ANALYTICALLY IMPORTANT TRANSPORTATION LINKS: A FIELD OF INFLUENCE APPROACH TO CGE MODELS

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RESUMO Alterações de coeficientes em modelos de equilíbrio geral têm sido amplamente exploradas em ambientes de preços fixos. Mais precisamente, desde o trabalho pioneiro de Sonis e Hewings (1989), o problema relativo a erro e sensibilidade em modelos de insumo-produto atingiu um novo estágio operacional. O conceito de "campo de influência" foi introduzido, proporcionando uma abordagem mais geral para o problema de mudanças técnicas em sistemas de insumo-produto. O caráter geral do método permitiu a avaliação sistemática de alterações em coeficientes individuais ou conjuntos de coeficientes. Desde então, várias aplicações foram feitas para diferentes estruturas de economias reais. Entretanto, no contexto de modelos de equilíbrio geral com preços flexíveis (modelos EGC), poucas tentativas foram feitas em busca de uma abordagem mais geral para lidar com análise de sensibilidade estrutural. Neste artigo, consideramos a questão da análise de sensibilidade estrutural em modelos EGC. Mais especificamente, partimos do conceito de "*inverse important coefficients*", da literatura de campo de influência, para identificar elos de transporte estratégicos em um sistema inter-regional integrado. Dada a natureza de modelos EGC, podemos expandir o conceito de mensuração de campo de influência para gerar estruturas de influência baseadas em diferentes objetivos de política.

Palavras-Chaves: técnicas computacionais, campo de influência, modelos de insumo-produto, modelos de equilíbrio geral computável.
Código JEL: C63, C67, C68

ABSTRACT Coefficient change in general equilibrium models have been widely explored in the context of fixed price environments. More precisely, since the pioneer work by Sonis and Hewings (1989), the issue of error and sensitivity in input-output analysis has reached a new operational stage. The concept of "field of influence" was introduced providing a more general approach to the problem of input coefficient change in input-output systems. The method was general enough to cover changes in an individual coefficient, in two or more coefficients, and in rows or columns coefficients. Since then, a wide range of applications has taken place for various structures of real economies. However, in the context of flexible prices general equilibrium models (CGE models), few attempts have been made in order to provide a more general approach to deal with structural sensitivity analysis. In this paper we look at the issue of structural sensitivity analysis in CGE models. More specifically, we borrowed from the field of influence literature the idea of inverse important coefficients in order to identify strategic transportation links in the context of the Brazilian interregional system. Given the nature of CGE models, we can also expand the concept of measurement of the field of influence statistics in order to generate qualitative structures of influences based on different policy targets.

Keywords: computational techniques, field of influence, input-output models, computable general equilibrium models

1. Introduction

The study of the propagation of structural changes in economic systems has received renewed attention in the last two decades. In the input-output literature, the two main streams of research consider either the combined elements of different input-output systems, incorporating a disequilibrium component in one of the systems, or the intertemporal comparison of isolated structures in equilibrium. The latter and more traditional approach develops and utilizes methods of key sector analysis in an attempt to uncover similarities and differences in the structure of the economies over time. By exploring different methods of comparative structure analysis, it is hoped that the complementarity among them might result in a better appreciation of the full dimensions of differences and similarities that might exist. The other approach provides a range of alternative combinations reflecting differential technological hypotheses within an economy based on existing input-output tables for a given region. This method, based on the principles of *qualitative or structural sensitivity analysis*,[1] incorporates specific information to the model's results, which contributes to increased robustness through the use of possible structural scenarios. It may also contemplate analytically important elements in the economic structure by considering small changes in specific cells or group of cells.

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[1] The term "qualitative sensitivity analysis" is used as opposed to "quantitative sensitivity analysis", which is the common practice adopted to define most-important coefficients in an economic system. Usually, the coefficients are allowed to deviate over a range centered in the initial assigned values, or to present a small increase/decrease in one direction, which does not address properly the cases of known structural changes over time, as information is left out (see Haddad, 1999).

general enough to cover changes in an individual coefficient, in two or more coefficients, and in rows or columns coefficients. Since then, a wide range of applications has taken place for various structures of real economies [see, for example, Van der Linden *et al.,* 2000; Domingues *et al*. 2002; Percoco *et al*. 2006].

However, in the context of flexible price general equilibrium models (CGE models), few attempts have been made to provide a more general approach to deal with structural sensitivity analysis. Usual exercises consider only alternative specification of structural coefficients using different data sets [e.g. Gazel, 1994; Haddad *et al*. 2002]. Harrison *et al*. (1993) explored the computational challenges involved in generating uncertainty around parameter estimates and their implications for confidence (robustness) of the model results.

It has been argued that, given the intrinsic uncertainty in the shock magnitudes and parameter values in CGE applications, sensitivity tests are an important next step in the more formal evaluation of the robustness of CGE analysis and the fight against the "black-box syndrome". However, some important points should be addressed in order to have a better understanding of the sensitivity of the models' results. In similar fashion to the fields of influence approach for input-output models developed by Sonis and Hewings (1989, 1992), attention needs to be directed to the most important synergetic interactions in a CGE model. It is important to try to assemble information on the parameters, shocks and database flows, for example, that are the *analytically* most important in generating the model outcomes, in order to direct efforts to a more detailed investigation.[2]

In this paper, we look at the issue of structural sensitivity analysis in CGE models. However, in contrast to Harrison *et al*. (1993), attention here is directed to a CGE model that has been linked with a transportation network system. More specifically, we borrowed from the field of influence literature the idea of inverse important coefficients in order to identify strategic transportation links in the context of the Brazilian interregional system. There is an extensive literature on the identification of important transportation links, measuring the impacts for example, of highway disruptions due to reconstruction or bridge failures. Sohn *et al.* (2003) explored this issue of transportation link importance in the context of analysis of the potential impacts of an earthquake centered in the lower Midwest of the US. Kim *et al* (2004) considered a transportation link's importance in welfare terms for an ambitious highway expansion program in Korea. The analysis was conducted

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[2] See Domingues *et al*. (2004).

by integrating a multiregional CGE model and a transportation network. Given the nature of CGE models, we can also expand the concept of measurement of the field of influence statistics in order to generate qualitative structures of influences based on different policy targets.

