Road Access and the Spatial Pattern of Long-term Local Development in Brazil

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Abstract

This paper studies the impact of the rapid expansion of the Brazilian road network, which occurred during the 1960s to the 2000s, on the growth and spatial allocation of population and economic activity across the country's municipalities. It addresses the problem of endogeneity in infrastructure supply and location by using an original empirical strategy, based on a "historical natural experiment" constituted by the creation of the new federal capital city Brasília in 1960. The results reveal a dual pattern of development, with improved transport connections increasing concentration of economic activity and population around the main centers in the South of the country, while spurring the emergence of secondary economic centres in the less dense North. The spatial impacts on GDP and population roughly balance, meaning that the effects on GDP per capita are minimal.

JEL classification: O18, N76, N96, R40, R11, R12, F15

Keywords: Transport costs, Infrastructure, Roads, Brazil

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1 Introduction

Large scale investment programs in road infrastructure are often hailed as an important element of long-term development strategies, as there is growing evidence that they reduce trade costs, connect remote locations to markets, boost productivity by facilitating access to cheaper inputs and reduce inventory costs among others. However, they also have important geographic redistribution effects, favoring some locations and regions at the expense of others. To date the empirical knowledge on the long-term impact of investments in transportation corridors on the spatial distribution of economic activities in developing countries is still limited.

This paper studies the impact of the rapid expansion of the Brazilian road network, which occurred from the 1960s to the 2000s, on the growth and spatial allocation of population and economic activity across the country's municipalities. It does so by exploiting successive census data between 1970 and 2000, aggregated at the municipality level, together with a composite measure of the cost of access from each individual location to both the State capital and São Paulo in each decade from the late 1960s to the 1990s.

The inherent difficulty to this type of study is the potential non random placement of roads, which are likely to be allocated to specific locations according to observed or unobserved characteristics that are not orthogonal to their development potential. Indeed, roads might be built to serve in priority growing locations or those with suitable geographic characteristics, in which case their estimated impact would be upwardly biased. Alternatively, policymakers may want to cater to the needs of lagging regions, with opposite effects. Finally, examples of infrastructure works allocated for political reasons rather than economic rationales abound,[1] again potentially biasing estimates towards zero.

We address this problem by using an original empirical strategy, based on a "historical natural experiment" constituted by the creation of the Nation federal capital city Brasília in 1960. Brasília was built from scratch between 1956 and 1960, in a previously unpopulated area, selected because of its geographic centrality. In following decades, an important part of the road construction program

[1] See for example Cadot, Röller and Stephan (2006).

was geared towards connecting the new city to other main population and economic centers. The resulting radial highway system also incidentally connected other inland municipalities along the way. However, whether these urban centers were close or farther away from the corridors was mostly due to luck rather than to their specific economic or geographic characteristics. Municipalities closer to the roads built after the creation of Brasília subsequently benefited from larger improvements in their road access to major economic centers.

We exploit this by superimposing onto a map of Brazil straight lines, which connect the country's capital to 13 State capitals and ports chosen according to their population size and economic importance in 1956, the year of the decision to build Brasília. We then create buffer zones at 10km intervals around these lines, to measure the percentage of each municipality lying within each successive range, and construct a municipality-level distance index capturing proximity to the lines.

Because we are interested in the dynamic effect of the improvement in the local costs of access over the next 3 decades, we interact this index with several time-varying State-level measures, capturing 5-years average of total state public spending, as well as measures of the stocks of both federal and municipal roads within each state. Using these variables as instruments for the cost of access measures provides us with a first stage that captures, within each state, the share of the improvement in cost of access due to new investments and additions to the stock of roads, which can be ascribed to each district according to its distance to the closest exogenous straight line.

This instrumental strategy is then used to assess the impact of improvements in the cost of access on local-level changes in population and GDP, as well as GDP per capita. In a nutshell, the results support a story of a dual geographical pattern. In the more developed Southern part of Brazil, improvements in travel costs implied a growing concentration of population and economic activity in large circles of up to several hundreds kilometers around the main urban areas. Looking in detail at the population movements, it appears that where the effects of reduction in travel costs were positive, there were concomitant reductions in local urban and female shares, possibly suggesting an intensification of commuting patterns of mostly male migrants between secondary towns and the main cities. In terms of production, these areas went through an increase in the share of tertiary service activities and a reduction in that of their industrial counterparts. In turn, Northern State capitals underwent the opposite process, with reductions in travel cost spurring concentration of population and economic activity away from the main urban centers, therefore generating the emergence of numerous secondary urban centers. Finally, the spatial impacts on GDP and population roughly balance, meaning that the net effect on GDP per capita appear mostly insignificant.

This paper adds to a recent strand of literature that tackles the issue of transportation infrastructure impact using spatially disaggregated data. First it is related to contributions that have found evidence of specific positive impacts of infrastructure access on a number of development outcomes, such as trade (Donaldson, 2010; Michaels, 2008), firms' growth and efficiency (Datta, 2012; Ghani, Goswami and Kerr, 2013), urban growth (Duranton and Turner, 2011), population (Atack et al., 2009), and income levels (Storeygard, 2012, Banerjee, Duflo and Qian, 2012). We share with this last paper (as well as Donaldson and Hornbeck, 2012) the use of straight lines based on historical preconditions to provide an exogenous measure of access to modern transportation corridors. However, the quality of the Brazilian data allows us to innovate by using the measures of distance to the lines to instrument the actual time-varying cost of access variables, which capture both the distance and the quality of connections to the country's main economic centers.

Our work also relates to a growing body of applied work that analyzes the impact of transportation investment on the changes in location patterns of agents and economic activity by integrating insights from economic geography models (Lall et al.,2004 and 2009; Roberts et al., 2012; Baum-Snow, 2007; Baum-Snow et al., 2012; Faber, 2012).Finally, our paper relates to the literature that uses Brazil as a testing ground for the link between improvements in different types of infrastructure and economic outcomes, including Lipscomb, Mobarak and Barham (2013) on electricity, and Chein and Assuncio (2009) on roads, migration and labor markets.

We add to these two strands of literature by being able to provide a unprecedented view into the long-run transformation of a large emerging country through the analysis of a longer period (30 years) than studied before, and by looking at the within-municipalities effects of improvements in access over time. We also provide a detailed look into the channels of these changes by analyzing the impact on urban/rural and female/male population shares, as well as local GDP data broken down by sectors.

Our analysis highlights the long term center-periphery agglomeration effects determining population movements and GDP growth across the whole Brazilian territory, over a period in which the world's fifth largest country went from being a low income to an upper middle income country. Our findings are important because they illustrate the conditions shaping varying geographical concentration effects, resulting in very different long-term development patterns and policy implications.

The paper is structured as follows. Section 2 details the state of Brazilian infrastructure since the 1960s and the relevant institutional facts. Section 3 presents the data and the empirical strategy, discussing the validity of the instrumental approach. Section 4 presents and discusses the results, Section 5 goes through a number of robustness tests and extensions, and Section 6 concludes.

2 Brazilian Infrastructure

As of 2008, Brazil had just over 1.7 million kilometers of roads, around 10 kilometers per thousand habitants, of which only 12% were paved and close to one third concentrated in the Southeast Region. The road sector, especially the highway system, has been the primary internal mode of transport for both freight and passengers in Brazil throughout the period. According to computation by Castro (2004), as of 1999 truck transport by road represented an overwhelming 82.1% of domestic freight output, and 93.6% of related expenses. Over 60% of cargo was transported by road in 2011.[2]

Between 1952, which corresponds to the earliest available aggregate paved road data, and 2000, there was a 471% increase in total road length. In the same period, GDP grew by 883%. This development of the road network was accompanied by a surge in the number of vehicles available, which went from around 6 vehicles per thousand habitants in 1945, to 37 in 1970, then more than doubled to 84 in the 1970-1980 decade, reaching 135 in 2000 and 219 in 2011.[3]

While in the 1950s, most new connections were between State capitals along the Atlantic coast, from the 1960s, new penetration corridors started linking the hinterland main urban centers, e.g., connecting Brasília to São Paulo, Belo Horizonte or Belém.[4]

[2]See http://www.brasil.gov.br/sobre/tourism/infrastructure/roads, Revista CNT no.206 novembro 2012

[3]Mitchell (1995), Ipea data.

[4]This part draws mostly on Castro (2004) and World Bank (2008).

Concomitantly, there was a rapid expansion of the agricultural frontier towards the center-west part of the country, and an increase in the output share of the three less developed macroregions (North, Northeast and Center-west), which went from 17.3% in 1975 to 24% in 1996.

