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LINKING INTERREGIONAL CGE MODELS WITH GEO-CODED TRANSPORTATION NETWORK INFRASTRUCTURE MODELS

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Abstract: In this paper we use a fully operational interregional (interstate) CGE model implemented for the Brazilian economy, based on previous work by the author and associates, in order to assess the likely regional effects of transportation policy changes in Brazil. Among the features embedded in this framework, modeling of external scale economies and transportation costs provides an innovative way of dealing explicitly with theoretical issues related to integrated regional systems. The model is calibrated for 27 regions. The explicit modeling of transportation costs built into the interregional CGE model, based on origin-destination flows, which takes into account the spatial structure of the Brazilian economy, creates the capability of integrating the interstate CGE model with a geo-coded transportation network model, enhancing the potential of the framework in understanding the role of infrastructure on regional development. Further extensions of the current model specification for integrating other features of transport planning in a continental industrializing country like Brazil are discussed, with the goal of building a bridge between conventional transport planning practices and the innovative use of CGE models. In order to illustrate the analytical power of the integrated system, we will present a set of simulations, which will evaluate the regional impacts of a physical/qualitative change in the Brazilian road network (i.e. a highway improvement), in accordance with recent policy developments in Brazil. Rather than providing a critical evaluation of this debate, we intend to emphasize the likely structural impacts of such policies. We expect that the results will reinforce the need to better specifying spatial interactions in interregional CGE models.

1. Introduction

The development of regional and interregional CGE modeling has experienced, in the last ten years, an upsurge in interest. Different models have been built for different regions of the world. Research groups, located especially in Australia, Brazil, Canada, Germany, Scotland, and U.S., as well as individual researchers, contributed to these developments through the specification and implementation of a variety of alternative models. Recent theoretical developments in the New Economic Geography bring new challenges to regional scientists, in general, and interregional CGE modelers, in particular.[2] 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.

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2 See, for instance, Fujita *et al*. (1999) and Fujita and Thisse (2002).

Among the potential uses of interregional CGE models, we can mention the analysis of transport planning policies with ranging effects on regional and national economies (including common markets as the European Union, MERCOSUR or NAFTA areas). National and/or statewide transport planning is a widely institutionalized process in several countries. The use of model based analytical procedures is in the state of practice, including the application of conventional input-output methods for forecasting freight movements. Nevertheless, the feedback impact of transport actions on the regional and/or national economies is not fully accounted for in these procedures. In recent years, the development of improved techniques was the focus of several efforts joining the transport and economics research fields in the USA (e.g. Friez *et al*., 1998) and the EU (e.g. Bröcker *et al*., 2001), without forgetting efforts of Asian countries (e.g. Miyagi, 2001) and Brazil (e.g. Pietrantonio, 1999).

Investments in highways and other forms of improvements in the transportation system represent an important way of achieving regional and national economic growth. Expansion and improvements of transportation facilities can be used as a means to reduce firms' transaction costs and to expand the economic opportunities in a region/country, as it potentially helps to increase income and improve the standard of living of the resident population.

As reported in Weisbrod e Treyz (1998), studies that attempt to identify the national implications of investments in transportation infrastructure tend to focus the analysis on productivity gains, defined, in general terms, as the ratio between output and primary factors. From a regional perspective, income generation due to the expansion of existing plants or the arrival of new firms has always been perceived as a benefit to be pursued by governments. However, from a national perspective, accepting the view that, in essence, productivity is the main element driving economic growth, the relocation of firms inside the national economic space can only be seen as a benefit if there is an underlying productivity element associated with this movement (over the costs of relocation).

However, investments in transportation, in addition to its impact on systemic productivity, have potential differential impacts across economic spaces. Spatially localized interventions may increase regional competitiveness. External scale economies and accessibility effects would produce the expansion or contraction of the local firms' market areas and generate opportunities to access broader input markets. One of the fundamental elements to be taken into account is the spatial interaction among regions: changes in a given location may result in changes in other regions through the various types of relations (complementary and competitive) associated with the regional agents in the relevant economic spaces.

In this context, the modeling procedure developed in this paper represents an attempt to address some of these issues in the context of a unified approach, which enables the proper treatment of the role of transportation infrastructure in the allocation of resources in a given economy. The explicit modeling of transportation costs, in an interregional CGE model integrated to a geo-coded transportation network infrastructure model, will allow us to assess, under a macro spatial perspective, the economic effects of specific transportation projects and programs.

The remainder of the paper is organized in five sections. First, after this introduction, we discuss briefly modeling issues associated with the treatment of transportation costs. Second, an overview of the interregional CGE model to be used in the simulations (B-MARIA-27) is presented, focusing on its general features. Third, we provide a detailed presentation of our modeling strategy to link the interregional CGE model with the geo-coded transportation network infrastructure model. After that, an illustrative simulation is designed and implemented, and the main results are discussed. Final remarks follow in an attempt to evaluate our findings and put them into perspective, considering their extension and limitations.

2. Modeling Issues

It has been noticed elsewhere (Haddad, 2004) that current CGE models are not without their limitations to represent spatial phenomena. Isard's vision of integrated modeling, which anticipated the proposals reported in Isard and Anselin (1982), provided a road map for the development of more sophisticated analysis of spatial economic systems (Hewings, 1986; Hewings *et al*. 2003). Given their many virtues, though, if adequately coped, interregional CGE models are the main candidates for the core subsystem in a fully integrated system.

Methodological advances should also be pursued to reach the planners. Spatial infrastructure and spatial socio-economic phenomena are key elements that shape and help better understanding economic spaces. In one of its relevant dimensions, a framework incorporating the explicit modeling of transportation costs, based on the capability of integrating the interregional CGE model with a geo-coded transportation network model, enhances the potential of the integrated system in understanding the role of infrastructure on regional development. Initial attempts to link a transportation network model with an interregional CGE model are documented in Kim and Hewings (2002, 2003), with appealing results for regional planners.

The embedding of spatial trade flows into economic modeling, especially those related to interregional trade linkages, usually should go along with the specification of transportation services. Given existing interregional CGE models, one can identify at least three approaches for introducing the representation of transportation, all of them considering the fact that transportation is a resource-demanding activity. This basic assumption is essential if one intends to properly model an interregional CGE framework, invalidating the model's results if not considered (see Isard *et al*., 1998)

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

Second, one can assume transport services to be produced by a special optimizing transport sector. A fully specified production possibility frontier (PPF) has to be introduced for the transportation sector, which produces goods consumed directly by users and consumed to facilitate trade, i.e. transport services are used to ship commodities from the point of production to the point of consumption. The explicit modeling of such transportation services and the costs of moving products based on origin-destination pairs represent a major theoretical advance (Isard *et al.*, 1998), even though it makes the model structure rather complicated in practice (Bröcker, 1998b). The model can be calibrated by taking into account the specific transportation cost structure of each commodity flow, providing spatial price differentiation, which indirectly addresses the issue related to regional transportation infrastructure efficiency. In this sense, space plays a major role.[3] Examples can be found in Haddad (1999), and Haddad and Hewings (2001).