The paper is divided into four other sections, in addition to this introduction. Section 2 discusses the methodological issues related to the equivalence of the mathematical structures of CGE models of the Johansen class, and input-output models. Section 3 provides some insights of the translation of the field of influence approach developed for input-output systems into the CGE context. Section 4 presents an application of the method to identify analytically important transportation links for different policy purposes. The analysis is further completed by mapping the results into the Brazilian spatial economic infrastructure. Final remarks follow in the last section.

2. Structural Equivalence of Johansen-type CGE Models and Input-output Models

In this section, we present the mathematical structure of Johansen-type CGE models and input-output models. It is our intention to show that they share similar mathematical properties, providing opportunities for sharing methodological approaches usually adopted in only one of the cases. As the developments of these analytical tools rarely have been tied to each other, future research activity based on their structural equivalence may enhance the synergy between the fields.

2.1. Mathematical Structure of Johansen-type CGE Models

We consider, in this paper, a class of CGE models known as Johansen-type CGE models in that the solutions are obtained by solving the system of *linearized* equations of the model.[3] A typical result shows the percentage change in the set of endogenous variables, after a policy is carried out, compared to their values in the absence of such policy, in a given environment.

In Johansen-type CGE models, the system of linearized equations of the model can be written as

$$F(V) = 0 \tag{1}$$

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[3] More details can be found in Dixon *et al*. (1982, 1992), and Dixon and Parmenter (1996).

where V is an equilibrium vector of length n (number of variables), and F is a vector function of length m (number of equations), which is assumed to be differentiable. Regarding the dimensions, n and m, it is assumed that the total number of variables is greater than the total number of equations in the system, i.e., $n > m$. Thus, $(n - m)$ variables must be set exogenously. Examples of economic variables contained in the vector V include quantities, prices, taxes, and technological coefficients. The economic relations depicted in the system (1) are comprised of equations representing household and other final demands for commodities, equations for intermediate and primary-factor inputs, pricing equations relating commodity prices to cost, and market clearing equations for primary factors and commodities, among others. For the purpose of calibration of the system, it is fundamental to assume that an initial solution, V^*, is known. In other words, $\exists V = V^* s.t.\ F(V^*) = 0$.

Given the initial solution, V^*, the basic approach used to compute a new set of solutions to the model starts with assigning the variables to the exogenous and endogenous categories.[4] Let V_1 be the vector of m endogenous variables, and V_2 be the vector of $(n - m)$ exogenous variables. Equation (1) can be rewritten as:

$$F(V_1, V_2) = 0 \qquad (2)$$

By totally differentiating (2), we get:

$$F_1(V^*)dV_1 + F_2(V^*)dV_2 = 0 \qquad (3)$$

where F_1 and F_2 are matrices of partial derivatives of F evaluated at V^*. Solving (3) for dV_1, we have:

$$dV_1 = \underbrace{\left[-F_1^{-1}(V^*)F_2(V^*)\right]}_{B(V^*)} dV_2 \qquad (4)$$

or

$$dV_1 = B(V^*)dV_2 \qquad (5)$$

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[4] The following describes the one-step Johansen/Euler solution.

It is assumed that the relevant inverse, $F_1^{-1}(V^*)$, exists.[5]

2.2. Mathematical Structure of Input-output Models

The well-known input-output model shares the same mathematical structure of equation (5). An input-output model can be represented by the expression:

$$X = (I - A)^{-1} Y \tag{6}$$

where X is a vector of sectoral gross output, Y is a vector of sectoral final demand, and $(I - A)^{-1}$ is the Leontief inverse.

Again, whether or not there is a unique solution depends on whether or not $(I - A)$ is singular.[6] If the elements in $(I - A)^{-1}$ are denoted by α_{ij}, then the dependence of each of the gross outputs on each of the final demands becomes evident, as $(I - A)^{-1}$ can also be interpreted as a matrix of partial derivatives, in that $\partial X_i / \partial Y_j = \alpha_{ij}$.

Both equations (5) and (6) are parallel to the form $AX = B$ that is usually used to denote a set of linear equations. The difference is purely notational.

Table 1.
Mathematical Equivalence of Johansen-type
CGE Models and I-O Models

	Johansen-type CGE model	***Input-output model***

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[5] Because $B(V^*)$ is the matrix of first-order partial derivatives of *F*, evaluated at the initial values of the model's variables, V^*, the solution achieved by the procedure described above represents an approximation of the "true" solution. As one moves away from V^*, the partial derivatives of *F* are also moving. This fact produces errors between the model solution and the "true" solution derived from any change in the initial set of exogenous variables, due to the linearization of the equations of the model. To solve this problem, and, thus, get more accurate results, a multi-step computation procedure can be introduced, in which the exogenous shock is divided into *p* equal parts. Hence, a sequence of Johansen-style computations is used, in which the matrix *B* is reevaluated at each step.

[6] See Miller and Blair (1985).

General form:	$F(V_1, V_2) = 0$	$(I - A)X - Y = 0$
Solution form:	$dV_1 = B(V^*)dV_2$	$X = (I - A)^{-1}Y$

3. The Field of Influence Approach

Disequilibrium-based methods depart from disturbances in the existing system to generate a new equilibrium comparable to the original one. Commonly known as sensitivity analysis, under the field of influence approach, it usually has two main uses. First, one might consider small coefficient changes in order to assess how "influential" a coefficient or a set of coefficients is to the system as a whole; secondly, for known structural changes, one might be interested in assessing the impacts of given functional changes. It is important to notice that disequilibrium-based methods all have corresponding changes in the equilibrium-based methods, as the former is rooted in the comparison of various equilibrated systems.