Brazil is South America's first, and the world's fifth largest country, both by geographical area (over 8.5 million km^2) and by population (close to 200 million). This geographical dispersion leads us to believe that for municipalities in regions distant from the country's economic core (the States of Minas Gerais, São Paulo and Rio de Janeiro), access to the local State capital may be more important than access to São Paulo, which in many cases would be several thousands of kilometers away. However, it also remains a quite centralized country. The Southeast region represents around 60% of overall GDP, and as of the early 2000s the port of Santos, in the State of São Paulo, accounted for 38% of all import and export activity going through Brazilian ports, serving 13 States almost exclusively and part of the commerce of all 27 States, and moving close to 6.5% of the country's GDP (World Bank, 2008). This justifies that the cost of access to São Paulo may be relevant even for municipalities in remote Northern locations. In each case, we will therefore report results for both cost of access variables, i.e., to São Paulo as well as to the local State capital, as well as the results broken down between South (South, Southeast) and North Brazil (North, Northeast and Center-west).

3 Data and Empirical Strategy

3.1 Census Data

Brazil is divided into 5 regions, containing 26 states and the federal district of Brasília, which in turn contain (in 2010) 5,564 municipalities. Our analysis focuses on the impacts of road access at the municipality level, the smallest level of government and administration within Brazil. Municipalities are based around an urban area, from which they take their name and where their government is based. If a secondary urban area grows within the municipality, the municipality often divides into two, leading to a large increase in the number of municipalities over the last 50 years. Between 1960 and 2010 the number of municipalities in Brazil has increased from 2,767 to today's 5,564.

To ensure that the geographical focus of our data is consistent over time, we therefore use Minimal Comparable Areas (MCAs), a geographical division of Brazil created by the Institute of Applied Economic Research (IPEA).[5] MCAs aggregate municipalities into the smallest possible groupings, such that the boundaries of these groups do not change over time. Our specific geographical unit used is AMC 70-00, covering 3,599 areas that allow us to compare data at any point between 1970 and 2000.

The Brazilian Institute of Geography and Statistics (IBGE) holds records from the decennial national census, which provides much of our data requirements. The censuses give detailed data on Brazil at ten-yearly intervals, between 1960 and the most recent in 2010. From this we are able to extract economic and social data at the MCA, state, and regional level. This data includes access to services, such as toilets, lighting and drinking water, population figures, and development measures including literacy rates and health indicators. The data is compiled at the MCA level by IPEA. For GDP measures, we use data provided by IBGE which has been elaborated by IPEA.

In addition, we use geographical data from IBGE's 1998 Brazilian CIM map (International map of the world at the millionth scale) which was digitized in 2003. This map provides detailed geological and geographical coverage of Brazil, as well as providing the locations of cities and smaller population centres, road infrastructure and ports. From this we were able to locate the major economic centres of 1956, and construct lines from them leading to Brasília. By imposing the geographical boundaries of our MCAs we could then construct an index to measure how close each MCA is to these lines. More detail is given in section 3.4. In addition, we constructed various indicators such as distance from the coastline, area of MCA, direct distance to the state capital, and percentage of land suitable for development (i.e, not subject to severe flooding, covered by the Amazon, etc). We used the openware software Quantum GIS [6] to analyze our spatial data. Following our regressions, data could be re-inputted into QGIS to spatially represent our results.

3.2 Road Data

The cost of access measures are provided by Brazilian Institute of Applied Economic Research (IPEA), for 1968, 1980 and 1995. These measures were calculated

[5] IPEA is a federal public Foundation linked to the secretariat of Strategic Affairs of the Presidency of the Republic of the Brazil.

[6] Quantum GIS is an official project of the Open Source Geospatial Foundation (OSGeo) and is licensed under the GNU General Public License.

by Newton de Castro (2002) for every municipality in Brazil, and estimate the cost of travel to São Paulo and the State capital separately. The measures are an estimate of the cost of access in terms of quality adjusted kilometers to travel. Castro first identified main traffic nodes across Brazil. For each of these nodes, he identified the connecting roads, and their quality, for each of the three dates concerned. The distances between each node along the connecting roads was then calculated, with unpaved roads being weighted at 1.5 times that of paved roads due to the increased time cost of travel, and waterways weighted at 10 times the cost of paved roads. From this, Castro was able to establish the shortest route between each node and the State Capital and São Paulo.

If multiple routes lay within one municipality, Castro took the average of the travel costs from these nodes as the cost of access measure. If the municipality contained no nodes, he took the travel cost from the node of the neighboring municipality, adding the expected distance from this node weighted by 2 to represent the likely poor quality of any connection.

What these measures provide us with is a detailed mapping of the costs of access to state capitals and São Paulo, and the changes over time. These costs are kilometer equivalent, and therefore give us a clear spatial understanding of what they mean in terms of actual distances.

3.3 Main Specification

Our objective is to estimate the long-term effect of improvements in road access on a number of socioeconomic outcome variables at the local (MCA) level. The basic estimating equation is of the form:

$$Y_{ist} = \alpha_0 + \alpha_1 R_{ist} + \alpha_2 R_{ist}^2 + X_{ist}'\alpha_3 + \theta_i + \theta_{st} + \varepsilon_{ist}, \quad (1)$$

where Y_{it} is the outcome of interest in MCA i, in State s, at time t, R_{ist} is a cost of access measure, X_{ist} are MCA level time-variant controls, and the $\theta's$ are MCA and State-time fixed effects. We thus allow for different trends across States.

The quadratic cost of access term is systematically included to account for potential non-linearities that are typically expected in economic geography models. This allows us to highlight potential spatial concentration effects, which could derive from changes in transport costs over time.

Note that the use of a quadratic term in the fixed effects specification (1) implicitly reintroduces some “betweeness” in our estimation. Indeed, as it is specified here, the fixed effects imply that the term R is demeaned after being squared, which implies that its interpretation is in term of "global" non-linearity, i.e., how the within effect varies between observations with different cost of access.[7]

To address the potential correlation between the independent variable of interest R_{ist} and the error term related to the non-random placement of roads ($Cov(R, \varepsilon) \neq 0$), our instrumental strategy uses the distance from the lines described above to estimate the following first stage equation:

$$R_{ist} = \beta_0 + X_{ist}\beta_1 + (Dist_{is} * Z_{st})\beta_2 + (Dist_{is}^2 * Z_{st})\beta_3 + \theta_i + \theta_{st} + \varepsilon_{ist}, \qquad (2)$$

where our instrumental variable $Dist_{is} * Z_{st}$ is defined as the product of a district distance to the straight lines, $Dist_{is}$, and a vector of State-level time-varying variables Z_{st}, which includes a 5-years average of total State spending up to year t, and measures of the number of kilometers of federal and municipal roads per squared-kilometers in the State in each period.[8]

We need excludability of the instruments, i.e., that they affect the outcome of interest only through road access, conditional on the controls, which include any MCA level time invariant aspects, state-time specific shocks, as well as a number of time-variant factors we control for explicitly. These include in particular access to electricity, water, and sewage.

Given the inclusion of district and state-year fixed effects, this implies that our first stage captures, within each state, the share of the improvement in road access resulting from State investments and the building up of federal and State roads, which can be ascribed to each district according to its distance to the closest exogenous straight line. The next subsection discusses our instrumental strategy in more details.

3.4 Instrumental strategy

We use the location of the Nation federal capital city Brasília, which was created in 1960, as a natural experiment. Brasília is located in the Central-West region of Brazil, on the Planalto Central plateau. The city was built ex nihilo between 1956 and 1960, in an unpopulated and desertic area, at the initiative of then President

[7]Alternatively, a within-group non-linearity would require demeaning R before squaring it (see McIntosh and Schlenker, 2006). It is however not relevant for us here.

[8]These are chosen to be 1968, 1980 and 1995 to match the date of the cost of access measures.

Juscelino Kubitschek. Brasília de facto replaced Rio de Janeiro, which had played the role of capital of Brazil since 1763.

