Duplication of the Fernão Dias Highway: A General Equilibrium Analysis

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Abstract

This paper quantifies the aggregate and regional welfare effects of the duplication of the Fernão Dias highway (BR-381), as well as its impact on regional equity, using a spatial computable general equilibrium model that incorporates transportation costs. The consequences in terms of efficiency and equity are quantified by simulating travel time reduction and freight decrease due to the duplication of the highway. The general equilibrium model is specified for five industries (agriculture and animal husbandry, mining, manufacturing industries, construction and services), twelve domestic regions, three external regions and two production factors (labor and other factors). In aggregate terms, the results reveal that the travel time effect does not yield welfare gains at all, but it enhances regional income inequalities. The freight effect overrides the travel time effect in the simulations. The spatial distribution of the results shows that the "winning" regions are those across which the duplicated sections of the BR-381 highway pass.

Revista EconomiA *December 2004*

Keywords: Spatial General Equilibrium Model, Transportation Costs, Fernão Dias Highway (BR-381)
JEL Classification: D58

Este trabalho quantifica os ganhos de bem-estar agregados e regionais da duplicação do trecho Belo-Horizonte-São Paulo da rodovia Fernão Dias (BR-381), bem como o seu impacto na eqüidade da renda regional, por intermédio de um modelo de equilíbrio geral aplicado espacial, que incorpora custos de transporte. As implicações em termos de eficiência e eqüidade são quantificadas por simular a redução do tempo de viagem e da diminuição do frete em decorrência da duplicação da rodovia. O modelo de equilíbrio geral é especificado para cinco setores (agropecuária, mineração, indústria, construção e serviços), doze regiões domésticas, três regiões externas e dois fatores de produção (trabalho e outros fatores). Três experimentos contrafactuais foram simulados, a saber, o efeito-tempo de viagem, efeito-frete e o efeito-total. Em termos agregados, os resultados revelam que o efeito-tempo de viagem não gera nenhum ganho de bem-estar social agregadamente, embora aguce a desigualdade de renda regional. O efeito-frete promove tanto a eficiência quanto a eqüidade de renda. O efeito-frete domina o efeito-tempo de viagem nas simulações. A distribuição espacial dos resultados, por sua vez, mostra que as regiões "vencedoras" são aquelas por onde cruzam os trechos duplicados da rodovia BR-381.

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1 Introduction

The duplication of the Fernão Dias Highway (BR-381) began in October 1993, and was financed by the state governments of São Paulo and Minas Gerais and by the federal government with the support from the Inter-American Development Bank (IADB). Once the highway duplication is unfinished, it is time now to assess the benefits (albeit partial) of this work.

The cardinal importance of the Fernão Dias highway lies in the fact that, together with BR-116, it is one of the major Brazilian roads, interconnecting three states, and acting as a transportation corridor for the supply of the domestic and export markets.

The aim of the present paper is to quantify the static welfare gains that result from the duplication of BR-381 using a spatial computable general equilibrium (SCGE) model for the state of Minas Gerais. However, the intention is not only to compute the aggregate gains, but also the spatial distribution of these gains across regions.

There are three basic reasons why SCGE is more appropriate to estimate the regional effects of the highway duplication than partial equilibrium methods (e.g.: econometric method). First, the phenomenon under investigation involves the interaction of several markets and complex feedback mechanisms.

Secondly, the highway duplication results in the redistribution of the interregional trade flow. Therefore, it is reasonable to admit that welfare gains will increase in some regions and decrease in others.

Thirdly, an SCGE model is laid on a solid microeconometric basis and is consequently less susceptible to Lucas' criticism, being one more advantage over more mechanical methods (e.g.: input-output techniques or gravitational model) or, again, to the econometric model. Furthermore, the regional allocation of results and welfare gains per region are based on the same microeconomically consistent theoretical framework.

The duplication of BR-381 reduces transportation costs, which include all the costs associated with the connection between two geographically separate regions. Transportation costs include two components: travel time and freight rates. The analysis, based on the project that fostered the political decision to carry the highway duplication forward, will take into consideration the influence of travel time reduction (by a decrease in travel distances) and the decrease in freight rates.

As previously mentioned, the present study considers the static welfare gains derived from the reallocation of resources, especially the redistribution of trade flows resulting from the duplication and improvement of BR-381. There is another source of static welfare gains – product diversity – not captured by the computable general equilibrium model used herein.

The results of this study show that efficiency or equity varies according to the travel time effect or freight effect. However, the freight effect prevails over the travel time effect in terms of economic efficiency. The travel time reduction resulting from the highway duplication does not seem to have any significant macroeconomic impact in the state of Minas Gerais. On the other hand, the spatial distribution of welfare gains is asymmetric, regardless of the type of simulation used.