The concept of field of influence (Sonis and Hewings, 1989, 1992) is mainly concerned with the problem of coefficient change, namely the influence of a change in one or more direct coefficients on the associated Leontief inverse. Since, given an economic system, some coefficients are more "influential" than others, the sector responsible for the greater changes in the economy can be determined. In the simplest case, i.e., the case in which a small enough change, ε, occurs in only one input parameter, a_{ij}, the basic solution of the coefficient change problem may be presented as follows

Define:

$A = \|a_{ij}\|$ is the matrix of direct input coefficients;

$E = \|\varepsilon_{ij}\|$ is the matrix of incremental changes in the direct input coefficients;

$B = (I - A)^{-1} = \|b_{ij}\|$ is the Leontief inverse before changes;

$B(\varepsilon) = (I - A - E)^{-1} = \|b_{ij}(\varepsilon)\|$ is the Leontief inverse after changes.

Using the notion of inverse-important input coefficients, which is based on the conception of the field of influence associated with the change in only one input coefficient, assume that this change occurs in location (i_1, j_1), that is,

$$\varepsilon_{ij} = \begin{cases} \varepsilon & i = i_1, j = j_1 \\ 0 & i \neq i_1, j \neq j_1 \end{cases} \tag{7}$$

The field of influence can be derived from the approximate relation:

$$F\left(\varepsilon_{ij}\right) \cong \frac{\left[B\left(\varepsilon_{ij}\right) - B\right]}{\varepsilon_{ij}} \tag{8}$$

Where $F(\varepsilon_{ij})$ is the matrix of the field of influence of the change on the input coefficient, a_{ij}. For every coefficient, a_{ij}, there will be an associated field of influence matrix. In order to determine which coefficients have the greater field of influence, reference is made to the rank-size ordering of the elements, S_{ij}, from the largest to the smallest ones. Therefore, for every matrix $F(\varepsilon_{ij})$, there will be an associated value given by:

$$S_{ij} = \sum_{k=1}^{n}\sum_{l=1}^{n}\left[f_{kl}\left(\varepsilon_{ij}\right)\right] \tag{9}$$

Thus, from the values of S_{ij}, a hierarchy can be developed of the direct coefficients based on their field of influence, i.e., ranking sectoral relations in terms of their sensitivity to changes, in a sense that they will be responsible for more significant impacts on the economy.

A similar idea can be implemented in the context of Johansen-type CGE models. Given the nature of the specification of such models, the analytical capability is much broader as the values of the corresponding S_{ij} can be defined using various possibilities of models' outcomes.

In terms of defining the fields of influence of incremental changes in specific technical relations, the more convenient way to implement it is to define technical changes in the input-output relations embedded in the CGE structural coefficients. In the context of a specification of a system of equations of a CES nest, typically used in CGE modeling, the introduction of technical change terms generates the following general pattern in the relevant percentage-change equations:

Original CES pattern:

$$x = x_{average} - \sigma\left(p - p_{average}\right) \qquad (10)$$

$$p_{average} = \sum_i S_i p_i \qquad (11)$$

With technical change:

$x \rightarrow x - a$

$p \rightarrow p + a$

$$x - a = x_{average} - \sigma\left(p + a - p_{average}\right) \qquad (10')$$

$$p_{average} = \sum_i S_i\left(p_i + a_i\right) \qquad (11')$$

Where x and p represent percentage-change in the quantity and price of a given demanded input; $x_{average}$ and $p_{average}$ represent, respectively, percentage-change in the quantity and price of the relevant bundle in which the demanded input is contained; the a's are quantity-augmenting technical change terms; and S_i's are the weights of each input in the composition of the bundle price.

To generate the field of influence of a given coefficient change, one needs to carry out a simulation of a small enough shock on the appropriate technical change term.

4. Analytically Important Transportation Link

In order to address the issue of identification of the *analytically* most important structural links in generating CGE model outcomes for the case where a CGE model has been linked with a network-based transportation system, we proceed with a thorough decomposition of the results of simulations that considers the role played by various small changes in specific transportation costs. These incremental changes are associated with (a group of) coefficient changes computed from the information contained in the initial solution, V^*. In other words, we explicitly take into account the role played by each transportation link – 27x27 in total – in generating the model's results.[7]

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[7] The model used is the B-MARIA-27 model, described in Haddad and Hewings (2005). The model recognizes the economies of 27 Brazilian states. Results are based on a bottom-up approach – national results are obtained from the aggregation of regional results. The model identifies 8 sectors in each state producing 8 commodities, one representative household in each state, regional governments and one Federal government, and a single foreign consumer who trades with each state. Special groups of equations define government finances, accumulation relations, and regional labor markets. It allows

Thus, one can identify the fields of influence of various structural links associated with specific policy outcomes.

For each transportation link, we calculate its contribution to specific outcomes, considering different dimensions of regional policy.[8] Impacts on regional efficiency and welfare are considered. We look at the effects on regional efficiency, through the differential impacts on GDP growth for the five Brazilian macro regions (North, Northeast, Southeast, South and Center-West), and for the country as a whole (systemic efficiency). Moreover, we consider the differential impacts on regional welfare, looking at the specific macro regional results, and also at total national welfare. Scaffolding of the spatial results is considered in order to evaluate analytically important transportation links to optimize specific policy goals.

To obtain a finer perspective on the analytically most important transportation links for optimizing a given policy target (regional/national efficiency/welfare), we decompose the results into state-to-state links. Key links based on their influence on each policy strategy (regional/national GDP growth and welfare) are highlighted in Figures 1-12. Notice that the set of most-influential transportation links varies according to different (spatial) policy targets.

4.1. Reaching the Planner

The graphical analysis presented in the previous section can be further expanded to a proper spatial dimension, more appropriate to subsidize transportation policies. The idea is to map each interstate link into the transportation network. Let us consider, for instance, the case in which the policy goal is to increase overall efficiency in the country (Figure 12). If we consider the analytically most important transportation links that influence GDP growth, as highlighted in the Figure, 28 out of the first 30 are spatially concentrated in the eastern part of the country, in a region that includes the following states: Paraíba, Pernambuco, Bahia, Espírito Santo, Minas Gerais, Rio de Janeiro, São Paulo, Paraná, Santa Catarina e Rio Grande do Sul (Map 1).