Finally, a third approach to introduce transportation into CGE models consists of the development of a satellite module for the transportation system. The transportation subsystem is usually exogenously modeled, generating transportation inputs that feed the production functions in the CGE model. In this case, there is no micro-foundation behind the satellite model, as is the case of the behavioral equations in the interregional CGE core. Roson (1994) and Kim and Hewings (2002, 2003) provide some examples of this approach.

3. The Interregional CGE Model

Our departure point is the B-MARIA model, developed by Haddad (1999). The B-MARIA model – and its extensions – has been widely used for assessing regional impacts of economic policies in Brazil. Since the publishing of the reference text, various studies have been undertaken using, as the basic analytical tool, variations of the original model.[4] Moreover, critical reviews of the model can be found in the *Journal of Regional Science* (Polenske, 2002), *Economic Systems Research* (Siriwardana, 2001) and in *Papers in Regional Science* (Azzoni, 2001).

Studies using the B-MARIA model and its extensions benefit from the modeling flexibility that allows users to deal with the differentiated impacts of policies across regions and sectors in the interregional Brazilian system. Departing from its basic structure, variations in the general characteristics (regional and sectoral settings, benchmark year) have been implemented, together with methodological extensions (e.g. treatment of the external

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[3] A direct link between the stock of capital associated with the transport sector and the transportation infrastructure network can be derived. However, identification problems emerge as one cannot properly identify the magnitudes for the aforementioned link with the public stock of transportation infrastructure, limiting analytical possibilities with a geo-coded information system.

[4] Among them, three doctoral dissertations: Domingues (2002), Perobelli (2004) and Porsse (2004), the latter at the concluding stage.

sector, finer disaggregation of public sector accounts). Some examples of applications include: prospective studies on the Brazilian regional dynamics [Baer *et al*., (1998); Haddad *et al*. (1999]; evaluation of the trade liberalization process in the early 1990s [Haddad and Hewings (2000a); Haddad and Azzoni (2001)]; assessment of the impacts of investments in the automobile sector [Haddad and Hewings (1999)]; evaluation of the transportation component of the costs of doing business in Brazil – the so-called "Custo Brasil" [Haddad and Hewings (2001)]; methodological evaluation of structural coefficients and behavioral parameters of the model [Haddad *et al*. (2002)]; assessment of regional impacts of trade agreements [Domingues (2002)]; methodological developments for the study of tax competition in Brazil [Haddad and Domingues (2003); Porsse (2004)]; and, finally, the analysis of trade interactions among Brazilian states [Perobelli (2004)].

The theoretical structure of the B-MARIA model is well documented. In addition to the reference readings provided in Haddad (1999) and Haddad and Hewings (1997), which present the model in detail, Domingues (2002) and Perobelli (2004) also present extended versions of the model, focusing on some of its new developments and calibration procedures.

3.1. Basic Features of the B-MARIA and B-MARIA-27 Models

The structure of the interstate CGE model used in our simulations, B-MARIA-27, represents a further development of the **B**razilian **M**ultisectoral **A**nd **R**egional/**I**nterregional **A**nalysis Model (B-MARIA), the first fully operational interregional CGE model for Brazil.[5] Its theoretical structure builds on the MONASH-MRF Model (Peter *et al*., 1996), which represents one multi-regional framework in the ORANI suite of CGE models of the Australian economy. The interstate version of B-MARIA, used in this research, contains over 600,000 equations, and it is designed for policy analysis. Agents' behavior is modeled at the regional level, accommodating variations in the structure of regional economies. Regarding the regional setting, the main innovation in the B-MARIA-27 model is the detailed treatment of interstate trade flows in the Brazilian economy, in which the markets of state flows are fully specified for each origin and destination. The model recognizes the economies of 27 Brazilian regions, corresponding to the 26 states and the Federal District (Map 3.1). Results are based on a bottom-up approach – i.e. national results are obtained from the aggregation of regional results. The model identifies 8 production/investment sectors in each region producing 8 commodities (Table 3.1), one representative household in each region, regional governments and one Federal government, and a single foreign area who trades with each domestic region. Three local primary factors are used in the production process, according to regional endowments (land, capital and labor). The model is calibrated for 1996; a rather complete data set is available for 1996, which is the year of the last publication of the full national input-output tables that served as the basis for the estimation of the interstate input-output database (Haddad *et al*., 2002), facilitating the choice of the base year.

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

Map 3.1. Regional Setting in B-MARIA-27

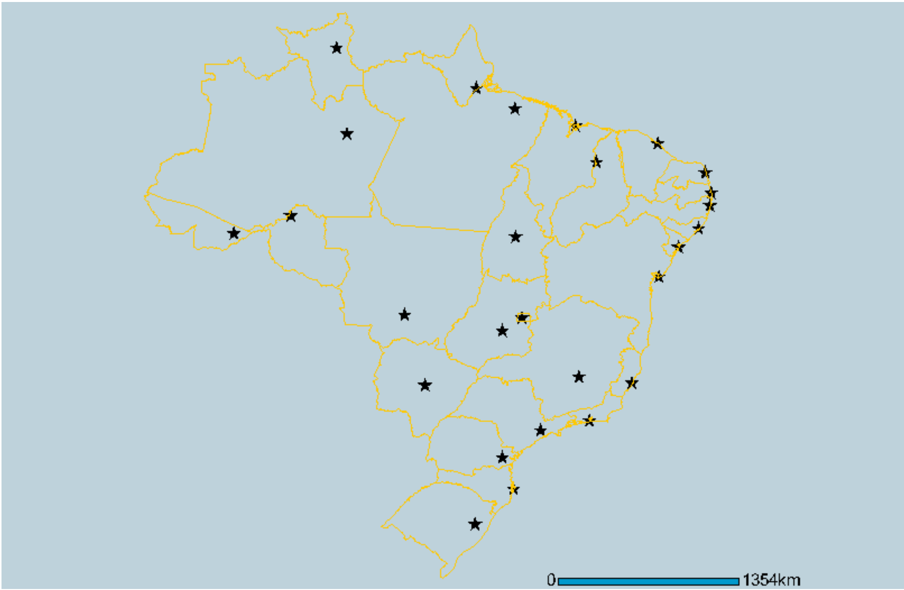

Table 3.1. Sectors in the B-MARIA-27 Model

1	Agriculture
2	Mining and manufacturing
3	Public utilities
4	Construction
5	Trade
6	Financial institutions
7	Public administration
8	Transportation and other services

The B-MARIA framework includes explicitly some important elements from an interregional system, needed to better understand macro spatial phenomena, namely: interregional flows of goods and services, transportation costs based on origin-destination pairs, interregional movement of primary factors, regionalization of the transactions of the public sector, and regional labor markets segmentation. We list below the additional structural modifications implemented in the basic model, related both to specification issues and to changes in the database.

