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THE UNDERGROUND ECONOMY: TRACKING THE WIDER IMPACTS OF THE SÃO PAULO SUBWAY SYSTEM

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Abstract. Over one million workers commute daily to São Paulo city center, using different modes of transportation. The São Paulo subway network reaches 74.2 kilometers of length and is involved in around 20% of the commuting trips by public transportation, enhancing mobility and productivity of workers. This paper uses an integrated framework to assess the wider economic impacts of the existing underground metro infrastructure. We consider links between mobility, accessibility and labor productivity in the context of a detailed metropolitan system embedded in the national economy. Simulation results from a spatial computable general equilibrium model integrated to a transportation model suggest positive economic impacts that go beyond the city limits. While 32% of the impacts accrue to the city of São Paulo, the remaining 68% benefit other municipalities in the metropolitan area (11%), in the State of São Paulo (12.0%) and in the rest of the country (45%). The estimated impact on annual Brazilian GDP is equivalent to approximately 65% of the construction cost of the whole network.

1. Introduction

In 1998 Aschauer asked the question: “Is public expenditure productive?” In the last several decades, a great deal of research has focused on the measurement of the impact of public investment including analyses that have attempted to identify the main channels through which public capital may affect growth: a direct productivity and cost effect of infrastructure, a complementarity effect on private capital, and possible crowding out effects on private investment (Agénor, 2012). In large metropolitan areas, the provision of public infrastructure (and increasingly its maintenance) has become a source of intense debate, especially in an era of declining fiscal resource and limited appetite on the part of the general public for increased taxes.

Part of the problem comes from imperfections in measurement of the productivity enhancements that are derived from public infrastructure. In many cases, only partial equilibrium estimates have been made, discounting the full, economy-wide implications of the public investment. A second issue, raised many years ago by Fogel (1964) in the context of the role of railroads in US economic growth, is the degree to which the improvements in productivity are embodied or disembodied in a specific type of public capital. In the context of the present paper, the issue is the specificity of productivity gains to a metropolitan economy that can be ascribed to the existence of the subway system compared to two counter factuals – its removal (i.e. the impact on the metropolitan economy without a subway) and an abstract model (in this case, bus rapid transit) that shares many of the same characteristics of a subway system (dedicated lines, limited stops etc.). The differences in outcomes will go some way towards documenting the degree to which productivity improvements are of a generic nature (i.e. the disembodied effects that come from any public system that moves people within a metropolitan region) as opposed to the specific benefits that are derived from a subway system (the embodied effects that are ascribed only to a subway system).

The methodology employed in the paper share some of the same conceptual characteristics as the Dietzenbacher and Los (1998) hypothetical extraction method in input-output systems where the economic impact of the removal of one or more sectors is evaluated.

Although the system-wide impacts will be estimated, the benefits of a subway system extend beyond productivity measurements. These additional dimensions would include impacts on health (environmental metrics)[1], accidents, mobility and income (in terms of equity) and household budgets (in terms of expenditures). Further, the impacts presented in this paper only include the effects on individual movements and do not account for the potentially significant effect on freight flows and costs within the metropolitan region.

In the next section, the region of focus is described, along with some pertinent characteristics about the economic structure, commuting patterns, the role of Sao Paulo's external trade and the nature and extent of public transit. Section 3 discusses the modeling strategy that is centered on a spatial general equilibrium model (SCGE); econometric estimation of some direct main changes in the transit system (e.g., the removal of the subway system) are then fed in the SCGE model to capture the system-

[1] Silva et al. (2012) analyze the benefits of the São Paulo subway in terms of the air pollution in the city, analyzing both the health outcomes and the related economic burden.

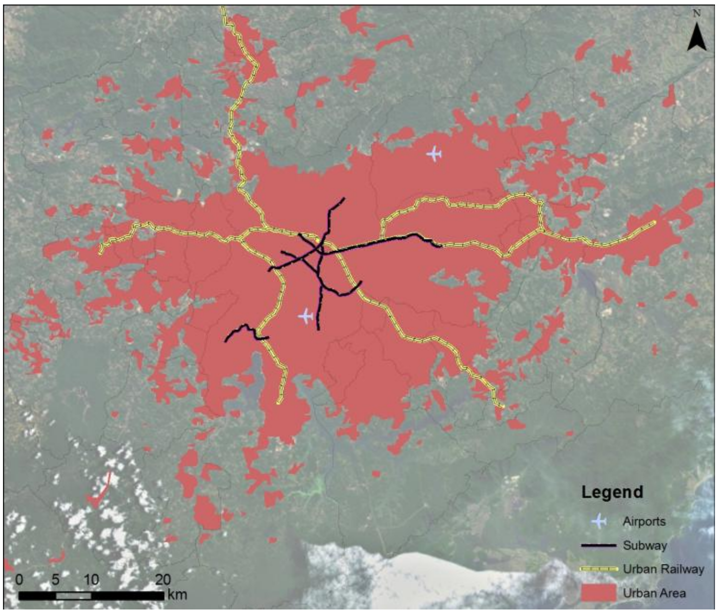
wide impacts. Thereafter, section 4 presents the empirical results from a counterfactual experiment in which the subway (underground) was assumed to have been removed. The results explore the differences in terms of workers' productivity, and in terms of value added (GRP/GDP) for the city and for other regions of the country. Section 5 discusses the SCGE simulations for the extraction scenario under a mixed short-run/long-run closure (endogenous capital stocks but fixed housing stocks and residential locations). The paper concludes with some summary remarks and the opportunities to extend the analysis.

2. The Study Region

The Sao Paulo Subway System (*Metro*) is the main rapid-transit system in the city of São Paulo and the largest in Brazil. It is also the second largest system in South America and the third largest in Latin America, behind the Mexico City Metro and the Santiago Metro. The Metro has a length of 74.3 kilometers (46.2 miles), distributed into five underground lines with 64 stations. The subway system carries 4,000,000 passengers a day – even though it is far from covering the entire urban area in the city of São Paulo –, running only within the city limits. Although with a limited territorial cover, it plays an important role in passenger mobility in the São Paulo Metropolitan Region (SPMR), as the system is interlinked with the São Paulo Metropolitan Trains Company (CPTM) and with other modal transportation terminals in the city of São Paulo (Figure 1).[2]

[2] www.metro.sp.gov.br

Figure 1. The Subway and Railway Systems



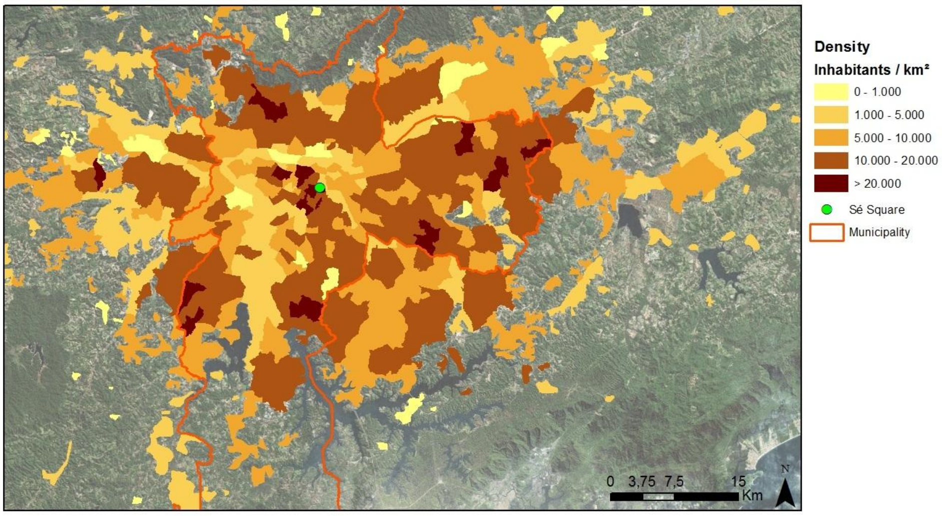
The SPMR, the main economic and financial center of Brazil, consists of 39 municipalities in an intense process of conurbation. It is the fourth largest urban agglomeration of the world, and the largest urban agglomeration in the country, with about 10% of the national population (around 20 million inhabitants), and responsible for 19% of Brazilian GDP. The city of São Paulo is the core of the metropolitan area and accounts for 5.9% of the country's population and 12% of its GDP (Table 1).