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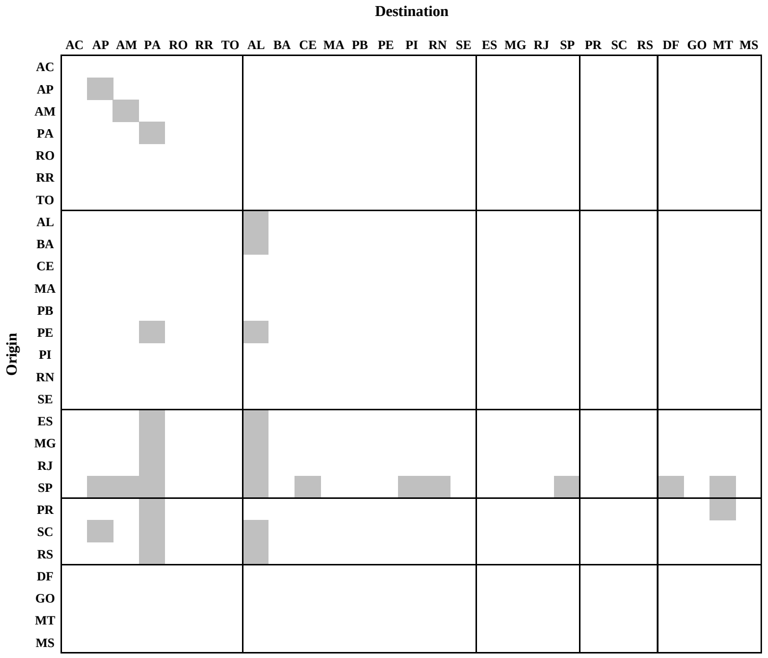
considering the two-way dimension of a transportation link between to regions, i.e. the way “in” and the way “out”.

[8] The results refer to a long-run environment, as it seems to be more closely linked to expected outcomes of transportation policies.

Considering only the structural axes (transport corridors) in the existing transportation network, two longitudinal[9] roads are candidates for most relevant physical transportation links for Brazilian systemic competitiveness.

Figure 1
Long-Run Analytically Important Transportation
Links Based on Regional Welfare*: North



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

Figure 2.
Long-Run Analytically Important Transportation
Links Based on Regional Welfare*: Northeast

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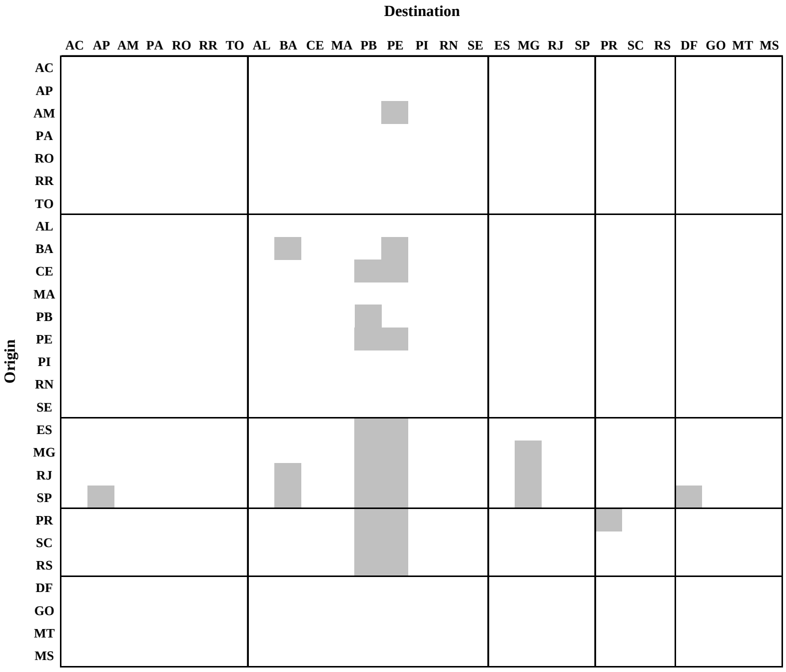
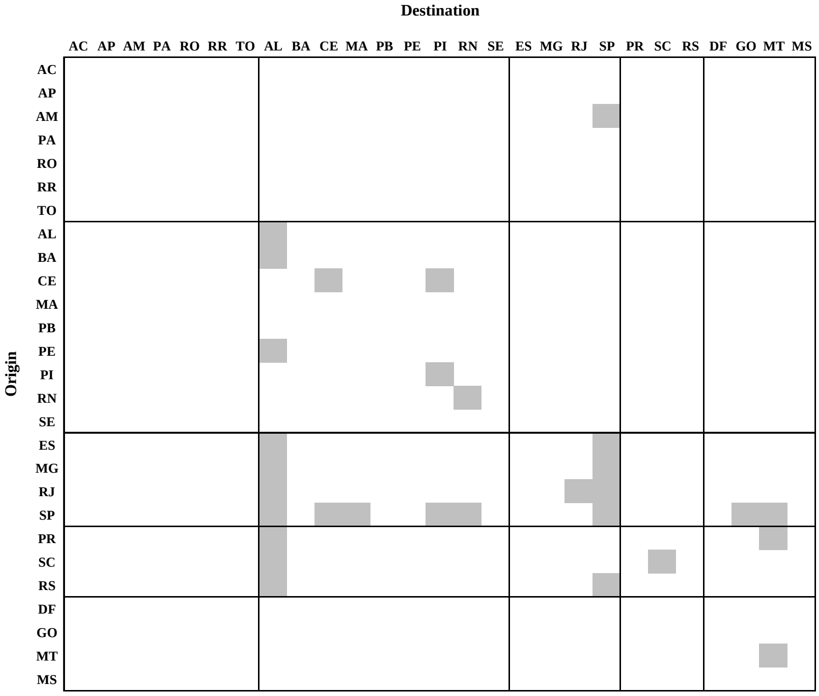
[9] Brazilian roads are divided into radial, longitudinal, transversal, diagonal and linking roads.



