework, or basic theoretical framework, can be a Walrasian general equilibrium model, where the variables of interest are identified and casual relationships are determined. The functional framework is composed of algebraic equations of the implemented model, which mathematically represent the analytical framework. The numerical framework represents the set of coefficients (signs and magnitudes) that form the functional framework of the model.

There has been an increasing concern in the literature regarding the numerical framework of computable general equilibrium models (CGE). The key issue is the influence of the parameters used for the results or the robustness of the results in relation to the different sets of parameters. In the absence of more appropriate estimates for these parameters – a situation that is common to most researchers – the sensitivity analysis in computable models is of paramount importance.

This paper is organized into four sections. Section 2 introduces the sensitivity analysis in CGE models. Section 3 presents the CGE model employed in this study to exemplify the use of the systematic sensitivity analysis, as well as the simulation implemented. Section 4 describes the results and section 5 concludes.

2. Systematic Sensitivity Analysis, CGE Models and Gaussian Quadratures[1]

A general equilibrium model can be seen in general form as:

$$F\left(v,a\right)=0 \tag{1}$$

Where v stands for the vector of endogenous variables and a is the vector of exogenous variables (parameters, shares, etc.). The solution of equation (1) can be defined as $v^*(a)$ and $v^*(a)H(a)$ as the vector of results of interest. Economic models normally use estimates of behavioral parameters. For instance, estimates of import substitution elasticities are very relevant in the study of trade policies. Considering that these estimates are random variables, the calculation of mean results for the endogenous variables takes the form:

$$E\left[H(a)\right]=\int_{\Omega}H(a)g(a)da \tag{2}$$

Therefore, the calculation of the variance of results can be obtained by

$$E\left[\left(H(a)-E\left[H(a)\right]\right)^2\right]=\int_{\Omega}\left(H(a)-E\left[H(a)\right]\right)^2g(a)da \tag{3}$$

[1]This section draws on Arndt (1996).

where $g(a)$ is a multivariate density function.

Simulations with computable general equilibrium (CGE) models can be regarded as numerical integration problems, from (2) and (3). The advantage of this approach is that it allows handling, simultaneously, the model solution and the random nature of exogenous variables. This approach tends to be more accurate than the traditional one, based only on the mean values of the exogenous variables.[2] In addition, standard deviation estimates can be easily obtained from the estimated means.

Numerical methods, such as the Monte Carlo method or Gaussian quadratures (GQ), can be used to calculate the mean values in (2). Once the estimates of mean results are obtained, standard deviation estimates are easily calculated. Based on hypotheses about the distribution of exogenous variables, this approach allows for the systematic investigation of the impact of the uncertainty over the values of key exogenous variables. Chebychev's inequality can also be used in the construction of confidence intervals for the model results. These intervals provide important information about the robustness of the results regarding the different values for the vector of exogenous variables and can help researchers to identify results that are relatively more reliant on the values of exogenous variables (parameters or shocks).

The use of numerical integration methods can be exemplified in the simple case of univariate integration:

$$\int_a^b f(x)g(x)dx \tag{4}$$

in which $g(x)$ is the density function.

If the integrand is difficult to evaluate analytically, as occurs in most CGE models, this integral can be approximated numerically. In general, numerical approximations take the form:

$$\sum_{j=1}^{J} w_j f\left(x^j\right) \tag{5}$$

where J represents the total number of evaluations of $f(.)$ and w_j represents the weight attached to each evaluation (Haber (1970)).

[2]In general, the expected value of a function differs from the value of the function in the expected mean value of the exogenous variable: $E[H(a)] \neq H(E[a])$. If $H(.)$ can be well approximated by a linear function in the region of integration, Ω, the right-hand side of the equation is a good approximation to the integral in equation (2). Significant approximation errors in the estimation of mean results can be obtained from the linear approximation of $H(.)$, by using mean values for exogenous variables. For example, in a non-linear model such as the GTAP (Hertel (1997)), simulating with the mean values of exogenous parameters, which is a common practice, can generate poor approximations for the mean results (Arndt (1996)). The extension of this error to the mean results depends on the model and also on aggregation and simulation.

The Monte Carlo approach is a special case in which J pseudo-random numbers are generated from a $g(x)$ distribution in the interval $[a, b]$. From then on, the integrand is evaluated J times, and a weight $1/J$ is attached to the results of each evaluation. The approximation will be good under extremely mild conditions for the integrand if J is sufficiently large. CGE models are the cases in which the integrand is difficult to evaluate numerically, and it would be desirable to keep the number of evaluations of the integrand, J, small. Therefore, appropriately chosen points within the interval $[a, b]$ and their associated weights w need to be considered.

The formulas used to produce this group of points and associated weights are called quadratures. Gaussian Quadratures (GQ) are especially appealing. In the case of the integration problem in equation (5), an order d GQ solves the system of equations:

$$\sum w_j \left(x^j\right)^S = \int_a^b (x)^S g(x)dx, \qquad s = 0, 1, 2, \cdots, d \tag{6}$$

Gaussian Quadratures are methods developed to approximate integration problems accurately while requiring a limited number of evaluations of the integrand. This method was very useful before the advent of the computer; nowadays, computing technology allows for the easy application of Monte Carlo methods to solve univariate integration problems. However, in the multivariate case, the Monte Carlo approximations are not always so practical. The development and regular use of extremely complex multivariate integrands, such as in global or interregional CGE models, implies that Monte Carlo simulations are not feasible, even with the best available computing technology. The use of multivariate Gaussian Quadratures for sensitivity analysis in CGE models was proposed by DeVuyst and Preckel (1997); Wigle (1991) discussed alternative approaches to analyzing the sensitivity of CGE models to parameters. Given a continuous distribution for several variables, a Gaussian quadrature for this distribution is a discrete distribution whose first moments are identical with those of the continuous distribution. The quadrature is said to be of order d if the first d moments agree.