Table 1. Basic indicators

	Area (000 km^2)	*Population (000 000)*	*GDP (USD billion)*	*Per capita GDP (USD)*	*HDI 2000*
City of São Paulo	1.5	11.3	194.6	17,221	0.841
SPMR	7.9	19.7	306.5	15,558	0.813
Brazil	8,514.9	190.8	1,619.2	8,486	0.665

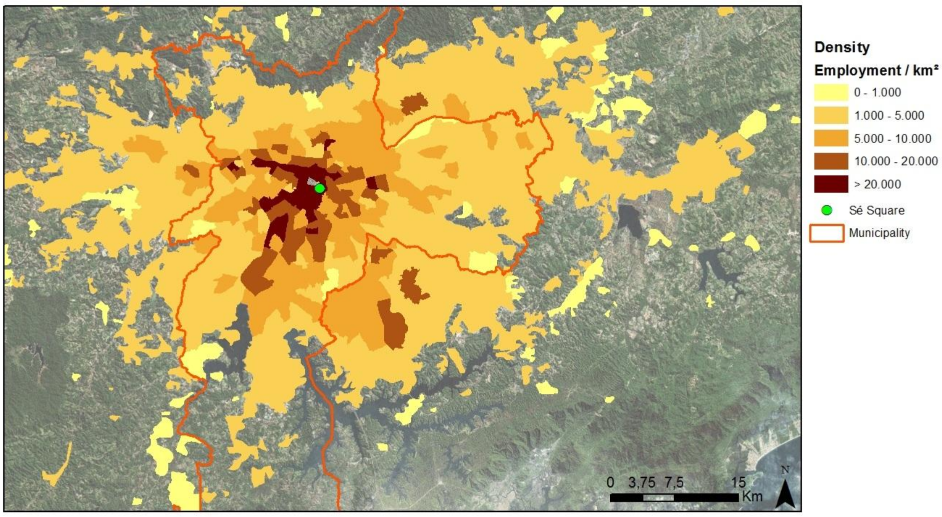
From a stylized perspective, one can notice the existence of an extended central business district (CBD) associated with the spatial configuration of economic activities in the metropolitan area. The CBD concentrates the jobs, while households are located in the surroundings of the center, with population density decay in the boundaries of the territory of the metropolis. As suggested in Figures 2 and 3, the internal organization of the SPMR can be approached by a Muth-Mills-Alonso urban model, having as the CBD the extended center of the city of Sao Paulo.

Figure 2. Population density in the SPMR



Source: Companhia do Metropolitano de São Paulo

Figure 3. Employment density in the SPMR

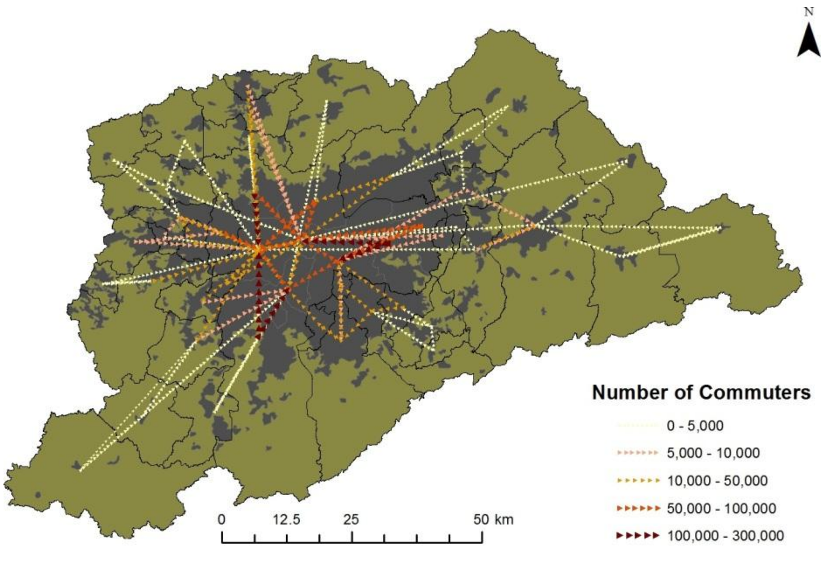


Source: Companhia do Metropolitano de São Paulo

According to the 2010 population census, the city of São Paulo received daily an inflow of almost 1 million commuters, representing 15.4% of workers in the city.[3] From the total number of commuters, 82.7% came from different municipalities within the metropolitan area. The Origin Destination (O-D) Survey for the SPMR reported, for 2007, commuting patterns based on 460 zones – aggregated into 47 regions in Figure 4 (nine administrative zones of the city of São Paulo and the remaining 38 municipalities in SPMR). The main attracting centers of commuters were the central and western zones of São Paulo, which respectively received a total of 180,000 and 300,000 commuters from other municipalities. On the other hand, the main origin municipalities of commuters were Guarulhos (138,000) and Osasco (105,000). In relative terms the municipalities of Francisco Morato and Franco da Rocha stand for having half of their workers commuting to São Paulo.

Regarding the commuting patterns within São Paulo, the peripheral zones ressemble peripheral municipalities, pouring workers to the central and western parts of the city; for example, from the one million workers residing on the southern zone, around 300,000 commuted to the western zone. In summary, the great majority of commuters' flows were from peripheral regions in São Paulo and other municipalities to the metropolitan business centers in the central and western zones of São Paulo city.

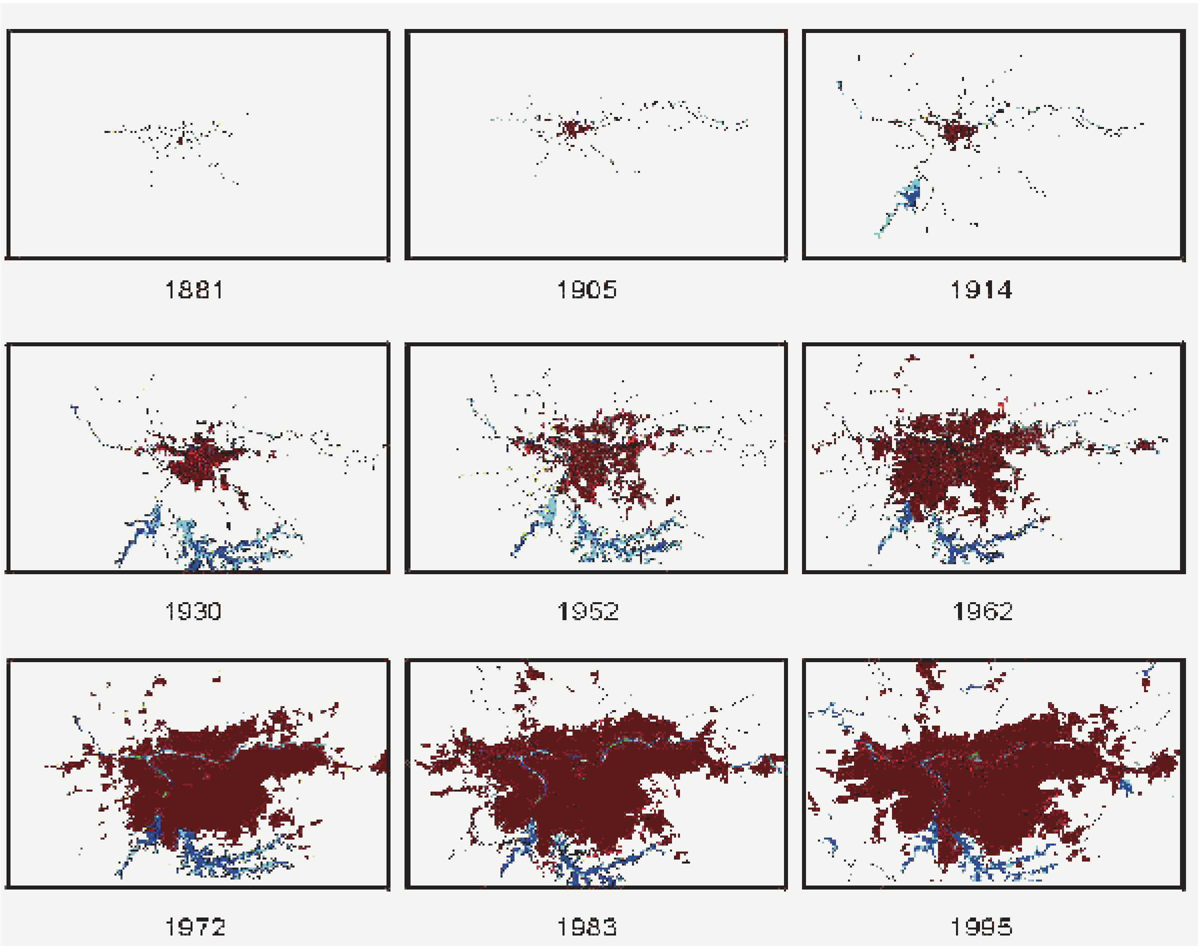
Figure 4. Main commuting flows, by origin