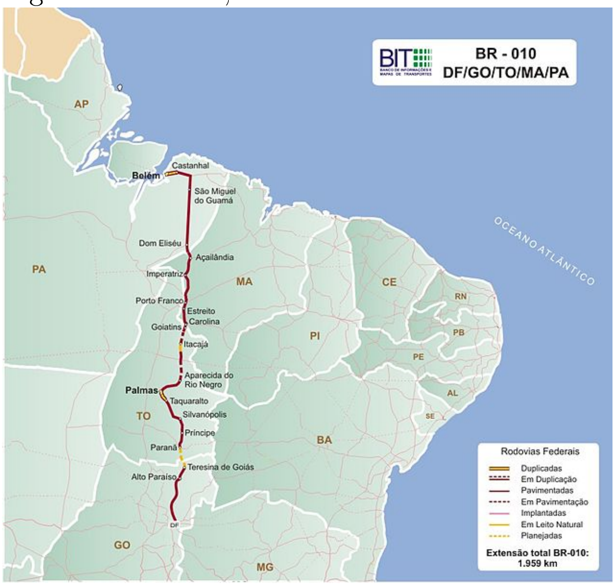
The objective, which has been traced back to José Bonifácio, advisor to Emperor Pedro I, who suggested in 1827 moving the capital away from the Southeast Region to a more central location and coined the name Brasília, was to move the political center of the country away from its economic heart, to foster neutrality and push the development of other regions of the country. It was formally written in the 1891 Constitution of the Brazilian Republic; a first location was chosen in 1894 and a first stone of Brasília laid in 1922 in a location called Planaltina, close to today's Brasília. However, it was only in 1955 that the Commission for the New Federal Capital chose the definitive location for Brasília, and it was Kubitschek's urge to see the city built, which led to its completion in three and a half years.

Since 1960, Brasília has been the seat of the three branches of the federal government, and it is also host to the headquarters of numerous Brazilian companies. Its population grew much faster than expected to reach 2,5 millions at the beginning of the 21st century, making it the fourth most populated city in Brazil.

The fact that Brasília's location was selected because of its centrality and build from scratch in a place which did not harbor any economic activity motivates our instrumental strategy. Indeed, following the inauguration of the city, it became necessary to connect it by road to other major cities. The radial highway system, composed of federal highways BR-010 to 090, was either built or radically improved after 1960.

The interesting fact is that in linking Brasília to these cities, it established corridors, which incidentally connected other urban centers along the way. For example, the BR-010, Belém-Brasília Highway, built between 1958 and 1960, was the first one to connect the Federal District and the State of Goiás, in the center of the country, to the State of Pará in the middle north region. In doing so, it also crossed the States of Tocantins and of Maranhão, connecting local urban centers, such as Palmas or Porto Franco, along the way (see Figure 1).

Figure 1: BR-010, Belém-Brasília



We capture these exogenous differences across urban centers in each States, i.e., differences related to their proximity to the corridors rather than their economic fundamentals, by computing for each MCA urban center a distance index to the closest hypothetical lines linking Brasília to a set of 13 major Brazilian cities, including the main State capitals and ports according to their population and economic importance in 1956. We start by creating successive buffer zones at 10km intervals around the lines (0-10km, 10-20km, etc.), and measure the percentage of each MCA within each zone (see Figure 2). From this, we compute the weighted sum of the shares of an MCA's area lying in each successive range (see Figure 3), and take the inverse to create an MCA-specific "Closeness to any line index", which is increasing in how close it is to any line. [9]

[9] More specifically, if 20% of an MCA was within 10km of a line, 40% between 10 and 20km and 40% between 20 and 30km, we would calculate 0.2x10 + 0.4.x20 + 0.4x30 = 22. This figure is then scaled down by 100, giving us values ranging between 0 and 10 - every MCA lies between 0 and 1000 km from a line. We then invert this, ie subtract the value from 10, to give us the closeness to the line. The value 22 is therefore reduced to 10-0.22=9.78, and is hence regarded as very close to the line. We calculated this measure taking into account the distance from all lines, and separately, the distance from the nearest line by constructing the index for all lines independently and taking the smallest value. The latter has the advantage of enabling us to determine if some lines, and hence some connections, are more important for development, by using lines-specific dummies or interactions in our estimations.The two are highly correlated at 0.97.

Figure 2: Construction of Buffer Zones

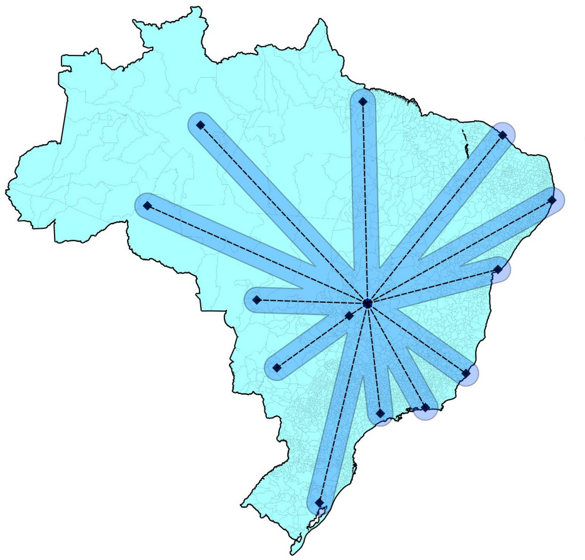
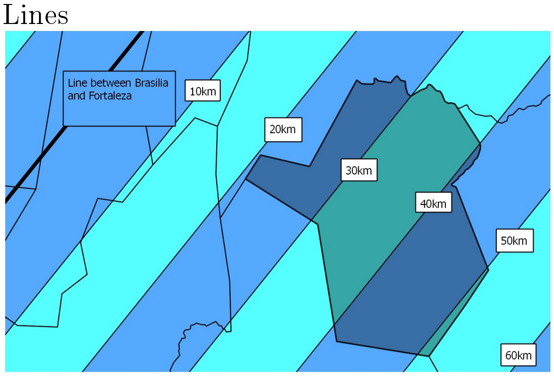


Figure 3: Construction of Distance from Lines



	Area km^2	Percentage %
0-10km	0	0
10-20km	0	0
20-30km	118	20.8
30-40km	246.1	43.4
40-50km	192.9	34.0
50-60km	0.6	1.8
Total Area	567.6	

MCA: 22 AMC7097 037

Index = (10 x 0) + (20 x 0) + (30 x .208) + (40 x .434) + (50 x .340) + (60 x .018) = 41.69 Closeness

Index = 10-41.69/100 = 5.83

We claim that Municipalities, such as Palmas or Porto Franco, which happened to be close the corridors connecting Brasília to other main cities subsequently experienced larger improvements in their road access to major economic centers, independently of their other economic or geographic characteristics, than other cities in these States located farther away from the corridors, such as Grajau.

This is clear in Figures 4 and 5, where we plot the closeness to any line index against the change in the cost of access to their State capital in both subperiods (1970-80 and 1980-2000).

Correlation between Closeness to Lines and Percentage Change in Cost of Access to State Capital

Figure 4: 1970-1980

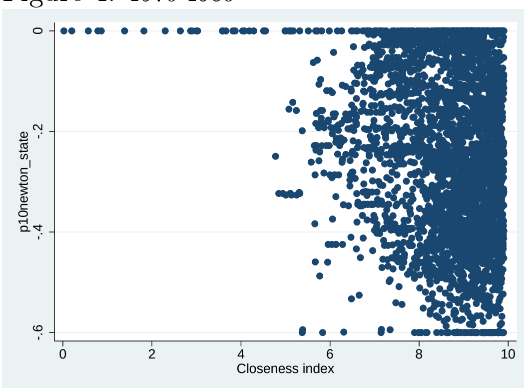
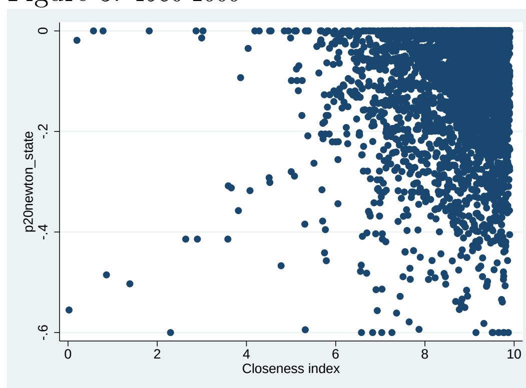


Figure 5: 1980-2000



Since our estimation strategy relies on within-municipalities changes over time, we use as instruments the interactions of the closeness index (and its square), which is time-invariant, with the State-level time-variant measures described above.