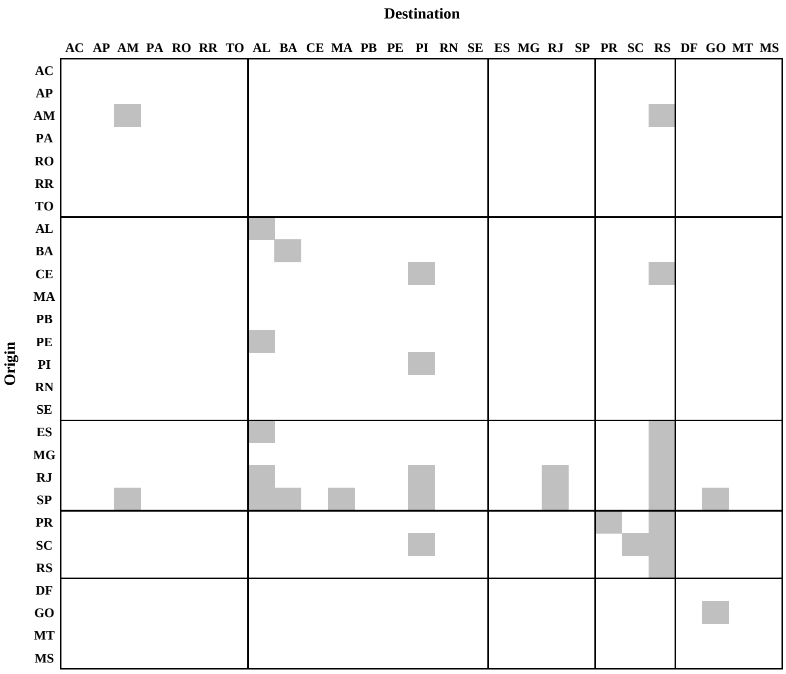
* Indicator of regional welfare: equivalent variation in the Northeast region

Figure 3
Long-Run Analytically Important Transportation Links Based on Regional Welfare*: Southeast



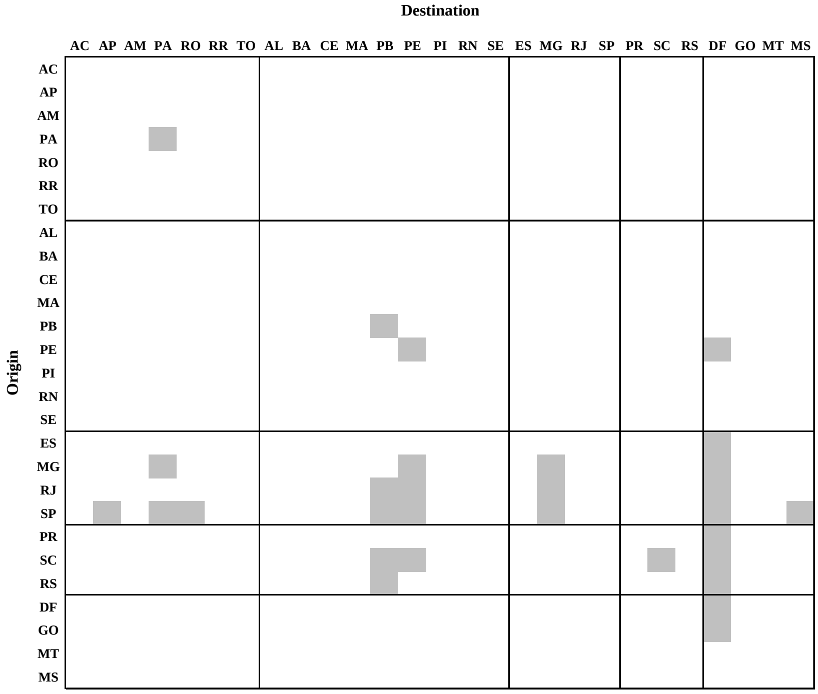
* Indicator of regional welfare: equivalent variation in the Southeast region

Figure 4
Long-Run Analytically Important Transportation
Links Based on Regional Welfare*: South



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

Figure 5
Long-Run Analytically Important Transportation
Links Based on Regional Welfare*: Center-West



Destination

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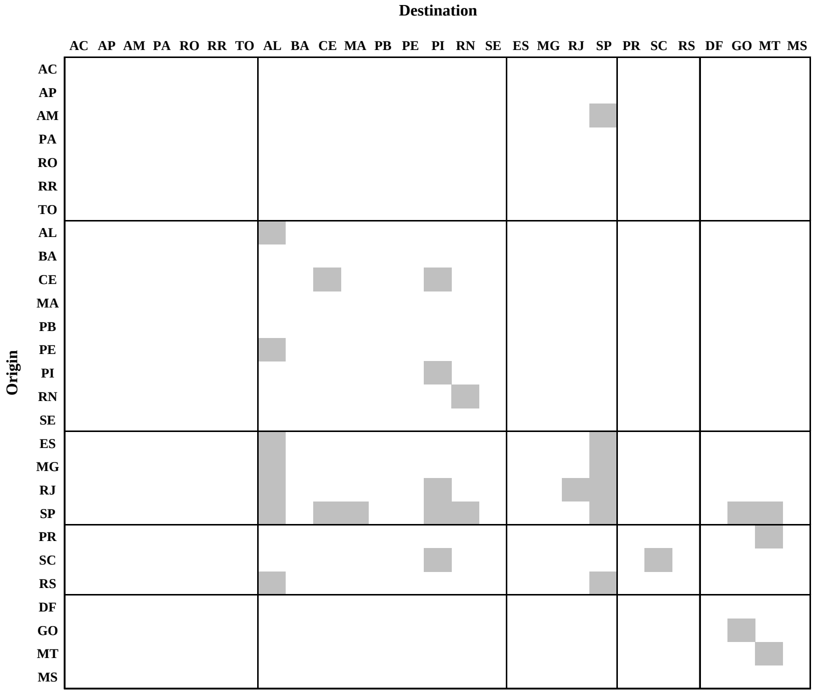
* Indicator of regional welfare: equivalent variation in the Center-West region

Figure 6
Long-Run Analytically Important Transportation
Links Based on National Welfare*: Brazil