[3] Around 170 thousands of São Paulo residents commuted daily to other cities, especially in the SPMR.

The rapid process of urban expansion around São Paulo's CBD (Figure 5) was not followed by the implementation of adequate public transport infrastructure, causing important urban mobility problems.[4] The heavy reliance upon motorized traffic still poses a challenge for planners. While the number of private vehicles in Sao Paulo is approaching seven million, public investment has been marked by scarce expansion of public transportation alternatives – subway, train and buses (Silva et al., 2012). Moreover, the average travel time by public transportation has been increasing steadily, reaching 67 minutes in 2007 (59 minutes in 1997).[5] Similarly, average travel time by private cars rose from 27 minutes in 1997 to 31 in 2007.

Figure 5. Urban sprawl of the SPMR, 1881-1995



Source: CESAD-FAU/USP – http://www.cesadweb.fau.usp.br/

[4] See Biderman (2008) for an overview of the urban transport infrastructure in Sao Paulo.
[5] From the total trips to work in 2007, 44.6% were made by public transportation, of which 19.1% were partially or completely made by subway. As for those individuals working in São Paulo, 47.9% of trips to work were made by public transportation (25.6% of which using the subway system).

Since the early 1970s, the SPMR has undergone major structural changes, transformed from dominance by traditional manufacturing to more sophisticated services.[6] The hollowing-out process of the metropolitan area associated with the geographical de-concentration of the manufacturing sector has imposed a new structure of interregional dependence in which SPMR plays a specific role. On one hand, a typical establishment is now less dependent both on sources of inputs and on markets within the metropolitan area. On the other hand, fragmentation is now a characteristic of production with longer value chains based on the organization of production to exploit economies of scale in individual plants in specialized component production – and shipping to other plants elsewhere to add further components (Hewings and Parr, 2009; see also Jones and Kierzkowski, 2005). Table 2 reveals the structure of interregional and international trade flows with special attention to the city of São Paulo and the remaining metropolitan area. The São Paulo city is directly involved in 14.1% of all trade flows of the country, including both domestic and international trade partners. Intra-city trade corresponds to 36.6% of total trade flows of the city, while the remaining 63.4% are distributed between interregional trade (17.0% within the metropolitan area and 38.6% with other Brazilian regions) and international trade (7.8%). This important share of domestic trade outside the metropolitan area reflects the aforementioned process of hollowing-out and spatial fragmentation that started during the 1970s in Brazil, when the manufacturing sector relocate to other regions outside the SPMR (Diniz, 1994). A closer look at the structure of trade flows by sectoral products reveals the stronger dependence of São Paulo city on primary and manufactured products from outside the metropolitan boundaries and a relative self-sufficiency in services.

It is in this context that the assessment of the impacts of the existing infrastructure of the underground metro system of the city of São Paulo is to be undertaken. Even though there is a perception that, apart from the convenience to users and the benefits to the green economy, the subway system in São Paulo could produce wider effects stretching beyond regional boundaries, with positive externalities to the state and national economies, this is, to our knowledge, the first attempt to address this issue in an integrated modeling approach.

[6] The share of SPMR in the national manufacturing output dropped from over 40% in the 1970s to less than 20% in the recent years.

Table 2. Structure of trade flows in Brazil, 2008 (in % of total)

Primary (8.5% of total flows)

		Destination				
		SPC	*SPMR*	*RSP*	*RB*	*ROW*
Origin	*São Paulo City (SPC)*	0,00	0,01	0,00	0,00	0,00
	Rest of SPMR (SPMR)	0,01	0,02	0,01	0,00	0,00
	Rest of São Paulo State (RSP)	0,54	0,35	3,60	1,88	0,26
	Rest of Brazil (RB)	1,93	1,58	13,25	47,67	16,88
	Rest of the world (ROW)	0,28	0,35	3,46	7,93	0,00

Manufacturing (36.6% of total flows)

		Destination				
		SPC	*SPMR*	*RSP*	*RB*	*ROW*
Origin	*São Paulo City (SPC)*	1,81	1,03	0,82	1,46	0,55
	Rest of SPMR (SPMR)	1,77	2,14	1,00	1,65	0,89
	Rest of São Paulo State (RSP)	2,31	1,52	8,10	7,06	3,32
	Rest of Brazil (RB)	1,00	0,64	3,14	39,87	6,50
	Rest of the world (ROW)	1,28	1,06	2,36	8,74	0,00

Services (54.9% of total flows)

		Destination				
		SPC	*SPMR*	*RSP*	*RB*	*ROW*
Origin	*São Paulo City (SPC)*	8,22	1,82	2,01	3,32	0,46
	Rest of SPMR (SPMR)	0,68	3,02	0,49	0,81	0,18
	Rest of São Paulo State (RSP)	0,28	0,22	9,04	1,89	0,40
	Rest of Brazil (RB)	0,20	0,18	1,34	61,13	1,98
	Rest of the world (ROW)	0,27	0,14	0,33	1,59	0,00

Total (100.0% of total flows)

		Destination				
		SPC	*SPMR*	*RSP*	*RB*	*ROW*
Origin	*São Paulo City (SPC)*	5,17	1,38	1,41	2,36	0,45
	Rest of SPMR (SPMR)	1,02	2,44	0,64	1,05	0,42
	Rest of São Paulo State (RSP)	1,04	0,71	8,23	3,78	1,46
	Rest of Brazil (RB)	0,64	0,46	3,01	52,20	4,90
	Rest of the world (ROW)	0,64	0,49	1,34	4,75	0,00

Source: SCGE database

3. Modeling Framework

Assessing the economic contribution of a part of metropolitan region's transportation infrastructure requires some consideration of the likely paths of interactions consequent upon the hypothetical removal of the subway system. Accordingly, the process adopted here is to extract the initial causality path and to estimate the initial reactions econometrically and then to feed the results back into a spatial computable general equilibrium (SCGE) model to capture the system wide impacts. By so doing the paths of reaction can be revealed and modified where necessary; the alternative would have been to hypothesize some form of "delta" to change the accessibility matrix or commuting time without considering the behavioral relationships that would generate the changes.