4 Results

Table A1 in the Appendix shows our first-stage output. As can be seen, our instruments strongly predict the MCA-level change in travel cost to both São Paulo and the State capital between 1970 and 2000. In the simple specification with the cost of access and its square, the F-statistic for the joint significance of the excluded instruments is 8.8 and 10.9 for the State capital and São Paulo respectively. When a Northern dummy interaction is added, the equivalent values are 16.7 and 21.5. Because we control for district and state-year fixed effects, the estimated impacts actually captures the fact that district closer to the straight lines benefited proportional more or less from a within-State change in the Z variables, i.e., State spending, and the stocks of different types of roads.[10]

For the travel cost to the State capital, the results consistently show that the effect of federal roads is positive and significant close to the lines, i.e., for all MCAs

[10] The mixed derivatives of the instruments with respect to the closeness index and the vector Z is given by $\frac{\partial Travel\ Cost}{\partial Dist \partial Z} = \beta_3 + 2\beta_4 Dist_{is}$.

with a closeness index above 8.3 an increase in Z reduces travel cost.[11] The effects are reversed and become negative for values below these thresholds. In turn, for municipal roads we find the opposite effect, with a threshold of 8.1.

The results are similar for travel cost to São Paulo, with closeness index thresholds of 7.5, and 6.8 for federal and municipal roads respectively. Additionally, State spending also has a negative impact for all locations close enough to the lines (threshold of 8.8).

The likely intuition for these results is that federal roads are built mostly to connect to the main radial highways, thus benefiting locations closer to these corridors proportionally more, while the reverse holds for municipal roads. Interestingly, State spending appears to favor locations away from the corridors relatively more.

We now look at the results concerning the impact of road development on population and output. As cost of access only decrease over time in our sample, we frame our discussion in terms of the impact of a reduction in the cost of access variable on the dependent variable of interest. Both the dependent variables and the cost of access are logged.

4.1 Population

Columns 1 to 4 in Table 1 show the results for estimating (1) on the whole sample of Brazilian MCAs, with Y_{it} equal to the log of MCA i total population at time t. Controls include the proportion of households with access to water, electricity and mains sewage, as well as district, and State-time fixed effects. The OLS outcomes in columns 1 and 2 show that the reduction in the cost of travel that occurred since the 1970s had strongly non-linear effects on local population pattern. Population increased in areas close enough to São Paulo or the State capitals, but this effect was reversed for locations which effective distance to the main centers exceeded a threshold equal to 330km for São Paulo and 250km for State capitals.[12] The 2SLS estimations in columns 3 and 4 confirm these results, although the 2SLS coefficients are between 200 and 340% larger than their OLS counterpart. This is not surprising, as our identification strategy exploits the quasi-random assignment of roads resulting from the creation of Brasília, which should indeed imply that OLS estimates are downwards biased.

[11] That is, for MCAs closer to the lines.

[12] Exp[2.3278/(2x0.2005)]=332; Exp[1.5387/(2x0.1389)]=254.

As a result, the 2SLS impact of cost reductions is stronger for locations within short effective distances from the main urban centers, and it declines faster as this distance grows. The new thresholds are now 570km for São Paulo and 235km for state capitals. In all cases, the coefficients are significant at the 1% level. These results, which are identified at the within-MCA level, mean that controlling for MCA time-invariant characteristics, those municipalities that experienced the larger improvements in their access cost also subsequently saw their population increase, up to the respective effective threshold distances.

In columns 5 and 6, we add an interaction with a dummy equal to 1 for all MCA in the Northern part of the country, which comprises 1,429 MCAs. This addresses the possibility discussed in Section 2 above that effects may differ qualitatively between these two regions. The coefficients for MCAs in the Southern region are by and large unchanged in magnitude and significance. An improvement in access to both São Paulo and the State capital generates an increase in population, up to an effective distance threshold of 430km and 360km respectively. The results for Northern MCAs, however, are dramatically altered. First, the dummy interactions are now insignificant for access to São Paulo, which is not really surprising, as the closest MCAs are more than 1200 effective kilometers away. In fact, any improvement in access to São Paulo should be explained by better access to the state capital, so this variable should capture the bulk of the effect on population movements in the North. On the other hand, the net effect of improved access to the state capital is now reversed. All locations around Northern State capital experience a population decrease, up to an effective distance of approximately 320km.[13]

Quick computations provide a feel of how marginal effects vary for two different locations with effective distance equal to 150 and 1100 km, in the two regions respectively. Take the specification using cost of travel to the State capital. In the South, for a location 150km away from its State capital a 10% reduction in the cost of access implies a 9% increase in population. In turn, a similar reduction in travel cost for a location 1100km away would imply a 11% decrease in population. Conversely, in the North, a location 150km away from its State capital would experience a 4% decrease in population as a result of a 10% reduction in the cost of access, while the same percentual reduction in travel cost for a location 1100km

[13] A F-test fails to reject joint significance of the direct effect of travel costs plus its interaction with the North dummy at the 1% level.

away would generate a 7% increase in population.[14] Given that in our sample, the cost of travel to São Paulo and the State capitals fell by 44% and 33% on average between 1968 and 1995, the implied population changes are quite substantial.

Consistently with the demographic evidence about the intense migration process towards main urban centers which took place over that period, our results also show that in the South a process concentration around the main urban centers happened through a densification of relatively large circles, of approximately 400km around these metropolitan areas. For example Martine and McGranahan (2010) document that the annual growth rate of the nine cities officially defined as 'metropolitan regions' was 4.5% between 1940 and 1970, and 3.8% between 1970 and 1980.[15] Meanwhile, in the North the improved access drained locations close to the state capitals, and a secondary concentration process occurred in locations more than 300 effective km away from the capitals.

Table 2 provides further details of this process, by looking at the changes in urban and rural shares across the country's MCAs. In column 1, the reduction of access costs to São Paulo appears to have led to an across the board decrease in the local urban shares of population in the South (the squared term is insignificant, and the threshold is well out of sample), and to the reversed process in the North (up to an effective distance of more than 1,700km). Interestingly, this therefore means that the densification in the South took place mostly through an extension of the non-urban part of intermediate municipalities, while in the North, remote places lost population but became more urban in the process. On the other hand, the impact of a reduction of access costs to the state capitals on urban-rural shares appears insignificant.

Columns 3 and 4 shows changes in female-male shares of the population as a result of reduction in travel costs. In the South, better access to São Paulo and to the State capital unambiguously reduces MCAs' female population share, while for Northern MCA, where only access to the State capital matters, better access translates into higher female shares up to 240km away from the capital. This pattern is consistent with international evidence showing that women, especially those in younger age group, move to urban center in greater numbers than men, driven by both work and marriage prospects (e.g., Edlund, 2000).

[14]Figures 6-9 in the Appendix provides a full set of illustrative marginal effects for population, GDP and GDP per capita.

[15]These are São Paulo, Rio de Janeiro, Recife, Belo Horizonte, Porto Alegre, Salvador, Fortaleza, Curitiba, and Belem.

This is consistent with a story in which the population movements were strongly mediated by the large road development program which started in the 1960s following the creation of Brasília. Clearly, migration was still predominantly directed towards the southeast, and in particular the São Paulo-Rio de Janeiro axis, and was more important in the female part of the population, but there is also evidence of a more scattered migration process towards smaller cities in the North. This helps reconciliate salient Brazilian demographic facts, and in particular the evidence that the process of "centralized urbanization", i.e., of concentration towards the country's main urban centers, was paralleled by a "localized urbanization" process. Indeed, there were 82 localities with 20,000 or more inhabitants in 1950, and 660 in 2000. Of these, the number of localities with between 20,000 and 100,000 inhabitants went from 69 to 545 over the same period.

Overall, the findings in this Section show a picture of increased population in the urban centers as a result of the development of the Brazilian radial highway system, together with an increased urbanization of many intermediate size cities across the country, and especially in the North. Moreover, they also indicate that this migration trend did still concentrate to a large extent in the South-Southeast part of the country and was especially female-driven.

4.2 Output

Table 3 shows the results from estimating (1), where the left-hand side variable is log municipal-level GDP. Columns 1 and 2 report OLS results for Brazil as a whole. The coefficients of the access to São Paulo variable imply an increase in GDP for all MCAs distant less than 675km, and a decrease after that, while reductions in the cost of access to the state capital imply a similar effect, with a threshold of 310km.

In columns 3 and 4, the 2SLS estimate of access to São Paulo appears to increase GDP for all sample locations distant less than 140km, and decrease it beyond that, while reductions of travel cost to the MCA's State capital produce the same impact in a radius of 220km. Again, 2SLS coefficients are much larger than their OLS counterparts and significant at the 1% level.

