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The Brasília Experiment

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 from 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 location by using an original empirical strategy, based on the "historical natural experiment" constituted by the creation of the new federal capital city Brasília in 1960. The results reveal a dual pattern, 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 centers in the less developed North, in line with predictions in terms of agglomeration economies. Over the period, roads are shown to account for half of pcGDP growth and to spur a significant decrease in spatial inequality.

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The Brasília Experiment: Road Access and the Spatial Pattern of Long-term Local Development in Brazil

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1 Introduction

Brasília, Brazil's current federal capital city, was built from scratch between 1956 and 1960, in a previously unpopulated area selected because of its geographic centrality, at the initiative of then President Juscelino Kubitschek, who wanted to shift the country's center of gravity away from the Southern coastal region. The following decades were also characterized by one of the largest post war infrastructure development program worldwide, as Brazil paved over 150,000 km of roads.[1]

An important share of this national road construction program was geared towards connecting the new capital to other main population and economic centers. The resulting radial highway system also incidentally connected other inland municipalities along the way. Proximity to the roads built after the creation of Brasília was a key factor in explaining the subsequent changes in local access to major economic centers. However, whether municipalities were close to or far from the new corridors was mostly due to luck rather than to their specific economic or geographic characteristics.

We exploit this "historical natural experiment" to study the impact of the rapid expansion of the Brazilian road network on the growth and spatial allocation of population and economic activity across the country's municipalities between 1970 and 2000. This allows us to solve the main difficulty inherent to eliciting the impact of roads, namely their potential non random placement. Indeed, roads are likely to be allocated to specific locations according to observed or unobserved characteristics that are not orthogonal to their development potential. For example, they may be prioritized in fast growing municipalities or in 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,[2] potentially biasing estimates towards zero.

Our empirical strategy is based on superimposing onto a map of Brazil eight

[1] Mitchell (1995) and World Bank (2008). This figure excludes urban roads.

[2] See for example Cadot, Roller and Stephan (2006) and Burgess et al. (2013).

straight lines, coinciding with the subsequent shape of the radial highway system, which connect the country's new capital to 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 a municipality-level distance index capturing proximity to the lines, and use it to instrument the subsequent municipality-level improvement in road access over time, and assess its impact on local-level changes in population and GDP, as well as GDP per capita. Our main results exploit 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 its State capital in each decade from the late 1960s to the 1990s.

After developing a simple theoretical framework, we present three sets of results. First, the effect of road access improvements on population and GDP supports a story of a dual geographical pattern. In the more developed Southern part of Brazil, improvements in travel costs resulted in a growing concentration of population and economic activity in large radiuses of up to several hundreds kilometers around the main urban areas. The population movements were clearly quantitatively more important than the spatial changes in GDP and GDP per capita. Northern State capitals underwent the opposite process, with reductions in travel costs spurring a 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 balanced, meaning that the net effect on GDP per capita appears mostly insignificant.

Second, we show that this dual pattern can be explained by variations in road endpoints along a number of characteristics that proxy for the agglomeration economies described in the urban literature. As predicted by our model, an improvement of road infrastructure, through the implied reduction in effective distance, spurs agglomeration towards urban areas if these have a high enough wage rental ratio, which happens if they are large enough, have a high stock of human capital, a high industry to service ratio, and good amenities. The opposite dispersion process occurs otherwise.

Third, we relate the municipality-level marginal effects of road access improvements to the relative size of these locations as compared to the endpoints on the relevant line connecting them. Again, a dual pattern appears. In the South it is the smaller municipalities that gain the most from reduced access costs. There is therefore a combination of induced spatial dispersion, in the sense of the spatial growth literature, together with a home market effect-like geographical concentration process, as these small locations are mostly located around the main urban centers. On the other hand, the results for the North show a positive impact of better road access for a group of approximately 30 large municipalities, indicating spatial concentration, together with geographical dispersion, as these locations are intermediate size cities away from the main urban centers.

Finally, our results indicate that the causal growth effect of the radial highway network development for the country was huge, accounting for almost half of the 136% growth in per capita GDP over the period, and that the geographical redistribution effects were important. Looking at changes in the spatial Gini coefficient across municipalities and regions, we estimate that spatial inequality was significantly reduced particularly due to positive growth impacts in the North and Center West.

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), land values (Donaldson and Hornbeck, 2012) and income levels (Storeygard, 2012, Banerjee, Duflo and Qian, 2012).[3] This last paper was the first one to use 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

[3]More broadly, our paper also 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 Assuncao (2009) on roads, migration and labor markets, and Da Mata et al. (2007) on city growth.

measures of distance to the lines to instrument the time-varying cost of access variables, which capture both the distance and the quality of connections to the country's main economic centers. Doing this allows us to derive the causal effect of the improvement in road access that followed the development of the radial highway system, and to produce the overall counterfactual growth estimates mentioned above.

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., 2013; Faber, 2012). We add to these strands of literature by being able to provide an 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, thus providing results on the local-level country-wide changes in the distribution of outcomes.

Finally, by looking at the relationship between the impact of road improvements and the spatial characteristics of each location, it also relates to the work on spatial development of Desmet and Rossi-Hansberg (2009, 2014). In doing so, we effectively combine insights from the infrastructure literature that uses spatially disaggregated data and looks at the geography of infrastructure impacts, with those from the spatial development literature that characterizes spatial effects in terms of concentration / dispersion of activities across locations of different sizes.

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 of similar investments across space.

The paper is structured as follows. Section 2 develops a simple theoretical framework to guide our empirical exercise. Section 3 details the state of Brazilian infrastructure since the 1960s and the relevant institutional facts. Section 4 presents the different sources of data used in the paper. Section 5 introduces the empirical strategy and discusses the validity of the instrumental approach. Section 6 presents the main results and a number of robustness tests. Section 7 develops the implications for spatial vs. geographical development. Section 8 presents the growth counterfactual computations. Section 9 concludes. Additional material, results, and robustness checks are provided in the Appendix.

2 A Simple Model

Consider the following simple model, which breeds two main ingredients: a basic production function framework inspired from Banerjee et al. (2012), and insights from the urban literature on how agglomeration economies determine the strength of urban areas' pull factors.

There are two regions, the Center and the Periphery denoted by subscript $i \in \{c, p\}$. Each region is populated by n_i firms of similar size, which produce a tradable good using labor L_i and capital K_i. Total regional output is then given by $Y_i = A_i K_i^{\alpha} L_i^{1-\alpha}$, where A is the usual technological progress term. Factors of productions verify $L_c + L_p = L$ and $K_c + K_p = K$, where L and K are total national endowments.

Assume that all technological progress takes place in the center,[4] so that $A_c = A^0 \left(\overline{K}_c\right)^{\beta_c}$, where $\overline{K}_c = \frac{K_c}{n_c}$, and $A_p = A^0$ (i.e., $\beta_p = 0$). One interpretation is that the Center represents an urban area with corresponding agglomeration economies to be defined below, while the Periphery encompasses surrounding rural areas where only traditional production techniques are used.

All goods and factors are mobile across regions at a cost, and we model this process following Banerjee et al. (2012). We assume that goods move at a cost, related to distance d, with $d_c = 0$ and $d_p \equiv d > 0$, so that the price of the tradable good is p in the Center and $p(1-d)$ in the Periphery. Denoting by r_c and w_c the rental rate of capital and the wage in the Center, the cost of moving factors

[4] This is without loss of generality. The important assumption is that technological progress is higher in the center.

across space can be formalized by assuming that the corresponding values in the Periphery are $r_p = (1 - \rho d) r_c$ and $w_p = (1 - \eta d) w_c$ respectively. Thus, η and ρ parametrize the size of the discounts on the price of factors that stem from the combination of distance and productivity differences between the Center and the Periphery.

Maximizing profit in each region, and plugging the resulting $\frac{K}{L}$ relationship into the regional production function yields (derivations are detailed in the Appendix):

$$\frac{Y_i}{L_i} = \left[\frac{(1-\eta d) w_c}{(1-\rho d) r_c} \frac{\alpha}{1-\alpha} \right]^{\alpha+\beta_i} L_i^{\beta_i}. \tag{1}$$

In the spirit of the urban literature, factors will move across space until the utility per worker is equalized across locations. Formally, we consider that the product per worker is equalized across space, so $\frac{Y_c}{L_c} = \frac{Y_p}{L_p}$. This will be the case if for example workers own the firms in their region, and all profits are redistributed as dividends.

Combining (1) for all i, and using the fact that $L_c + L_p = L$ and $\beta_p = 0$, we obtain:

$$L_c = \left[\frac{(1-\eta d) w_c}{(1-\rho d) r_c} \frac{\alpha}{1-\alpha} \right]^{-1}. \tag{2}$$

We are interested in the comparative statics with respect to d. It is straightforward to observe that the sign of the derivative of the right hand side depends on the sign of $\rho - \eta$. The following proposition states the main results of interest for our empirical exercise.

Proposition 1 $\frac{\partial L_c}{\partial d} \geq 0$ *(resp.* $\leq$*) if and only if* $\rho \geq \eta$ *(resp.* $\leq$*). This also implies that* $\frac{\partial Y_c}{\partial d} \geq 0$ *(resp.* $\leq$*) if and only if* $\rho \geq \eta$ *(resp.* $\leq$*).*

Intuitively, when d goes down, which can be for example thought of as a reduction in effective distance resulting from the construction of new or better roads, agglomeration in the Center occurs if the relative moving costs of factors are such that capital moves more freely than labor. Straightforward computations show that, given the assumptions on relative prices of factors between the Center and the Periphery, this condition can be reformulated in terms of relative wage-rental price ratios:

$$\rho \leq \eta \Longleftrightarrow \frac{w_c}{r_c} \geq \frac{w_p}{r_p}.$$

This means that there will be agglomeration in the Center if the wage-rental price ratio is higher there. To flesh out what drives the relative level of this ratio, consider the conditions that determine the relative opportunity cost of factors in the urban growth literature.[5]

The productivity of labor and the wage-rental price ratio will be higher in metropolitan areas that are larger, as measured by population or output, and exhibit a high industry to service ratio. These are precisely the settings in which, at least during early stages of development, urban externalities have been shown to be stronger.[6] In the Marshallian approach, these aspects may be thought of as capturing labor market pooling and input sharing channels. Moreover, we expect a higher relative wage in cities with better human capital and higher costs of living as determined by better quality amenities. These again can be related directly to other classical motives for external economies. The first one relates to knowledge spillovers, found in cities with better human capital, while the second one is connected to urban areas with better amenities having less of the urban diseconomies generally associated with large cities, such as congestion and poor infrastructure.[7]

Let us denote the factors mentioned above by S for city size, H the average level of human capital, $\frac{Ind}{Serv}$ the industry-service ratio, and M the quality of amenities. The link between agglomeration economies and these parameters then leads to the following corollary.