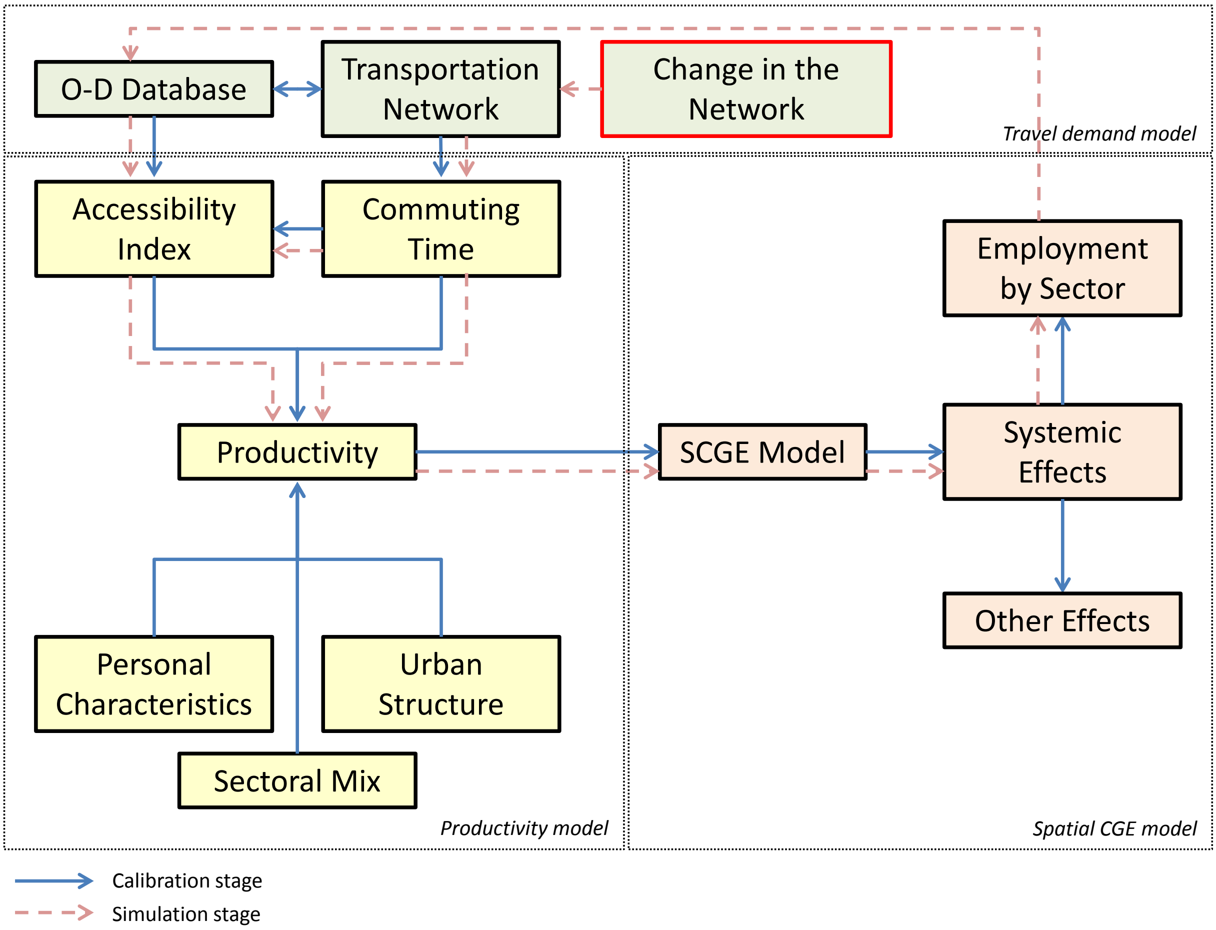
Large-scale modeling relies heavily on the integration or linkage of different sub-models. The usual process of integrating or linking models consists of endogeneizing exogenous components of one of them through components of another or many others. Integration occurs in cases when researchers are able to reconcile models in a unified system in which components are tied through hard links. In the more often instances when models are treated separately, the adopted strategy is to have a series of them linked, as the output of one is used as the input to others through soft links (Boyce, 1988; Hewings et al., 2003). The use of more straightforward soft links requires only the endogenous variables from one model to be mapped to exogenous variables of other model(s). However, there may be instances in which researchers want to generate results consistent with a given subset of variables that are endogenous to both models. This is usually accomplished by the use of more complex hard links between models. In this paper we look at this issue from a different perspective in the context of a semi-iterative approach based on several rounds of integration through soft links.

In essence the procedure for change moves along the following path (Figure 6). We depart from a travel demand model specified for the SPMR and simulated with the software *Emme 4*.[7] From the supply side, the model considers the road network and the public transport system of metro lines, suburban rail and buses; from the demand side, it uses the O-D database, which includes a large sample of households and their individual

[7] The model was implemented by the engineering company *TTC – Engenharia de Tráfego e de Transportes*, São Paulo, Brazil.

household members, as well as their travel behavior.[8] After the traffic allocation, the travel demand model provides as outputs, for each origin-destination pair of zones, the generalized cost, choosing the mode combination and path with the smallest generalized cost possible and allocating the user over this choice. Another output of interest is the commuting time matrix displaying the total time of trips made from each origin to each destination with the smallest generalized cost by both public and private transportation (weighting the walking time, the waiting time and the time spent in the vehicle(s)).

Figure 6. The integrated modeling framework



The commuting time matrix, together with the O-D database, provides the necessary information for the construction of the accessibility index, another key variable in the integrated modeling. The index measures accessibility to jobs in SPMR, and follows a

[8] Within the whole SPMR, over 91.000 individuals filled in the O-D questionnaire. They are related to 30,855 different households, living in 460 zones. The minimum number of individuals per zone is 77, the maximum 649. There is information for about almost 170,000 trips, of which 40 percent are trips to work and 28 percent trips to school.

gravitational formulation as proposed by Hansen (1959), weighting the opportunities according to the impedance to achieve them (Vieira and Haddad, 2012).[9]

The linkage variable with the SCGE model is labor productivity by origin-destination pairs. The productivity model is based on the econometric estimation of a wage equation drawn from the urban economics literature. The model is estimated from the O-D micro data. The regression analysis of the wage equation considers the earnings of each worker in the sample as the dependent variable, and a set of independent variables controlling for individual and geographical location characteristics. Commuting time and the accessibility index are the two independent variables which provide, in the calibration stage, the soft links with the travel demand model. Long commute is expected to decrease works productivity as longer commuting time may induce workers to arrive late at work, or leave earlier, and increase the number of days absent (Van Ommeren and Gutièrrez-i-Puigarnau, 2009); moreover workers experiencing longer commuting trips may also become less productive as they provide lower effort levels than those residing closer to jobs (Zenou, 2002). Agglomeration economies, captured by the accessibility index, are also expected to positively influence workers' earnings. Workers are paid more in large and denser markets because they are more productive there due to the presence of agglomeration economies (Melo and Graham, 2009).[10]

In addition to a vector of individual characteristics (years of education, age and gender), other controls in the productivity model include municipality (place of work) and sectoral dummies. While the municipality dummies attempt to capture the urban structure and the peaks and valleys of the wage surface in a multi-centric urban configuration (Fujita and Ogawa, 1982), the sectoral dummies take into account the industry-mix and differences in wages (and productivity) across sectors within the metropolitan area.

In the simulation stage, one may want to consider changes in the physical transportation network. For instance, one may want to assess the spatial economic effects of an

[9] Opportunities are defined as the number of jobs in each zone, and impedance as an inverse exponential function of travel time between each pair of zones.