In columns 5 and 6, we introduce interactions with a North dummy. This specification increase the significance of all coefficients. The increasing-then-decreasing pattern hold for both Southern and Northern regions when it comes to access to São Paulo, with respective thresholds of 110 and 1800 km (meaning that most locations in the North are in the decreasing region of parameters), and for access to the state capital in the South, with a threshold of 385km. On the other hand, a reversed decreasing then increasing pattern hold for access to the state capital in the North, with a 440km threshold.

Similarly to the changes in population, improved road access therefore appears to have generated relative gains in GDP around metropolitan areas in the South, and relative losses around such areas in the North. A possible interpretation is that a classical home market effect was at play in the South around the São Paulo-Rio region, while in the North, improved road connections led to a concentration of activity away from the main centers itself.

Next, we investigate specific areas of production to see if they can help explain this pattern. In Table 4, we run similar estimations for the (log) GDP of agriculture, industry, and services. Overall, the results are in line with those for aggregate GDP. In the South, sector-level production increases as a result of improvement in cost of access around State capitals and São Paulo, and the effect is reversed as effective distance grows. In the North, a reversed pattern again holds around State capitals. Although all sectors appear to display similar spatial dynamics, it is possible that differences in growth rates led to changes in their relative weight, qualitatively altering the mix of local production. To inquire this, Table 5 shows a similar set of estimations where the dependent variables are now sector shares in total GDP. Insights are much less clear, with few significant results. In the South, there are indications of a relative decrease of industry (up to between 540 and 820km) compensated by an increase of services, while in the North the share of services decreases close to State capitals (the effect is reversed after 120km).

4.3 GDP per capita

Table 6 shows the results for GDP per capita. Columns 1 and 2 show again the non-linear impacts of a fall in travel costs, in an OLS regression. For areas nearest the state capital and São Paulo, as travel costs fall, GDP per capita also falls. This is consistent with the idea that these areas gain in population, as commuters move in to be near the main urban centres. However, beyond a certain point, we see, with respect to both São Paulo and the State Capitals, that GDP per capita increases with a fall in travel costs.

As we move to columns 3 and 4 and the 2SLS estimates, these results become even more pronounced for access to São Paulo. As travel costs fall, the areas nearest the city see a reduction in GDP per capita, driven by an increase in population which is larger than the increase in GDP. However, for the state capitals, the result is no longer significant. The increase in GDP and Population seen near urban areas more of less balances, ensuring that GDP per capita remains the same, when everything else is controlled for.

Similar results are found when the North dummy interaction is included. However, now although access to the state capital is insignificant in its effect, the sign is reversed for the South, suggesting improved access for the nearest located municipalities in having a positive, if small, impact on GDP per capita. In general however we cannot conclude that these impacts are important, and it appears that the population and GDP effects from improved access to the state capital cancel out across Brazil.

We observe a dual pattern; in the South both Population and GDP increase around main urban centers (the home market effect). Services increase, and industry decreases; in the North both Population and GDP decrease, and services in state capital areas decrease, suggesting the creation of secondary centers once reduced travel costs permit it. There is no real discernible effect on per capita GDP, beyond a wealth concentration effect around main centers in the South.

4.4 End Points

The result discussed above include a breakdown of Brazil according to whether a municipality is in the North or the South of the country. The data however, can be disaggregated further, and we can study which transport corridors have a greater impact on local GDP and population. In the New Economic Geography literature, the impacts of a reduction in travel costs depend on the comparison of the economic situation of the two nodes; if one is larger, more productive, or better connected than the other, we can expect to see economic activity relocating to this larger center, at the expense of the other. If they are more evenly balanced, or the end point is small and economically underdeveloped, we may see both nodes benefiting from the reduction in transport costs. This theory could potentially correspond to what we are observing in the above results.

Using a dummy for each of the transport corridors constructed, one for every city end point, we can determine whether particular characteristics of the end points determine the impact improved transport access has. Table 7 shows the regression outputs for each line, indicating only those results that are significant at 10%.

São Paulo has the largest positive pull on population; as transport costs to São Paulo fall, the municipalities along this transport corridor see an increase in population, up to a threshold of over 500 km. Similar effects are observed for Porto Alegre and Salvador, major port cities. Both São Paulo and Porto Alegre have an agglomerating influence on GDP; as transport costs to these state capitals fall, affected municipalities within approximately 800 have GDP growth as a result.

The opposite effects are seen in cities including Fortaleza, Goiania and Porto Velho. These are the poorest cities in 1970 in terms of GDP per capita, and hence are potentially exerting less of an agglomeration force; municipalities that are well connected to these cities see a fall in population, which reverses at a distance of 130km in Goiania, and over 400km for Porto Velho. This is suggestive that the agglomerating forces are weaker around less dominant cities. Improved access to these poorer cities results in secondary town formation, instead of the large agglomeration patterns observed around São Paulo.

In terms of GDP Belém and Goiania observe similar effects, in that for municipalities located near the state capitals, the effect of improved transportation is to decrease local GDP. These two cities with low GDP per capita again seem to supporting secondary city formation.

The results for Goiania are particularly large. These require further investigation, as they may in part be attributable to the fact that the transport link through Goiania would be also connecting to Campo Grande.

Following on in Table 8, here we observe the correlations between: the calculate marginal effects of improved access to the State Capital and São Paulo on population, GDP and per capita GDP; and the characteristics of transport corridor end points in 1970. A negative marginal effect means that a fall in transport costs results in an increase in the variable of question, GDP, population of GDP per capita. In these correlations, we observe that the greater the urban population and GDP of the end point at the time of road construction, the lower the marginal effect of access to the state capital and of access to Sao Paulo on population and GDP. This means that a fall in transport costs to both the State Capital and Sao Paulo leads to a greater increase in municipality population and GDP for those municipalities located on links connecting to large and rich cities. When the links connect to cities with a smaller urban population and GDP, the marginal effects are more likely to be positive, meaning that a fall in transport costs results in a fall in local population and GDP. Again, this suggests that the more powerful cities are exerting a positive impact on locations that are well-connected to them, attracting populations to these areas.

In addition, this effect seems to be related to the importance of industry in the end-point city. For cities with a large industry base, the marginal effect is more likely to be negative, and hence the population in connected municipalities will increase with a fall in transport costs; workers are relocating to the city and sub-region and generating GDP there. The opposite occurs if the city is service based. Here the population and GDP in connected municipalities would fall relative to those connected to less service-based cities.

5 Conclusions

Using a unique situation, the construction of Brasília, we have been able to exploit an exogenous impulse in constructing new highway networks within Brazil in order to extract the impact of highway networks on economic activity. Our results show striking differences across Brazil, and the richer denser South has observed different spatial patterns of economic development to the North in the decades that followed Brasília's construction.

In the South of Brazil, we are seeing strong patterns of agglomeration. Richer, denser cities are attracting workers to well connected municipalities, where there is both population and GDP growth. The combine effects on GDP per capita are however ambiguous. In the North however, the smaller cities are creating secondary city effects. Those areas that are now better connected see a fall in GDP and population if they are near to the original end point. However, when they are beyond a threshold of 320km, population increases, and beyond 440km, GDP increases.

Breaking these results down according to end point characteristics, we observe that these effects are correlated to the wealth and population of the end point. A richer end point exerts a stronger agglomeration effect.

These results help to explain how the shape of a highway network impacts economic development. The effects of a highway on local GDP and population depend not only on having improved transport access, but also on where this improved access leads to. Connecting hinterland regions could lead to an increase or decrease in population and GDP in these areas, and these changes can in part be explained by the economic characteristics of the end-points.