First, we have introduced the possibility of (external) non-constant returns in the production process. This extension is essential to adequately represent one of the functioning mechanisms of a spatial economy. The modeling procedure adopted in B-MARIA-27 uses constant elasticity of substitution (CES) nests to specify the production technology. Given the property of standard CES functions, non-constant returns are ruled out. However, one can modify assumptions on the parameters values in order to introduce non-constant returns to scale. Changes in the production functions of the manufacturing sector[6] in each one of the 27 Brazilian states were implemented in order to incorporate non-constant returns to scale, a fundamental assumption for the analysis of integrated interregional systems. We kept the hierarchy of the nested CES structure of production, which is very convenient for the purpose of calibration (Bröcker, 1998), but we modified the hypotheses on parameters values, leading to a more general form. This modeling trick allows for the introduction of parametric external scale economies (rationalized as agglomeration economies), by exploring local properties of the CES function. Care should be taken in order to keep local convexity properties of the functional forms to guarantee, from the theoretical point of view, existence of the equilibrium.

The second modification, which addresses some of the modeling issues discussed in the previous section, refers to the introduction of links between the interregional CGE core and a geo-coded transportation network infrastructure model, allowing for a more adequate characterization of the spatial structure of the economy, in which the role of the transportation infrastructure and the friction of distance is explicitly considered. Within this more sophisticated specification of transportation costs, the analytical possibility of dealing with scale effects to transportation is also introduced.

Other lesser change considers the addition of a welfare measure, the equivalent variation, derived from the underlying properties of the utility function. In the pubic debate, as observed by Dixon e Rimmer (2002), it is often useful to summarize the various results from the CGE simulations into one or two figures. In the presentation of the model's results, we usually consider two basic measures: the first considers the percentage changes in the real GRP, an indicator of economic growth; the second refers to the equivalent variation, an indicator of welfare, and is included in the model in terms of monetary units of the benchmark year (BRL millions of 1996).[7]

Moreover, another less relevant modification – because it is not operational yet – is the introduction of a potential link between the B-MARIA framework and the financial sector through the credit market. Essentially, we have established a relationship between the demand for capital goods and the demand for labor, and a reference interest rate. In both cases, the financing cost is potentially considered in: a) the short run (the need for financing working capital), and b) the long run (investment in fixed capital).

Changes in the database, in addition to those reported in Perobelli (2004), were also introduced: a) econometric estimates of scale parameters; b) econometric estimates of regional trade elasticities; c) new estimates of international trade elasticities [Tourinho *et al*. (2002); and Haddad and Domingues (2001)]; d) new estimates of income-elasticities (Asano and Fiuza, 2003); and e) new estimates of regional capital stocks.

3.2. Structural Database

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[6] Only the manufacturing activities were contemplated with this change due to data availability for estimation of the relevant parameters.
[7] In the presentation of the results, in this paper, we will focus only on the economic growth indicator.

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

3.3. Behavioral Parameters

Experience with the B-MARIA framework has suggested that interregional substitution is the key mechanism that drives model's spatial results. In general, interregional linkages play an important role in the functioning of interregional CGE models. These linkages are driven by trade relations (commodity flows), and by factor mobility (capital and labor migration). In the first case, of direct interest to our exercise, interregional trade flows should be incorporated into the model. Thus, interregional input-output databases are required to calibrate the model, and regional trade elasticities play a crucial role in the adjustment process.

One data-related problem that modelers frequently face is the lack of such trade elasticities at the regional level. The pocket rule is to use international trade elasticities as benchmarks for "best guess" procedures. However, a recent study by Bilgic *et al*. (2002) tends to refute the hypothesis that international trade elasticities are lower bounds for regional trade elasticities for comparable goods, an assumption widely accepted by CGE modelers. Their estimates of regional trade elasticities for the U.S. economy challenged the prevailing view and called the attention of modelers for proper estimation of key parameters. In this sense, an extra effort was undertaken to estimate model-consistent regional trade elasticities for Brazil, to be used in the B-MARIA-27 Model.

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

4. Modeling of Transportation Costs

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

The role of margin-commodities is to facilitate flows of commodities from points of production or points of entry to either domestic users or ports of exit. Margin-commodities, or, simply, margins, include transportation and trade services, which take account of transfer costs in a broad sense.[8] Margins on commodities used by industry, investors, and households are assumed to be produced at the point of consumption. Margins on exports are assumed to be produced at the point of production. The general functional form used for the margin demand equation is presented below:

$$XMARG(i,s,q,r) = AMARG\_I(s,q,r) * [\eta(i,s,q,r) * X(i,s,q)^{\theta(i,s,q,r)}] \quad (1)$$