[10] This approach takes a micro view from the three potential determinants of urban efficiency, the three *"S"*s in Prud'homme and Lee (1999): the size of the city; the speed at which people (and goods) are moved; and the sprawl or the relative location of jobs and homes in the city.

investment in a new subway line, expenditures in bus corridors improvement, or even the adoption of an urban toll system, all of which will have direct impacts on generalized travel costs, either by reducing travel time or by directly changing out-of-the pocket payments. The challenge becomes one of finding ways to translate such policies into changes in the labor productivity matrix[11] derived from changes in the commuting time matrix, mimicking potential reductions/increases in the travel time between two or more zones. Such a matrix serves as the basis for integrating the travel demand and the productivity models to the SCGE model in the simulation phase. While in the calibration stage it is assumed that the labor productivity matrix is a unity matrix in the benchmark year, percentage changes in its original values are calculated, so that an interface with the SCGE model is created. As in the calibration of the labor demand equations the labor productivity variables are also set to unity, the new information generated by the travel demand and productivity model can be suitably incorporated in the spatial CGE model.

Thus, changes in the physical network will generate new commuting time estimates through the travel demand model, which, in turn, will affect productivity both directly and indirectly (through changes in accessibility). With this new set of information, changes in labor productivity are generated, by zone of residence and zone of work, and further aggregated at the municipality level so that it can be used as inputs for shocking the labor productivity variables in the SCGE model.

Estimating the wider impacts at the regional and national levels

In order to estimate the total impacts of changes in the existing transport infrastructure in SPMR, a SCGE model is used. It is a model based on simultaneous optimization of the behavior of individual consumers and firms, subject to resource constraints. When extended into a multi-regional framework, the model is able to provide the spatial distribution of impacts.

The specification of the SCGE model uses as its departure point the B-MARIA model, developed by Haddad and Hewings (1997) and Haddad (1999). The B-MARIA model –

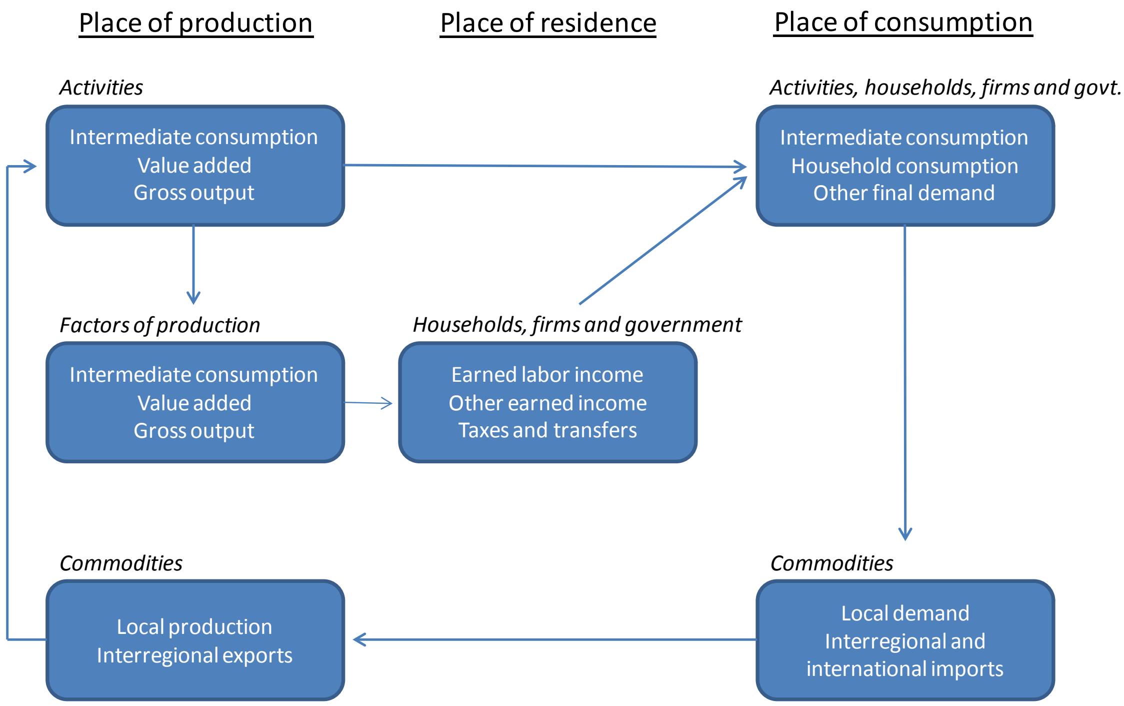
[11] The labor productivity matrix provides, for each pair of origin-destination, information on average worker productivity by place of residence and place of work.

and its extensions – has been widely used for assessing regional impacts of economic policies in Brazil. Since the publication of the reference text, various studies have been undertaken using, as their basic analytical tool, variations of the original model. The theoretical structure of the B-MARIA model is well documented. Results are based on a bottom-up approach – i.e. national results are obtained from the aggregation of regional results. The model identifies different production/investment sectors in each region producing different commodities, one representative household in each region, regional governments and one Federal government, and a single foreign area that trades with each domestic region, through a network of ports of exit and ports of entry. Three local primary factors are used in the production process, according to regional endowments (land, capital and labor).

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 have also introduced the possibility of (external) non-constant returns in the production process, following Haddad and Hewings (2005). This extension is essential to adequately represent one of the functioning mechanisms of a spatial economy. The model used here is structurally calibrated for 2008. The calibration of the SCGE model is based on a fully specified interregional input-output system considering 41 regions, 56 sectors and 110 products.[12] It is a database at the municipal level for the year 2008 which focuses on the SPMR, that is, it covers the 39 municipalities that compose the metropolitan area, the rest of the state of São Paulo and the rest of Brazil. Furthermore, it maps the inter-industrial relations by place of production; the payments to labor factor by place of residence; and the consumption structure by place of consumption (Figure 7).[13]

[12] Due to computational constraints, we have used an aggregated version with 8 sectors and 8 products.
[13] These different spatial dimensions follow the tradition found in metropolitan input-output models (Hewings et al., 2001; Jun, 2004).

Figure 7. Input-output relations embedded in the spatial CGE model



The first run of the SCGE model uses as inputs the productivity changes computed from the information on the after-shock commuting time matrix and the non-behavioral micro-simulation based on the econometrically estimated parameters for commuting time and accessibility variables, given the original O-D database. The systemic effects are calculated and changes in sectoral employment in the SPMR regions comprise a subset of the SCGE results. This information is then introduced into the O-D original database, generating changes in the accessibility measure[14], which, on its turn, produces further changes in the productivity matrix. A second run of the SCGE takes place, and this iterative process continues until convergence of the results is reached.

4. Computation of Productivity Shocks

What if the underground did not exist? What would be the difference in terms of workers' productivity? And in terms of value added (GRP/GDP) for the city and for other regions of the country? To address these questions, we follow the simulation

[14] Residential location is assumed unchanged.

strategy discussed in the previous section. In what follows, we first describe the main transmission channels through the modeling chain, from the computation of the productivity shocks to the economy-wide impacts.

The first step is to run the travel demand model removing the subway network. As the metro facilitates the movement of people from different parts of the urban area, it is expected that we observe an increase in commuting time for various pairs of origin-destination. The intensity of the changes will be dependent upon the weight trips to work using the subway have in the composition of total trips to work by residents in a given location (zone). Figure 8 depicts the percentage changes in commuting time computed for each of the 460 zones in the O-D database.