Corollary 2 *There exist thresholds S^*, H^*, ${\frac{Ind}{Serv}}^*$, and M^*, above which (resp. below which) $\rho \leq \eta$ and $\frac{\partial L_c}{\partial d} \leq 0$ (resp. $\rho \geq \eta$ and $\frac{\partial L_c}{\partial d} \geq 0$), i.e., above which there*

[5] See for example Rosenthal and Strange (2004), and Duranton and Puga (2013).

[6] Henderson (2010).

[7] These agglomeration economies could be built into the model by assuming for example that that they affect technical change directly. As will become clear below, technical change still plays a role in this model, as in its absence, labor would not move at all.

is agglomeration (resp. dispersion) in the Center as a result of a fall in transport costs.

This indicates that the improvement of road infrastructure and the subsequent reduction in transport costs is likely to spur agglomeration in cities which are large enough, have a high stock of human capital, a high industry to service ratio, and good amenities. In our empirical exercise below, we will establish when there is agglomeration vs. dispersion around main urban centers in the Brazilian case, and test directly for the determinants of these alternative patterns of agglomeration, and for the existence of the thresholds characterized in the Corollary.

3 Brazilian Infrastructure

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). As of 2008, it 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 historically been the primary internal mode of transport for both freight and passengers in Brazil. According to computation by Castro (2004), as of 1999 truck transport by road represented 82.1% of domestic freight output, and 93.6% of related expenses. Over 60% of cargo was transported by road in 2011.[8]

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.[9]

While in the 1950s, most new connections were between State capitals along the Atlantic coast, from the 1960s, new penetration corridors started linking the

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

[9]Mitchell (1995), Ipea data.

hinterland main urban centers, e.g., connecting Brasília to São Paulo, Belo Horizonte or Belém.[10]

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.

The country's extension and geographical dispersion implies 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 still 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).

As a result, we expect the strength of the pull factor exerted by metropolitan areas to differ across the country's main regions. In the main text, we therefore use changes in the cost of access to the local State capitals as our main explanatory variable, and report results for the whole country, as well as those broken down between South (South, Southeast) and North Brazil (North, Northeast and Center-west). In the Appendix, we also report results using as an alternative measure the cost of access to São Paulo.

4 Data

4.1 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

[10]Castro (2004) and World Bank (2008).

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, it often divides into two, leading to a large increase in the number of municipalities over the last 50 years: between 1960 and 2010 their number 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).[11] MCAs aggregate municipalities into the smallest possible groupings, such that the boundaries of these groups do not change over time. The specific geographical unit used is AMC 70-00, which covers 3,599 areas, allowing us to compare data at any point between 1970 and 2000.[12]

The Brazilian Institute of Geography and Statistics (IBGE) holds records from the decennial national census, which provides much of our data requirements. From the censuses between 1970 and 2000, we extracted economic and social data at the MCA, state, and regional level. This data includes local GDP measures, aggregated and by main sectors,[13] access to infrastructure services such as electricity, drinking water, and toilets, population figures, and development outcomes such as literacy rates and health indicators.

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 the locations of cities and smaller population centers, road infrastructure and ports. From this we were able to locate the major economic centers 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

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

[12] In what follows, we use the terms municipalities and MCAs indistinctly to mean AMC 70-00, unless specified otherwise. In the robustness section, we also use an alternative grouping, AMC 40-00, to conduct pre-treatment tests.

[13] A detailed description of how the municipality-level production data was constructed can be found in the Appendix.

each MCA is to these lines. More detail is given in section 4.3. 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 to analyze our spatial data.[14] Following our regressions, data could be re-inputted into QGIS to spatially represent our results.

4.2 Road Data

The cost of access measures are provided by IPEA. These measures were computed by Newton de Castro (2002) for every municipality in Brazil, and summarize the cost of travel, in terms of quality adjusted kilometers to travel, to São Paulo and the State capital respectively for 1968, 1980, and 1995.[15]

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

4.3 Distance to the Lines

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 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 Bonifacio, 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 push the development of other regions. It was formally written in the 1891 Constitution of the

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

[15] See technical details in the Appendix.

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, until Kubitschek's presidency the idea was never given serious consideration by Brazilian politicians (see Smith, 2002). 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.

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 080, was either built or radically improved after 1960 (see Figure 1).

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 Maranhéo, connecting local urban centers along the way, while other municipalities were located farther away from the road corridor. However, these differences in distance from the roads were unrelated to their other economic or geographic characteristics.

We capture these differences in proximity to the corridors, by computing for each MCA a distance index to the closest hypothetical lines linking Brasília to a set of 8 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 log.[16]

Table 1 outlines the main variables used in the analysis.

5 Empirical Strategy

5.1 Reduced Form

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. Consider first the following simple reduced form model in levels:

$$Y_{is} = \alpha_0 + \alpha_1 D_{is} + X'_{is}\alpha_2 + \theta_s + \varepsilon_{is}, \tag{3}$$

where Y_{is} is the outcome of interest in MCA i and State s in 2000, estimated as a function of distance to the lines D_{is} and a set of controls for MCAs initial conditions and fixed characteristics X_{is}, as well as State fixed effects. Results for this specification are in Table 2. Over the period 1970-2000, municipalities closer to the lines experienced increases in population, GDP and GDP per capita relative to their more distant counterparts (column 1). The respective elasticities are 0.107, 0.181, and 0.074, and are statistically significant at the 1% level. Following the discussion in section 2 above, in column 2, we introduce an interaction between distance and a Northern dummy. The effects are similar, and stronger in the Southern part of the country, with elasticities of 0.151, 0.242, and 0.092 for population, GDP and GDP per capita respectively, compared to values of 0.026, 0.067, and 0.041 for the North. An F-test fails to reject that these North effects are equal to zero for both population and GDP. [17]

[16] 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 and then take the log. 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 differentiate between lines, and hence connections, by using lines-specific dummies or interactions in our estimations.The two are highly correlated at 0.97.

[17] When, however, we introduce squared distances to the lines to control for potential non-linearities, tests find the North effects on population to be significant at 1%.

We can benchmark the magnitude of these effects to those in Banerjee et al (2012), who use a similar specification for China over the period 1986-2003. Comparing the 25th- to the 75th-percentile MCA in terms of distance shows that the latter is 4.2 time further away from the line. The corresponding gaps in population, GDP and GDP per capita are 34.2%, 57.9%, and 23.6% respectively.[18] By comparison, between 1970 and 2000, the total increase in these variables were 64%, 287%, and 136%.[19]

For population, the differences stemming from the distance to the line represents over half of the change over the 1970-2000 period, while for GDP and GDP per capita, the same ratio is only 20% and 17%.[20] These preliminary results therefore indicate that population movements were a major force behind the effects attributable to the construction of the radial highway system in Brazil. They also show that distance to the lines mattered for subsequent outcomes. We now turn to the instrumental variable strategy.

5.2 Instrumental Strategy: Pooled Cross-Section

Equation (3) is the reduced form of a two stage strategy using distance to the lines as an instrumental variable to address the potential correlation between the independent variable of interest R_{is}, the cost of access to the State capital of MCA i in State s, and the error term related to the non-random placement of roads ($Cov(R, \varepsilon) \neq 0$). Consider the pooled cross-section second stage given by:

$$Y_{is} = \beta_0 + \beta_1 R_{is} + \beta_2 \left(R_{is}\right)^2 + X_{is}' \beta_3 + \theta_s + \varepsilon_{is}. \tag{4}$$

The quadratic cost of access term is systematically included to account for potential non-linearities that are typically expected in economic geography models.[21] In particular, as discussed in the model above, we expect the strength and nature

[18] 0.107*3.2=0.342, 0.181*3.2=0.579, and 0.074*3.2=0.236.

[19] The annual growth rates were 2%, 5.1% and 3% for population, GDP and GDP per capita respectively. These rates differ slightly from official rates, as our sample excludes the lines end points and a few remote MCAs.

[20] In the Appendix, Table A2 presents the results from the reduced form estimated in differences (where the dependent variable in (3) is replaced by ΔY_{is}). The main results are unchanged.

[21] See for example Baldwin et al. (2003) and Combes, Mayer and Thisse (2008) for textbook treatment.

of spatial concentration effects deriving from changes in transport costs between any pair of points over time to differ according to a number of characteristics of end points (i.e., in this case the main economic centers connected by the roads), such as their relative size, amenities, or their economic specialization.

The corresponding first stage equation is:

$$R_{is} = \beta_4 + \beta_5 Dist_{is} + X_{is}^{'}\beta_6 + \theta_s + \varepsilon_{is}. \tag{5}$$

In this simple version, identification relies on the fact that municipalities experienced larger improvements in their road access to major economic centers over the period of interest, the closer they were to the constructed corridors. Moreover, the excludability condition also requires that distance to the lines affect the outcomes Y_{is} only through its impact on the change in the cost of access (i.e., only through road access), conditional on the controls, which may potentially include State fixed effects, and MCA-level time invariant aspects X_{is}, such as access to other infrastructure services (electricity, water, and sewage) in 1970 and the subsequent change in access to these services between 1970 and 2000, and geographical controls such as an amazon dummy, and distance to Brasilia, São Paulo, the State capital, and the coast among others.

We systematically interact R and R^2 with a dummy equal to 1 for all MCA in the Northern part of the country, which comprises 1,429 municipalities. This addresses the possibility discussed in Section 2 above that effects may differ qualitatively between these two regions. The results for the year 2000 are in Table 3.[22]

The negative signs of the cost of access variable in columns 1 and 2 indicate that the reduction in the cost of access had a positive and significant effect on population and GDP. The quadratic terms in turn are positive, and significant at the 10% level for population, indicating a non-linear effect. Thus, better access to the State capital increased population and GDP around State capitals, but the effect is reversed when effective distance exceeds a threshold equal to 360km.

On the other hand, the effect is completely reversed, though much weaker, in

[22]Estimates are calculated using the command ivreg2 (Baum et al. 2010), clustering at the municipality level.

the North: all locations around Northern State capital experienced a population and a GDP decrease, as shown by the positive values that result from summing up the coefficients of cost of access and its interaction with the Northern dummy, and the net negative values of the squared terms. The corresponding thresholds are 240km for population and 35km for GDP, beyond which the effect of a fall in cost of access on population and GDP becomes positive again.[23]

Finally, results for GDP per capita are overall not significant, in line with the assumption of our theoretical framework.

This dual pattern of agglomeration around urban centers in the South and dispersion away from such centers in the North, is the first core result of our analysis. We will show below that it is very robust across specifications.

These results also vindicate our instrumental strategy. Note that first stage regressions (see Appendix A1) show that the instrument is a strong predictor of MCA-level travel cost to the State capital. The F-statistics for the joint significance of the excluded instruments are good, at 36 and 54. However, the remaining issue with such specifications is that distance to the lines may affect outcomes through other channels not controlled for. We include time invariant controls, however the lines may impact through channels including time-variant municipality-level aspects such as electrification or extension of the water and sewage network. To address this, we move to a specification, which uses the full panel structure of the data.