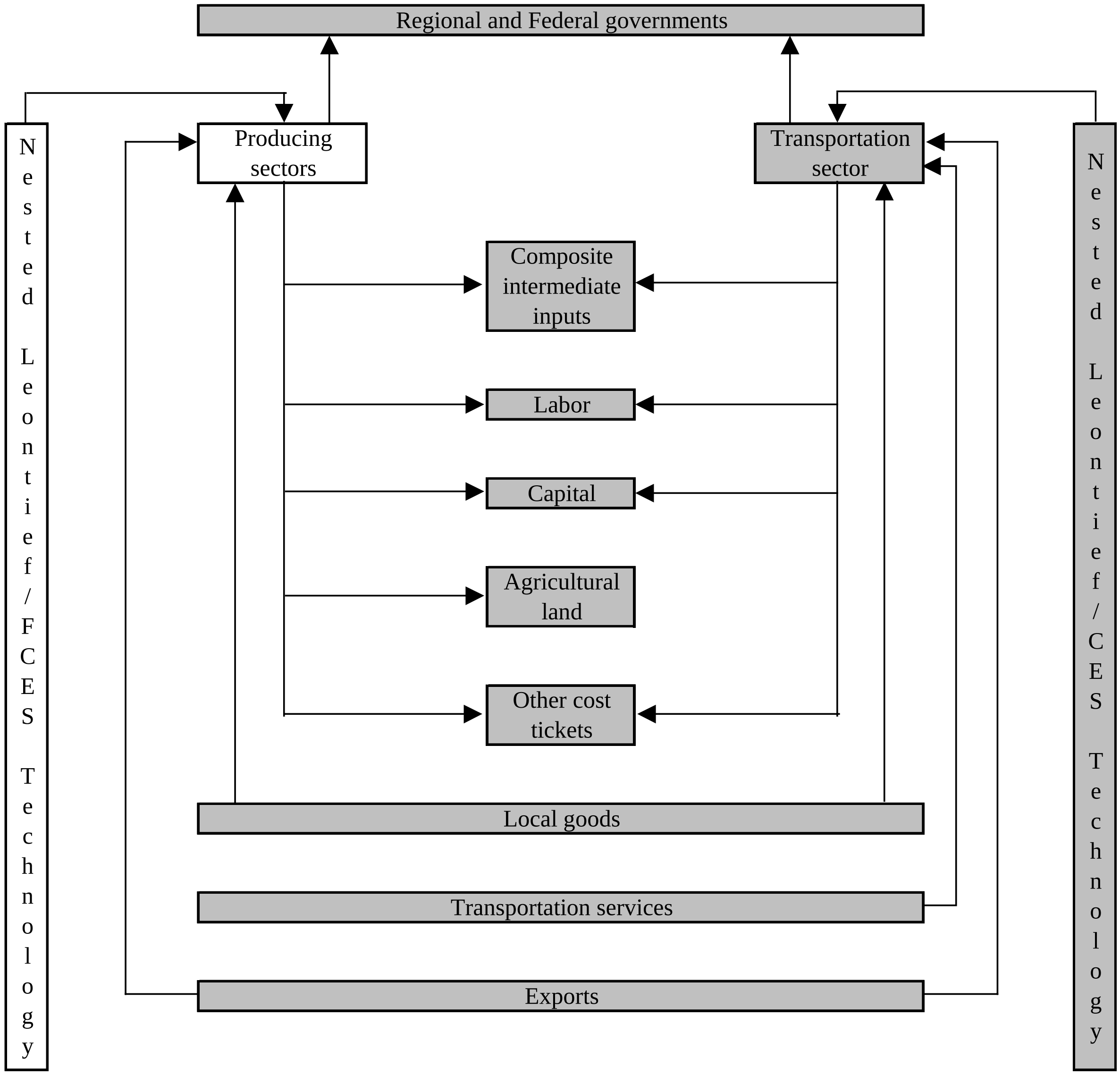
where *XMARG(i,s,q,r)* is the margin *r* on the flow of commodity *i*, produced in region *s* and consumed in region *q*; *AMARG_I(s,q,r)* is a technology variable related to specific origin-destination flows; $\eta(i,s,q,r)$ is the margin rate on specific basic flows; *X(i,s,q)* is the flow of commodity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

The margin demand equation (1) shows that the demand for margins is proportional to the commodity flow with which the margin is associated; moreover, a technical change component is also included in the specification in order to allow for changes in the implicit transportation rate.

In B-MARIA-27, the specification of transportation services considers a regional resource-demanding optimizing transportation sector. Figure 4.1 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 based on the conventional Armington assumption. 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.

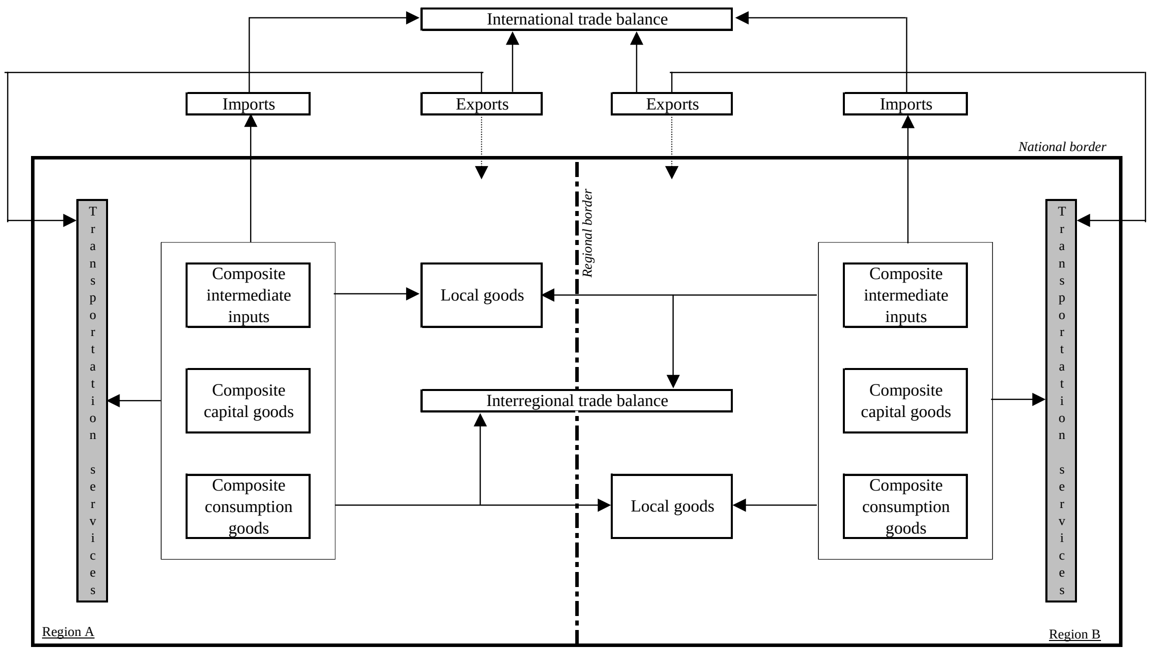
[8] Hereafter, transportation services and margins will be used interchangeably.

Figure 4.1. Flowchart with Regional Production Technology in B-MARIA-27: Highlighting the Transportation Sector



The supply of the transportation sector meets margin and non-margin demands. In the former case, Figure 4.2 illustrates the role of transportation services in the process of facilitating commodity flows. In a given consuming region, regionally produced transportation services provide the main mechanism to physically bring products (intermediate inputs, and capital and consumption goods) from different sources (local, other regions, other countries) to within the regional border. Also, foreign exporters use transportation services to take exports from the production site to the respective port of exit.

Figure 4.2. The Role of Transportation Services in B-MARIA-27: Illustrative Flowchart in a Two-Region Integrated Framework



The explicit modeling of transportation costs, based on origin-destination flows, which takes into account the spatial structure of the Brazilian economy, creates the capability of integrating the interstate CGE model with a geo-coded transportation network model, enhancing the potential of the framework in understanding the role of infrastructure on regional development. Two options for integration are available, using the linearized version of the model, in which equation (1) becomes:

$$xm\arg(i,s,q,r) = am\arg\_i(s,q,r) + \theta(i,s,q,r) * x(i,s,q) \qquad (2)$$

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

3.4.1. Integration in the Calibration Phase

In the interstate CGE model, it is assumed that the *locus* of production and consumption in each state is located in the state capital. Thus, the relevant distances associated with the flows of commodities from points of production to points of consumption are represented by a matrix of distances between state capitals. Moreover, in order to take into account intrastate transfer costs, it is assumed that trade within the state takes place on a fictious route between the capital and a point located at a distance equal to half the implicit radius related to the state area.[9] The transport model calculates the minimum interstate time-distances, considering the existing road network in 1997. As Castro *et al*. (1999) observe, road transportation (i.e. truck) is responsible for the largest share of interstate trade in Brazil, accounting for well over 70% of the total value transported. In Brazil's North, however, fluvial transportation is particularly important, but the low quality of the services implies equivalent (high) logistic costs.