Following this introduction, the paper is organized as follows. Section II describes the history of the Fernão Dias highway and its economic and strategic importance. Section III outlines the SCGE model, explaining the logic behind its construction and its main ideas. Section IV shows the design of the counterfactual experiments set up to assess the influence of the highway duplication on the economic system of the state of Minas Gerais. The results are displayed, interpreted and discussed in Section V. The last section concludes.

2 The Fernão Dias Highway (BR-381)

The Fernão Dias highway (BR-381), named after the Brazilian explorer who went into the hinterlands of São Paulo and Minas Gerais in search of emeralds following paths that resemble the current shape of the highway, began to be constructed in the last century, in the 1950s. The connection between Belo Horizonte and Pouso Alegre was inaugurated in 1960, during the tenure of president Juscelino Kubistcheck, when the duplication works were still unfinished. However, the highway was finished only in 1961 after the completion of the works in the state of São Paulo.

BR-381 connects two major Brazilian cities – Belo Horizonte and São Paulo – with a diagonal length of 563.2 kilometers. According to the State Road Department of Minas Gerais (DER-MG), 43% of the state's economy, 20% of the total production of the industrial parks of Minas Gerais and São Paulo, approximately 60% of Brazil's production of pig iron and nearly three million tons of the agricultural production of Minas Gerais are transported across BR-381, with an average traffic flow of over 15 thousand vehicles (buses, trucks and cars) a day. Moreover, 25% of the population of Minas Gerais lives and works in the area of influence.

The first project for the duplication of the highway section that extended 90 kilometers between the boundaries of the state of

Minas Gerais and the state capital of São Paulo was launched in 1973, thanks to the fact that the Brazilian Highway Department (DNER) had observed, in the previous year, that the highway section in the state of São Paulo would eventually exceed its capacity. However, such project could not be carried out due to budgetary constraints.

In the late 1980s, several sections of the highway were resurfaced and new road signs were installed. These were indeed the last relevant improvements made before the duplication works. In spite of this, the roadbed conditions were poor because of heavy rains and usual landslides.

In the early 1990s, the state governments of Minas Gerais and São Paulo and the federal government submitted a project proposal to the Inter-American Development Bank requesting a loan for the duplication of the Fernão Dias highway between Belo Horizonte and São Paulo (see Map 1).

After the project was approved, the duplication of the highway sections between Belo Horizonte and São Paulo was implemented in two stages. In stage I, which began in October 1993, the sections between Belo Horizonte and the Nepomuceno junction, with 217.2 kilometers in the state of Minas Gerais, and between the Via Dom Pedro I junction and BR-116 junction (Guarulhos/São Paulo), with 53 kilometers in the state of São Paulo, were duplicated. In stage II, the sections between the Nepomuceno junction and the state boundaries of Minas Gerais and São Paulo, with 256 kilometers in the state of Minas Gerais, and between the state boundaries of Minas Gerais and São Paulo and the Via Dom Pedro I junction, with 37 kilometers in the state of São Paulo, were duplicated (Duplicação, 1992, p. 3).

More than ten years after the duplication works were started, 7% of the section between Belo Horizonte and São Paulo has not

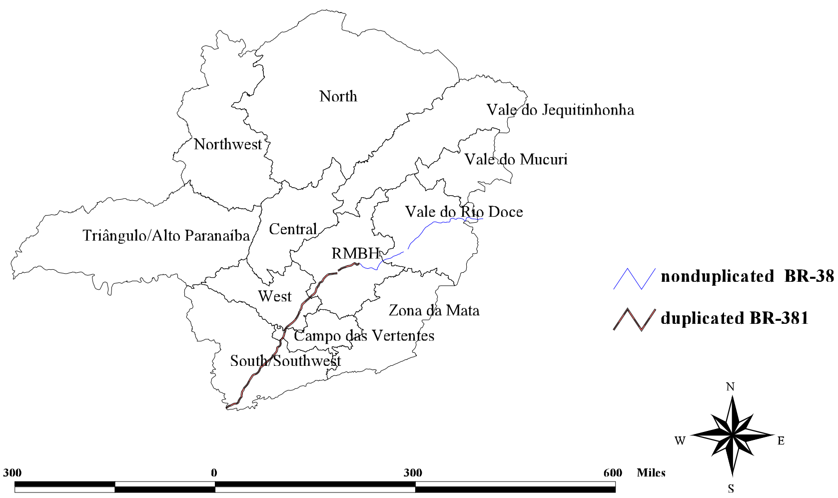

Fig. 1. Minas Gerais and the BR-381 (Fernão Dias) Highway

been duplicated yet (35 kilometers in the south of Minas Gerais, including the construction of access roads, pedestrian bridges and overpasses). Due to poor roadbed maintenance, 40 kilometers of the duplicated highway in the São Paulo section need to be repaired. The duplication works were interrupted in October 2002. The Ministry of Transportation announced the completion of the duplication works of the BR-381 highway section in August 2003. In August 2004, the works were still unfinished.