The GQ method, as implemented in the GEMPACK software (Harrison and Pearson (2002)), follows a method developed by Stroud (1957) for drawing order three GQs for symmetric distributions. Since it is an order three approximation, the first three moments are the same as those for the continuous distribution. The first moment is the mean and the second one is the standard deviation. These quadratures are only valid for distributions made up of one or more symmetric distributions, which vary independently. This methodology is very appealing because of its modest requirements. For a model with n random exogenous variables, this method allows for the systematic sensitivity analysis of these n exogenous variables using only $2n$ points or solutions of the model.[3]

[3] Arndt (1996) describes that systematic sensitivity analysis in a model that takes 5 minutes

Formula (7) was developed by Stroud (1957) to derive equally weighted order three quadratures for symmetric, independent distributions of mean zero and standard deviation one. Let n be the number of random exogenous variables and $\Gamma_k(\gamma_{k1}, \gamma_{k2}, \ldots, \gamma_{kn})$ the k^{th} quadrature point ($k = 1, 2, \ldots, 2n$). With $r = 1, 2, \ldots, n/2|$, where $n/2|$ denotes the greatest integer not exceeding $n/2$, the points may be derived by:

$$\gamma_{2r-1} = \sqrt{2}\cos\left(\frac{(2r-1)\,k\pi}{n}\right) \qquad \gamma_{2r} = \sqrt{2}\sin\left(\frac{(2r-1)\,k\pi}{n}\right) \tag{7}$$

Once the weights, w_k, are identical and must sum to 1, then $w_k = 1/2n$.

Stroud proves that points derived from the above formula satisfy the following condition for an order three approximation of a multivariate distribution of exogenous variables x:

$$\sum_{j=1}^{J} w_j \prod_{m=1}^{M} (x_m)^{l_m} = \int_{\Omega} \left[\prod_{m=1}^{M} (x_m)^{l_m}\right] g(x)dx \tag{8}$$

for all combinations of non-negative integers l_m such that $\sum_{m=1}^{M} l_m \leq d$.

Suppose one wants to implement a sensitivity analysis with respect to a symmetrically distributed exogenous variable $x(x_1, x_2, \ldots, x_n)$, a column vector of size n with mean μ and variance-covariance matrix $\sum$. If $\sum$ is diagonal, the desired quadrature, Φ, can be obtained by:

$$\Phi = \mu + \Gamma\sqrt{\sum} \tag{9}$$

If $\sum$ is not diagonal, a diagonal matrix, D, can be obtained using a Cholesky factorization, $\sum = LDL^t$. The quadrature from equation (9) is then transformed to $\Gamma^* = \Gamma L$ and Φ can be obtained by:

$$\Phi = \mu + \Gamma^*\sqrt{D} \tag{10}$$

It is not clear how many orders a GQ should have to produce an accurate fit. The result depends on the integrand, in this case the CGE model, and also on the simulation and aggregation implemented. Experience indicates that the estimates of the means and standard deviations produced are usually fairly accurate. Arndt (1996) has made some comparison for the GTAP model and has concluded that order three approximations were quite good, as order three and order nine

to be solved using Monte Carlo replications would take approximately 3.5 days. On the other hand, the Stroud method allows for an accurate sensitivity analysis of 15 exogenous variables in 2.5 hours. If the results are reasonably approximated by an order three polynomial, the sensitivity analysis via GQ will be quite accurate despite the limited number of model evaluations.

approximations matched to the first four decimal points. In general, higher order quadratures produce better approximations.

In summary, Gaussian quadratures can provide a practical tool to conduct systematic sensitivity analysis in large CGE models. Two conditions must be met to employ this analysis. First, random exogenous variables should be distributed symmetrically. Secondly, the model results should be reasonably well approximated by an order three polynomial. In this case, the Stroud formula can be easily employed to obtain quadratures, or points where the model will be evaluated. This method allows us to obtain good approximations of means of model results and associated standard deviations. This additional information is very important to evaluate the robustness of model results, instead of simply running the model at mean values for random exogenous variables.

In the next section, we present the model used to exemplify the application of the systematic sensitivity analysis.

3. Model and Simulation

SPARTA (*São Paulo Applied Regional Trade Analysis*) is an interregional CGE model developed for the analysis of the economy of São Paulo and of Brazil (Domingues (2002)). Its theoretical framework is similar to the B-MARIA model (Haddad (1999)) and follows the Australian tradition of general equilibrium models.[4]

The SPARTA model divides the Brazilian economy into two regions, São Paulo and Other Regions, and identifies seven foreign markets: Argentina, other Mercosur countries, other FTAA countries, NAFTA, the European Union, Japan and the Rest of the World. The calibration data are those for 1996, and 42 productive sectors and investment goods are specified for each region. The productive sectors use two local primary factors (capital and labor). The final demand consists of household consumption, investment, exports, and regional and federal government consumption. The regional governments are sources of exclusively local demands and expenditure, comprising the state and municipal levels of public administration in each region.[5]

The main innovation in the SPARTA model is the detailed treatment of external flows, with the specification of origin and destination markets for trade with foreign markets. This specification follows the one implemented in the EFES-IT model (Haddad et al. (2002)), and it is common in national and global CGE mod-

[4]Following this tradition, the models use Johansen's approach, where the mathematical structure is represented by a set of linearized equations and solutions are obtained as growth rates. In the Brazilian economy, the PAPA (Guilhoto (1995)) and EFES (Haddad and Domingues (2001)) models use this approach.