6 Appendices

Table A1 First Stage

VARIABLES	(1) Brazil Log State Capital Travel Cost	(2) Brazil Log Sao Paulo Travel Cost	(3) Brazil Log State Capital Travel Cost with North dummy	(4) Brazil Log Sao Paulo Travel Cost with North dummy	(5) Brazil Log State Capital Travel Cost	(6) Brazil Log Sao Paulo Travel Cost	(7) Brazil Log State Capital Travel Cost with North dummy	(8) Brazil Log Sao Paulo Travel Cost with North dummy
Closeness x km of federal paved roads/km2 in state	-0.2621	-1.1140***	-0.4640	-2.4591***	23.6747***	11.4817***	-7.1754	22.3976***
	(0.5005)	(0.3345)	(0.5542)	(0.4114)	(7.0541)	(3.7005)	(9.1481)	(7.3679)
Closeness x Ln(5 year average state total spending/area)	-0.0132***	0.0047**	0.0090**	0.0184***	-0.0228	-0.0394***	-0.0431	-0.1855***
	(0.0033)	(0.0021)	(0.0041)	(0.0029)	(0.0158)	(0.0076)	(0.0697)	(0.0482)
Closeness x km of municipal roads/km2 in state	-0.0064	-0.0269***	-0.0497***	-0.0493***	-0.6298***	-0.3498***	-0.3434	-0.0703
	(0.0143)	(0.0081)	(0.0149)	(0.0085)	(0.1994)	(0.1135)	(0.2111)	(0.1308)
Northern * Closeness x km of federal paved roads/km2 in state			-7.1430***	3.9278***			143.9158***	8.8318
			(1.6197)	(0.5384)			(19.6926)	(8.5315)
Northern * Closeness x Ln(5 year average state total spending/area)			-0.0317***	-0.0264***			0.0217	0.1658***
			(0.0062)	(0.0033)			(0.0714)	(0.0485)
Northern * Closeness x km of municipal roads/km2 in state			0.6605***	0.0926***			-6.7973***	-1.8325***
			(0.0794)	(0.0265)			(0.8623)	(0.3409)
Closeness squared x km of federal paved roads/km2 in state					-1.4278***	-0.7709***	0.3996	-1.4188***
					(0.4155)	(0.2227)	(0.5366)	(0.4356)
Closeness squared x Ln(5 year average state total spending/area)					0.0004	0.0029***	0.0029	0.0116***
					(0.0010)	(0.0005)	(0.0041)	(0.0028)
Closeness squared x km of municipal roads/km2 in state					0.0391***	0.0198***	0.0185	0.0025
					(0.0125)	(0.0071)	(0.0131)	(0.0081)
Northern * Closeness squared x km of federal paved roads/km2 in state							-8.8290***	-0.3169
							(1.1481)	(0.5019)
Northern * Closeness squared x Ln(5 year average state total spending/area)							-0.0036	-0.0108***
							(0.0042)	(0.0029)
Northern * Closeness squared x km of municipal roads/km2 in state							0.4444***	0.1086***
							(0.0519)	(0.0203)
year==1980	0.4656***	-0.0527	0.4154***	-0.0497	-0.2208	-0.4254***	0.8723***	0.5043**
	(0.1385)	(0.0534)	(0.1477)	(0.0557)	(0.1370)	(0.0575)	(0.3373)	(0.1967)
year==2000	-0.2048**	-0.5172***	-0.2214**	-0.4969***	-0.9182***	-0.8389***	-0.0301	0.0217
	(0.0877)	(0.0521)	(0.0880)	(0.0520)	(0.0988)	(0.0528)	(0.3268)	(0.1939)
Constant	7.2639***	7.3176***	6.2008***	6.9875***	7.7576***	8.8174***	9.0145***	12.0688***
	(0.2433)	(0.1499)	(0.2513)	(0.1462)	(0.5494)	(0.2580)	(1.5093)	(1.0329)
Observations	10,633	10,645	10,633	10,645	10,633	10,645	10,633	10,645
R^2	0.7824	0.9544	0.7853	0.9551	0.7834	0.9549	0.7887	0.9554
Number of _ID	3,585	3,589	3,585	3,589	3,585	3,589	3,585	3,589
F Test all instruments significant	11.28	8.642	16.67	21.46	8.832	10.86	16.01	13.51
All prob>F	2.30e-07	1.03e-05	0	0	1.39e-09	0	0	0
F Test1 fed inst+north*fed inst significant			26.08	18.33			61.33	49.71
Test1 prob>F			3.45e-07	1.90e-05			0	0
F Test2 state inst+north*state inst significant			21.25	19.53			1.409	8.652
Test 2 prob>F			4.16e-06	1.02e-05			0.235	0.00329
F Test3 mun inst+north*mun inst significant			11.10	33.61			2.646	0.289
Test 2 prob>F			0.000874	7.30e-09			0.104	0.591
F Test4 fed inst2+north*fed inst2 significant							68.83	45.90
Test4 prob>F							0	0
F Test5 state inst2+north*state inst2 significant							0.290	2.875
Test 5 prob>F							0.590	0.0901
F Test6 mun inst2+north*mun inst2 significant							1.986	0.0929
Test 6 prob>F							0.159	0.761

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

Table 1 Population

VARIABLES	(1) Log Population OLS	(2) Log Population OLS	(3) Log Population 2SLS	(4) Log Population 2SLS	(5) Log Population 2SLS with North dummy	(6) Log Population 2SLS with North dummy
Log Cost of travel to Sao Paulo	-2.3281***		-7.1739***		-5.3889***	
	(0.2167)		(0.8353)		(0.6369)	
Northern * Log Cost of travel to Sao Paulo					-2.4538	
					(7.1031)	
Log Cost of travel to State Capital		-1.5378***		-6.7873***		-5.9061***
		(0.1364)		(0.7186)		(0.5817)
Northern * Log Cost of travel to State Capital						9.0646***
						(1.2511)
Squared Log Cost of travel to Sao Paulo	0.2006***		0.5657***		0.4443***	
	(0.0153)		(0.0486)		(0.0370)	
Northern * Squared Log Cost of travel to Sao Paulo					0.0873	
					(0.4471)	
Squared Log Cost of travel to State Capital		0.1388***		0.6218***		0.5014***
		(0.0120)		(0.0670)		(0.0443)
Northern * Squared Log Cost of travel to State Capital						-0.7751***
						(0.0961)
year==1980	0.6554***	0.3710***	0.2630	-0.0063	0.8508*	1.0491**
	(0.0671)	(0.0633)	(0.4013)	(0.4819)	(0.4592)	(0.4298)
year==2000	1.8139***	1.2476***	1.9998***	1.5956***	2.0372***	1.2851***
	(0.1796)	(0.1693)	(0.3994)	(0.4467)	(0.3636)	(0.4010)
Constant	15.5234***	13.6430***	30.8331***	27.1265***	30.0215***	16.2065***
	(0.8050)	(0.3979)	(3.8472)	(2.1963)	(10.4601)	(1.3876)
Observations	10,920	10,908	10,645	10,633	10,645	10,633
R^2	0.4361	0.4290				
Number of _ID	3,640	3,636	3,589	3,585	3,589	3,585

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

Table 2 Population Shares

VARIABLES	(1) Log Urban Share of Population 2SLS with North dummy	(2) Log Urban Share of Population 2SLS with North dummy	(3) Log Female Share of Population 2SLS with North dummy	(4) Log Female Share of Population 2SLS with North dummy
Log Cost of travel to Sao Paulo	0.4401**		0.0992***	
	(0.1923)		(0.0218)	
Northern * Log Cost of travel to Sao Paulo	-5.9791***		0.2136	
	(2.1442)		(0.2427)	
Squared Log Cost of travel to Sao Paulo	-0.0146		-0.0046***	
	(0.0112)		(0.0013)	
Northern * Squared Log Cost of travel to Sao Paulo	0.3850***		-0.0124	
	(0.1349)		(0.0153)	
Log Cost of travel to State Capital		-0.2407		0.0518***
		(0.1543)		(0.0194)
Northern * Log Cost of travel to State Capital		0.1169		-0.2024***
		(0.3319)		(0.0417)
Squared Log Cost of travel to State Capital		0.0151		-0.0011
		(0.0118)		(0.0015)
Northern * Squared Log Cost of travel to State Capital		-0.0091		0.0148***
		(0.0255)		(0.0032)
year==1980	-0.5151***	-0.2670**	0.0231	0.0149
	(0.1386)	(0.1140)	(0.0157)	(0.0143)
year==2000	-0.0122	-0.1930*	0.0389***	0.0427***
	(0.1098)	(0.1064)	(0.0124)	(0.0134)
Constant	6.9624**	1.0603***	-0.3555	0.4795***
	(3.1575)	(0.3681)	(0.3574)	(0.0463)
Observations	10,645	10,633	10,645	10,633
Number of _ID	3,589	3,585	3,589	3,585