3 Model

Because of the paucity of regional data, the spatial computable general equilibrium model developed in the present study for the regions of Minas Gerais – hereinafter referred to as the MINAS-SPACE model – is based on the principle of parsimony, as described by Bröcker (1998) and Bröcker and Schneider (2002). The dearth of data in most statistical agencies results in the lack of reliable information about interregional trade flows and stocks of regional production factors.

The principle of parsimony does not allow the estimation of interregional trade flows through methods that do not have a solid microeconomic basis, such as the gravitational model or input-output regionalization methods. In practical terms, the principle of parsimony rests upon three premises: the pooling concept (Nijkamp (1986)), the Armington specification (1969) and the iceberg transportation cost assumption, proposed by Samuelson (1954)[1].

The pooling concept means that consumers and producers do not meet directly in the market as producers do among themselves. Transportation agents coordinate the execution of functions existing between production and consumption across regions. There lies the importance of the pool good, which is a composite of commodity i, a combination of R commodities i, obtained from all domestic producer regions, and of L commodities i imported from external regions by the transportation agent. That is, the transportation activity serves a dual purpose: first, the commodities produced by all source regions are transported to the destination region; secondly, the commodities are combined into a pool good in the destination region and then deliveries are made to final consumers (families) or to intermediate consumers (firms).

Transportation technology – assumed to be the same in all destination regions – is represented by nested constant elasticity of substitution (CES) functions. At this point, the Armington assumption is used, which postulates imperfect substitutability between the commodities produced in the regions. Thus, in the

[1] For a detailed description of the variables and equations of the MINAS-SPACE, see Almeida (2003).

destination region, the pool good does not consist only of the commodity with the lowest CIF price, because the commodities from different regions are not identical. The Armington specification is adopted to differentiate commodities by source region.

Due to the spatial nature of the model, the commodity prices include transportation costs, regarded as necessary for the transportation of commodities across regions. Therefore, there exists an interregional trade barrier which, to be removed, involves some costs. For the sake of simplicity, iceberg transportation costs are adopted, which originally means that a portion of the transported commodity dissipates during transportation [2]. This is the same as to think that a portion of the commodity "melted away" during transportation (as if it were an iceberg floating in the ocean).

Even though this type of iceberg cost seems quite restrictive in the sense that it is only valid for some commodities, one should not forget that the iceberg cost is only a metaphor used to deal with a general idea of transportation cost. In the model, as all commodities have to overcome geographical distances in order to reach the consumer regions, the minimum cost function is denoted by the commodity prices plus transportation costs, constituting the prices of pool goods, according to the iceberg cost metaphor.

The modeling of iceberg transportation costs is relatively simple from a mathematical point of view. The output prices are multiplied by a factor such as $e^{\eta^i z_{rs}}$. This factor contains two

[2] An example of that is the transportation of diesel oil by truck, in which some gallons of diesel oil are used in the fuel tank of the truck so that it can arrive at the destination region. Consequently, on arriving at the destination, there would be fewer gallons of diesel oil in the truck cab.

components: η^i, which denotes the freight for commodity i, and z_{rs}, the distance (or travel time) of the route between the source region r and the destination region s. In the subsequent section, these two components will be dealt with in order to design the counterfactual experiments to be simulated.

The consequence of combining the Armington specification with the iceberg transportation cost assumption is that the demand varies geographically, such that there is a higher demand for the commodities of the closest neighboring regions.

The major advantage of this model is that it foregoes interregional trade flows. The final and intermediate demands for pool goods – which determine the interregional trade flows – are a result of the optimizing behavior of families and firms. The most important is that such demands, and the flows associated with them, are modified according to this optimizing behavior determined after each shock or change to the institutional environment.

The MINAS-SPACE model is used for a comparative statistics analysis. To do so, we assume an open economy with I sectors, R domestic regions and L external regions. There are four activities in this economy: production, transportation, final demand and export.

The final demand activity is carried out by families. Each region contains a representative family, which owns production factors. The representative R families derive their income from selling these production factors to firms, spend their entire income on the consumption of pool goods, and do not save. For simplification, the preferences, whose formal specification is a constant elasticity of the substitution function, are identical for all representative families in the regions.

The production activity is performed in each region by I firms that purchase the intermediate inputs from the pool good of the destination region and buy the primary inputs from the representative family for their production, according to a linear homogeneous production technology, represented by nested constant elasticity of substitution functions and Leontief functions.

The MINAS-SPACE model is developed for an open economy in which only the behavior of economic agents in Minas Gerais is optimized. The model's external sector, in its turn, is represented by a set of export demand and import supply functions. There are L external regions and, in each external region l, there are I export agents, which form the export pool goods, based on the transportation of products from all domestic R regions. Due to the spatial nature of the model, it is necessary to have a regional distribution of exports and imports according to the Armington specification. The export activity is also carried out by means of a CES linear homogeneous production technology.