[5]The complete model has 380,762 equations and 388,319 variables. The full description of the model and of the database is presented in Domingues (2002). A miniature version is available at www.econ.fea.usp.br/nereus.

els.[6] The SPARTA core module comprises blocks of equations that determine the relationship between supply and demand, derived from optimizing behavior, and market equilibrium conditions. In addition, several regional and national aggregates are defined, such as level of aggregate employment, trade balance and price indices. Next, we present the main theoretical aspects of the model.

3.1 Production technology

Figure 1 illustrates the production technology used in the SPARTA model, a usual specification in regional models. This specification defines three levels of optimization for the productive process of firms. The dashed lines indicate the functional forms specified in each stage. Fixed proportion combinations of intermediate inputs and primary factors are assumed at the first level, through the Leontief specification. The second level involves substitution between domestically produced and imported inputs on one side, and substitution between capital and labor on the other side. A constant elasticity substitution (CES) function is used for the combination of inputs and primary factors. At the third level, bundles of domestically produced and imported intermediate inputs are formed as combinations of inputs from different sources. Again, a CES function is used to combine goods from different sources. Domestically produced inputs come from two regions (either from São Paulo or from other Brazilian regions). Imported goods come from seven foreign markets.

The use of CES functions in the production technology implies the adoption of the so-called Armington assumption (Armington (1969)) for product differentiation. Due to this hypothesis, goods from different sources are regarded as imperfect substitutes. For instance, agricultural and livestock products from São Paulo are different from the agricultural and livestock products from other Brazilian regions with regard to their use in the productive process (third level in Figure 1). This treatment permits the model to exhibit non-specialized intrasectoral market patterns, an important empirical regularity described in the literature.[7] However, some of the characteristics of the Armington specification have been criticized. As demonstrated by Hertel (1997), this specification implies non-substitutability between intermediate inputs and primary factors, besides independence between imported intermediate and domestically produced inputs, a fact that goes against the evidence of strong substitutability between inputs. The exogenous characteristic of product differentiation has received criticisms, which is in contradiction to the literature about industrial organization, imperfect competition and international trade. The adoption of these characteristics demands additional information about industrial concentration and economies of scale from CGE models, but this

[6] For instance, in the GTAP model (Hertel (1997)) and in Campos-Filho (1998).

[7] For product differentiation in the foreign market and CGE models, see De-Melo and Robinson (1989). The behavior of several classes of CES functions is analyzed in Perroni and Rutherford (1995).

information is rarely available for the Brazilian case. Haddad and Hewings (2004) introduced increasing returns in an interregional equilibrium model for the Brazilian economy, investigating the effects of this specification on simulations of change in transportation costs.

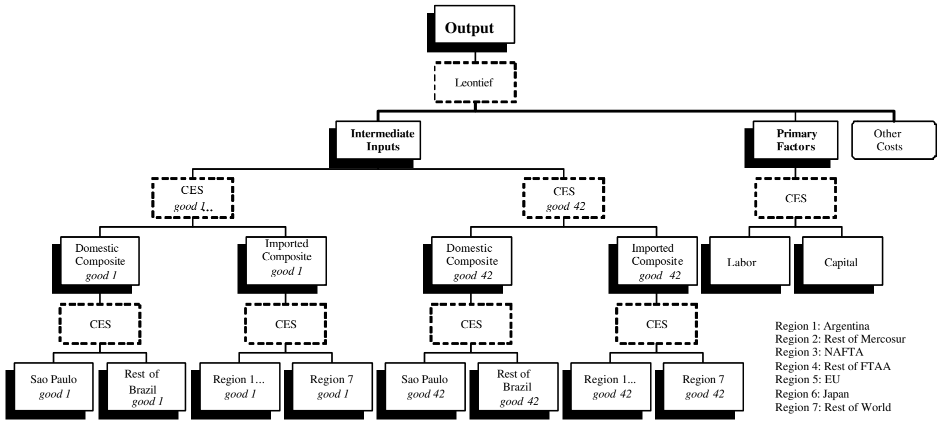

Figure 1
Grouped structure of regional production technology

3.2 Household demand

Each region has a group of representative families which buy domestic goods (either locally produced or from other regions) and imported goods (from seven foreign markets). The specification of household demand, in each region, is based on a CES/linear expenditure system (LES) preference function. The demand equations are derived from a utility maximization problem, whose solution follows hierarchical steps, similar to the ones shown in Figure 1. At the bottom level, substitution occurs across different domestic and imported sources of supply. At the subsequent upper level, substitution occurs between domestic composite and imported goods. The utility derived from the consumption of domestic and imported composite goods is maximized according to a Stone-Geary utility function. This specification gives rise to the linear expenditure system (LES), in which the expenditure share above the subsistence level for each good represents a constant proportion of the total subsistence expenditure of each regional family.[8]

[8] For the parameters necessary for the calibration of this specification, see Dixon et al. (1982). The LES specification is non-homothetic, such that the increase in the household expenditure (income) causes changes in the share of goods in overall expenditure, *ceteris paribus*.

3.3 Demand for investment goods

Investors are a category of use of final demand, and are responsible for capital formation in each regional sector. They choose the inputs used in the capital formation process through cost minimization using a hierarchically structured technology. This technology is similar to the production technology, with some adaptations. As occurs with the production technology, the capital good is produced by domestic and imported inputs. At the third level, an aggregate bundle of intermediate goods (domestic and imported) is formed as the combination of inputs from different sources. A CES function is used in the combination of goods from different sources. Differently from the production technology, primary factors are not used directly as input for capital formation, but used indirectly through inputs in sectoral production, especially in the construction sector. The level of regional investment in capital goods by sector is determined by the capital accumulation block.

3.4 Export and government demand

All exported goods have downward sloping demand curves for their own prices in the world market. A vector of elasticity defines the response of foreign demand to changes in the FOB price of regional exports. Hypothetically, these elasticities are identical by region and different by good.