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

Table 3 GDP

	(1)	(2)	(3)	(4)	(5)	(6)
	Log GDP	Log GDP	Log GDP	Log GDP	Log GDP	Log GDP
VARIABLES	OLS	OLS	2SLS	2SLS	2SLS with North dummy	2SLS with North dummy
Log Cost of travel to Sao Paulo	-1.8744***		-4.1963***		-3.6504***	
	(0.3165)		(1.4125)		(1.1397)	
Northern * Log Cost of travel to Sao Paulo					-28.8895**	
					(12.7111)	
Log Cost of travel to State Capital		-0.8389***		-5.7909***		-6.9611***
		(0.1853)		(1.0689)		(0.9730)
Northern * Log Cost of travel to State Capital						11.4651***
						(2.0926)
Squared Log Cost of travel to Sao Paulo	0.1439***		0.4216***		0.3868***	
	(0.0227)		(0.0823)		(0.0661)	
Northern * Squared Log Cost of travel to Sao Paulo					1.7779**	
					(0.8000)	
Squared Log Cost of travel to State Capital		0.0732***		0.5359***		0.5844***
		(0.0164)		(0.0996)		(0.0742)
Northern * Squared Log Cost of travel to State Capital						-0.9551***
						(0.1607)
year==1980	0.6604***	0.5056***	1.1851*	0.7396	0.4251	1.5805**
	(0.1673)	(0.1663)	(0.6786)	(0.7168)	(0.8218)	(0.7190)
year==2000	1.9462***	1.6280***	3.5340***	2.6098***	3.5736***	2.1845***
	(0.1827)	(0.1731)	(0.6754)	(0.6645)	(0.6507)	(0.6707)
Constant	15.5408***	11.8543***	16.5663**	24.1868***	60.7225***	16.2953***
	(1.1691)	(0.5394)	(6.5059)	(3.2668)	(18.7185)	(2.3209)
Observations	10,920	10,908	10,645	10,633	10,645	10,633
R^2	0.7364	0.7350				
Number of _ID	3,640	3,636	3,589	3,585	3,589	3,585

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

Table 4 GDP by sector

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	Log GDP agriculture	Log GDP agriculture	Log GDP industry	Log GDP industry	Log GDP services	Log GDP services
Log Cost of travel to Sao Paulo	-2.1969		-1.6696		-5.4659***	
	(1.4926)		(1.8681)		(1.0717)	
Northern * Log Cost of travel to Sao Paulo	-29.3392*		-2.8528		-40.7817***	
	(16.6798)		(20.8202)		(11.9525)	
Log Cost of travel to State Capital		-4.4054***		-2.7987*		-8.9974***
		(1.2444)		(1.5380)		(1.0042)
Northern * Log Cost of travel to State Capital		6.9730***		7.4073**		15.7532***
		(2.6673)		(3.3097)		(2.1597)
Squared Log Cost of travel to Sao Paulo	0.2401***		0.2103*		0.5123***	
	(0.0870)		(0.1084)		(0.0622)	
Northern * Squared Log Cost of travel to Sao Paulo	1.8293*		0.1187		2.4702***	
	(1.0498)		(1.3104)		(0.7523)	
Squared Log Cost of travel to State Capital		0.3843***		0.2678**		0.7133***
		(0.0956)		(0.1172)		(0.0765)
Northern * Squared Log Cost of travel to State Capital		-0.5759***		-0.6663***		-1.3324***
		(0.2048)		(0.2542)		(0.1659)
year==1980	1.1008	2.2103**	1.6720	2.0052*	-0.3183	1.4108*
	(1.0783)	(0.9150)	(1.3470)	(1.1360)	(0.7728)	(0.7420)
year==2000	3.0297***	2.2059***	2.3587**	1.6680	3.4152***	1.6777**
	(0.8554)	(0.8545)	(1.0668)	(1.0599)	(0.6119)	(0.6922)
Constant	57.2314**	12.2325***	13.3360	5.8053	86.1764***	18.1182***
	(24.5926)	(2.9692)	(30.6404)	(3.6666)	(17.6014)	(2.3953)
Observations	10,633	10,621	10,639	10,627	10,645	10,633
Number of _ID	3,587	3,583	3,589	3,585	3,589	3,585

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

Table 5 GDP sector shares

VARIABLES	(1) Share GDP agriculture	(2) Share GDP agriculture	(3) Share GDP industry	(4) Share GDP industry	(5) Share GDP services	(6) Share GDP services
Log Cost of travel to Sao Paulo	-0.0495		0.5396**		-0.7737**	
	(0.3649)		(0.2561)		(0.3393)	
Northern * Log Cost of travel to Sao Paulo	-0.6309		2.7595		-3.9377	
	(4.0693)		(2.8566)		(3.7836)	
Log Cost of travel to State Capital		-0.0347		0.7747***		-0.6094**
		(0.3033)		(0.2143)		(0.2884)
Northern * Log Cost of travel to State Capital		-0.9234		-0.8038*		1.5845**
		(0.6522)		(0.4608)		(0.6203)
Squared Log Cost of travel to Sao Paulo	-0.0019		-0.0427***		0.0439**	
	(0.0212)		(0.0149)		(0.0197)	
Northern * Squared Log Cost of travel to Sao Paulo	0.0543		-0.1718		0.2261	
	(0.2561)		(0.1798)		(0.2381)	
Squared Log Cost of travel to State Capital		0.0012		-0.0576***		0.0310
		(0.0231)		(0.0163)		(0.0220)
Northern * Squared Log Cost of travel to State Capital		0.0852*		0.0619*		-0.1338***
		(0.0501)		(0.0354)		(0.0476)
year==1980	0.1102	0.1161	0.1607	0.0734	-0.3678	-0.1929
	(0.2631)	(0.2241)	(0.1847)	(0.1583)	(0.2446)	(0.2131)
year==2000	0.0642	0.1002	-0.1700	-0.0501	-0.1547	-0.2270
	(0.2083)	(0.2090)	(0.1462)	(0.1477)	(0.1937)	(0.1988)
Constant	1.6095	1.6489**	-5.8688	-1.4444***	10.4063*	1.1220
	(5.9926)	(0.7234)	(4.2067)	(0.5111)	(5.5717)	(0.6880)
Observations	10,645	10,633	10,645	10,633	10,645	10,633
Number of _ID	3,589	3,585	3,589	3,585	3,589	3,585

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

Table 6 GDP per capita

VARIABLES	(1) Log GDP per capita OLS	(2) Log GDP per capita OLS	(3) Log GDP per capita 2SLS	(4) Log GDP per capita 2SLS	(5) Log GDP per capita 2SLS with North dummy	(6) Log GDP per capita 2SLS with North dummy
Log Cost of travel to Sao Paulo	0.4537*		2.9776**		1.7385*	
	(0.2497)		(1.1762)		(0.9539)	
Northern * Log Cost of travel to Sao Paulo					-26.4357**	
					(10.6390)	
Log Cost of travel to State Capital		0.6989***		0.9964		-1.0549
		(0.1346)		(0.8144)		(0.7626)
Northern * Log Cost of travel to State Capital						2.4005
						(1.6401)
Squared Log Cost of travel to Sao Paulo	-0.0566***		-0.1440**		-0.0575	
	(0.0182)		(0.0685)		(0.0554)	
Northern * Squared Log Cost of travel to Sao Paulo					1.6905**	
					(0.6696)	
Squared Log Cost of travel to State Capital		-0.0655***		-0.0858		0.0830
		(0.0121)		(0.0759)		(0.0581)
Northern * Squared Log Cost of travel to State Capital						-0.1800
						(0.1260)
year==1980	0.0050	0.1345	0.9222	0.7459	-0.4257	0.5314
	(0.1085)	(0.1064)	(0.5650)	(0.5461)	(0.6878)	(0.5635)
year==2000	0.1323	0.3804***	1.5342***	1.0141**	1.5364***	0.8994*
	(0.0858)	(0.0474)	(0.5625)	(0.5062)	(0.5447)	(0.5256)
Constant	0.0174	-1.7887***	-14.2667***	-2.9398	30.7010*	0.0888
	(0.8999)	(0.3910)	(5.4176)	(2.4888)	(15.6670)	(1.8189)
Observations	10,920	10,908	10,645	10,633	10,645	10,633
R^2	0.7260	0.7260				
Number of _ID	3,640	3,636	3,589	3,585	3,589	3,585