Once the output of the travel demand model is generated, the productivity shocks can be computed through the use of non-behavioral micro-simulation (MS) techniques which combine the O-D sample survey data with SAM data to yield predicted labor productivity changes for all workers covered by the macro SCGE model. After the productivity model is estimated using the variables which are available in the O-D survey, the parameters estimates from the regression (using the full household survey) are used to predict productivity changes in the labor groups in the SCGE database. For each worker in the survey, the parameter estimates from the applicable regression (Table 3) are combined in order to obtain an imputed value for individual wages. This information is aggregated according to the SCGE groups (conditional on geographical location) providing the counterfactual (estimated labor income in an economy without the subway system) to be compared with the benchmark ("observed" labor income). Figures 9 and 10 highlight the changes in labor productivity considering, respectively, the direct contribution of changes in commuting time and their indirect contribution through changes in accessibility. It shows the results for groups of workers by place of residence and place of work. While the direct effect of commuting time on labor productivity reveals a fairly concentric pattern in which productivity of commuters from peripheral municipalities that work in São Paulo is more affected, the indirect effect on agglomeration economies seems to be dominant not only in terms of magnitude but also in terms of territorial scope. The overall labor productivity changes in the metropolitan economy, by place (municipality) of work (production), are presented in Figure 11, showing those municipalities that perceive greater impacts.

Table 3. Estimated Parameters of the Productivity Model used in the MS

Dependent variable = WAGE

Variables	*Coefficients*
TIME	***-0.02714***
ACCESS	***0.23321***
C	5.77565
GENDER	-0.25140
IND	0.07823
SERV	0.02660
EDUC2	0.10212
EDUC3	0.24925
EDUC4	0.49347
EDUC5	1.13517
AGE	0.03880
AGESQ	-0.00029
PLACE OF WORK DUMMIES	YES

WAGE = wage (log); TIME = commuting time (log); ACCESS = accessibility index – public transportation (log); GENDER = dummy variable – female =1; IND = dummy variable for sectoral of activity – manufacturing = 1; SERV = dummy variable for sectoral of activity – service = 1; EDUC2 = dummy variable for schooling – elementary; EDUC3 = dummy variable for schooling – middle school; EDUC4 = dummy variable for schooling – high school; EDUC5 = dummy variable for schooling – college; AGE = age;AGESQ = square of age. All variables are statistically significant at 5%. R^2 = 0.42688

Figure 8. Changes in commuting time

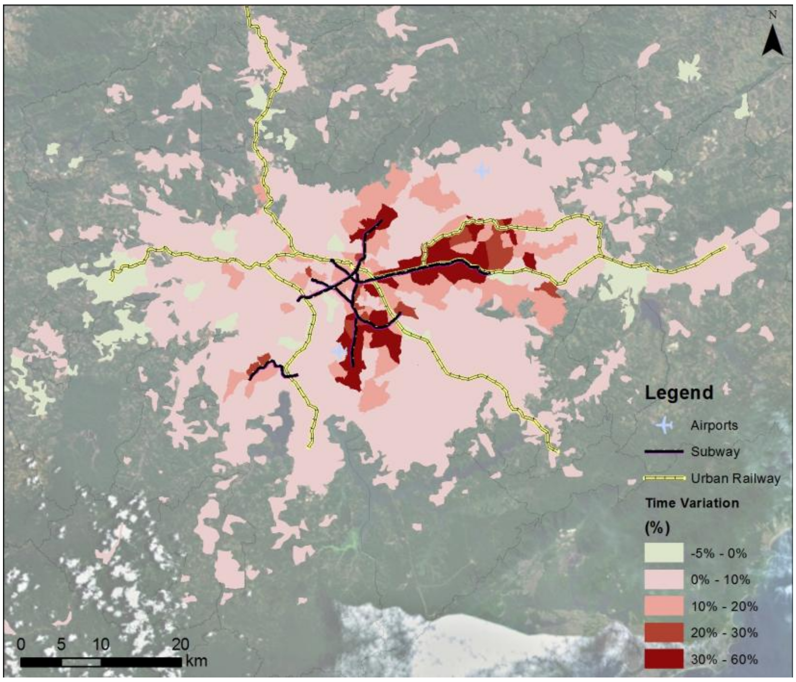


Figure 9. Changes in labor productivity due to changes in commuting time (by place of residence and place of work)

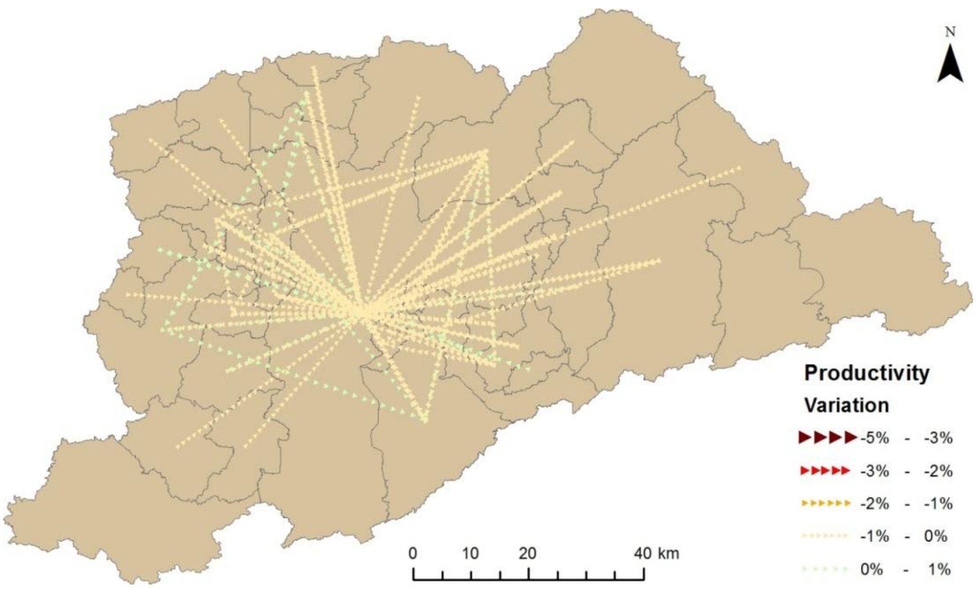


Figure 10. Changes in labor productivity due to changes in accessibility (by place of residence and place of work)

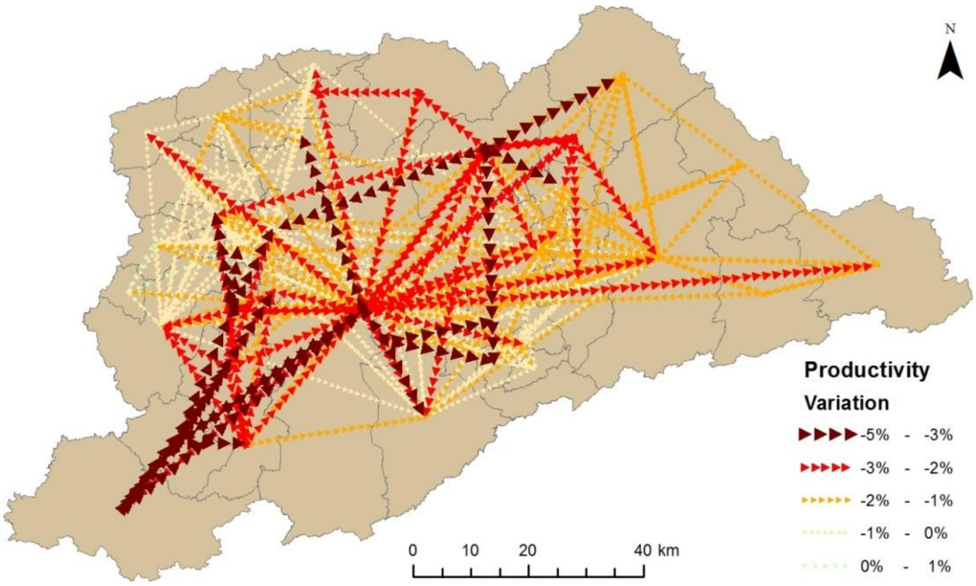
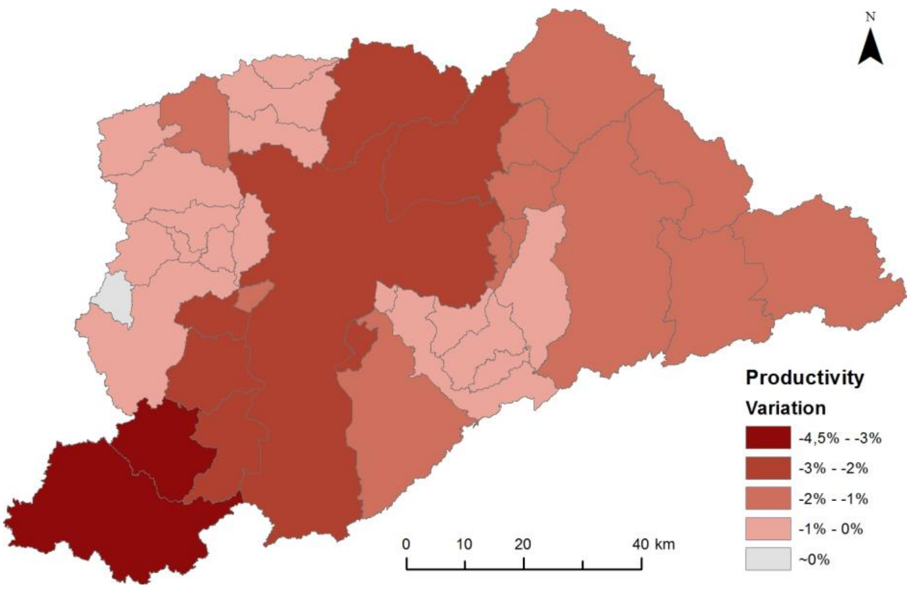