The government demand for public goods is based on the isolation of the consumption of public goods by the regional and federal governments, obtained from the input-output matrix. However, productive activities carried out by the public sector cannot be dissociated from those performed by the private sector. Thus, the government's entrepreneurial behavior is dictated by the same cost minimization assumptions adopted by the private sector. This hypothesis may be considered more appropriate, at first, for the Brazilian economy, since the privatization process implemented in the 1990s substantially reduced the participation of the government in the productive sector (Haddad (1999)). Public goods consumption is set to maintain a constant proportion with regional private consumption, in the case of regional governments, and with national private consumption, in the case of the federal government.

3.5 Capital accumulation and investment

Some qualifications are necessary for the specification of capital formation and investment in the model. As discussed in Dixon et al. (1982), the modeling of these components is basically concerned with how investment expenditures are allocated both by sector and by region, and not with the aggregate private investment in constructions, machinery and equipment. On top of that, the temporal conception of investment used is not precisely related to a time frame; this would be a necessary characteristic if the model had the aim to explain the investment expansion path over time. Therefore, the main concern regarding the investment modeling is to capture the effects of the shocks (*e.g.*: trade liberalization) on the allocation of current investment expenditure across sectors and regions.

3.6 Labor market and regional migration

The model adopts quite a simple and flexible specification for the labor market. The population in each region is defined exogenously through the interaction of demographic variables and interregional migration variables, and there is also a connection between regional population and labor supply. Given the specification of the labor market functioning, labor supply can be determined by interregional wage differentials or by regional unemployment rates, along with demographic variables, often defined exogenously. In summary, both labor supply and wage differentials may determine unemployment rates or, alternatively, labor supply and unemployment rates will determine wage differentials. The choice of any of these alternatives has a relevant influence on simulation results. As this study uses a long-run closure for the model and does not adopt any population growth rate, the national labor supply is fixed, implying that the national wage responds endogenously. On the other hand, labor supply in each region responds endogenously so as to maintain the wage differentials. The sectors that are relatively favored in each region attract regional and national labor force, but labor costs tend to rise in the whole economy.

3.7 Other specifications

The government finance module incorporates equations determining the gross regional product for each region, through the decomposition and modeling of its components, on both the expenditure and income sides. Budget deficits of the regional and federal governments are also defined, as well as the aggregate household consumption functions in each region (disaggregated into the main sources of income and in the respective tax duties). Other definitions in the model include tax rates, basic prices, and purchase prices of commodities, tax revenues, margins, components of the gross domestic product (GDP) and gross regional product (GRP), regional and national price indices, factor prices, aggregate employment and money wage settings.

3.8 Closures

The SPARTA model can be used for short-run and long-run comparative static simulations. The basic distinction between these two types of closure lies in the treatment given to the microeconomic approach to capital stock adjustment. Capital stocks are held fixed in the short run, whereas in the long run, policy changes may affect capital stocks in each region.[9]

[9] For closures in CGE models, see, for instance, Dixon and Parmenter (1996), Dixon et al. (1982).

In the short-run closure, besides the hypothesis of interindustry and interregional immobility of capital, the regional population and labor supply are fixed, the regional wage differentials are constant and the national real wage is fixed. Regional employment is driven by the assumptions on wage rates, which indirectly determine regional unemployment rates. Thus, changes in the demand for labor are met by changes in regional unemployment rates, keeping the national real wage and the interregional wage differentials fixed. On the demand side, investment expenditures are exogenous – firms cannot reassess investment decisions in the short run. Household consumption follows household disposable income, and government consumption, at both regional and federal levels, is fixed (alternatively, government deficit can be set exogenously, allowing government expenditures to change). Finally, the technology variables are exogenous, given that the model does not present any endogenous growth theory.

In the long-run closure, capital and labor are mobile across sectors and regions. Aggregate employment is determined by population growth, labor force participation rates, and the natural rate of unemployment. The distribution of labor force across regions and sectors is totally determined endogenously. Labor is attracted to more competitive sectors in more favored geographical areas. Likewise, capital is directed towards more attractive sectors. This movement keeps the rates of return at their initial levels.

The behavior of federal and regional governments in relation to closures is also different. In the short run, there is no budgetary constraint, and government deficit responds endogenously. In the long-run closure, government deficit is held fixed, in such a way revenues (e.g.: taxes on the payment of non-wage factors) respond endogenously in order to bring the deficit back to its status in the base year. Usually, in both closures, government consumption is exogenous and fixed.

3.9 Simulation

In this study, the SPARTA model is used to assess the results of the Free Trade Area of the Americas (FTAA) for Brazilian regions.[10] In the simulation, only import tariff barriers in the Brazilian bilateral trade with FTAA countries are taken into consideration. In this way, the simulation does not eliminate all tariff barriers in the FTAA, since the trade barriers between other members of the FTAA remain unchanged. To simulate the elimination of tariff barriers between all member countries and to obtain endogenous responses for all regions, a global CGE model (*e.g.* GTAP) would be necessary.

The simulation implemented with the model represents the elimination of bilateral import tariffs for industrial goods (S2 to S32) and agricultural and livestock

[10] The model and simulation were implemented using GEMPACK 7.0 (Harrison and Pearson (2002)). The abridged version of the model, used in the simulation, has 20,015 equations and 27,043 variables. The simulation was made in a Pentium III with 256MB RAM, using Euler approximation in 1-2-4 steps. The simulation took around two minutes.

products (S1) between Brazil and four countries or blocs: Argentina, other Mercosur countries, NAFTA and other FTAA members. This simulation is implemented in both economic environments (short- and long-run closures). The removal of import tariffs in Brazil for products from the FTAA occurs directly by elimination of the import tax on the respective flow. The removal of tariffs on Brazilian exports in the FTAA is approximated by "equivalent subsidies" to exports. The value of this subsidy is calculated in such a way that it cancels out the effect of import tariffs on the foreign market. The tariffs and sectors contained in the model are shown in the Appendix, at the end of the paper. It is important to specify some limitations of this simulation. First, Mercosur is not fully implemented in the database; therefore, there are different tariffs among the bloc countries. Secondly, as foreign markets are exogenous to the model, the simulation does not capture the effects of the removal of tariffs on the other FTAA members, such as between Argentina and other Latin American countries, or between Argentina and NAFTA.