5.3 Instrumental Strategy: Within-Municipality Identification

Consider the following second stage equation:

$$Y_{ist} = \alpha_0 + \alpha_1 R_{ist} + \alpha_2 R_{ist}^2 + X'_{ist}\alpha_3 + \theta_i + \theta_{st} + \varepsilon_{ist}, \tag{6}$$

where Y_{ist} is the outcome of interest (population, GDP, GDP per capita) in MCA i, in State s, at time t, R_{ist} is the time-variant cost of access, X_{ist} are MCA level

[23] F tests do not reject that the combined effects in the North equal zero, implying that the effects observed in the North are very weak.

time-variant controls, and the $\theta's$ are MCA and State-time fixed effects. We thus allow for different trends across States.

Note that the use of a quadratic term in the fixed effects specification (6) 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.[24]

The instrumental strategy now relies on the following first stage equation:

$$R_{ist} = \beta_0 + X_{ist}\beta_1 + (Dist_{is} * Z_{st})\beta_2 + \theta_i + \theta_{st} + \varepsilon_{ist}, \tag{7}$$

where our instrumental variable $Dist_{is} * Z_{st}$ is defined as the product of MCA distance to the straight lines, $Dist_{is}$, and a vector of State-level time-varying variables Z_{st}, which includes the stocks of the number of kilometers of federal, State, and municipal roads per squared-kilometers in the State in each period.[25]

The validity of the conditional excludability of the instruments is reinforced by the fact that we are now able to include any MCA level time-invariant aspects, captured by MCA fixed effects, a number of time-variant factors, including state-time specific shocks θ_{st}, and infrastructure services (electricity, water, and sewage) access in each period.

Given the inclusion of MCA 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 the building up of federal, State, and municipal roads, which can be ascribed to each district according to its distance to the closest exogenous straight line.[26]

To control for the potential correlation of errors within municipalities over time, and across municipalities within each state for a given year, we use multiway clustering provided by the stata command xtivreg2 (see Schaffer, 2010). This

[24] 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.

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

[26] This strategy is similar to the use of geologic characteristics interacted with State-level time varying aspects, to instrument for the within-State placement of dams in India (Duflo and Pande, 2007).

ensures the consistent estimation of our standard errors, as shown by Baum, Schaffer and Stillman (2003 and 2007).[27]

Table A3 in the appendix shows the first-stage results. Our instruments strongly predict the MCA-level change in travel cost to the State capital. The F-statistic for the joint significance of the excluded instruments is 12.8, and 12.9 when a Northern dummy interaction is added.

The results indicate heterogeneous treatment effects across instruments. In columns 1, they indicate that locations benefited more from federal paved roads the farther away they are from the lines. The likely intuition for these results is that federal roads, which include in particular the longitudinal, transversal and diagonal road systems, are built mostly to connect and fill the space between the main radial highways, thus benefiting locations farther away from these corridors proportionally more. When interactions with the North dummy are included, we find that locations benefited more from state roads the closer they are to the lines in the South, while the reverse holds for the North; conversely locations benefited more from municipal roads the farther away they are from the lines in the South, and the reverse holds for the North.

As such, these results suggest that the way proximity to the lines has influenced improvements in cost of access to major urban center differs qualitatively between the South and the North. The next section looks at the second stage results concerning the impact of road development on population, output, and per capita GDP.

6 Results

6.1 Population

Table 4, panel A, shows the results from estimating (6) on the whole sample of Brazilian MCAs, with Y_{ist} 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 in each period, as well as district, and state-time fixed effects.

[27]We partial out the exogenous variables, including our municipality level controls and state year interactions, to allow this estimation.

The OLS outcome in column 1 shows that the effect of a reduction in the cost of access is positive, as places experiencing larger reductions (a larger negative value of the explanatory variable) had a bigger population increase. Moreover, the effect is strongly non-linear, as witnessed by the squared term. Population increased in areas close enough to the State capitals, but this effect was reversed for locations, which effective distance to the main centers exceeded a threshold equal to 250km.[28]

The instrumental estimation in column 2 is likewise significant at the 1% level and confirms the OLS results, although the 2SLS coefficients are about 3 times larger than their OLS counterpart. This is as expected since our identification strategy exploits the politically-driven assignment of roads to previously underdeveloped areas resulting from the creation of Brasília, which should indeed imply that OLS estimates are downward biased.

As a result, the 2SLS impact of cost of access reductions is stronger for locations within short effective distances from the main urban centers, and it declines faster as this distance grows. The new threshold is now 530km from the 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 column 3, we add the interaction with the Northern dummy. The coefficients for MCAs in the Southern region are by and large unchanged in magnitude and significance. An improvement in access to the State capital generates an increase in population, up to an effective distance threshold of 390km.

The results for Northern MCAs, however, are again dramatically altered, in line with our earlier pooled estimates. First, the dummy interactions are significant at the 1% for the state capital. 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 90km, while population increases in MCAs farther away. An F-test of the sum of the squared

[28] Exp[1.5387/(2x0.1389)]=254.

term and its interaction with the North dummy reject that it is equal to zero at 10%, confirming the significance of a reverse non-linear effect in the North.

Based on the specification in column 3, Table 5 shows how elasticities vary for three different locations with effective distance equal to 50, 150, and 1000 km. In the South, for a location 50km away from its State capital a 1% reduction in the cost of access implies a 2% increase in population. This falls to a 0.9% increase 150km away, and finally reverses to a 0.9% decrease 1000km away. Conversely, in the North, a location 50km away from its State capital would experience a 0.2% decrease in population as a result of a 1% reduction in the cost of access, a 0.2% increase 150km away, and a 0.8% increase 1000km away. Given that in our sample the cost of access to the State capitals fell by 33% on average between 1968 and 1995, the implied population movements are quite substantial.

The results are illustrated in Figure 4, which represents on the Brazilian map the partial marginal effects at the mean for population corresponding to the specifications of column 3. For each MCA i, the color on the map corresponds to the value $\hat{\alpha}_1 + 2.\hat{\alpha}_2 \bar{R}_i$, where $\bar{R}_i$ is the average cost of access over the 1970 to 2000 period. Blue MCAs are those where this value is negative (i.e., when a fall in cost of access leads to an increase in population), the more so the darker the shade, while red MCAs are those with positive values (i.e., where there is a population decrease). Excluded MCAs are shown in white. The pattern discussed above is readily apparent, with large blue circles around the main urban center in the South and red areas beyond that, and the reverse pattern in the North

These figures show that in the South a process of concentration around the main metropolitan centers happened in relatively large circles, of approximately 300 to 400km diameter. Meanwhile, in the North the improved access drained locations close to the state capitals, and a secondary concentration process occurred in locations more than 100 effective km away from the capitals.[29]

This is consistent with the demographic evidence about the intense migration process towards main urban centers which took place over that period. Looking at the nine cities officially defined as 'metropolitan regions', Martine and Mc-

[29] Panels A and B of Table A4 in the Appendix present similar estimations for urban/rural and male/female population shares. It shows that Southern locations at less than 90km have higher female shares.

Granahan (2010) document that the annual growth rate of the five located in the South (São Paulo, Rio de Janeiro, Belo Horizonte, Porto Alegre, and Curitiba) accounted for 33% of overall national population growth between 1970 and 1980, while the four in the North (Recife, Salvador, Fortaleza, and Belem) accounted for only 8%.[30]

It also fits the evidence in Chein and Assuncao (2009). Analyzing the impact of the construction in the 1970s of the Belém-Teresina road (BR-316, i.e., one of the diagonal roads), which connected the North and Northeast parts of the country and completed the Belém-Brasília road (BR-010) in providing access to East Amazonia, they show that its completion generated an increase in population density and in the number of cities (a 50% increase, from 218 to 344 cities) along its path that vastly exceeded the country average.

Overall, the findings in this Section support 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 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.

6.2 Output

Table 4, panel B, shows the results from estimating (6), where the left-hand side variable is log municipal-level GDP. The overall pattern mirrors that found for population. The OLS results (column 4) show strongly significant and non-linear effect of improvements in the cost of access to the State capital on GDP. This is

[30] Table 7, page 18. The corresponding numbers are 22% (South) and 8% (North) for 1980-1991, and 26% (South) and 10% (North) for 1991-2000.

confirmed by the 2SLS results (column 5), which are again larger than their OLS counterparts. The effect of a fall in cost of access is positive up to a threshold of 610km.

When introducing interactions with a North dummy, we find again the dual pattern unveiled above for population, with an increasing-then-decreasing pattern in the South and a threshold of 488km, and a reversed decreasing-then-increasing pattern in the North, with a 70km threshold. An F-test of the sum of the squared term and its interaction with the North dummy supports the significance of the non-linear effect in the North.

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 close to such areas in the North and an increasingly positive effect farther away. A possible interpretation is that a classical home market effect was at play in the South, in particular around the São Paulo region, while in the North, improved road connections led to a concentration of activity away from the main centers and towards secondary urban centers located along the new road connections.

Columns 3 and 4 in Table 5 shows the resulting elasticities for locations with effective distance equal to 50, 150, and 1000 km in both regions, based on the specification in column 3 of Panel B, Table 4. In the South, for a location 50km away from its State capital a 1% reduction in the cost of access implies a 2.1% increase in GDP, a 1.1% increase 150km away, and 0.6% decrease 1000km away. In the North, a location 50km away from its State capital would experience a 0.2% decrease in GDP, a 0.3% increase 150km away, and a 1.2% increase 1000km away.

These results are illustrated in Figure 5, where the pattern for GDP is very similar to that found in Figure 4 for population.

6.3 GDP per capita

Panel C in Table 4 shows the results for GDP per capita. In column 7, the OLS results are significant and display again a non-linear impact of a fall in travel costs, although now the effect is negative for locations close to the State capitals.

In column 8, only the squared term of the 2SLS estimates is significant at the 10% level, and in column 3, the results from the specifications including a North dummy interaction are not significant at conventional levels. Thus, we cannot conclude that these impacts are important, and it appears that the population and GDP effects from improved access to the State capitals cancel out across Brazil, consistently with the assumption of the model.

6.4 Urban Externalities Determinants and Agglomeration Thresholds

Our model relates the nature of the agglomeration pattern to the strength of agglomeration economies in the main connected urban areas. We now test explicitly whether our main result, the dual pattern between South and North, can be explained by such externalities along four main dimensions: city size, average level of human capital, the industry-service ratio, and the quality of amenities.