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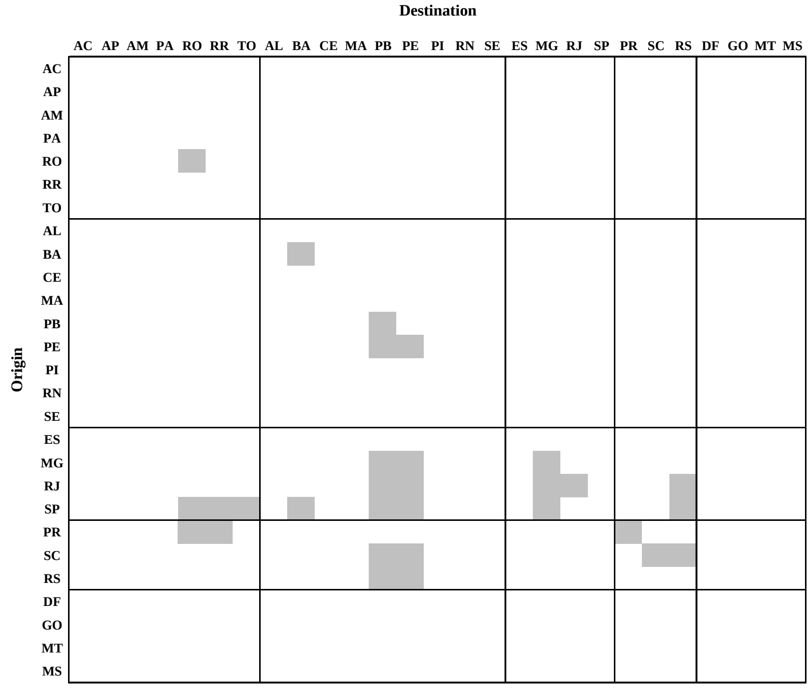
* Indicator of regional welfare: national equivalent variation

Figure 7
Long-Run Analytically Important Transportation Links Based on Regional Efficiency*: North



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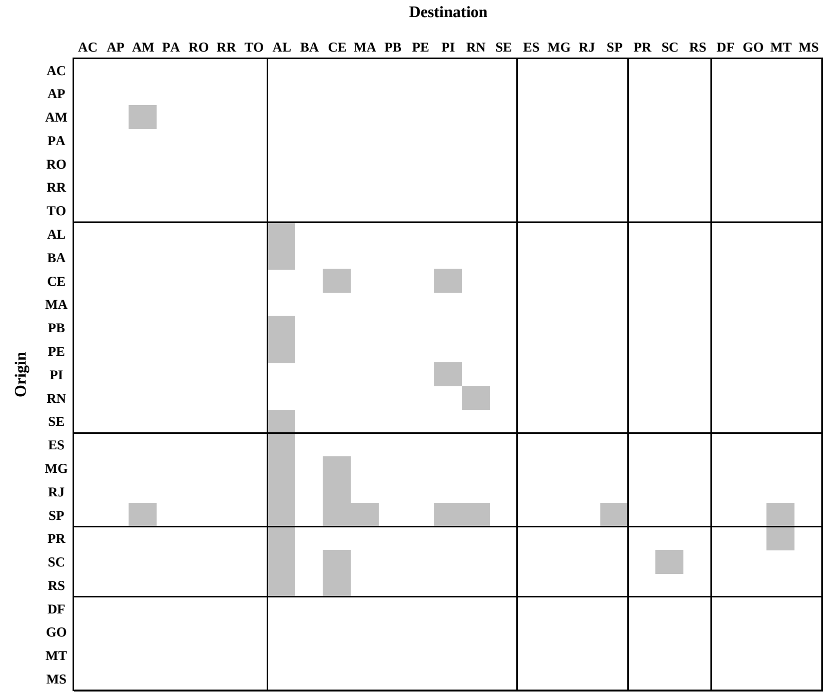
* Indicator of regional efficiency: GDP growth in the North region

Figure 8
Long-Run Analytically Important Transportation Links Based on Regional Efficiency*: Northeast



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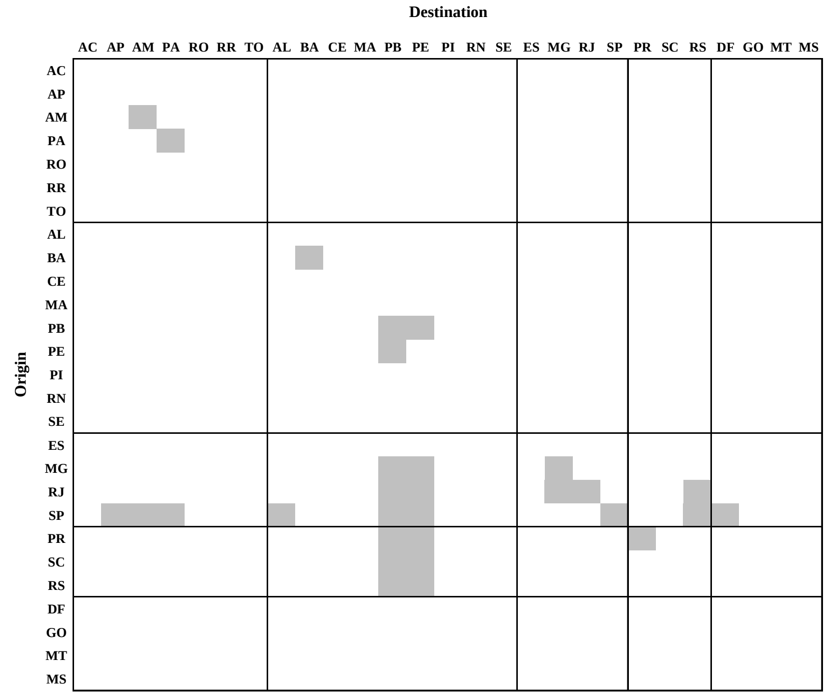
* Indicator of regional efficiency: GDP growth in the Northeast region