4. Results and Systematic Sensitivity Analysis

The set of shocks specified for the FTAA simulation results in lower costs of Brazilian imports from this bloc and by the lower prices of Brazilian exports to this market. From these shocks, a simultaneous set of decisions about supply and demand, consumption and investment, is affected, both at the sectoral and regional levels. The CGE model is appropriate for treating all these changes in a simultaneous, integrated and consistent framework.

Table 1 shows some aggregate results of the simulation in the short and long run. A characteristic of the bottom-up approach, where national economy is an aggregation of regional spaces, is that national results are weighted averages of the rates of variation of the respective regional variables. The simulation results indicate that the impact of the FTAA on the GDP is positive in the short and long term, but much more expressive in the latter. However, the regional distribution of this growth is not homogeneous. The variation of GDP in São Paulo is higher than that for the rest of Brazil in the short run and, in the long run, the economic growth in the state of São Paulo occurs *vis-à-vis* the decrease in economic activity of other regions. This tendency towards an increase in regional inequality as a result of trade liberalization agreements was also observed in Haddad and Azzoni (2001).

The basic difference between short-run and long-run closures can be observed in the results for investment, employment and population . In the short run, the sectoral (and regional) capital stock is fixed, hence the zero change in investment. In this closure, nominal wage is indexed to the CPI (fixed real wage) and the increase in the level of regional employment represents a decrease in regional rates of unemployment (labor cannot move across regions in the short run). In the long run, there is interregional and interindustry mobility of capital and labor. In this case, the increase in the level of economic activity in São Paulo occurs concomitantly with the mobility of capital and labor to this region, since, on average, the sectors in São Paulo receive relatively more benefits. Migration is responsible for the increase in labor supply in the economy of São Paulo and for a consequent decrease in labor supply in the rest of Brazil (regional rates of unemployment are fixed in the long run). In the long run, the domestic labor supply is fixed and nominal (and real) wage responds endogenously.

The aggregate gains for the economy of São Paulo (in terms of positive GDP growth) can also be explained by the changes in the GDP components (expenditure side). In the long run, private consumption and investment show positive changes in the economy of São Paulo, in contrast to the reduction of these components in other Brazilian regions. The foreign trade balance in the long run exerts a positive impact on both regions. These results indicate that the economy of São Paulo is economically more capable of capturing the results of Brazil's participation in the FTAA than the rest of Brazil. The domestic trade balance benefits other Brazilian regions in relation to São Paulo; thus, the domestic trade acts as a cushion against the negative effects of consumption and investment in the rest of Brazil.

Table 1
FTAA simulation - macroeconomic results

	Short run			Long run		
	Brazil	São Paulo	Rest of Brazil	Brazil	São Paulo	Rest of Brazil
Real GDP* (%var.)	0.086	0.118	0.069	0.359	1.232	-0.127
Real Household Consumption (% var.)	0.068	0.188	0.023	-0.441	0.905	-0.948
Foreign Trade Balance (var. R$ billion)	-0.595	-0.243	-0.352	2.327	0.617	1.710
Domestic Trade Balance (var. R$ billion)	0.000	-0.279	0.279	0.000	-2.780	2.780
Real Investment (% var.)	0.000	0.000	0.000	0.634	4.497	-1.023
Population (% var.)	0.000	0.000	0.000	0.000	1.472	-0.409
Employment (% var.)	0.109	0.161	0.094	0.000	1.472	-0.409
Nominal wage (% var.)	-0.153	-0.153	-0.153	-2.295	-3.533	-1.710

* Gross Regional Product (GRP) for São Paulo and Rest of Brazil

4.1 Systematic sensitivity analysis

A key aspect of the simulations carried out in this study is the elasticities of substitution used in the Armington structure. In the SPARTA model, these elasticities are employed in three ways, for three categories of use (production, household consumption and demand for investment goods): first, in the substitution between the goods imported from seven external markets; secondly, in the substitution between the goods from the two domestic regions (São Paulo and the rest of Brazil); thirdly, between each unit of imported composite and domestic composite goods. At each of these levels, different elasticities are used by commodity, but not by category of use. A total of 378 elasticities of substitution are used in the model.

The values of these parameters in the SPARTA model were obtained based on the estimates found in the literature and are similar to those used for Brazil in Haddad (1999). In general, there is greater substitutability in consumption goods (textile, clothing, footwear and foods) and less substitutability in capital goods, electrical equipment, electronic equipment and agricultural and livestock products. The degree of substitution between the imported and domestic composite goods is half that which is adopted between regional and import flows. In the long run, the substitution between imported goods is 20% higher. The base values used for these parameters were extracted from the literature and are not based on empirical evidence or on econometric estimates adapted to the model, although they are consistent with a recent study for the Brazilian economy (Tourinho et al. (2002)). Thus, there is some uncertainty about the values of the elasticities of substitution used in the model, and consequently in the results obtained from the simulations. The FTAA simulation has a direct impact on the relative prices of the foreign market, bringing benefits for the FTAA, regarding the origin of imports and the destination of exports, as well as for imported goods *vis-à-vis* domestic goods, *ceteris-paribus*. The degree of substitution used in the model, based on Armington elasticities, to a large extent, will determine other effects on the economy.