Table 6 presents the results from a specification in which the second stage takes the form:

$$Y_{ist} = \alpha_0 + \alpha_1 R_{ist} + \alpha_2 R_{ist}^2 + + \alpha_3 \left(R_{ist} * W_j\right) + \alpha_4 \left(R_{ist}^2 * W_j\right) + X_{ist}' \alpha_5 + \theta_i + \theta_{st} + \varepsilon_{ist}, \quad (8)$$

where W_j is the initial characteristic of the endpoint city of the nearest line to each municipality; i.e., alternatively the endpoint GDP (as a proxy for size),[31] the average rate of water access (as a proxy for amenities), average years of schooling of the endpoint population (as a proxy for human capital), and the manufacturing-services ratio.

The results are striking. As predicted, along the four dimensions included, endpoints with W_j characteristics above given thresholds displays an effect consistent with the agglomeration pattern observed in the South: Population and GDP increase near state capitals, and decreases beyond a certain distance. On the other hand, below the thresholds, the effects are similar to those for the North: population and GDP decreases with a fall in cost of access near State capitals, and secondary centers are formed further away.

[31] Estimations using population as a proxy for size, not included here, yield very similar results.

Moreover, these effects are strongly significant (at the 1% level) and all threshold values are within our sample. Simply looking at the values of W for which the direct effect of R changes sign, in panel A, the GDP thresholds above which agglomeration occurs in the center for population and GDP respectively are 4.2 to 4.5 million R$. In panel B, agglomeration occurs for population whenever average water access exceeds 38% of the endpoint population,[32] while for GDP the value is 42%. In panel C, agglomeration happens above 3.6 years of schooling. Finally, in panel D, population agglomerates whenever the initial industry to service ratio exceeds 45%, while the threshold value for GDP is 53%.[33]

Comparing these thresholds with the actual figures for the end cities in 1970, we see a clear pattern as to which cities exceed the thresholds. São Paulo originally had levels of each of these four characteristics high enough to provoke agglomeration forces, with Rio de Janeiro following in all but the industry to services ratio. In water access and education, both Bélem and Salvador also exceeded the thresholds necessary for agglomeration. Among the characteristics we consider, none of the other end point cities had values high enough to drive agglomeration.

Figure A1 to A4 in the Appendix represents on the Brazilian map the partial marginal effects corresponding to these specifications (for GDP as the dependent variable, with population driving similar results) and provide a visual display of the complete agglomeration effects. These are clear around the historically large and important urban centers (São Paulo, Rio de Janeiro, Salvador), as well as around Campo Grande in the South, while dispersion effects are seen around the lesser developed end points. In the map for the manufacturing to services ratio, however, this is less pronounced as only São Paulo reached the critical threshold necessary to induce agglomeration along this dimension in 1970. We conclude that the dual agglomeration vs. dispersion pattern observed as a result of the construction of the Brazilian radial highway system is consistent with the insights

[32] Feler and Henderson (2011) have suggested that some localities may voluntarily withhold water provision to poor neighborhood as way to deter in-migration.

[33] Note that these thresholds are calculated using the interaction with cost of access. Simple calculations show that the coefficients on the squared interactions result in similar thresholds. Of course, other characteristics of endpoints not included here may drive agglomeration/dispersion effects, and we must be aware of the high correlation between the end point characteristics discussed; it is not possible from this analysis to pinpoint the exact characteristics driving the effects.

from the urban literature on agglomeration economies.

6.5 End Points

As mentioned, the thresholds above are only indicative of the level where the total effect of R actually reverses. Another way to differentiate across urban areas is to disaggregate the data further, and disentangle the impact of each transport corridor on local GDP and population. To this end, we estimate a specification using a dummy for each of the lines constructed interacted with R_{ist}, the cost of access variable. Table 7 shows the output for each line, characterized by its end point city.

São Paulo appears to have the largest positive pull on both population and GDP; as transport costs to the State capitals fall, the municipalities along this transport corridor see an increase in these two dimensions, up to a threshold of over 650 and 830km. A similar effect is observed for Campo Grande in the South, with thresholds 320 and 690km.[34] On the other hand, Belem, Salvador, and Porto Velho lose population, as does Rio de Janeiro, which displays a negative, although small, marginal effect. Results for GDP per capita are again mostly not significant, apart from the negative effect around Rio de Janeiro, and the negative effect of improved access to the State capital around Fortaleza up to 100km and Cuiaba up to 270km.

Finally, Cuiaba and Porto Velho deserve special mention, as these two cities in the West of the country boast very negative effects of improved access along most dimensions. It is possible that given their location, they suffered from the increasing attractiveness of the new capital Brasilia. Similarly, the effects on the dynamics of the Rio de Janeiro metropole might also relate to the specific impact of losing the capital to Brasilia.

[34] Among the 72 cities that had more than 100,000 habitants in 1970, Campo Grande is the fastest growing one over 1970-2000 (Da Mata et al., 2005).

6.6 Robustness Checks

We first provide a placebo test on the effect of lines, using the period before the construction of Brasilia. This in effect shows the absence of pre-treatment trend differences between places near and far the lines. For our estimations to be valid, we need the positioning of the straight lines following the construction of Brasilia to be an exogenous shock, in the sense that being near a future line prior to 1960 had no impact on GDP and population level or growth during this earlier time period.

Table 8 shows a reduced form estimation in differences:[35]

$$Y_{is} = \alpha_0 + \alpha_1 D_{is} + X'_{is}\alpha_2 + \theta_s + \varepsilon_{is}, \tag{9}$$

where Y_{is} is the change in the outcome of interest in MCA i and State s over the period of interest (alternatively 1970-2000 and 1950-1960), estimated again as a function of distance to the lines D_{is} and a set of controls for MCAs initial conditions and fixed characteristics X_{is}, as well as State fixed effects.

The observations are now at the AMC 40-00 level, which is a time-invariant geographical grouping similar in nature to the AMC 70-00 used for the main analysis, however with geographical boundaries consistent from 1940 onwards. Using this unit reduces the number of observations to 1,275 minimal comparable areas, compared to 3,559 for AMC 70-00.

The first panel shows the reduced form for 1970-2000, which confirms, using fewer observations at a different geographical aggregation, the positive and significant impact on GDP and population of being near a line in the period following the construction of Brasília. However, the second panel, which looks at the changes in population, GDP and GDP per capita between 1950 and 1960, shows insignificant results across the board: the distance from a line had no impact on the changes in these outcome variables prior to the construction of Brasília.

The fact that it was only following the inauguration of Brasília that popu-

[35]Of course, since no cost of access data is available before 1968, we can only perform these reduced form estimates.

lation and GDP growth were affected by municipalities' position relative to the future lines supports our exogeneity argument in two ways. First, it comforts us in thinking that there are no fundamental differences in observed or unobserved characteristics that would explain different subsequent trends across municipalities. Second, it also suggests that the investments in transport corridors along these routes were not anticipated by economic agents.

In Table 9, we run the standard two stage least squares regression as in Table 4, however now using this alternative level of aggregation of municipalities, AMC 40-00. By using an aggregation level that is approximately three times that of our main estimations, we are able to assess the existence of potential spillovers across geographical areas. If such spillovers are important, one would expect the estimated coefficients to rise with the level of aggregation (see Holtz-Eakin, 1994). The coefficients are very similar in size and significance to those in Table 4, indicating that the spillover elasticity is close to zero.

Tables A5 and A6 in the Appendix provide additional robustness checks, which support our main results. Table A5 adds a time interaction term on initial municipality levels of water, electricity and toilet access, to control for trends in improvements in other infrastructure services. This both reinforces our conditional excludability condition and controls for the fact that the effects reported may capture municipalities nearer the straight lines having benefit from more investment in other infrastructure services, for example electricity networks, along the routes connecting main urban centers.

Table A6 shows weighted estimations, in which we weight the municipality-level observations by $1/area$. This is to control for the asymmetry in municipalities' size, as those in the North are substantially bigger and less dense.

7 The Geography of Agglomeration and Dispersion

Having established the main agglomeration vs. dispersion pattern across Brazil during the 1970-2000 period, and tested explicitly for the agglomeration economies effects put forward in the theoretical model, this section relates the geographic dimension of this process to the spatial growth literature, focusing on the relationship between the size of locations and their subsequent growth pattern.[36] Figures 6 and 7 present scatter plots of the marginal effects of a fall in transport cost on population as a function of the difference between the size of each MCA, captured alternatively by GDP or population at the beginning of the period, and the size of the relevant end point.

In Figure 6, we plot the marginal effects $(\hat{\alpha}_1 + 2.\hat{\alpha}_2 \bar{R}_i)$ against the difference in log GDP between each MCA and its end point. Results for the South are in the upper part, while those for the North are in the bottom one. Figure 7 shows similar plots where the difference between each MCA and its end point is expressed in terms of population. Figure A5 and A6 in the Appendix repeat the same configuration for the marginal effects of a fall in transport cost on GDP.

In all figures, the results for the South show clearly that the more negative marginal effects (thus implying an increase in population) are concentrated among the smaller municipalities (log difference above 5, so for municipalities at least 150 times smaller than the end point). This drives the overall negative trend line. Moreover, we know from Section 6 that geographically these small municipalities, where the positive effects of roads are stronger, are mostly located in circles around the main urban centers in the South. We therefore have a road-induced spatial dispersion process, in the sense of Desmet and Rossi-Hansberg (2009), as population and GDP growth induces less spatial concentration of population and GDP. However, our estimates add an additional element, in the form of a geographical concentration process akin to a home market effect, as these small locations are mostly located around main urban centers.

On the other hand, the results for the North show clearly a group of approximately 30 relatively large MCAs (log difference between 2 and 4, equivalent to those municipalities being between 7 and 50 times smaller than the end point in 1970), which drive the positive overall trend. Here, we therefore observe spatial concentration, as larger locations grow more. From Figure 5, we can infer that this process of spatial concentration goes together with geographical dispersion, as these locations are intermediate size cities inside the country and away from

[36] See for example Desmet and Rossi-Hansberg (2009, 2014).

the main urban centers.[37]

8 Growth Effects

Using our estimates, we are able to estimate the direct impact of the reductions in cost of access to State capitals between 1970 and 2000 on GDP.

For municipality i, we compute the overall effect of a fall in R_i between 1970 and 2000:

$$\Delta\widehat{Y}_i = \widehat{\beta}_1 \Delta R_i^{(70-2000)} + \widehat{\beta}_2 \Delta R_i^{2(70-2000)}$$

This gives the change in the dependent variable Y_i that can be attributed to the change in the cost of access.[38]

In this simple computation, improvements in transport contributed to 58% of GDP per capita growth during this time period. Total GDP per capita grew by 136% over the 30 year period, so an estimated 45% of this can be attributed to road improvements.

Figure A7 in the Appendix illustrates, at the State level, the ratio between the effect of road improvements on GDP per capita growth and the actual growth experienced over this time. The positive effects on GDP per capita were most pronounced in the North West, particularly in Acre and Pará. This region is historically poorer and less industrialized, and the road improvements appear to have played a crucial role in connecting municipalities there. In contrast, Rio de Janeiro and neighboring Minas Gerais and Espirito Santo on the South East coast suffered from these new connections, as our estimates yield negative causal effects. This may partially be explained by the fact that the capital moved away from this region.