An environment of perfect competition is assumed, where firms, transportation agents and export agents minimize unit costs. In view of the linear homogeneity of technologies, this assumption implies that, in equilibrium, prices equal unit costs and, consequently, there is no possibility to make pure profits in the economy.

In this model with parsimonious data requirements, the public sector and investments are not modeled. Government expenditures and investments are included in the final demand, but there are no specific equations to represent their behavior.

As the model consists of a non-linear system of equations, Newton's algorithm is used to find a solution (Bröcker (1998); Almeida (2003)). The solution is achieved when one finds a factor-price vector and an import price vector for which all excess demand for factors and excess demand for imports are null.

With regard to the labor market, two types of closure are adopted in the MINAS-SPACE model: the flexible wage rate policy (also known as neoclassical closure) and the fixed wage rate policy (also known as Keynesian closure) [3].

The neoclassical closure was used for the simulations in the present study. This type of closure establishes that there exists equilibrium when the exogenous labor supply equals the demand for labor in all markets, and that full employment is the mere consequence of this equilibrium. In this closure, the labor market contemplates only price adjustments, that is, when temporary disequilibrium occurs, wages conveniently adjust until the equilibrium is restored. Consequently, the resource allocation mechanism is the major force that runs the model to an equilibrium. Furthermore, the neoclassical closure combines with a long-term perspective of the economic system, in which all prices are flexible.

The model is divided into five sectors (agriculture and animal husbandry, mining, manufacturing industry, construction and services) and into twelve domestic regions, which are the mesoregions defined by the IBGE (Brazilian Institute of Geography and Statistics) for the state of Minas Gerais (Northwest, North, Vale do Jequitinhonha, Vale do Mucuri, Vale do Rio Doce, Zona da Mata, Campo das Vertentes, South/Southwest, West, Central, Triângulo/Alto Paranaíba and RMBH). The external regions are the state of São Paulo, the state of Rio de Janeiro and the Rest of Brazil.

The database for the model included different sources of data. An

[3] For simulations with the same model, using the Keynesian closure, see Almeida (2004).

important component of the database is the interregional input-output table for Minas Gerais/Rest of Brazil available for the year 1996, elaborated by the Development Bank of Minas Gerais S. A and by FIPE (Economic Research Institute) (BDMG/Fipe (2001); Domingues and Haddad (2002)).

Regional wages and employment data were extracted from the 1991 IBGE Census, from the Brazilian National Household Sample Survey (PNAD) and from the Annual Record of Social Information (RAIS). Export and import information on Minas Gerais and external regions (São Paulo, Rio de Janeiro and Rest of Brazil) was obtained from the Brazilian National Council for Fiscal Policy (Confaz). The elasticities used in the model come from several sources in the literature (Guilhoto (1995); Bröcker and Schneider (2002)). Freight rates for agriculture and animal husbandry and for the manufacturing industry were estimated econometrically using the database of the Agricultural Cargo Freight Information System (Sifreca-Esalq/USP).

The distance matrix between the meso-regions of Minas Gerais was calculated using the coordinates of the main city in each meso-region, based on the data presented in Cesar (1999). With regard to the matrix between the meso-regions and "external regions" (São Paulo, Rio de Janeiro and the Rest of Brazil), the distances were computed by considering the main headquarters of these regions, namely, the city of São Paulo, the city of Rio de Janeiro and Distrito Federal, respectively. Distance is calculated based on minimum road lengths (Cesar (1999), p. 112).

4 Counterfactual Experiments

In general terms, a highway duplication allows reducing transportation costs. Since transportation costs depend on distance (travel time) and freight rates, a duplicated highway exerts influence on both travel time and freight. Road infrastructure improvement reduces travel time due to better roadbed conditions. The freight rates are reduced with the highway duplication, as the operating cost for the road transportation of commodities decreases.

The next section simulates three counterfactual experiments related to the duplication of BR-381 by manipulating two components of transportation costs: travel time effect, freight effect and the overall effect. The latter encompasses the previous two effects.

It is necessary to estimate the variations in travel time and freight rates after the highway duplication in order to quantify the welfare gains. In specific terms, such quantification was obtained from the project proposed in 1992 by the state governments of Minas Gerais and São Paulo and by the federal government, with the support from the IADB, for the external financing of the highway duplication works.

The quantification of vehicle operating costs was carried out in compliance with the international methodology:

> *"The procedure used to calculate operating costs was based on the VOC (Vehicle Operating Costs) submodel of the 'Highway Design and Maintenance Standard Model' (HDM-3) and on the method recommended by the 'Highway Capacity Manual' (HCM)".*

> *"The HCM allowed estimating the speed of vehicles in relation to*

traffic volume and to highway capacity. The VOC submodel allowed calculating the vehicle operating costs for situations with and without a project, in function of the speeds calculated by the HCM, and also allowed estimating the speed of vehicles under free-flowing conditions, considering the characteristics of the vehicles and the physical characteristics of the road" (p. 168).