The systematic sensitivity analysis employed in this study consisted in testing the substitution structure between goods. The test established a 50% interval for the substitution parameters, with a triangular, symmetric and independent distribution. Thus, intervals were established for 378 model parameters. Stroud's method for Gaussian quadratures required 756 (= 2*378) solves, and yielded mean results and standard deviations for 7,028 endogenous variables. As each solve took approximately two minutes, the sensitivity analysis took around 25 hours.[11]

Table 2 shows the results of the sensitivity analysis for a set of selected endogenous variables. The reported confidence intervals are obtained through the estimated mean and standard deviation, using Chebychev's inequality (Greene (1993)). Chebychev's inequality implies bounds of 4.47 standard deviations from the mean, for a 95% confidence interval. If the sign of this confidence interval changes or is too large for the analyzed variable, we may conclude that the variable is particularly sensitive to the parameter in question.[12]

The long-run FTAA simulation reveals that the results are robust for a significant interval of substitution parameters. Due to the presence of these parameters in different parts of the model, this result is quite surprising. Some confidence intervals, however, appear to be relatively large and should receive special attention.

[11] A more computationally economical alternative was to establish joint distributions by commodity, which decreased the number of simulations to 18, and the overall time for the sensitivity analysis to 36 minutes. The results obtained with this alternative were quite similar.

[12] Since the Stroud formula for GQ has symmetric, independent distributions with mean zero and standard deviation one fore the analyzed parameter, then Chebychev's inequality implies a very conservative estimate of confidence intervals. As the SPARTA model is a set of linearized equations, a normal distribution can be used to construct less conservative confidence intervals (we would like to thank Sueli Moro and an anonymous referee for making this point clearer).

For instance, the increase in real investment in São Paulo has significant intervals, showing the importance of substitution parameters for the result of this variable. We may suppose that if the degree of substitution between goods of different types is low, the movement of investment to São Paulo is less significant. The result of the domestic trade balance also indicates that there may be a significant change in the results depending on the degree of substitution used; low elasticities may change domestic balance in nearly R$ 450 millions (currency as of 1996).

An in-depth analysis in a larger set of results for the endogenous variables indicated that aggregate results are more robust. Sectoral variables, such as levels of activity, capital formation and employment, showed, in some cases, qualitative changes. Table 3 shows the result for the level of activity of sectors in São Paulo. In the footwear and dairy product sectors there are qualitative changes in the result, and confidence intervals are quite significant for plastic material and oil extraction. Therefore, conclusions about the impact of the FTAA on the level of activity of these sectors should be carefully weighed, since the results are significantly reliant on the substitution parameter values.

Table 2
Systematic sensitivity analysis of substitution parameters
selected macroeconomic variables

(Long-run FTAA Simulation)		
	95% confidence interval	
Real GDP (% var.)		
Brazil	0.332	0.387
São Paulo	1.091	1.378
Other Brazilian Regions	-0.169	-0.086
Real Household Consumption (% var.)		
Brazil	-0.484	-0.396
São Paulo	0.776	1.037
Other Brazilian Regions	-1.001	-0.895
Real Investment (% var.)		
Brazil	0.536	0.735
São Paulo	3.396	5.649
Other Brazilian Regions	-1.444	-0.620
Foreign Trade Balance (var. R$ billions)		
Brazil	2.083	2.569
São Paulo	0.517	0.713
Other Brazilian Regions	1.482	1.833
Domestic Trade Balance (var. R$ billions)		
São Paulo	-3.015	-2.552
Other Brazilian Regions	2.552	3.015
Employment (% var.)		
São Paulo	1.306	1.643
Other Brazilian Regions	-0.456	-0.362
Nominal Wage (% var.)		
Brazil	-2.360	-2.229
São Paulo	-3.683	-3.388
Other Brazilian Regions	-1.776	-1.640

Table 3
Systematic sensitivity analysis of substitution parameters
% variation in the level of sectoral activity in São Paulo

(*Long-run FTAA Simulation*)		
	95% confidence interval	
Agriculture and animal husbandry	0.739	0.848
Mineral extraction	1.486	1.962
Extraction of oil, gas and others	0.180	1.002
Non-metallic minerals	1.091	1.435
Steel	1.557	1.820
Non-ferrous metals	1.175	1.529
Other metallurgical products	1.069	1.281
Machinery and tractors	1.656	1.979
Electrical equipment	0.427	0.637
Electronic equipment	0.855	1.156
Cars, trucks and buses	0.626	1.193
Other vehicles, parts and accessories	0.790	0.934
Wood products and furniture	0.585	0.768
Paper and printing	0.554	0.688
Rubber	0.722	1.183
Non-petrochemical products	0.767	0.883
Oil refinement and petrochemicals	0.952	1.284
Miscellaneous chemical products	0.940	1.152
Pharmaceuticals and perfumery	0.611	0.812
Plastic material	0.217	1.310
Textiles	1.839	2.517
Clothing and accessories	0.148	0.602
Footwear, leather and fur products	-1.187	1.433
Coffee industry	1.063	1.152
Processed vegetables	1.558	2.428
Meats	0.709	0.824
Milk and dairy products	-1.183	0.420
Sugar industry	0.476	0.768
Vegetable oils	0.588	0.714
Beverages and other foods	0.538	0.813
Miscellaneous industries	0.583	0.818

5. Final Remarks

The broader utilization of CGE models for Brazil has become a landmark in recent literature in several respects. However, the improvement in the econometric estimation of the parameters used does not occur at the same pace, which is often related to the paucity of data. Qualitative tests have been applied in some cases, but systematic aspects regarding the sensitivity of results are not properly evaluated in this fashion. In a recent description (Domingues (2002)) of CGE models applied to Brazil between 1995 and 2002, only three out of 32 studies reported on qualitative sensitivity tests: Haddad (1999), Hinojosa-Ojeda and Robinson (2000) and Mensbrugghe and Guerrero (2000). Studies that use the GTAP model for Brazil, which became popular for analyzing the impact of trade agreements, have not given due attention to the parameters used in the simulations and to their role in the results and conclusions obtained (*e.g.* Teixeira (1998); Figueiredo et al. (2001); Pereira (2001a), Pereira (2001b); Gurgel et al. (2002)).