With the variation in impact of costs of access spatially, it is interesting to see how the reduced costs of access also impacted inequality across municipalities.

[37] Unfortunately, data on specific subsectors, which would be needed to perform a finer analysis of the dynamics among specific manufacturing and service activities, is only available from 1980. It is the object of a separate paper.

[38] Note that we can also calculate an estimate of this from the marginal effect $\widehat{\beta}_1 + 2\widehat{\beta}_2\overline{R}_i$ multiplied by the change in costs of access. However the marginal effect corresponds to an infinitesimally small change, and as the size of the changes vary greatly across municipalities, the full calculation detailed in the text is preferred.

Between 1970 and 2000, the actual Gini coefficient on GDP per capita across municipalities, measuring inequality in average incomes, fell from 0.47 to 0.41. Using the municipal level residual share of observed 1970-2000 growth not related to roads, and extrapolating to the aggregate level attained in 2000, allows us to derive counterfactual estimates of local GDP per capita levels in 2000 if relative costs of access had not change.[39] This set of estimates indicates that, without the improved road network, the Gini inequality would have increased over the same time period to 0.50. As a comparison, taxes and transfers currently contribute to a 0.06 reduction in Brazil's Gini coefficient (ECLAC, 2013). Road improvements therefore were key to the reductions in inequality observed in Brazil over this time period. Moreover, while every regions saw a fall in inequality, the reduction attributable to roads is most pronounced in the South of Brazil.

9 Conclusion

Using a unique quasi-natural experiment, the construction of Brasilia, we have been able to exploit an exogenous impulse in constructing a new radial highway network within Brazil to identify the impact of improvements in road access on population and economic activity over three decades.

Our results reveal striking differences across Brazil. In the country's richer and denser South, both population and GDP, especially services, increase around main urban centers. Moreover, we uncover a pattern of combined spatial dispersion, as small municipalities experience stronger marginal effects of improved road access, and geographical concentration, as these municipalities are concentrated around the main metropolitan areas.

In the North, the reverse pattern holds: both population and GDP decrease around state capital areas, suggesting the creation of secondary urban centers. This goes together with a process of combined spatial concentration, as relatively larger locations benefit more from improved road access, and geographical dispersion, as these are located away from the main metropolitan areas. Finally,

[39] This is of course an extreme counterfactual. Alternative scenario would require modeling the impact of a different spatial distribution of road investments on the reduction in costs of access.

in terms of magnitude, population movement appear to be large when benchmarked to overall growth over the period, but they are mostly compensated by GDP changes, so that no discernible effect on per capita GDP is found. The absence of institutional barriers to migration likely explain that these results differ qualitatively from those found for China by Banerjee et al. (2012).

Consistent with a simple theoretical framework, we present evidence that these dual results are driven by the difference between endpoint characteristics in terms of agglomeration economies related to size, human capital, industrialization and amenities.

Spatially, the reductions in costs of access to State Capitals over the period has resulted in a fall in inequality across municipalities, and has been of particular benefit to the North West of Brazil and the coastal South East, except around Rio de Janeiro.

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 initial economic characteristics of the end-points.

In further research, we are extending our empirical framework to analyze other outcomes that interact in crucial ways with the development of the road network, including the evolution of the spatial manufacturing vs. services specialization pattern, deforestation, and access to health facilities and health outcomes.

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11 Tables

Table 1: Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	No. Obs.
GDP	144,084	702,828	89	16,510,600	10932
Population	29297	80155	732	2238526	10932
Cost of access	517	431	0	5949	10932
Distance from Brasilia	1020	424	49	2843	10932
Distance from State Capital	241	157.647	0	1365.742	10932
Area	2095	12627	3.6	367,300	10932
Prop. homes with water	0.34	0.29	0	1	10932
Prop. homes with toilets	0.15	0.24	0	0.98	10932
Prop homes with lights	0.53	0.35	0	1	10932
GDP/cap	3.06	5.85	0.046	455.9	10932
Female Share of Population	0.49	0.015	0.37	0.57	10932
Urban Share of Population	0.47	0.25	0.013	1	10932

Table 1 presents descriptive statistics for the main variables used in the empirical analysis. All variables are observed at the municipality (MCA) and year level. We use census data from 1970, 1980, and 2000. GDP and GDP per capita are in constant 2000 Real. Cost of Access is in effective, quality-adjusted kilometers. Distances are in km. Area is measured in squared km. Proportions of homes with the different types of services, and population shares, are in %.

Table 2: Reduced Form in Levels, 2000

	A		B		C	
	Log Population		Log GDP		Log GDP/cap	
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Log Distance from Lines	-0.1070***	-0.1508***	-0.1808***	-0.2422***	-0.0738***	-0.0915***
	(0.0265)	(0.0335)	(0.0307)	(0.0382)	(0.0110)	(0.0133)
Northern * Distance		0.1251***		0.1757***		0.0506**
		(0.0481)		(0.0561)		(0.0219)
Constant	9.7647***	9.1278***	11.6470***	10.7526***	1.8823***	1.6248***
	(0.5470)	(0.5949)	(0.5796)	(0.6304)	(0.2120)	(0.2266)
Observations	3,644	3,644	3,644	3,644	3,644	3,644
R^2	0.3217	0.3230	0.4193	0.4210	0.6705	0.6711
Chi2 distance+north*distance=0		0.472		2.213		4.965
Prob > chi2		0.492		0.137		0.0259

Table 2 reports OLS estimations of log population (col. 1 & 2), log GDP (col. 3 & 4) and log GDP per capita (col. 5 & 6) in municipality i and State s in 2000, estimated as a function of distance to the lines and a set of controls including state dummies, as well as the municipality distance to Brasília, Sao Paulo and the state capital, dummies for whether the Amazon intersects with the municipality, and whether the municipality is near the coast, and the municipality's area, and water, toilet and light access. Standard errors clustered at the municipality level are in parentheses. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 3: Pooled Cross Section

VARIABLES	Log Population	Log GDP	Log GDP/capita
	(1)	(2)	(3)
Log Cost of Access	-10.1820*	-10.5636	-0.3816
	(5.4248)	(6.6388)	(2.4552)
Squared Log Cost of Access	0.8639*	0.8176	-0.0463
	(0.5238)	(0.6400)	(0.2391)
Northern * Log Cost of Access	12.4319**	13.1466**	0.7148
	(4.8330)	(6.0229)	(2.6619)
Northern * Squared Log Cost of Access	-1.0691**	-1.1810**	-0.1119
	(0.4555)	(0.5658)	(0.2594)
Constant	2.2302	9.0431	6.8129**
	(4.5093)	(5.7891)	(3.1677)
Observations	3,638	3,638	3,638
R^2	0.0877	0.1766	0.3255

Table 3 reports the second stage of two-stage least square estimations of log population (col. 1), log GDP (col. 2) and log GDP per capita (col. 3) in municipality i and State s in 2000, estimated as a function of cost of access to the state capital and cost of access squared, using the command ivreg2 (Baum et al. 2010). The Cost of access variables are instrumented using distance to the lines (see first stage in the Appendix). Controls include state dummies, as well as the municipalities distance to Brasília, Sao Paulo and the state capital, dummies for whether the Amazon intersects with the municipality, and whether the municipality is near the coast, and the municipalities area, and water, toilet and light access. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors clustered at the municipality level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 4: Two Stage Least Squares: Population and GDP

	A			B			C		
	Log Population			Log GDP			Log GDP/cap		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	OLS	2SLS	2SLS	OLS	2SLS	2SLS	OLS	2SLS	2SLS
Log Cost of Access	-1.5387***	-5.7270***	-6.0744***	-0.8400*	-4.9568***	-5.9352***	0.6987***	0.7702	0.1392
	(0.3328)	(0.9157)	(0.9180)	(0.4303)	(1.1820)	(1.0131)	(0.1925)	(0.8656)	(0.8014)
Squared Log Cost of Access	0.1389***	0.4706***	0.5171***	0.0734*	0.4003***	0.4831***	-0.0655***	-0.0703	-0.0340
	(0.0313)	(0.0635)	(0.0730)	(0.0403)	(0.0766)	(0.0732)	(0.0178)	(0.0519)	(0.0445)
Northern * Log Cost of Access			7.4368***			8.2782***			0.8414
			(1.5808)			(2.0918)			(2.0337)
Northern * Squared Log Cost of Access			-0.6652***			-0.7378***			-0.0726
			(0.1213)			(0.1630)			(0.1570)
Observations	10,914	10,914	10,914	10,914	10,914	10,914	10,914	10,914	10,914
R^2	0.4290			0.7349			0.7260		
Number of _ID	3,638	3,638	3,638	3,638	3,638	3,638	3,638	3,638	3,638

Table 4 reports the second stage of two-stage least square estimations of log population (col. 1 to 3), log GDP (col. 4 to 6) and log GDP per capita (col. 7 to 9) in municipality i, State s, and time t, estimated as a function of cost of access to the state capital and cost of access squared, using the command xtivreg2 (Schaffer, 2010). The Cost of access variables are instrumented using distance to the lines, interacted with measures of the stocks in kilometers of federal, state, and municipal roads per squared-kilometers in State s at time t (see first stage in the Appendix). Controls include municipality fixed effects, state-year dummies, as well as the municipalities average water, toilet and light access in each period t, partialled out for the estimation of the standard errors. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors double-clustered at the municipality and state-year level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 5: Elasticity of Population and GDP with a change in State Capital access costs

	Population		GDP	
	South	North	South	North
50km	-2.0	+0.2	-2.1	+0.2
150km	-0.9	-0.2	-1.1	-0.3
1000km	+0.9	-0.8	+0.6	-1.2

Table 5 shows the distance-elasticities of population and GDP for three locations with effective distance equal to 50, 150, and 1000 km, computed from the specification in column 3 of Table 4 for population, and on column 6, table 4 for GDP.