Traffic volumes were econometrically estimated for medium and heavy trucks and semi-trailers according to a percentage determined by traffic counts and source-destination surveys conducted on highway BR-381 and on its area of influence, so as to obtain a weighted average for the operating cost in the truck category.

Table 1 shows the truck operating costs according to highway section (adapted for the present study).

Table 1
Truck Operating Costs

Highway(Km-Km)	Meso-region	Operating cost	
Section		Current(Cr$-Km-vehicle)	Future(Cr$-Km-vehicle)
420-432	RMBH	1,403.83	1,104.66
432-441	RMBH	1,214.58	1,073.64
441-455	RMBH	1,203.61	1,185.08
455-509	RMBH	1,598.22	1,185.08
509-535	West	1,336.57	1,204.41
535-560	West	1,396.16	1,185.95
560-584	West	1,592.16	1,170.43
584-604	West	1,541.18	1,125.48
604-626	West	1,688.61	1,283.62
626-637	West	1,653.33	1,247.92
637-651	Campos das Vertentes	1,653.33	1,247.92
651-699	South-southwest	1,599.98	1,235.24
699-745	South-southwest	1,260.53	1,166.02
745-768	South-southwest	1,202.32	1,164.28
768-791	South-southwest	1,119.07	1,086.70
791-843	South-southwest	1,217.79	1,083.83
843-893	South-southwest	1,520.62	1,190.77
Average	–	1,423.64	1,173.00

Source - Adapted from **Duplicação** (1992, p. 169).

In the model, freights are sorted out by commodities. Since the inputs used to calculate the operating cost are common to the transportation of any commodities, we decided to apply the operating cost reduction to the freight rates. One should recall that freight, defined as the price of transportation service, differs from transportation cost because it includes a rate of economic profit. Nevertheless, perfect competition is assumed in the model, producing a zero economic profit.

It would be a mistake to apply all the average reduction in operating costs to the freight value shown in Table 1, as the latter includes all the flow of commodities through the road network and not only through one single highway, even though BR-381 is the major road network of the state of Minas Gerais. Hence, we used the information provided by DER/MG that 43% of the economy of the state of Minas Gerais is transported via the highway and we applied this percentage to the reduction in the operating cost of trucks to estimate the extent to which commodity freight rates should be reduced. Thus, we obtained a percentage of 7.57% that should be deduced from the freights of all commodities.

Travel time reduction was estimated in function of the operating speed of vehicles before and after the highway duplication. The duplicated section of the highway crosses the meso-regions from Belo Horizonte up to the boundary with the state of São Paulo in the following order: metropolitan area of Belo Horizonte, western Minas Gerais, Campo das Vertentes and southern/southwestern Minas Gerais.

Some adaptations are necessary in order to set up the counterfactual experiment based on the travel time effect. First, as the area of influence around the Fernão Dias highway is believed to be large, travel time reductions were applied to the distance matrix between the meso-regions. Travel time reductions were calculated for different sections of the highway within the same meso-region and between meso-regions. We calculated the weighted average (by the distance between highway sections) of these reductions for each section in order to assess travel time reduction within the meso-region. Travel time reduction between two meso-regions, in its turn, was obtained by the average reduction in travel time of all sections belonging to the two meso-regions, weighted by the distance between highway sections. Therefore, the shocks to be applied to the counterfactual experiment to simulate the travel time effect are based on the matrix of travel distance parameters, shown in Table 2.

The time travel reduction between the southern/southwestern meso-region and the city of São Paulo, final destination of the duplicated highway section, was also calculated, using the same criterion established for the quantifications in Table 2. Such reduction was calculated as being 35.9%. To simulate the travel time effect, an equilibrium is computed with an interregional distance matrix modified by the impact of the duplication of BR-381, as described in Table 2.

Table 2. Matrix with the Variation of Interregional Distances for Minas Gerais

Regions	Northwest	North	Jequi-tinhonha	Mucuri	Triângulo	Central	RMBH	Vale do Rio Doce	West	South/ Southwest	Campos das Vertentes	Zona da Mata
Northwest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
North	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jequi-tinhonha	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mucuri	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Triângulo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Central	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RMBH	0.0	0.0	0.0	0.0	0.0	0.0	-28.4	0.0	-29.8	0.0	0.0	0.0
Vale do Rio Doce	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West	0.0	0.0	0.0	0.0	0.0	0.0	-29.8	0.0	-31.4	0.0	-32.4	0.0
South/ Southwest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-33.0	-33.3	0.0
Campo das Vertentes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-32.4	-33.3	-39.0	0.0
Zona da Mata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: Based on information on Duplicação (1992, p. 172–174)

Before carrying out the experiment simulations, it is worth highlighting the driving forces behind the causal mechanism of the impact of transportation cost variation on the MINAS-SPACE model. At the aggregate level, a reduction in transportation costs – which, in the model, is represented by freight decrease, η_i, or by travel time reduction, z_{rs}, – seems to cause a decrease in the prices of pool goods at first, which will later result in an increase in real family income, improving welfare. This generalized increase in the real income occurs as an increase in the final demand of families, pushing up the output level of firms. In order to increase production, firms have to use more labor and other factors, increasing the prices of these factors, and eventually increasing the income of these families again.