This paper sought to illustrate the use of a tool for the systematic sensitivity analysis in computable general equilibrium models, which is readily available to researchers in this field. This tool can substantially improve the acceptance of the results obtained from these models in that the role and relevance of parameters can be evaluated. This type of analysis allows identifying the key parameters for the results in question in specific simulations with a CGE model. Based on that, further investigation and, occasionally, an econometric estimation, may be performed to improve the estimation of relevant parameters.[13]

Systematic sensitivity analysis can also be adequately applied in case of uncertainty about the magnitude of shocks. For instance, in trade liberalization simulations, sometimes the extent of tariff reduction is uncertain, suggesting that it would be far more useful to employ intervals at which tariff reduction is more likely. The procedure described in this paper can be used as an alternative in this case and can be implemented in CGE models at low costs. Thus, analysts obtain important qualitative responses from the simulation, improving the analysis and understanding of the results.

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[13] Arndt and Hertel (1997) use the systematic sensitivity analysis to empirically evaluate the response of real wage to technological improvements in a trade model of the Ricardo-Viner type, based on the structure and database of the GTAP model. This model is used to simulate the implication of a technological improvement in the Japanese industrial sector on the U.S. real wage. The study concludes that the result is ambiguous and depends essentially on the values of the substitution parameters for capital and labor. This conclusion is important to qualify previous analytical results, which predicted a decrease in the U.S. real wage due to technological gains in the Japanese industry (Batra (1992)).

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Appendix

Tariff Barriers in the FTAA

This paper used information from the GTAP model database for the construction of bilateral import tariffs between Brazil and the FTAA, which allows for some comparison with other trade integration studies. This database allowed obtaining import tariffs from the bilateral trade of Brazil with seven foreign markets specified in the SPARTA model.[14]

Table 4 shows Brazilian import tariffs per sector and origin market. Table 5 shows the Brazilian export tariffs according to destination market.[15] At the sectoral level, the largest Brazilian tariffs are levied on cars, clothing, footwear and plastic material. In case of export tariffs, the largest ones are levied on meets and beverages/other foods, sugar, clothing, plastic material and cars.

The estimated data on bilateral import tariffs between Brazil and foreign markets, to some extent, run counter to the idea of Mercosur customs union and Common External Tariff (CET), which would result in systematically lower Brazilian import tariffs for the bloc countries (Argentina and Rest of Mercosur), and in import tariffs in these markets that could benefit Brazil. There are two explanations for these results. First, there is a composition effect that tends to smooth specific high tariffs on the aggregate composite. For instance, in the case of NAFTA, although there may be a high import tariff in Brazil on tractors, the aggregate of machinery and tractors (S8) has a relatively low tariff due to the fact that the tax levied on machinery is lower. This composition effect can also have a spatial dimension, with different tariffs per country (*e.g.* Mexico in the NAFTA) which "disappear" in the aggregate. Secondly, the tariff composition of Mercosur is remarkably imperfect, with several exceptions to CET (e.g. Automotive Agreement). Finally, the database of the GTAP model version 4 does not include zero tariffs for several products, a feature that is also found in version 5 of this database. In the FTAA simulation implemented herein, the tariffs between Brazil and other Mercosur countries (Argentina and Uruguay) were eliminated by way of shocks; however, the tariffs between Argentina and Uruguay (markets that are exogenous to the model) still remain. In spite of this, the data obtained represent the major characteristics of the sectoral/regional framework of import tariffs in 1996. The simulation results are analyzed next.

[14] The GTAP database used herein (version 4) employs tariffs and foreign market subsidies and taxes and domestic production subsidies. The data represent the situation of the world economy in 1995, classified into 50 commodities and 45 regions. A sectoral adaptation was implemented so as to have GTAP data lined up with the sectors of the SPARTA model. A detailed description of this procedure is found in Domingues (2002).

[15] Import tariffs on services are null or extremely low in most cases, and therefore are not represented in these tables, and were not used in the simulations. The liberalization in the service sectors requires a different treatment due to the specificity of tariff barriers in these sectors (see, for instance, Oliveira-Jr. (2000)) on liberalization in Mercosur's service sectors.

Table A.1 – Brazilian import tariffs according to origin market, 1996 (% *ad valorem*)