Figure 11. Overall changes in labor productivity (by place of work)



5. The Economy-wide Impacts of the São Paulo Subway System

Results of the SCGE simulations for the extraction scenario were computed via a 1-2-4 Euler procedure with extrapolation, under a mixed short-run/long-run closure (endogenous capital stocks but fixed housing stocks and residential locations). Figure 12 presents the main causal relationships underlying the results. The simulation exercise departs from the estimates of reductions in labor productivity of workers that rely, directly or indirectly, on the subway system for daily commuting, discussed above. According to the model structure, this represents, on one hand, increases in the prices of composite commodities, with negative implications for real regional income: in this cost-competitiveness approach, firms become less competitive – as production costs go up (inputs are more costly); investors foresee potential lower returns – as the cost of producing capital also increases; and households decrease their real income, envisaging lower consumption possibilities. Lower real income generates lower domestic demand, while a decrease in the competitiveness of national and regional products discourages external demand. This creates room for decreasing firms' output – destined for both domestic and international markets – which requires less inputs and primary factors. Decreasing demand puts pressure on the factor markets for price decreases, with a concomitant expectation that the prices of domestic goods would decrease.

On the other hand, the reduction in labor productivity is also associated with an increase in the labor requirement per unit of output in those sectors that employ workers that are affected by the changes in commuting time. As production becomes more labor-intensive, *ceteris paribus*, demand for labor increases generating excess demand of labor in the economic system. This creates an upward pressure on wages as well as on capital rentals due to imperfect substitutability between the primary factors, which are passed on in the form of higher prices.

Second-order prices changes go in both directions – decrease and increase. The net effect is determined by the relative strength of the countervailing forces. Figure 12 summarizes the transmission mechanisms associated with major first-order and second-order effects in the adjustment process underlying the model's aggregate results.

Figure 12. Causal relations underlying the system of equations of the SCGE model

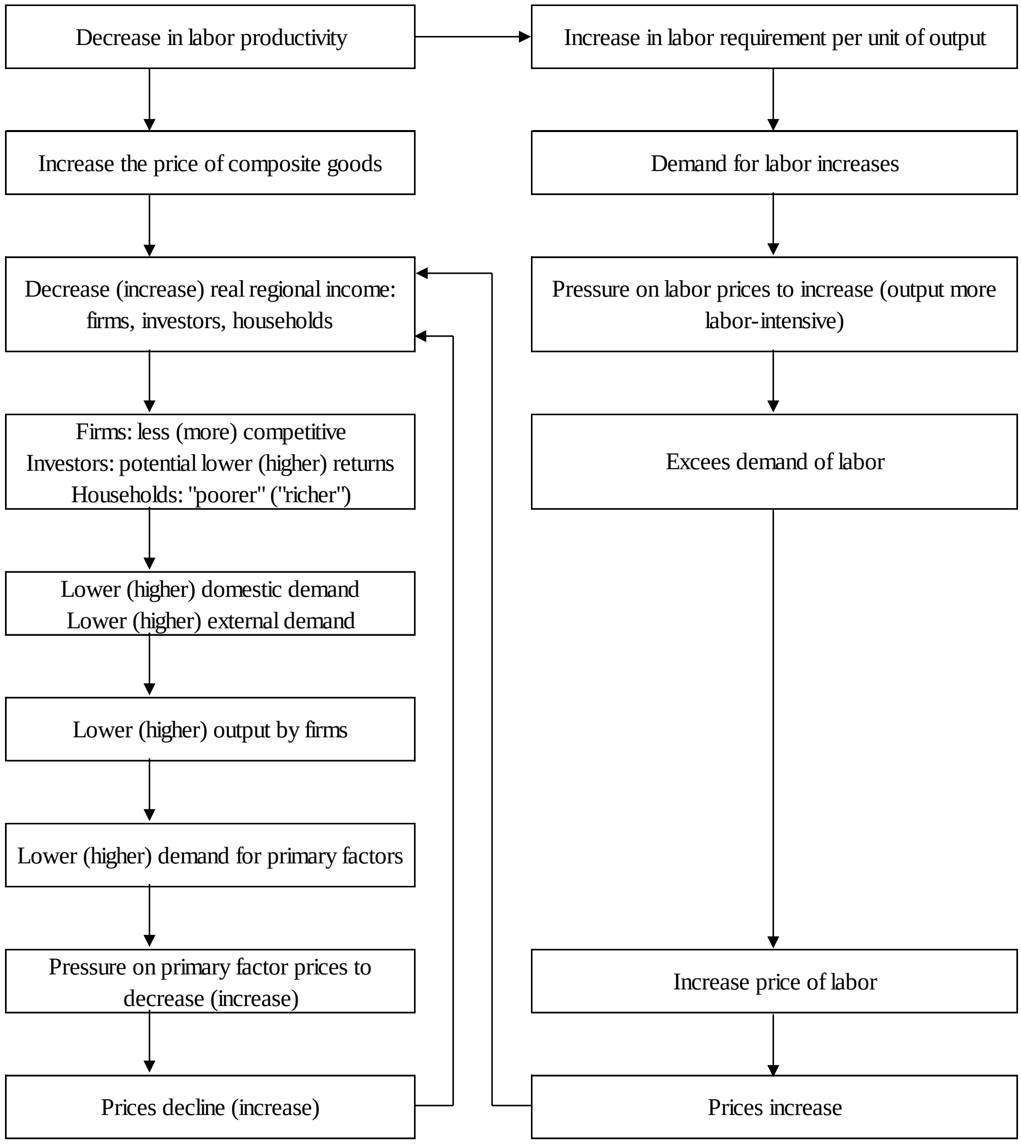


Table 4 shows the results for the macroeconomic effects of the removal of the subway system (extraction) generated by the SCGE simulation. An additional "control" simulation (BRT) was carried in order to assess the specific benefits that are derived from a subway system (embodied effects)[15] as opposed to the disembodied effects associated with its very existence.[16] It can be seen that it is expected the subway system

[15] In Tables 4 and 5, the disembodied effects of the subway system are presented in the "extraction" column, while the embodied effects in the "difference" column.