At the regional level, there are two effects on the price of a reduction in transportation costs, in the production sphere, between regions r and s. Firstly, there is a direct substitution effect which means that, in region s, it is more interesting to purchase commodities from region r and, as a result, this region will produce more commodities for region s. This is the direct substitution effect.

There is however an indirect substitution effect represented by the fact that producers in region r will buy more inputs to produce for region s. For the commodities produced in region r, the reduction in price occurs due to the competition for commodities from other regions, since markets are more accessible.

Also, there is the income effect, in which changes in price will eventually alter the real income, causing variations in demand and in output. It should be noted that incomes probably increase in the source region r, as well as in the destination region s, but they can increase or decrease in other regions.

At the regional level, some components of this mechanism may cause prices to rise. The easier access provided by the reduction in distances (or travel time) allows for an income effect, represented by a higher demand from other regions for products manufactured in region r, which at first had their prices lowered due to the reduction in transportation costs. One should underscore that this increase in the final demand of other regions results from the following: a substitution effect implied by the reduction in the price of commodities, and an income effect, caused by the increase in the real income. At the end, the prices of region r can increase if the income effect overrides the direct and indirect substitution effect described above.

As to the spatial impact on welfare and production level, an interesting causal mechanism is implicated. As Bröcker (1999) put it, as the new road connections or the improvement of the existing ones allow shortening distances and improving the access to regions, they can cause welfare losses to a certain region due to the redistribution of trade flows towards regions that have an easier access after the construction of the highways. Therefore, we have interregional trade diversions, which do not allow all regions to benefit from the reduction in transportation costs. A region that does not use the new road connection so often, but which usually engages in negotiations with regions that use the road connection more often, may observe the demand for their products get diverted to other places, which are more accessible to the consumer. So, the benefit from the reduction in transportation costs does not necessarily have to increase everywhere.

5 Results and Discussion

When the simulation of a counterfactual experiment is carried out, the computable general equilibrium models, especially interregional ones, provide a remarkable array of numerical results, which originate from the interaction of optimizing agents found in all sectors and in all regions. This is the main advantage of this quantitative method. However, due to the copious amount of data, this is usually a problem among researchers when analyzing and interpreting the results, even if they bear the causal mechanism and the logic operation of the model in mind. To overcome such difficulty, it is recommendable to construct some summarizing measures to evaluate the results.

In this model, welfare gains are the summarizing measures used to evaluate economic efficiency. Welfare gains measure the utility gains of the families, expressed as percentage variation, using the concept of relative equivalent variation. In the presence of a shock (or change in policy), this is defined as a percentage increase of the pre-shock income level that a family would need to receive in order to attain the after-shock level of utility at pre-shock prices, and that a family would have to get in order to attain the after-shock level of utility at pre-shock prices (Bröcker (1998)).

In addition to welfare gains, the results will be expressed as price index and Gini coefficient. The latter summarizes the results corresponding to regional equity.

The aggregate results of the three simulations developed in the previous section are shown in Table 3, as percentage variation, considering the 1996 benchmark values.

The separate simulation of the travel time effect of BR-381 duplication demonstrates no welfare gain, indicating that it does not

Table 3
Aggregate Results of the MINAS-SPACE Model

	Effect		
Result Indicators	Travel Time	Freight	Overall
Welfare gains	0.00	0.07	0.07
Gini coefficient	0.04	-0.18	-0.14
Price Index	-0.04	-0.26	-0.30

Source: Results obtained from the study.

have an aggregate effect in terms of efficiency for the economy as a whole. Furthermore, the regional income inequality, measured by the Gini coefficient, becomes a little more pronounced. By improving the major road connection in more developed regions of the state, there is a deleterious effect on the regional income equality. This occurs because the most developed regions are more accessible due to the reduction in transportation costs, and are more competitive than other regions, and thus the trade flows are redirected in their favor [4] .

The price index, in its turn, shows some decrease. Recalling the causal networks described in the previous section, this occurs because the substitution effect overrides the income effect. In other words, the direct reduction of pool goods owing to the reduction in transportation cost compensates for the higher demand from other regions (mainly from the closest neighboring regions) for the commodities produced by the regions where sections of the highway were duplicated.

The freight effect, simulated separately, offers higher efficiency, as

[4] The relationship between transportation and regional equity is subjected to the place where it occurs. This relationship was investigated by Almeida et al. (2003).

indicated by the welfare gains (0.07%). This increase in efficiency is intensified by a 0.26% reduction in the price index. Regional income equity is also improved, as indicated by a 0.18% reduction in the Gini coefficient. The stronger impact shows that the freight of commodities in all routes is reduced due to the improvement of the major transportation corridor.