Table 6: Urban Externalities Determinants

	A		B		C		D	
	Log Population	Log GDP	Log Population	Log GDP	Log Population	Log GDP	Log Population	Log GDP
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log Cost of Access	75.9705***	90.2216**	11.3460**	15.6656**	55.9865**	62.3531*	9.6092**	18.3237**
	(28.1222)	(44.6599)	(5.1993)	(7.5965)	(25.2434)	(35.2176)	(4.4838)	(7.5020)
Squared Log Cost of Access	-6.5690***	-8.0503**	-0.9461**	-1.3739**	-4.8515**	-5.5912*	-0.8567**	-1.7531**
	(2.4606)	(4.0200)	(0.4204)	(0.6336)	(2.1833)	(3.1029)	(0.4175)	(0.7062)
Log Cost of Access*Endpoint GDP	-4.9847***	-5.8956**						
	(1.7530)	(2.7911)						
Squared Log Cost of Access*Endpoint GDP	0.4305***	0.5242**						
	(0.1539)	(0.2525)						
Log Cost of Access*Endpoint Water Access			-29.8681***	-37.0684***				
			(9.0907)	(13.3603)				
Squared Log Cost of Access*Endpoint Water Access			2.6011***	3.3661***				
			(0.8038)	(1.2076)				
Log Cost of Access*Endpoint Average Schooling					-15.2353**	-16.7703*		
					(6.2808)	(8.7604)		
Squared Log Cost of Access*Endpoint Average Schooling					1.3375**	1.5205*		
					(0.5598)	(0.7911)		
Log Cost of Access*Endpoint Ratio Industry/Services							-21.2511***	-34.5385***
							(6.8059)	(11.4759)
Squared Log Cost of Access*Endpoint Ratio Industry/Services							1.7488***	3.0278***
							(0.5792)	(1.0482)
Thresholds	4.2 million R$	4.5 million R$	0.38	0.42	3.6	3.7	0.45	0.53
Observations	10,914	10,914	10,914	10,914	10,914	10,914	10,914	10,914
Number of _ID	3,638	3,638	3,638	3,638	3,638	3,638	3,638	3,638

Table 6 reports the second stage of two-stage least square estimations of log population (col. 1, 3, 5 and 7) and log GDP (col. 2, 4, 6, and 8) in municipality i, State s, and time t, estimated as a function of cost of access to the state capital and cost of access squared, as well as these interacted the following endpoint characteristics in 1970: GDP (col. 1 & 2), average rate of water access (col. 3 & 4), average years of schooling of the population (col. 5 & 6), and the manufacturing-services ratio (col. 7 & 8), using the command xtivreg2 (Schaffer, 2010). The Cost of access variables are instrumented using distance to the lines, interacted with measures of the stocks in kilometers of federal, state, and municipal roads per squared-kilometers in State s at time t (see first stage in the Appendix). Controls include municipality fixed effects, state-year dummies, as well as the municipalities average water, toilet and light access in each period t, partialled out for the estimation of the standard errors. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors double-clustered at the municipality and state-year level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 7: Thresholds of Effects of Roads

			Belém	Fortaleza	Salvador	Rio de Janeiro	São Paulo	Campo Grande	Cuiaba	Porto Velho
Initial Conditions of End Point	GDP R$2000		1,906,121	2,381,044	4,129,873	36,628,492	60,571,136	549,267	365,603	321,688
	Urban Population		602,829	827,682	1,004,673	4,251,918	5,872,318	131,138	116,675	59,607
	GDP/capita (R$2000)		3.009	2.775	4.100	8.615	10.224	3.917	1.754	2.896
	Prop GDP from agriculture		0.2%	0.4%	0.2%	0.0%	0.0%	6.0%	13.2%	19.9%
	Prop GDP from industry		23.3%	26.8%	26.5%	28.8%	46.8%	28.5%	11.5%	19.2%
	Prop GDP from services		76.6%	72.8%	73.3%	71.2%	53.2%	65.6%	75.4%	60.9%
Coefficient signs	State Capital Access	b1	3.91***	2.02	0.47*	0.09**	-5.66***	-3.63***	2.41	34.12***
	on Log Population	b2 (sq)	-0.35***	-0.18	-0.04**	-0.02**	0.44***	0.31***	-0.19	-2.84***
	State Capital Access	b1	1.19	4.07	-0.12	2.42	-5.63**	-5.76**	13.64*	40.91***
	on Log GDP	b2 (sq)	-0.20	-0.40	-0.01	-0.20	0.42***	0.44***	-1.19*	-3.47***
	State Capital Access	b1	-2.72	2.05**	-0.58	2.34**	0.04	-2.13	11.23***	6.79
	on Log GDP/capita	b2 (sq)	0.15	-0.22**	0.04	-0.18**	-0.02	0.13	-1.00***	-0.63
Thresholds (km equiv.)	Log Population		254	260	241	12	655	322	620	406
	Log GDP		20	156	0	454	831	692	307	362
	Log GDP/capita		7,437	103	2,589	642	3	4,653	270	217

Table 7 reports the second stage of two-stage least square estimations of log population, log GDP, and log GDP per capita in municipality i, State s, and time t, estimated as a function of cost of access to the state capital and cost of access squared, as well as these interacted with a dummy equal to one for the nearest line, using the command xtivreg2 (Schaffer, 2010). The upper panel reports 1970 characteristics (GDP, GDP per capita, population, share of GDP from agriculture, industry, and services) for each endpoint city. The intermediate panel reports the estimated coefficients for cost of access (b1) and cost of access squared (b2) for each endpoint city. The lower panel reports the thresholds corresponding to these coefficients. The Cost of access variables are instrumented using distance to the lines, interacted with measures of the stocks in kilometers of federal, state, and municipal roads per squared-kilometers in State s at time t (see first stage in the Appendix). Controls include municipality fixed effects, state-year dummies, as well as the municipalities average water, toilet and light access in each period t,using the command xtivreg2 (Schaffer, 2010). The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors double-clustered at the municipality and state-year level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 8: Robustness: Reduced Form, prior and after construction of Brasília

		A		B		C	
		Log Population		Log GDP		Log GDP/cap	
YEAR	VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Log Distance from Lines	-0.0796***	-0.1107***	-0.0243	-0.0814***	-0.0077	-0.0408**
		(0.0135)	(0.0164)	(0.0233)	(0.0248)	(0.0154)	(0.0189)
	Northern * Distance		0.0910***		0.1668***		0.0956***
			(0.0255)		(0.0484)		(0.0325)
	Log Population 1970	0.0753***	0.0743***				
		(0.0115)	(0.0114)				
1970-2000	Log GDP 1970			-0.0314**	-0.0336**		
				(0.0160)	(0.0159)		
	Log GDP per capita 1970					-0.4635***	-0.4671***
						(0.0409)	(0.0417)
	Constant	0.4898*	0.1485	3.4056***	2.7865***	2.2272***	1.8612***
	(0.2864)	(0.2898)	(0.5285)	(0.5616)	(0.3219)	(0.3555)	
	Observations	1,250	1,250	1,250	1,250	1,250	1,250
	R^2	0.2172	0.2243	0.1261	0.1356	0.3844	0.3893
	Log Distance from Lines	-0.0109	-0.0146	-0.0214	-0.0356*	-0.0257*	-0.0421***
		(0.0077)	(0.0096)	(0.0198)	(0.0213)	(0.0146)	(0.0147)
	Northern * Distance		0.0107		0.0414		0.0477
			(0.0141)		(0.0413)		(0.0321)
	Log Population 1950	0.0722***	0.0722***				
		(0.0085)	(0.0085)				
1950-1960	Log GDP 1950			0.0115	0.0112		
				(0.0147)	(0.0147)		
	Log GDP per capita 1950					-0.2635***	-0.2648***
						(0.0273)	(0.0274)
	Constant	-0.2759	-0.3172*	0.8268*	0.6699	0.6151*	0.4308
		(0.1688)	(0.1738)	(0.4498)	(0.4884)	(0.3436)	(0.3813)
	Observations	1,249	1,249	1,250	1,250	1,249	1,249
	R^2	0.1596	0.1600	0.1276	0.1284	0.2118	0.2132

Table 8 reports OLS estimations of changes in log population (col. 1 & 2), log GDP (col. 3 & 4) and log GDP per capita (col. 5 & 6) in municipality i and State s, estimated as a function of distance to the lines and a set of controls including state dummies, as well as the municipality distance to Brasília, Sao Paulo and the state capital, dummies for whether the Amazon intersects with the municipality, and whether the municipality is near the coast, and the municipality's area, and water, toilet and light access. The upper panel reports estimates of the 1970-2000 change in outcomes, while the lower panel reports estimates of the 1950-1960 changes. The geographical unit used is IPEA's 1940 Minimal Comparable Areas (AMC 40-00), which covers 1,275 municipal areas, comparable at any point between 1940 and 2000. Standard errors clustered at the municipality level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 9: Robustness: Two Stage Least Squares using AMC4000: Population and GDP

	A Log Population			B Log GDP			C Log GDP/cap		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	OLS	2SLS	2SLS	OLS	2SLS	2SLS	OLS	2SLS	2SLS
Log Cost of Access	-1.4845***	-6.8707***	-6.9634***	-0.3723	-3.2592**	-4.4121***	1.1129***	3.6089***	2.5513**
	(0.2383)	(1.1264)	(0.9398)	(0.3333)	(1.5740)	(1.2816)	(0.2029)	(1.2015)	(1.0182)
Squared Log Cost of Access	0.1289***	0.5127***	0.5397***	0.0242	0.2255**	0.3380***	-0.1048***	-0.2871***	-0.2017***
	(0.0199)	(0.0783)	(0.0685)	(0.0289)	(0.1097)	(0.0928)	(0.0179)	(0.0833)	(0.0718)
Northern * Log Cost of Access			7.1735***			8.0360***			0.8692
			(1.5334)			(2.4491)			(1.8937)
Northern * Squared Log Cost of Access			-0.5886***			-0.7424***			-0.1544
			(0.1194)			(0.2001)			(0.1597)
Observations	3,741	3,741	3,741	3,739	3,739	3,739	3,739	3,739	3,739
R^2	0.5881			0.7947			0.7602		
Number of _ID	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247	1,247

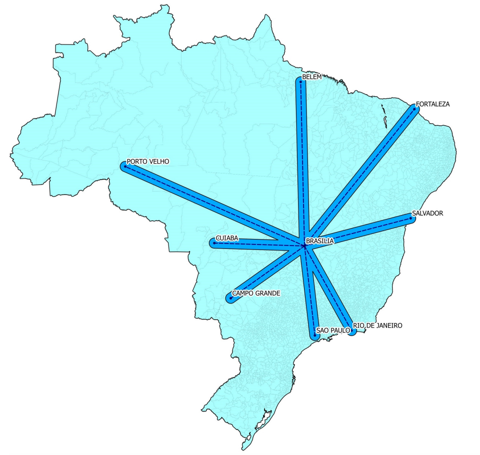
Table 9 reports the second stage of two-stage least square estimations of log population (col. 1 to 3), log GDP (col. 4 to 6) and log GDP per capita (col. 7 to 9) in municipality i, State s, and time t, estimated as a function of cost of access to the state capital and cost of access squared, using the command xtivreg2 (Schaffer, 2010). The Cost of access variables are instrumented using distance to the lines, interacted with measures of the stocks in kilometers of federal, state, and municipal roads per squared-kilometers in State s at time t (see first stage in the Appendix). Controls include municipality fixed effects, state-year dummies, as well as the municipalities' average water, toilet and light access in each period t, partialled out for the estimation of the standard errors. The geographical unit used is IPEA's 1940 Minimal Comparable Areas (AMC 40-00), which covers 1,275 municipal areas, comparable at any point between 1940 and 2000. Standard errors double-clustered at the municipality and state-year level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

12 Figures

Figure 1: Radial Roads

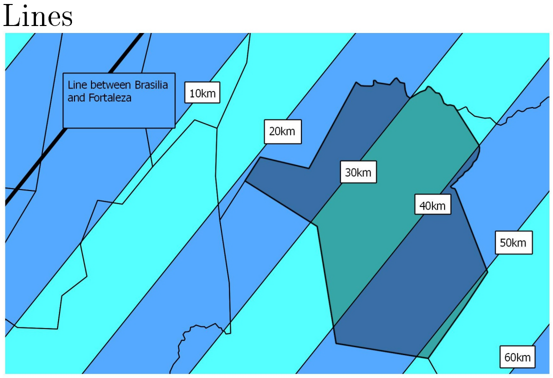
Map from Ministério dos Transportes, Brazil, showing radial roads connecting Brasília to economic centers.