The process of calibration of the B-MARIA-27 model requires information on the transport margins related to each commodity flow. Aggregated information for margins on intersectoral transactions, capital creation, household consumption, and exports are available at the national level. The problem remains to disaggregate this information considering previous spatial disaggregation of commodity flows in the generation of the interstate input-output accounts. Thus, given the available information – interstate/intrastate commodity flows, transport model, matrix of minimum interregional distances and national aggregates for specific margins, the strategy adopted considered the following steps:

1. In an attempt to capture scale effects in transportation – long-haul economies –, a tariff function was used to calculate implicit logistic road transport costs in the interstate Brazilian system.[10] The function considered was estimated by Castro *et al*. (1999), for 1994, using freight cost data: $tariff = 0.25 * dist^{0.73}$, where *tariff* is the (logistic) road transportation tariff; and *dist* refers to the geographical distance between two points. This information was then combined with the matrix of minimum interstate distances to generate a matrix of tariffs evaluated for each path. Long-haul effects are clearly perceived in Figure 4.3, which plots tariffs for different distances within the relevant range for Brazilian interstate trade.

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

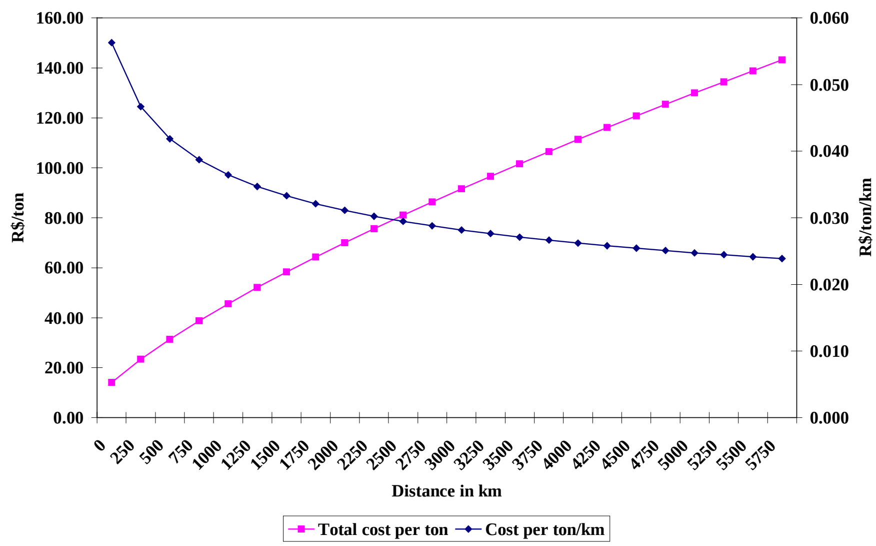
3. The estimates of the various commodity flows at basic values, embedded in the interstate input-output accounts, were then multiplied by the relevant indices from the normalized tariff matrix. This procedure provided the necessary information to generate a distribution matrix, which considered different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

4. Finally, the distribution matrix was applied to national totals, considering disaggregated national information on margins by different users, maximizing the

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

use of available information. Further balancing was necessary during the calibration of the model.

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



In summary, the calibration strategy adopted here takes into account explicitly, for each origin-destination pair, key elements of the Brazilian integrated interstate economic system, namely: a) the type of trade involved (margins vary according to specific commodity flows); b) the transportation network (distance matters); and c) scale effects in transportation, in the form of long-haul economies. Moreover, the possibility of dealing explicitly with increasing returns to transportation is also introduced in the simulation phase.

3.4.2. Integration in the Simulation Phase

When running simulations with B-MARIA-27, one may want to consider changes in the physical transportation network. For instance, one may want to assess the spatial economic effects of an investment in a new highway, expenditures in road improvement, or even the adoption of a toll system, all of which will have direct impacts on transportation costs, either by reducing travel time or by directly increasing out-of-the pocket transfer payments. The challenge becomes one of finding ways to translate such policies into changes in the matrix of minimum interregional (time) distances, mimicking potential reductions/increases in the distance between two or more points in space. Such a matrix serves as the basis for integrating the transport model to the interregional CGE model in the simulation phase.

One way to integrate both models, in a sequential path, requires the use of either the variable *amarg_i(s,q,r)* or the parameter $\theta(i,s,q,r)$, in equation (2), as linkage variables. Changes in the matrix of interregional distances are calculated in the geo-coded transportation network model, so that an interface with the interregional CGE model is created.[11] As in the specification of the margin demand equations the variable distance is only implicitly portrayed in the parameter $\eta(i,s,q,r)$, one has to come up with ways in which the information generated by the transport model can be suitably incorporated. Specific transfer rates are present in the model, and changes in them can be easily associated with changes in the matrix of distances through the logistic road transport cost function used to calibrate the model.

In the B-MARIA-27 model, information on implicit transfer (trade and transport) rates is available, and so is information on the relevant distances, enabling estimation of a model-consistent transportation cost function. With that in hand, changes in transfer rates can be estimated and incorporated into the interregional CGE model, as follows. Rearranging equation (1), we have:

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

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

$$xm\arg(i,s,q,r) - x(i,s,q) = am\arg\_i(s,q,r) \qquad (4)$$

The parameter $\theta(i,s,q,r)$ can also be used in the simulation phase, especially in sensitivity analysis experiments. Suppose, for instance, that scale effects to transportation appear for a given commodity flow, in a specific path. Changing assumptions on the values of $\theta(i,s,q,r)$ allows for addressing this issue in a proper way, instead of relying on hypotheses on the linkage variable, *AMARG_I(s,q,r)*. On this issue, Cukrowski and Fischer (2000), and Mansori (2003) have shown that these spatial implications are relevant in the context of international trade, and therefore, increasing returns to transportation should be carefully investigated in the regional context.

5. Illustrative Application

In this section, we illustrate the analytical capability of the integrated framework developed here in the evaluation of a specific transportation project. The case study under consideration refers to the project of improvement of the federal highway BR-381/MG/SP – Fernão Dias – in the track between the capital cities of Belo Horizonte, in the state of Minas Gerais, and São Paulo, in the state of São Paulo. The following analysis suggests a strategy of application of the framework developed here for the evaluation of a project in a systemic context, in its operational phase. The impacts of the investment phase are not considered in this illustrative exercise. The goal is to explore the characteristics of the integrated model in the simulation phase and not to proceed with a systematic evaluation of the project, which

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

is outside the scope of this paper. In what follows, we will assess the impacts on economic growth (real GDP results).