Obviously, these results reveal that the freight effect is stronger and predominates over the travel time effect, which has a small aggregate effect on the economy of Minas Gerais. The overall effect of the highway duplication results in welfare gains, which are intensified by a 0.30% reduction in the price index, since both the travel time and freight effects are taken into account in this simulation. Evidently, the freight effect has a stronger influence on the overall effect. With regard to regional equity, the Gini coefficient shows a 0.14% reduction, revealing a decrease in income inequality across regions.

Table 4 shows the regional results in terms of welfare gains, in percentage variation, considering the 1996 benchmark values.

As to the simulation of the travel time effect, the higher welfare gains were observed in the meso-regions through which the duplicated Fernão Dias highway passes, namely, Campo das Vertentes, southern/southwestern Minas and western Minas Gerais (see Map 2). The regions that are closer to São Paulo suffer a greater impact due to the fact that infrastructure improvement helps to integrate markets, promoting interregional trade and serving to reduce trade barriers. The southern/southwestern region of Minas Gerais, on the border of São Paulo, has the highest increase in efficiency. These gains, which suffer the influence of travel distance, are weakened as one moves farther from São Paulo, which has the largest market in Brazil. In sum, what captures our attention in this analysis is the asymmetric response of results across space.

The metropolitan area of Belo Horizonte, through which the highway passes as well, shows a small welfare loss (0.01%). All the other regions that do not have the duplicated highway within their territory have welfare loss due to trade diversions. This occurs because of the redistribution of trade flow to regions in the area of influence of the major transportation corridor of Minas Gerais, encouraged by road improvements, which reduce transportation costs and increase competition in the favored regions.

The spatial distribution of welfare gains to the freight effect is depicted in Map 3. The underdeveloped regions of Minas Gerais, such as the northwest, north, Vale do Jequitinhonha and Vale do Mucuri, benefit from the decrease in freight rates as a result of the duplication of BR-381. The benefit for these regions exceeds those of the regions where the highway was duplicated. The metropolitan area of Belo Horizonte was the region with the lowest welfare gain (0.02%) in this experiment, whereas Vale do Mucuri had the largest gain (0.32%).

As can be observed in Map 4, the spatial distribution of welfare gains between the regions for the overall effect has the same arrangement as that for the freight effect, since this effect prevails over the travel time effect. It is also important to note that Vale do Mucuri is the meso-region with the best performance (0.30%), whereas the metropolitan area of Belo Horizonte is the one with the worst results (0.01%).

Table 4
Regional Results of the MINAS-SPACE Model

Meso-regions	Effect		
	Travel Time	Freight	Overall
Northwest	-0.02	0.29	0.27
North	-0.02	0.25	0.23
Jequitinhonha	-0.02	0.28	0.26
Vale do Mucuri	-0.02	0.32	0.30
Triângulo/Alto Paranaíba	-0.02	0.17	0.16
Central	-0.02	0.08	0.07
RMBH	-0.01	0.02	0.01
Vale do Rio Doce	-0.02	0.20	0.18
West	0.05	0.04	0.08
South/Southwest	0.08	0.09	0.16
Campo das Vertentes	0.07	0.07	0.14
Zona da Mata	-0.02	0.10	0.09
Weighted average	0.00	0.07	0.07
Standard deviation	0.04	0.11	0.09
Maximum	0.08	0.32	0.30
Minimum	-0.02	0.02	0.01

Source: Results obtained from the study.

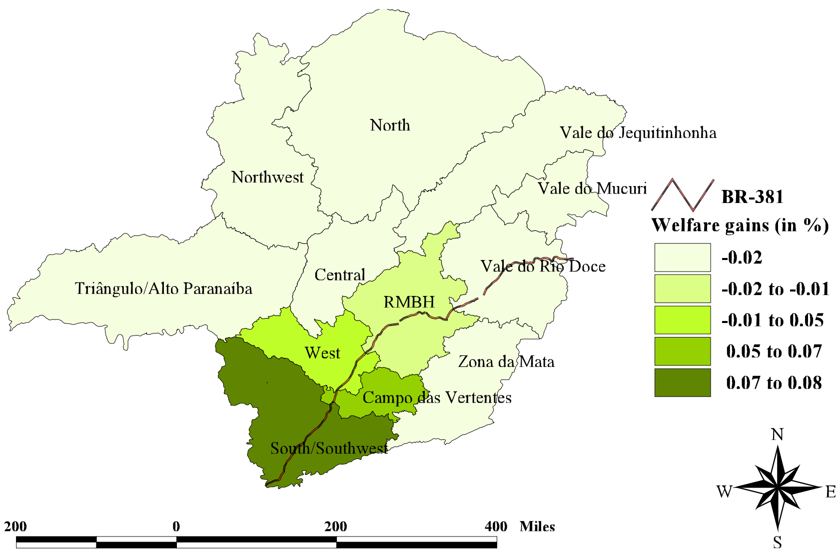

Fig. 2. Welfare Gains of the Experiment "Travel Time Effect"