Figure 9

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



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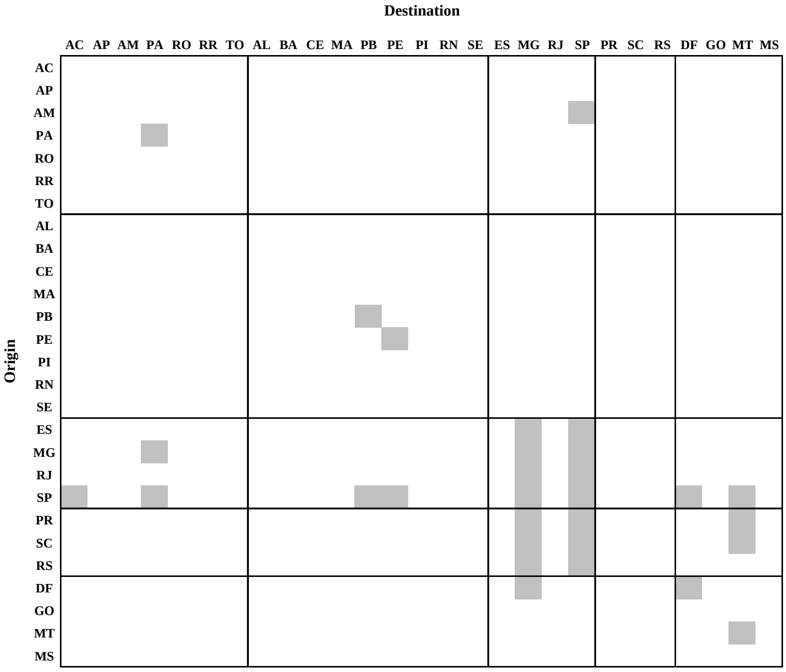
RJ												■	■					■	■				■				
SP		■	■	■				■				■	■							■			■	■			
PR												■	■								■						
SC												■	■														
RS												■	■														
DF																											
GO																											
MT																											
MS																											

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

Figure 10
Long-Run Analytically Important Transportation
Links Based on Regional Efficiency*: South



	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	RN	SE	ES	MG	RJ	SP	PR	SC	RS	DF	GO	MT	MS
AC																											
AP																											
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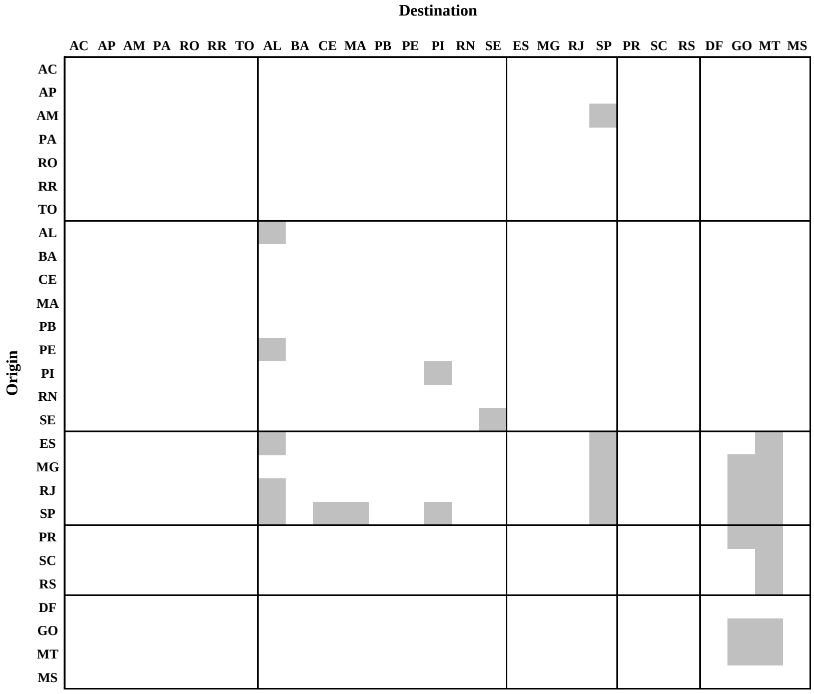
ES																		▨		▨							
MG				▨														▨		▨							
RJ																		▨		▨							
SP	▨			▨								▨	▨					▨		▨				▨		▨	
PR																		▨		▨						▨	
SC																		▨		▨						▨	
RS																		▨		▨							
DF																		▨						▨			
GO																											
MT																										▨	
MS																											

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

Figure 11
Long-Run Analytically Important Transportation
Links Based on Regional Efficiency*: Center-West



	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	RN	SE	ES	MG	RJ	SP	PR	SC	RS	DF	GO	MT	MS
AC																											
AP																											
AM																				▨							
PA																											
RO																											
RR																											
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CE																											
MA																											
PB																											
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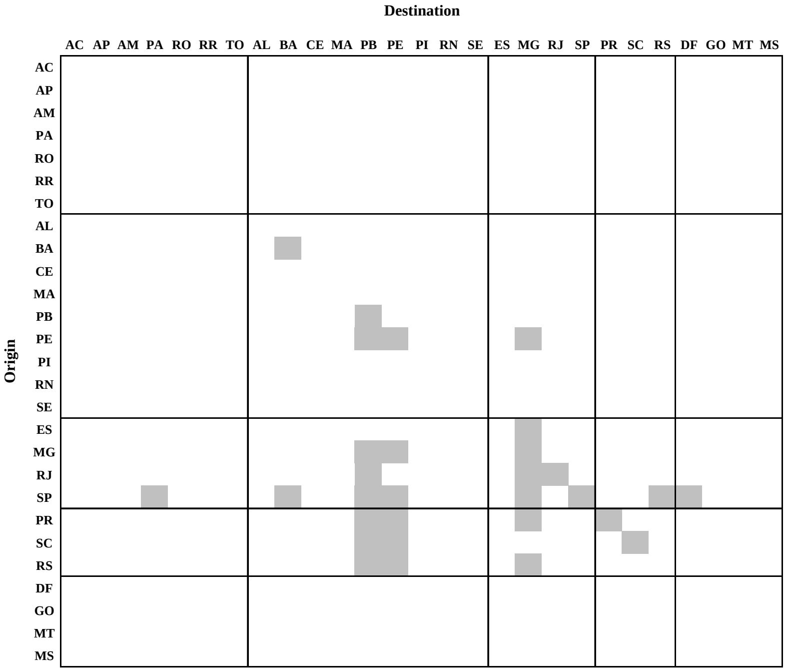
PI														▨													
RN																											
SE																▨											
ES								▨												▨						▨	
MG																				▨					▨	▨	
RJ								▨												▨					▨	▨	
SP								▨		▨	▨			▨						▨					▨	▨	
PR																									▨	▨	
SC																										▨	
RS																										▨	
DF																											
GO																									▨	▨	
MT																									▨	▨	
MS																											