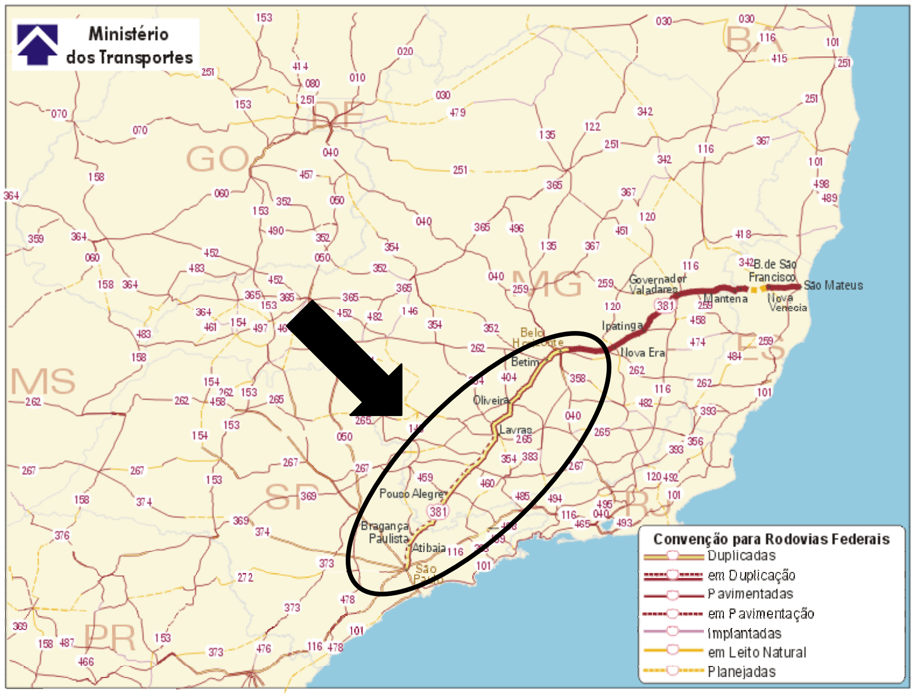
The characteristics of the project, currently in its concluding stages, are detailed in a document prepared by the Ministry of Transportation (1993). The guidelines that have been used to justify the choice of this specific track of the BR-381 highway to be improved are based upon the grounds of the strategic location of this network link in the national transportation system, which constitutes one of the main corridors in the more dynamic regions of the country.

With a total length of 563 km, between Belo Horizonte and São Paulo, the project consisted in the duplication of the existing road link in two distinct stages. The first stage considered the duplication of the first 217 km from Belo Horizonte, and the first 53 km from São Paulo. The second stage considered the remaining 293 km. Total costs of the first and second stages of the project were estimated in US$ 534 millions and US$ 446 millions, respectively.[12]

Considering the situation in 1996/1997, the first stage of the project was practically completed (Map 5.1), whose effects were already embedded in the initial calibration of the interregional CGE model. Thus, we used the parameters defined for the second stage in our simulation exercises.

[12] Values of December 1992 (1996 BRL 574.22 and BRL 479.59 millions, respectively).

Map 5.1. BR-381: Duplicated Track



Source: Ministry of Transportation (www.transportes.gov.br)

5.1. Simulation with the Transportation Network Model

Data on the Brazilian network were obtained from a commercially provided database (Logit, 2001). This data set, in the form used in this research, includes only the highway network and precludes the examination of multimodal alternatives.[13] All data manipulation and network calculations described below were carried out using the general and the transport planning modules of the TransCAD software, version 3.14 (Caliper, 1999).

The local network of the area around the capital city of each state was scrutinized so as to permit us to select a convenient centroid to link the regions' flows to the network. Speed data on links were revised and adjusted to represent the proposed scenarios based on rough engineering assumptions about free flow speeds (i.e. uncongested speeds), as our current approach does not recognize network congestion effects. All links of dual carriageway highways received a value compatible with current statutory speed limits for autos.[14] Data

[13] In true, just a minor change had to be made to this database as one of the state capitals, Macapá, does not have connection to the national highway system using land transport. A sketch fluvial/maritime pathway was included, linking to the Belém harbor and the national highway system. Travel speed along this route was set at 10 km/h in both directions (in waterway links, usual speeds are around 10 +/- 4 to 6 km/h, depending on downstream or upstream direction to movements in fluvial links and the alignment with maritime streams).

[14] In Brazil, since the new Highway Code introduced in 1998, the statutory speed limit on highways varies by vehicle type, being 110 km/h for autos, 90 km/h for buses and 80 km/h for trucks. Enforcement of speed limits is weak on most highways, except when covered by automatic speed control. Then the upper speed limit value (for autos) was used.

on other highways were kept as supplied and no change was made on their values on the working scenarios.

The calculation of the matrix of minimum travel time between Brazilian capital cities was carried out for the base scenario (the existing highway network) and an alternative scenario. This illustrative application is considering the duplication of the Fernão Dias carriageway as the alternative scenario, which was generated by adopting the maximum speed of a standard dual carriage highway (i.e. 110 km/h) for all the links in the extension of the duplication project. Then we simulated the travel time departing from each one of the 27 state capitals to the other capitals, building a square matrix of order $n = 27$.

In the calibration procedure of the model, we have used the reference matrix for minimum travel times, in hours, from state capital to state capital, according to the existing conditions of the transportation network in the country (the base scenario). Afterwards, we have estimated the new time matrix after the changes in the infrastructure, so that we could compare it with the benchmark. Thus, as we considered the Fernão Dias highway totally duplicated, total travel time from São Paulo to Belo Horizonte reduced from around seven to around five hours. But not only the travel time between these two cities altered, but also better accessibility could be perceived in the links between cities in the Northeast and the South of the country, for instance, whose trade flows also use the road links of the improvement under analysis. The time savings between capital cities should, then, be translated into transportation cost savings in order to feed the interregional CGE model and assess its spatial economic impacts.

5.2. Simulations with the Interregional CGE Model

Before the model became operational for the simulations in this exercise, an initial simulation was carried out in order to calibrate the matrix of minimum distances according to qualitative differences in the various road links. This procedure was undertaken by comparing the time matrix generated with uniform speed parameters for every road link to the time matrix generated with the calibrated speed parameters from the transportation model. The idea behind this procedure was to conceive an interface between time and geographical distances, which enter directly the logistic transportation cost function used to link the models.

After a physical intervention in the transportation network infrastructure (i.e. duplication of the BR-381 highway), we have to generate a new matrix of distances from the relations between the changes in the minimum travel times and the calibrated matrix. With this matrix in hand, we are ready to calculate the changes in transportation costs for each relevant track (in relation to the reference transportation costs), generating a matrix of shocks to our linkage variables (Table 5.1).[15] This procedure, however, is only valid for the estimation of the changes in interregional transportation cost. Changes in intra-regional transportation cost should be defined in alternative ways. In the case of the simulation of the impacts of the duplication of the Fernão Dias highway, we have not introduced any

[15] The cost function used is the same logistic road transport cost function used in the calibration process of the model.

additional procedure to define the shocks associated with changes in intra-regional costs, referring to flow within Minas Gerais and within São Paulo. Therefore, simulation results refer only to the effects of transportation cost reductions associated with interstate trade flows.