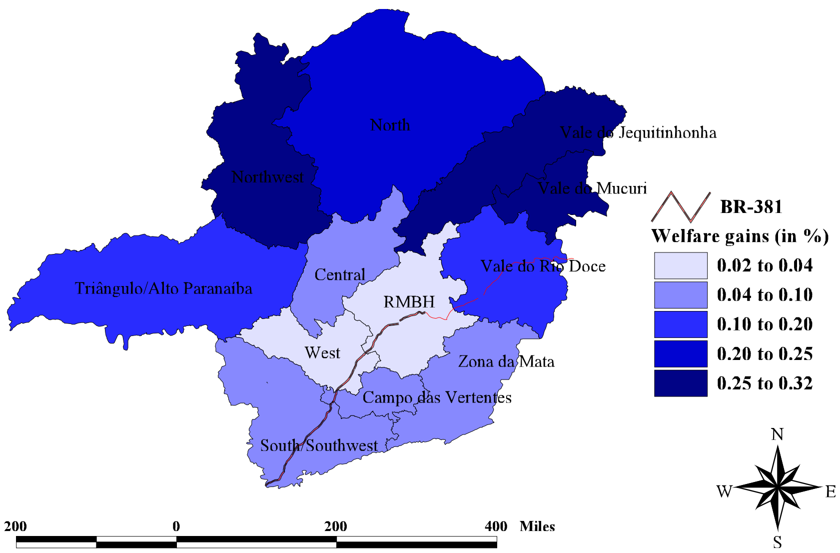

Fig. 3. Welfare Gains of the Experiment "Freight Effect"

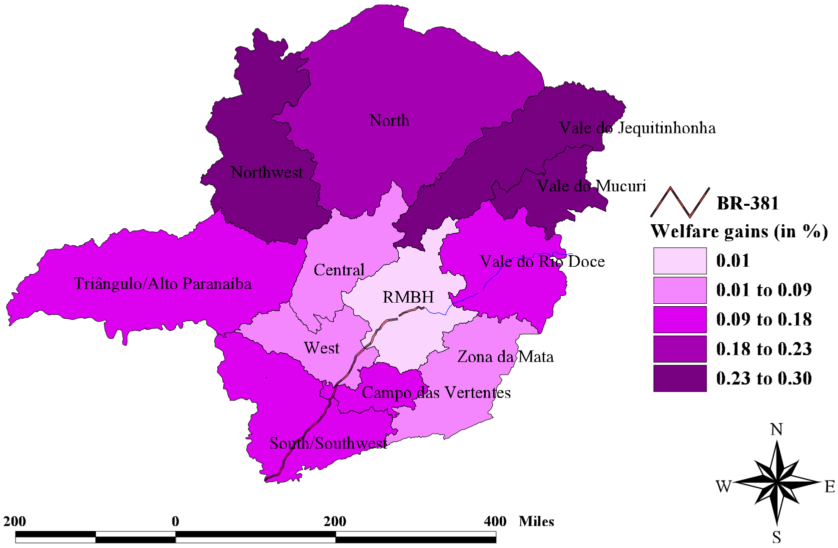

Fig. 4. Welfare Gains of the Experiment "Overall Effect"

6 Final Remarks

In aggregate terms, the results show that there was a zero impact of the duplication of Fernão Dias (BR-381) highway on the economic development of the state of Minas Gerais as far as the travel time effect is concerned. On top of that, the reduction in travel time winds up stimulating regional income inequality.

With regard to the freight effect, there is some evidence that it has a positive influence on the efficiency of the economic system, bringing welfare gains. Moreover, the freight effect promotes regional equity, as indicated by the Gini coefficient.

As for regional effects, the "winning" regions, that is, those with above-average results, are the meso-regions through which the duplicated highway passes. The "losing" regions are those far away from the regions crossed by the highway, which consequently have trade diversions caused by the redistribution of interregional trade flows.

In general, one may assert that the duplication of Fernão Dias (BR-381) highway between São Paulo and Belo Horizonte represents an improvement in transportation infrastructure, helping to overcome the hindrance to interregional economic integration, represented by travel time and freight. A stronger impact on regional equity could be felt if the highway duplication was carried forward and the rest of BR-381 was incorporated into the mesoregion of Vale do Rio Doce.

Albeit very promising, the model presented herein, or any other method, has some limitations in that it does not comprise all the benefits offered by the phenomenon under analysis. Regional welfare effects result only from the use of the duplicated highway for the transportation of commodities and services. Effects regarding the construction and maintenance of the highway are not taken into account. The benefit of the duplication of BR-381 regarding the reduction in traffic accidents was not an object of investigation. Furthermore, the model does not allow evaluating the spatial influence of increasing returns of scale, especially in some segments of the industrial sector, after the duplication of the highway.

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