[16] In the BRT simulation, in which the rail network is hypothetically replaced by a BRT system, operational characteristics of the network were changed in the travel demand model. More specifically, the speed decreased, on average, from 32 km/h to 21 km/h (the observed speed in some of the existing bus corridors in SPMR), and the interval between vehicles increased from 2 min to 4 min.

to contribute to the São Paulo city GRP by 1.713% and the national GDP by 0.634%. Despite the localized occurrence of the network within the city limits, it generates output growth beyond its territory. It also contributes to an increase in welfare of city residents (higher real household consumption), an increase in tax revenue[17], and an increase in the city's domestic and international competitiveness, as verified by the worsening of the interregional and international balances of trade after its removal. The national effects go in the same direction, with higher welfare and government expenditures, and an increase in the country's competitiveness in international markets.

From a spatial perspective, Figure 13 presents the (disembodied) impacts on municipalities in the SPMR. Noteworthy is that the economic effects are not only local – they spread across the space through production and income linkages. We see that the effects of the subway system are estimated to vary considerably across municipalities in the SPMR. As expected, the largest effects – besides that on São Paulo City – are projected to occur in municipalities with stronger production and income coefficients linked to the capital city.

When an alternative mode of transportation is considered, the macro embodied effects of the subway system go in the same direction, and their magnitudes, although diminished, are still very relevant. In money values, the total value added impact on the Brazilian economy is estimated to be BRL 19,325 million (extraction simulation), for a direct productivity effect of BRL million 4,196.5, so that the associated economy-wide impact multiplier is 4.6.[18] Considering only the intra-city impact, the multiplier is equivalent to 1.8 (Table 5). Given the existing spatial fragmentation observed in Brazil, and the structure of spatial dependence observed in the data (Table 2), the hierarchy of impacts shows the rest of Brazil as the second most affected region, with potential GRP losses similar in magnitude to those projected for the whole metropolitan region. The rest of the State of São Paulo, benefitted by the recent process of hollowing-out of the SPMR, presents potential GRP impacts similar to the totality of the other municipalities

[17] Our assumption regarding the adjustment in the real government expenditure considers constant marginal real budget deficits for both the regional and federal governments.

[18] According to different estimates for capital costs per route-kilometer in urban rail (Flyvbjerg et al., 2008), construction costs can rise to USD 200 million per kilometer for an underground railway in a difficult urban terrain with troublesome geology, and high costs for land acquisition and clearance for stations, relocation and compensation for existing businesses and residences, etc.. This figure seems to be appropriate for the case of São Paulo, as official estimates, usually underestimated, are in the vicinity of USD 150 million per kilometer.

in the SPMR. Roughly, the GDP impact in the extraction scenario is spatially distributed as follows: São Paulo City with a share of 32% in total disembodied effect; the rest of SPMR with 11%; the rest of São Paulo State with 12%, and the remaining 45% accruing to the rest of the country.

Figure 13. GRP gains in the RMSP municipalities (Extraction)

In % of 2008 GRP *In BRL 2008*

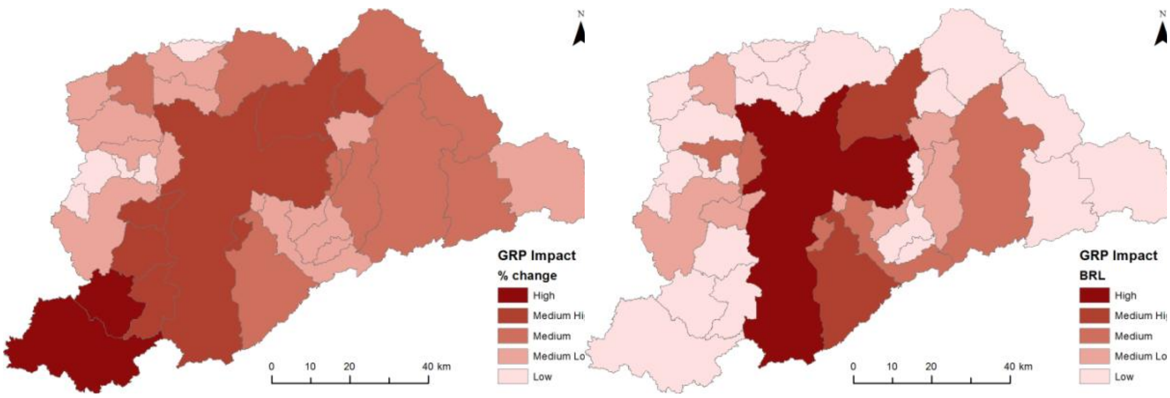


Table 4. Macroeconomic impacts of the subway system (in percentage change)

	Simulation		*Difference*
	Extraction	*BRT*	
City of São Paulo			
Real GRP	-1.713	-1.074	-0.638
Real household consumption	-1.663	-0.982	-0.680
Real government consumption - Regional	-1.854	-1.128	-0.726
Real government consumption - Federal	-0.520	-0.344	-0.176
Real investment	-0.338	-0.223	-0.115
Interregional export volume	-1.181	-0.766	-0.415
Interregioanal import volume	-0.771	-0.488	-0.284
International export volume	-2.716	-1.746	-0.970
International import volume	0.194	0.165	0.029
Brazil			
Real GDP	-0.634	-0.424	-0.211
Real household consumption	-0.458	-0.303	-0.155
Real investment	-0.232	-0.157	-0.074
Real government consumption - Regional	-0.599	-0.394	-0.205
Real government consumption - Federal	-0.520	-0.344	-0.176
International export volume	-1.089	-0.736	-0.353
International import volume	0.244	0.165	0.078

Table 5. Direct and total GRP/GDP impact (in BRL million)

	Simulation		*Difference*
	Extraction	*BRT*	
Direct (place of work)			
São Paulo City (SPC)	3358.0	1954.2	1403.8
Rest of SPMR (SPMR)	838.5	633.2	205.3
Total			
São Paulo City (SPC)	6154.7	3860.1	2294.6
Rest of SPMR (SPMR)	2172.0	1663.4	508.6
Rest of São Paulo State (RSP)	2296.8	1546.2	750.5
Rest of Brazil (RB)	8701.8	5836.0	2865.8
Brazil	19325.3	12905.7	6419.6
Intra-city multiplier	***1.8***	***2.0***	***1.6***
Economy-wide mutliplier	***4.6***	***5.0***	***4.0***

6. Final Remarks

The value of public investments, such as roads, sewer systems, educational facilities and public transit are often underappreciated by society as a whole. Individuals are much more aware of the negative effects such as when roads are flooded or public transit does not operate effectively, but they rarely have an appreciation for the quantitative and qualitative contribution that these investments make to enhancing the quality of life in large, complex metropolitan economies like São Paulo. While traffic congestion and delays in São Paulo imply significant cost burden that is shouldered by individuals and businesses alike, one only has to spend time in a city like Jakarta, Indonesia to gain an impression of the order of magnitude deterioration that would have occurred in São Paulo in the absence of the subway.

In terms of potential extensions, there are many that could be explored; one option would be to carefully consider the role of trip chaining and modal choice within the metropolitan region. Absent some options (such as the subway or bus rapid transit), would individuals choose different route choices as well as consider alternative bundling of trip purposes? How flexible is the housing market in responding to changes in accessibility? In addition, the analysis conducted here has focused on individual choices; consideration would also need to be made of the impacts of changes in public transit provision on freight movement within the metropolitan region and the movement of freight that originates outside the region and transects the region or is destined for example for the port of Santos. The public transit system is clearly reducing the number of private vehicles and thus enhancing the highway capacity; freight costs, in the absence of a major component of the transit system (the subway) would significantly increase intra-metropolitan freight transfer costs – reducing efficiency, increasing delays, requiring additions to fleet sizes to accommodate demands and so forth. Finally, there are the environmental costs that would also need to be considered; these costs could turn out to be some of the more important ones in terms of quality of life.

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Annex. The Regional Setting