Figure 2: Buffer Zones



Map constructed by authors, showing bands (100km) around the straights lines leading from Brasília to economic centres.

Figure 3: Construction of Distance from Lines



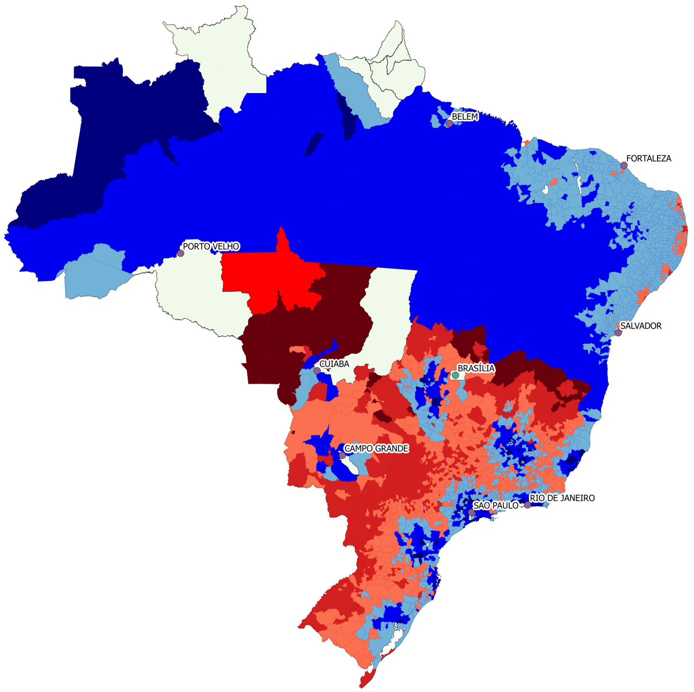
AMC: 22 AMC7097 037, with bands around straight lines displayed, allowing the calculation of the area of the AMC within each band.

	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 = (5 x 0) + (15 x 0) + (25 x .208) + (35 x .434) + (45 x .340) + (55 x .018) = 36.68

Figure 4: Marginal Effects of a fall in cost of access to the State Capital on Population



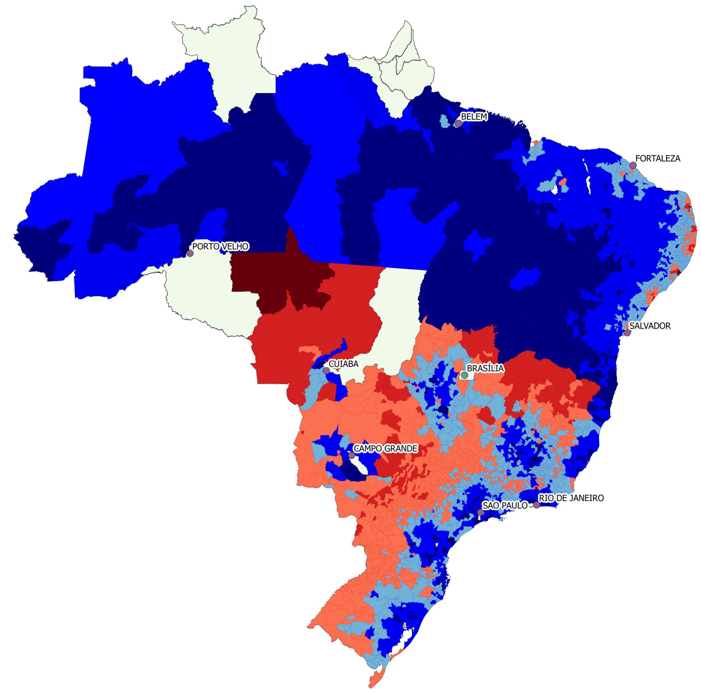
Deeper blues represent a stronger positive impact on population,

ie. a fall in travel costs to State Capital results in higher population.

Deeper reds represent a stronger negative impact.

Map constructed using estimates from table 4.

Figure 5: Marginal Effects of a fall in cost of access to the State Capital on GDP



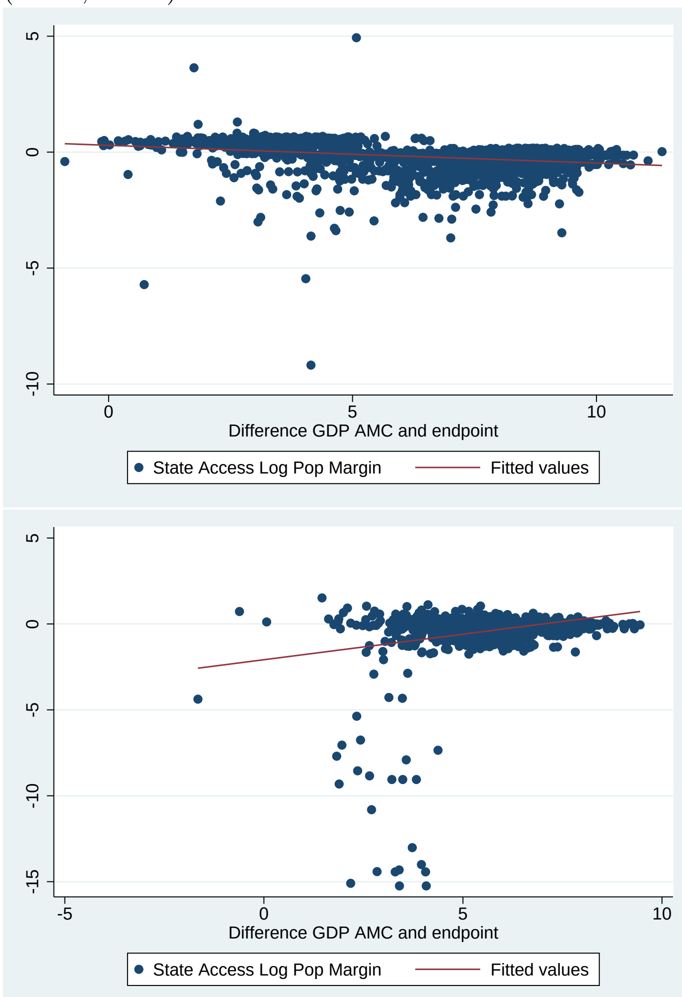
Deeper blues represent a stronger positive impact on GDP,

ie. a fall in travel costs to State Capital results in higher GDP.

Deeper reds represent a stronger negative impact.

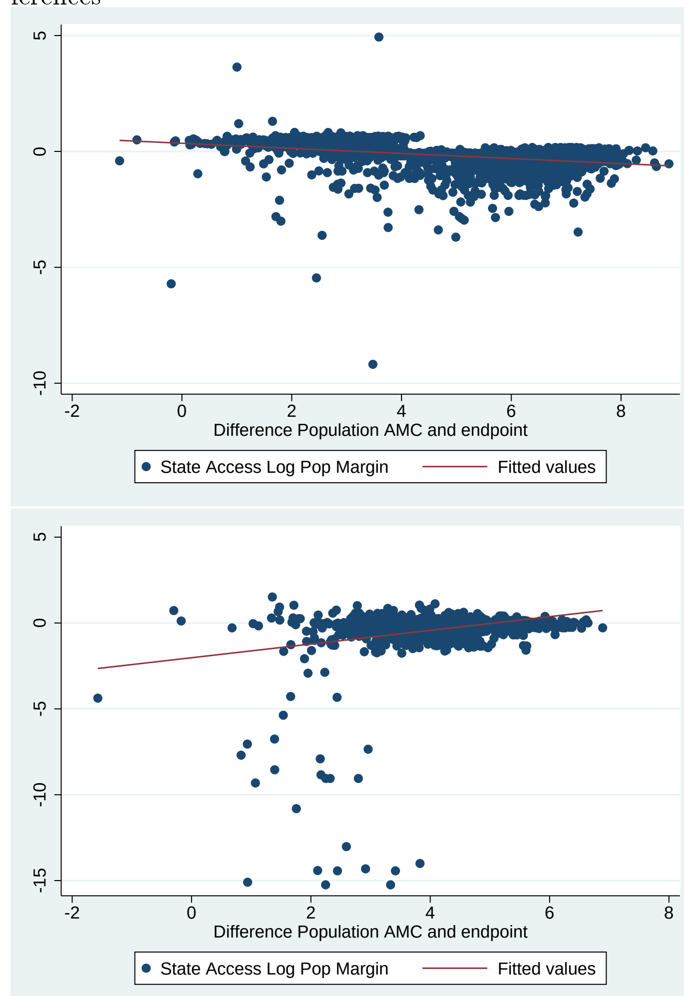
Map constructed using estimates from table 4.

Figure 6: Marginal Effects (Population) on GDP differences (South, North)



Marginal effects of a change in cost of access on population levels, against the difference in GDP between AMC and endpoint. Negative values occur when a fall in costs of access results in higher population levels.

Figure 7: Marginal Effects (Population) on Population differences



Marginal effects of a change in cost of access on population levels, against the difference in population between AMC and endpoint. Negative values occur when a fall in costs of access results in higher population levels.

Supplementary Appendix

(not for publication)

The Model

Given output $Y_i = A_i K_i^{\alpha} L_i^{1-\alpha}$, the profit maximization problem is t as:

$$\max_{K,L} p(1-d)A_i K_i^{\alpha} L_i^{1-\alpha} - w_c(1-\eta d)L - r_c(1-\rho d)K,$$

where d is equal to 0 if $i = c$, and is strictly positive and between 0 and 1 otherwise.

The first order conditions are given by:

$$(1-\eta d)w_c = p(1-d)A_i(1-\alpha)\left(\frac{K_i}{L_i}\right)^{\alpha}\overline{K}_i^{\beta_i},$$

and

$$(1-\rho d)r_c = p(1-d)A_i\alpha\left(\frac{L_i}{K_i}\right)^{1-\alpha}\overline{K}_i^{\beta_i}.$$

Expressing K as a function of L yields:

$$\frac{K_i}{L_i} = \frac{(1-\eta d)w_c}{(1-\rho d)r_c}\frac{\alpha}{1-\alpha}. \tag{1}$$

Reinserting this into the production function $Y_i = A_i K_i^{\alpha} L_i^{1-\alpha}$, we get equation (1).