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

Figure 12
Long-Run Analytically Important Transportation
Links Based on Systemic Efficiency*: Brazil



Destination

Origin	AC	AP	AM	PA	RO	RR	TO	AL	BA	CE	MA	PB	PE	PI	RN	SE	ES	MG	RJ	SP	PR	SC	RS	DF	GO	MT	MS
AC																											
AP																											
AM																											
PA																											
RO																											
RR																											
TO																											
AL																											
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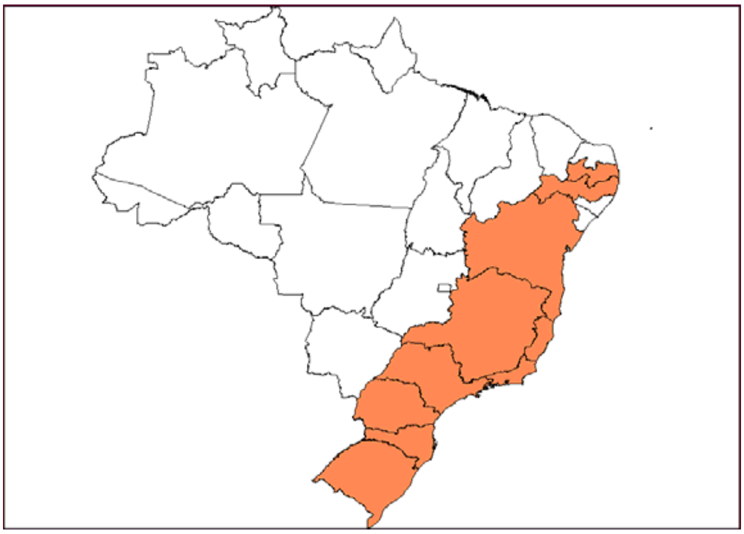
CE																											
MA																											
PB												▨															
PE												▨	▨					▨									
PI																											
RN																											
SE																											
ES																		▨									
MG												▨	▨					▨									
RJ												▨						▨	▨								
SP				▨					▨			▨	▨					▨		▨			▨	▨			
PR												▨	▨					▨			▨						
SC												▨	▨									▨					
RS												▨	▨					▨									
DF																											
GO																											
MT																											
MS																											

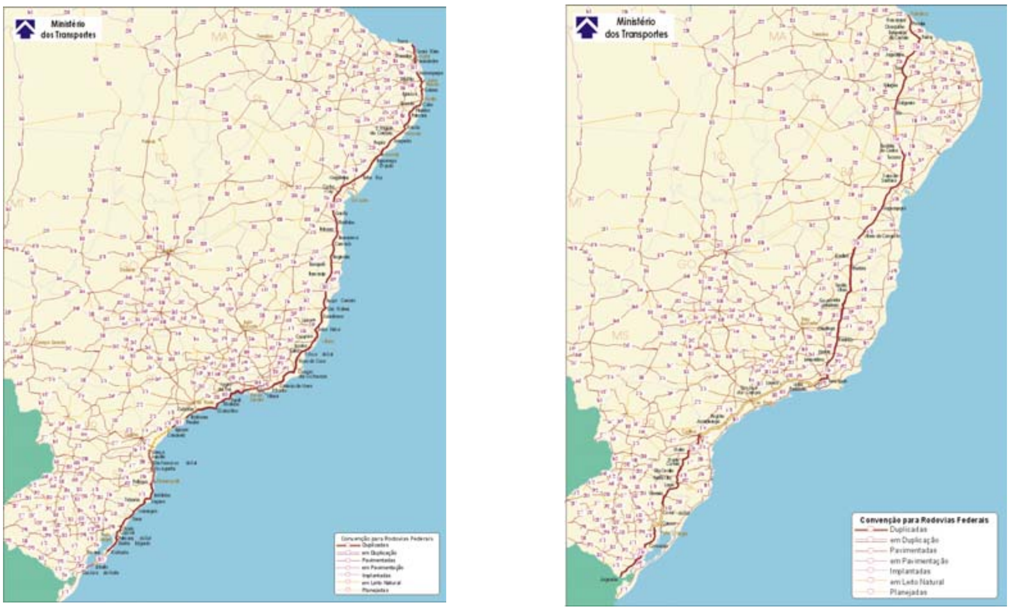
* Indicator of systemic efficiency: national GDP growth

The aforementioned states are located in the "direct area of influence" of two roads: BR-101, that goes from the Rio Grande do Norte to Rio Grande do Sul, following to coastal contour; and BR-116, that goes from Ceará to Rio Grande do Sul (Map 2). A more detailed study about these candidates would be the next logical step in order to better assess the possibilities relating transportation policies and national growth in the context of the existing spatial structure of the Brazilian economy.

Map 1
States Related to the Analytically Most Important
Transportation Links Based on Systemic Efficiency



Map 2. Selected Roads



BR-101

BR-116

5. Final Remarks

The main goal of this paper was to provide a common analytical framework to the application of the field of influence approach to a broader category of general equilibrium models, namely flexible prices general equilibrium models (CGE models). By exploring the mathematical structure of

Johansen-type CGE models, it was possible to show that their structural equivalence to input-output models allows the application of the original ideas elaborated by Sonis and Hewings (1989, 1992), through the use of technical change terms.

Such an approach was implemented in order to illustrate its analytical possibilities. In the case of our simulations, we have tried to identify analytically important transportation links in various contexts of regional/national policy goals. Results point to a promising research area, to further reinforce and investigate the role played by a (set of) coefficients generating structural models' outcomes. However, the notion of analytical importance in such linked models requires further elaboration. In particular, notion of capacity have different meanings and thus the ability of the production system to respond to short-run increases in demand may be different from the transportation system's capacity to absorb additional flows. In the latter case, adjustment of delivery schedules over a 24-hour period may accomplish a de facto increase in flows. These types of adjustments may not be possible in much of the productive system.

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