	Sector	Argentina	Rest of Mercosur	NAFTA	Rest of the FTAA	EU	Japan	Rest of The World
S1	Agriculture and animal husbandry	4.30	4.34	3.70	4.36	3.45	1.01	4.26
S2	Mineral extraction	1.50	30.99	0.13	1.17	2.77	0.00	2.04
S3	Extraction of oil, gas and others	11.48	2.04	2.04	11.40	7.25	0.00	9.18
S4	Non-metallic minerals	6.73	6.09	6.65	5.89	6.10	6.15	8.70
S5	Steel	5.25	4.64	5.51	4.23	5.41	5.89	5.35
S6	Non-ferrous metals	6.72	4.24	4.87	4.47	5.40	6.62	4.53
S7	Other metallurgical products	9.03	7.43	8.78	8.01	9.48	9.36	8.80
S8	Machinery and tractors	6.73	7.02	6.61	6.88	6.97	6.10	6.77
S9	Electrical equipment	9.68	10.11	9.51	9.91	10.03	8.78	9.74
S10	Electronic equipment	8.31	7.54	5.96	6.91	5.46	5.61	5.70
S11	Cars, trucks and buses	20.90	25.94	22.62	25.02	19.93	22.81	24.50
S12	Other vehicles, parts and accessories	9.02	9.06	3.56	13.65	7.88	10.42	9.00
S13	Wood products and furniture	7.17	6.33	9.66	11.28	7.45	12.36	12.06
S14	Paper and printing	2.69	2.20	2.85	2.79	3.85	2.91	4.13
S15	Rubber	11.36	10.76	7.12	7.55	7.86	7.39	6.79
S16	Non-petrochemical products	5.71	5.41	3.58	3.79	3.95	3.72	3.41
S17	Oil refinement and petrochemicals	9.72	8.86	3.33	1.59	9.43	9.25	8.16
S18	Miscellaneous chemical products	6.30	7.29	6.12	7.86	5.11	7.29	7.68
S19	Pharmaceuticals and perfumery	7.77	7.36	4.87	5.16	5.38	5.06	4.65
S20	Plastic material	16.63	15.75	10.42	11.05	11.51	10.82	9.94
S21	Textiles	4.25	4.98	5.86	7.16	9.31	11.68	10.58
S22	Clothing and accessories	7.39	9.79	10.70	12.60	17.52	20.92	18.67
S23	Footwear, leather and fur products	16.45	16.53	15.57	16.53	15.98	16.53	16.52
S24	Coffee industry	9.65	6.15	4.22	5.57	7.97	0.79	8.01
S25	Processed vegetables	2.78	4.63	3.15	4.68	4.46	6.77	2.82
S26	Meats	1.95	1.95	1.95	1.95	1.95	1.95	1.95
S27	Milk and dairy products	8.92	8.92	8.92	8.92	8.92	8.92	8.92
S28	Sugar industry	15.67	2.17	15.67	2.12	2.65	15.67	2.17
S29	Vegetable oils	4.65	4.11	3.86	4.13	1.23	4.56	2.66
S30	Beverages and other foods	3.16	3.16	8.81	17.90	23.98	29.25	1.60
S31	Miscellaneous industries	12.13	9.10	12.20	11.87	5.13	8.12	11.18

Source: elaborated by the author based on domestic accounts and on the GTAP.

Table A.2 – Brazilian export tariffs according to destination market, 1996
(% *ad valorem*)

	Sector	Argentina	Rest of Mercosur	NAFTA	Rest of the FTAA	EU	Japan	Rest of The World
S1	Agriculture and animal husbandry	2.81	4.02	4.65	5.75	1.98	0.16	9.96
S2	Mineral extraction	13.19	10.05	0.34	21.45	0.02	0.01	22.89
S3	Extraction of oil, gas and others	8.06	1.22	0.22	4.20	0.01	0.00	0.67
S4	Non-metallic minerals	8.43	10.09	3.36	8.20	3.46	0.96	12.28
S5	Steel	6.05	4.86	1.60	4.60	1.91	0.78	4.64
S6	Non-ferrous metals	7.30	7.05	1.21	7.35	1.33	0.29	6.69
S7	Other metallurgical products	9.85	7.41	1.41	7.43	2.54	0.67	9.21
S8	Machinery and tractors	2.84	2.42	0.57	3.50	1.25	0.07	4.56
S9	Electrical equipment	4.09	3.49	0.82	5.03	1.80	0.10	6.56
S10	Electronic equipment	1.44	1.17	0.42	2.25	1.23	0.13	2.90
S11	Cars, trucks and buses	14.17	8.89	1.19	10.39	6.45	0.00	25.20
S12	Other vehicles, parts and accessories	6.10	2.55	0.14	3.21	0.89	0.00	9.84
S13	Wood products and furniture	9.15	13.18	0.23	11.72	1.43	0.16	8.55
S14	Paper and printing	3.83	4.91	0.54	4.01	1.72	0.19	4.50
S15	Rubber	8.34	8.17	1.74	8.79	3.66	0.05	8.61
S16	Non-petrochemical products	4.19	4.11	0.87	4.42	1.84	0.03	4.33
S17	Oil refinement and petrochemicals	3.41	0.02	2.84	12.43	3.14	0.13	25.26
S18	Miscellaneous chemical products	3.86	3.79	0.81	4.07	1.70	0.02	3.99
S19	Pharmaceuticals and perfumery	5.71	5.59	1.19	6.01	2.51	0.03	5.89
S20	Plastic material	12.21	11.96	2.54	12.86	5.36	0.07	12.61
S21	Textiles	11.17	12.16	1.83	9.47	2.04	1.59	8.28
S22	Clothing and accessories	23.72	23.40	15.96	14.99	12.36	6.96	15.21
S23	Footwear, leather and fur products	14.78	13.01	6.97	9.30	4.22	14.80	11.57
S24	Coffee industry	3.86	4.90	8.79	9.15	1.76	0.08	16.01
S25	Processed vegetables	5.80	6.56	0.62	7.74	3.49	8.22	8.34
S26	Meats	4.25	1.20	0.25	5.62	20.45	51.03	8.75
S27	Milk and dairy products	15.97	18.04	16.38	7.18	116.34	350.49	100.75
S28	Sugar industry	16.15	7.97	60.51	25.57	74.96	139.87	14.46
S29	Vegetable oils	4.69	4.33	0.00	8.86	0.00	0.00	12.64
S30	Beverages and other foods	25.48	34.07	3.03	30.40	15.43	36.26	35.88
S31	Miscellaneous industries	10.66	5.78	1.01	10.62	3.34	1.14	7.24

Source: elaborated by the author based on domestic accounts and on the GTAP.