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.10

Table 7 End Points and Marginal Effects

			Belém	Fortaleza	Recife	Salvador	Vitoria	Rio de Janeiro	Sao Paulo	Porto Alegre	Goiania	Cuiaba	Porto Velho	Manaus
Initial Conditions of End Points	GDP (R$ 2000)		1,906,121	2,381,044	4,396,389	4,129,873	1,267,595	36,628,492	60,571,136	7,024,682	1,348,222	365,603	321,688	1,685,868
	Urban Population		602,829	827,682	1,120,751	1,004,673	132,036	4,251,918	5,872,318	869,730	385,832	116,675	59,607	322,762
	GDP/cap		3.01	2.78	3.81	4.10	9.53	8.61	10.22	7.93	3.09	1.75	2.90	3.16
	Prop GDP from agriculture		0%	0%	0%	0%	0%	0%	0%	0%	3%	13%	20%	13%
	Prop GDP from industry		23%	27%	20%	27%	13%	29%	47%	29%	20%	11%	19%	26%
	Prop GDP from services		77%	73%	79%	73%	87%	71%	53%	71%	77%	75%	61%	61%
Coefficient signs	State Capital Access, on Log Population	b1		3.65		-5.54			-7.29	-6.71	29.52		13.00	
		b2 (sq)		-0.31		0.40			0.58	0.53	-3.03	0.38	-1.06	
	Sao Paulo Access, on Log Population	b1	-12.37				-1.05	-2.05			-79.28	-27.40	8.47	5.83
		b2 (sq)	0.75				0.08	0.15			5.45	1.90	-0.55	-0.39
	State Capital Access, on Log GDP	b1	3.62				13.42		-7.30	-7.70	36.45	-6.34		
		b2 (sq)	-0.36						0.55	0.57	-3.79	0.56		
	Sao Paulo Access, on Log GDP	b1	-20.56		-6.69		20.68	0.62	-5.68	-6.74	-101.22		6.53	5.84
		b2 (sq)	1.19				-1.48	-0.09	0.35		6.88		-0.50	-0.45
	State Capital Access, on Log GDP per cap	b1	2.99			9.23	10.77			-0.99			-3.89	
		b2 (sq)	-0.26			-0.66	-0.89			0.04			0.27	
	Sao Paulo Access, on Log GDP per cap	b1				-28.33	21.73	2.67						
		b2 (sq)				1.85	-1.56	-0.23						
Thresholds (km equiv.)	Log Population	Sao Paulo	3981				601	1155			1448	1345	2207	1679
	Log Population	State Capital		353		966			518	588	130	189	449	
	Log GDP	Sao Paulo	5558		5256		1075	37	3712	1953	1564		660	675
	Log GDP	State Capital	148				485		770	889	123	275		
	Log GDP/capita	Sao Paulo				2100	1043	323						
	Log GDP/capita	State Capital	352			1093	413			176754			1412	

Table 8 Correlations between marginal effects and end-point characteristics

	Population		GDP		GDP per capita	
	Sao Paulo	State Capital	Sao Paulo	State Capital	Sao Paulo	State Capital
Urban Population	-0.41	-0.14	-0.31	-0.10	0.06	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.82)
GDP	-0.46	-0.09	-0.35	-0.11	0.07	-0.09
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
GDP per capita	-0.30	0.11	-0.20	-0.05	0.10	-0.21
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Percentage GDP Services	0.54	0.32	0.61	0.43	0.28	0.32
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Percentage GDP Agriculture	0.01	-0.15	-0.11	-0.13	-0.22	-0.04
	(0.46)	(0.00)	(0.00)	(0.00)	(0.00)	(0.03)
Percentage GDP Industry	-0.54	-0.26	-0.56	-0.38	-0.20	-0.31
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Note: P-values in parentheses

Figure 6: Marginal Effects of a fall in cost of access to the State Capital on GDP

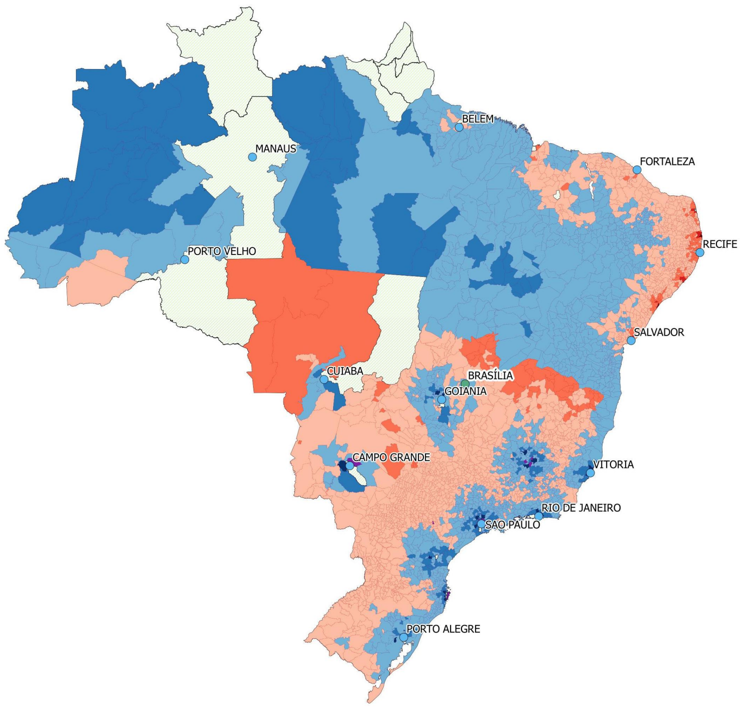


Figure 7: Marginal Effects of a fall in cost of access to the State Capital on Population

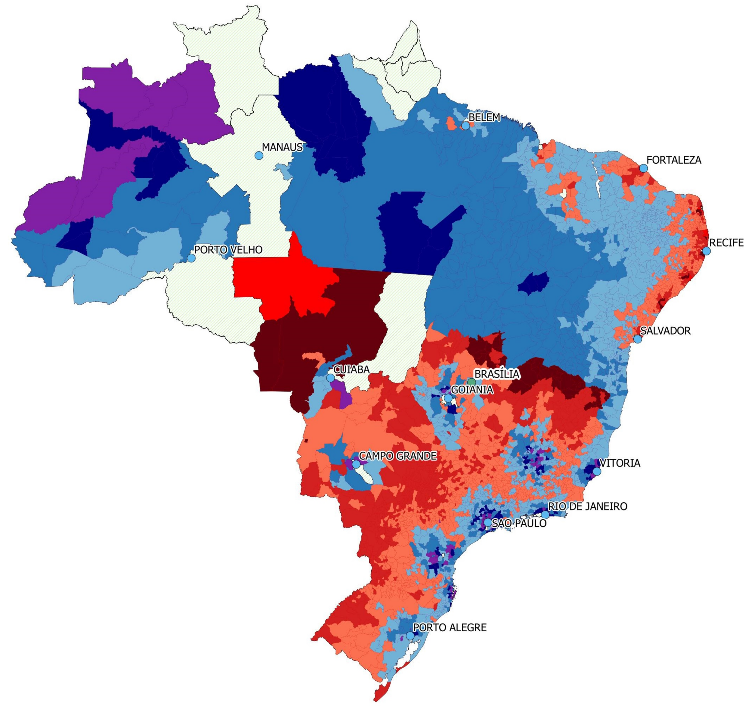
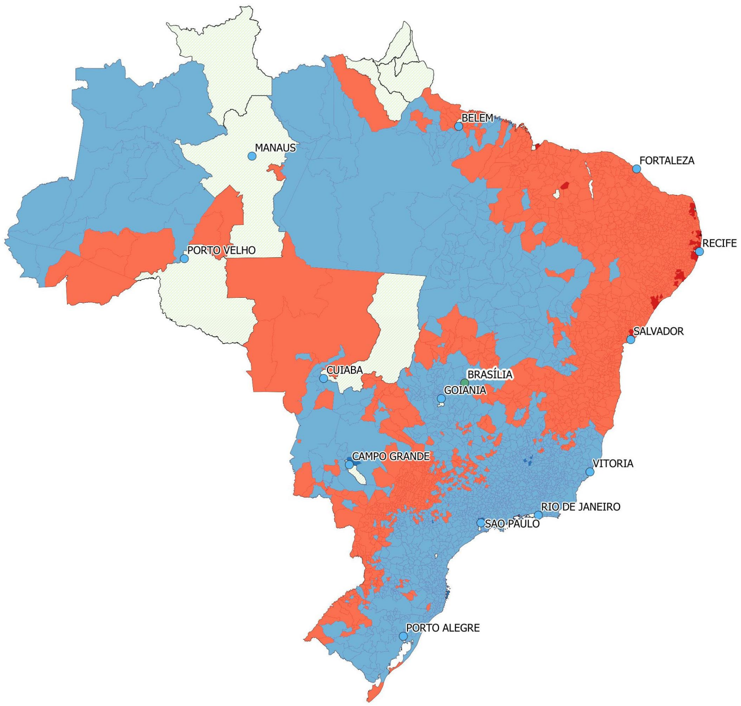


Figure 8: Marginal Effects of a fall in cost of access to the State Capital on GDP per capita



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