Table 5.1. Matrix of Shocks of the Linkage Variable Components *amarg_i(s,q,r): Percentage changes**

	Destination												
Origin	AL	BA	CE	PB	PE	RN	SE	MG	SP	PR	SC	RS	MS
AL	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.807	-0.713	-0.627	-0.558	0.000
BA	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-1.049	-0.842	-0.770	-0.670	0.000
CE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.666	-0.588	-0.525	-0.476	0.000
PB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.706	-0.635	-0.564	-0.507	0.000
PE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.757	-0.657	-0.600	-0.538	0.000
RN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.670	-0.606	-0.541	-0.488	0.000
SE	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.901	-0.760	-0.702	-0.619	0.000
MG	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-18.233	-10.688	-8.154	-6.242	-0.227
SP	-0.807	-1.049	-0.666	-0.706	-0.757	-0.670	-0.901	-18.233	0.000	0.000	0.000	0.000	0.000
PR	-0.713	-0.842	-0.588	-0.635	-0.657	-0.606	-0.760	-10.688	0.000	0.000	0.000	0.000	0.000
SC	-0.627	-0.770	-0.525	-0.564	-0.600	-0.541	-0.702	-8.154	0.000	0.000	0.000	0.000	0.000
RS	-0.558	-0.670	-0.476	-0.507	-0.538	-0.488	-0.619	-6.242	0.000	0.000	0.000	0.000	0.000
MS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.227	0.000	0.000	0.000	0.000	0.000

* Obs.: *r* = transportation services

5.3. Results

The B-MARIA-27 model was used to estimate the short run and long run impacts of the second stage of the project for the duplication of the BR-381 highway, during its operational phase. The main results are discussed below.[16]

5.3.1. Marginal Productivity of Investments

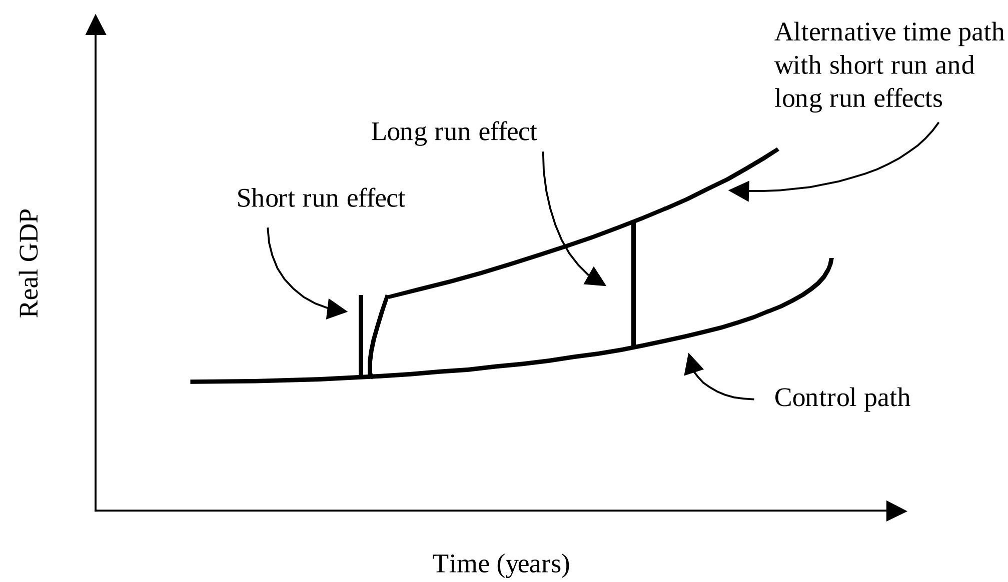
There is a series of partial criteria that can be used to analyze and evaluate alternative investment projects. According to the marginal productivity of investments approach, one attempts to maximize regional or national output – the marginal productivity of investments (or other scarce resources) – in different alternative projects; this approach for project selection is not adopted very often, among other reasons, due to methodological problems related to quantifying the marginal product attributable to a given production factor in a specific usage. The use of B-MARIA-27 presents itself as a methodological alternative to fill this gap.[17]

In aggregate terms, the investments under consideration, in its operational phase, have a potential impact on national growth: change of 0.0046% in real GDP (equivalent to BRL 38.4 millions) in the short run, and 0.0261% (BRL 215.9 millions) in the long run. An alternative "temporal" interpretation of the results of the comparative-static simulations is based on the embedded characteristics of the experiments. In essence, what a typical CGE

[16] Simulations results were computed using GEMPACK (Harrison and Pearson, 1994, 1996).
[17] We illustrate that with the case of the national GDP.

simulation does is to depart from an equilibrium of the circular flow of income of the economy, depicted numerically in the SAM, and reach another equilibrium – an updated version of the original SAM. Results are drawn from the comparison of the two equilibria. As in our model we deal with annual flows, we can interpret the resulting difference from adjustments to the shocks as a change in the flow of income of the economy in a typical year of the operation of the duplicated highway, representing a deviation in its underlying control (unrealistic) path, in this case only hypothetical (Figure 5.1). The question that is raised, however, refers to the relevant adjustment mechanisms for such interpretation. In our simulations, we have adopted two different closures that reflect adjustment mechanisms of the economy related to different hypotheses on factor market adjustment. Thus, we can consider the short run closure, more restrictive, as a response of the economy more likely to be perceived in the first years of the operation of the project, while the long run closure, more flexible, as a response more likely to be perceived in future years.[18]

Figure 5.1. Alternative Interpretation of the Comparative-static Simulation Results: Hypothetical Control Path[19]



We can use the comparative-static results to project the marginal flows of wealth in the country. To do so, we need additional information on the time horizon of the project. According to the information provided by the Ministry of Planning (1993), paving was dimensioned for lasting 20 years. With this parameter, we can calculate the present value (PV) of a marginal flow of GDP, continuous and constant over the period (Figure 5.2), under alternative discount rates, 3%, 5% e 8%.[20] The values used refer to both the short run

[18] Peter *et al*. (1996) report econometric studies that reinforce this speculation.
[19] Based on Horridge (2004).
[20] A more sophisticated approach to generate time results with the B-MARIA-27 model would consider a forecasting-type closure, in the tradition of the Monash model (Dixon and Rimmer, 2002). See also Giesecke and Madden's paper in this volume.

and long run simulations results, in 1996 BRL millions. Estimates are reported in Tables 5.2 and 5.3, which include the PV of the marginal flows of GDP, as well as an indicator of marginal productivity of the investments (MPI), calculated as the ratio of the PV of the marginal flows of GDP and the value of the investment.

Figure 5.2. Alternative Time Paths for National GDP

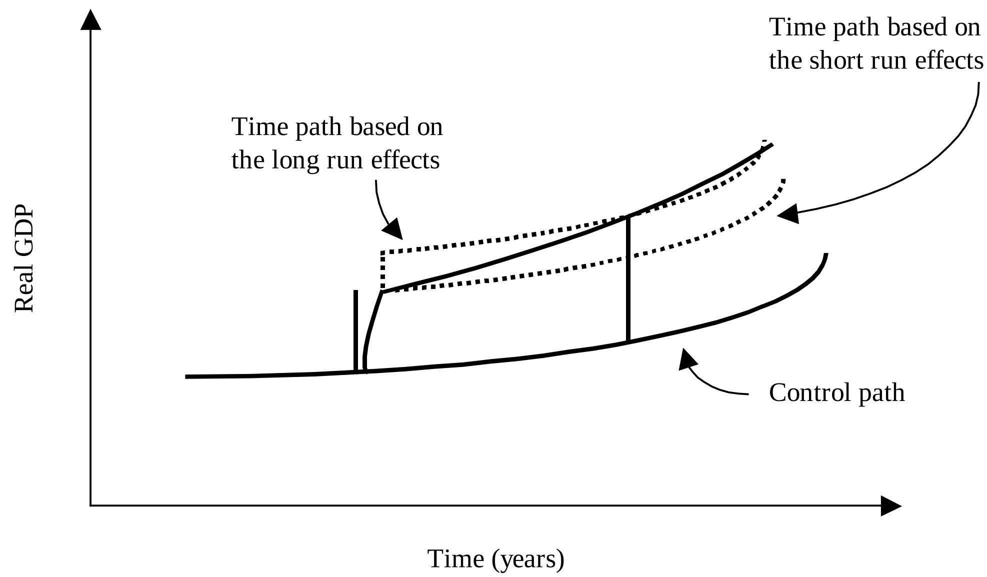


Table 5.2. Partial Criteria for the Evaluation of the BR-381 Project:
PV of the Marginal Flows of GDP in the Operational Phase (in 1996 BRL millions)

	Short run	*Long run*
PV (3%)	609.09	3428.62
PV (5%)	516.43	2907.06
PV (8%)	415.00	2336.09

Obs.: Value of investment = BRL 479.59 millions

Table 5.3. Partial Criteria for the Evaluation of the BR-381 Project:
Marginal Productivity of Investments in the Operational Phase[21]

	Short run	*Long run*
MPI (3%)	1.27	7.15
MPI (5%)	1.08	6.06
MPI (8%)	0.87	4.87

Obs.: Value of investment = BRL 479.59 millions

[21] The inverse of this relationship refers to the incremental capita-output ratio (ICOR), which informs the level of investment needed to generate one additional unity of output.

The results show that the marginal productivity of the project is magnified in the long run. As the project matures, productivity gains become more evident, as there is complementarity between investments in transportation and private investments. This relationship is captured in the model through the long run adjustment of capital stocks in the economy in the long run. The indicators presented here are very useful in a context of evaluation of alternative projects: in such cases, the choice should point to the project with higher MPI. It should be noticed that other partial indicators for project evaluation could also be derived from the model's results.

5.3.2. Spatial Impacts

Maps 5.2 and 5.3 present the state impacts, in the short run and in the long run, on efficiency. In the reading of the maps, hereafter, warm colors (orange and red) represent values above the average, in terms of standard deviations; cold colors (blue) represent values below the average, also in terms of standard deviations; warmer/colder colors represent outliers.

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

Short run results (Maps 5.2) represent a counterfactual situation characterized by less flexible mechanisms of interregional transmission, as the possibility of interregional factor mobility is precluded. In the case of Minas Gerais, there seems to be stronger competitive interdependence with the eastern economies of the Northeast, mainly the more industrialized ones. The results for real GDP, in percentage terms, make this feature more evident, as economic growth of Minas Gerais is verified at the expense of growth in those economies, even though the western economies of the Northeast, Tocantins and Mato Grosso present positive performance. In the short run, the economy of Minas Gerais polarizes the effects associated with the flows of intermediate inputs, widening its market area at the expense of not only the eastern economies of the Northeast, but also the economies of the South of the country. The results for real GDP, in monetary values, show that the states that receive the investments are those that concentrate most of the benefits.

In the long run (Map 5.3), the behavioral parameters have an even more prominent role in the functioning of the model. Re-location effects of capital and labor operate defining a new geography of winners and losers. The state of São Paulo places itself as the main attractor of economic activity, competing directly with Minas Gerais and its spatial competitors in the Northeast. The net result is the re-location of activities towards São Paulo, benefiting indirectly the economies that are more integrated to the markets in that state, namely Amazonas, Rio de Janeiro, Santa Catarina and Rio Grande do Sul.

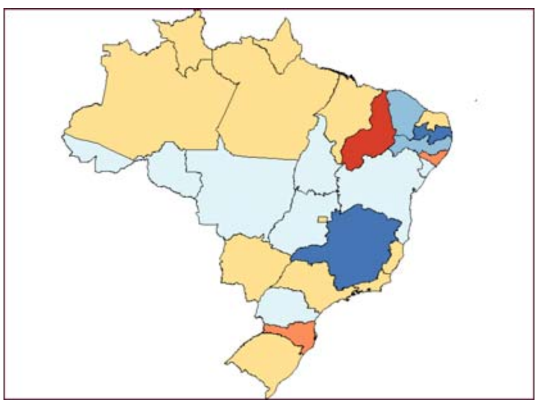
Map 5.2. State Results: Real GDP, Short Run

Percentage change

R$ millions

Map 5.3. State Results: Real GDP, Long Run

Percentage change



R$ millions

6. Final Remarks

It has been pointed out that interregional CGE models can potentially be used for the analysis of transport planning policies. In this paper, we have illustrated a way in which this potential use can be implemented. However, this tool is not yet a recurrent part of the transport planning process. To do so, further amendments are still needed, in order to cope with methodological advances both in economic and transport modeling.

Despite representing the effect of transport infrastructure in a consistent way, the use of current versions of interregional CGE models has some drawbacks when intended for replacing conventional models used in national or statewide transport planning. Future versions of interregional CGE models should envisage the incorporation of some usual features of conventional models of transport planning such as a multimodal view, quality and non-price attributes, congestion effects, and a finer spatial disaggregation to allow for intrastate analysis. To some extent, the integrated approach proposed here directly addresses some of these issues. More importantly, however, the results provided are encouraging in the sense that the broader issues dealt in this paper, while difficult, are not insurmountable.

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