It immediately follows that the derivative of the terms in bracket on the right hand side of equation (2) with respect to d is given by:

$$\frac{\partial \frac{(1-\eta d)w_c}{(1-\rho d)r_c}\frac{\alpha}{1-\alpha}}{\partial d} = \frac{\rho-\eta}{(1-\rho d)^2}\frac{w_c}{r_c}\frac{\alpha}{1-\alpha},$$

from which proposition 1 results.

Data

GDP Data

Andrade et al. (2004) describe the way IPEA estimates the municipality-level GDP data. The first step involves calculating a municipality-level proxy for the value added in agriculture, industry, and services respectively. For agriculture, it combines gross total production and total expenditures in the local agricultural sector from the Municipal Agricultural Census to generate a proxy for the value added by agriculture in each municipality, and similarly for the valued added in industry and services. This is then aggregated at the State level for every sector. Finally, the municipality-level shares in the State level value added in each sector are determined, and multiplied by the States' sector GDP as provided by IBGE. The result is a set of estimates of municipality sector-level GDP, which sum to equal total GDP.

Cost of Access Data

Castro first identified main traffic nodes across Brazil. For each of these nodes and each of the three dates concerned, he identified the shortest route to the State Capital and São Paulo, with the connecting roads, and their quality. The distances between each node were then calculated, with unpaved roads weighted at 1.5 times that of paved roads due to the increased time of travel, and waterways weighted at 10 times the cost of paved roads. 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 a neighboring municipality, adding the expected distance from this node weighted by 2 to represent the likely poor quality of any connection.

Reduced Form

Alternatively to model 3 in the main text, one can estimate the reduced form model in differences:

$$\Delta Y_{is} = \alpha_0 + \alpha_1 D_{is} + X_{is}'\alpha_2 + \theta_s + \varepsilon_{is}, \tag{2}$$

where ΔY_{is} is the change in the outcome of interest in MCA i and State s over the period of interest (alternatively 1970-2000, and sub-periods 1970-1980 or 1980-2000), estimated again as a function of distance to the lines D_{is} and a set of controls for MCAs' initial conditions and fixed characteristics X_{is}, as well as State fixed effects.

Results for this specification are in Table A2. Over the period 1970-2000, municipalities closer to the lines experienced increases in population, GDP and GDP per capita relative to their more distant counterparts (column 1). The respective elasticities are 0.068, 0.064, and 0.031 respectively and are statistically significant at the 1% level. When an interaction between distance and a Northern dummy is included, the effects are similar, and stronger in the Southern part of the country, with elasticities of 0.082, 0.096, and 0.044 for population, GDP and GDP per capita respectively, compared to values of 0.043, 0.09, and 0.035 for the North.[1]

All these results hold for the two sub-periods 1970-80, and 1980-2000, although for GDP per capita, the effect is only significant in the South, and in the second sub-period. In terms of magnitude, effects on population are stronger in the first sub-period, while for GDP they are stronger in the second one.

Benchmarking the magnitude of these effects as above, we find similar orders of magnitude, with differences stemming from the distance to the line representing one third of the change over the 1970-2000 period, while for GDP and GDP per capita, the same ratio is only 7.6% and 7.3%.

[1] An F test fails to reject that the combined effects in the North are equal to zero for both GDP and GDP per capita. The Northern Population effect is significant.

Additional Results

Population Shares

Table A4 in the appendix, Panels A and B, provide further details on the evolution of population, by looking at the changes in urban/rural and male/female shares across the country's MCAs.

We focus on the specification including the North dummy interactions. In Panel A, the impact of a reduction of access costs to the state capitals on urban-rural shares appears to be insignificant. In Panel B, Southern locations with effective distance less than 90km have higher female shares. These thresholds are close to the one found above for population. This is consistent with international evidence showing that women, especially those in younger age group, move to urban centers in greater numbers than men, driven by both work and marriage prospects (e.g., Edlund, 2000).

Sectors of Production

We investigate specific areas of production to see if they can help explain these results. In Table A4, panel C, we run estimations for the (log) GDP of agriculture, industry, and services. Improved access to State capitals leads again to the dual pattern found in Section 6. Industry and service GDP increase in the South around the urban centers and the effect is reversed as effective distance grows. The respective thresholds are 300km for services and 4650km for industry. In the North, a reversed pattern again holds close to State capitals, where both industry and service GDP decrease, while they start growing when distance exceeds 100 and 20km respectively.

Moreover, it is possible that differences in growth rates led to changes in the relative importance of each sector, qualitatively altering the mix of local production. To investigate this, panel D, shows a similar set of estimations where the dependent variables are now sector shares in total GDP. The results indicate a relative decrease of the share of industry around main urban centers in the South (up to 230km) compensated to some extent by an increase in agriculture and services.

Robustness Checks

First, in Table A5, we include a time interaction term on initial municipality levels of water, electricity and toilet access. This controls for trends in improvements in other infrastructure services. Municipalities nearer the straight lines may benefit from more investment in these other infrastructure services, for example electricity networks may be focused along the routes connecting main urban centers. Alternatively the lines may not affect provision of these services, with municipalities investing equally across space. Controlling for an overall trend in infrastructure improvements means that the coefficients on cost of access are purged from the effect of localized improvements in other services that are due to being nearer or further from these transport corridors, reinforcing our conditional excludability condition.

Panel A gives the Population results, in which we see that the sign of the effect remains the same, although the size is slightly reduced. This suggests that other infrastructure services are acting against this pull on population; improved services do not appear to be focused on the transport corridors, and hence may keep people from moving towards them. Similarly in the North, we find the results keep the same sign as in the standard regression in Table 4, however the size of the results is slightly smaller. The effect of a reduction in transport cost is reduced by local variations in improvements in other infrastructure services.

The same pattern is observed in the GDP results in panel B. The impact on GDP per capita in panel C shows the reverse effect to those seen in Table 4. However, as before, the effects are small and insignificant. This further suggests that the impact of reductions in cost of access on GDP per capita is ambiguous, and that the population and GDP effects cancel each other out on average.

As can be seen visually in Figures 4 and 5, municipalities in Brazil vary substantially in their area. To ensure our results are not biased by this size asymmetry, Table A6 shows weighted estimations, in which we weight the municipality-level observations by 1/area. In the South, the results are similar to those in Table

4, although the sizes of the effects are again slightly reduced. In the North, the GDP results remain similar to the standard regression in Table 4, while the population effects are reduced, with the direct effect of cost of access on population no longer being significant (the coefficient on squared cost of access is now only significant at 5%). The net effect of a reduction in the cost of access on population is now consistent with the Southern results, with population increasing around urban centers.

This is not surprising, as it is in the North where the majority of larger municipalities are located, so the weighted regression has a greater effect on this part of the data. This may be partly explained if the emerging secondary cities discussed in Section 6.1 are located in the larger municipalities observed in the North, and therefore their influence is reduced in the weighted regression, hiding their impact from our results. In consequence, we see GDP per capita being marginally affected in the North (at the 10% level), and locations near state capitals see a fall in their GDP per capita, as those locations further away gain from a reduction in transport costs; secondary centers of output are being formed, but population relocation to these areas does not entirely compensate for this.

Cost of Access to São Paulo

Table A7 shows the first-stage results when using the cost of access to São Paulo as the R variable in (6) and (7). The F-statistic for the joint significance of the excluded instruments is 19.3, and 14.5 when a Northern dummy interaction is added.

In terms of effects, locations benefited more from both state and municipal roads the closer they are to the lines, while the reverse hold for federal paved roads. However, as we would expect, interactions with a North dummy are not significant in this case. The closest Northern MCAs are more than 1,200 effective kilometers away from São Paulo.

Second stage results are in Table A8, with panel A corresponding to population, panel B to GDP, and panel C to GDP per capita. The OLS estimates in columns 1, 4 and 7 show outcomes very similar to those using the cost of access to the State capitals discussed in the main text. Both Population and GDP increased in areas close enough to São Paulo, and this effect was reversed for locations farther away. The results are confirmed by the 2SLS estimates in columns 2, 5 and 8, with larger values of the coefficients, and thresholds of 330km for population and 400km for GDP respectively.

For GDP per capita, the OLS results are significant and display again a non-linear impacts of a fall in travel costs, with locations close to São Paulo experiencing a decrease, and locations farther away an increase. The 2SLS estimates in column 8 are insignificant.

Finally, when adding an interaction with a dummy equal to 1 for Northern MCAs, the results for the South hold, but we fail to find the dual pattern uncovered for the cost of access to the State capitals. The fact that our instruments do not perform very well for Northern interactions, and that the point estimates for the South are largely unchanged in columns 3, 6 and 9 leads us to lend little credit to the North results.

Appendix Tables and Figures

Table 1: A1 First Stage Pooled Cross Section

VARIABLES	Log Cost of Access to State Capital (1)	Log Cost of Access to State Capital with North dummy (2)
Log Distance from Lines	0.0745***	0.1104***
	(0.0124)	(0.0150)
Northern * Distance		-0.1024***
		(0.0244)
Constant	5.6265***	6.1491***
	(0.2879)	(0.3115)
Observations	3,638	3,638
R^2	0.6503	0.6524
Chi2 all instruments significant	36.00	53.99
Prob.	0	0

Table A1 reports the first stage of the two-stage least square estimations reported in Table 3. It estimates cost of access to the state capital in municipality i and State s in 2000 as a function of distance to the lines. Controls include state dummies, as well as the municipalities distance to Brasília, Sao Paulo and the state capital, dummies for whether the Amazon intersects with the municipality, and whether the municipality is near the coast, and the municipalities area, and water, toilet and light access. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors clustered at the municipality level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 2: A2 Reduced Form

		A		B		C	
		Log Population		Log GDP		Log GDP/cap	
YEAR	VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
1970-2000	Log Distance from Lines	-0.0684***	-0.0823***	-0.0640***	-0.0961***	-0.0309***	-0.0435***
		(0.0102)	(0.0124)	(0.0159)	(0.0192)	(0.0099)	(0.0120)
	Northern * Distance		0.0391**		0.0903***		0.0354*
			(0.0199)		(0.0308)		(0.0191)
	Log Population 1970	0.0286***	0.0285***				
		(0.0086)	(0.0086)				
	Log GDP 1970			-0.1400***	-0.1398***		
				(0.0109)	(0.0109)		
	Log GDP per capita 1970					-0.6862***	-0.6857***
						(0.0142)	(0.0142)
	R^2	0.3688	0.3695	0.1920	0.1939	0.5172	0.5177
1970-1980	Log Distance from Lines	-0.0447***	-0.0545***	-0.0240*	-0.0370***	-0.0052	-0.0005
		(0.0057)	(0.0063)	(0.0127)	(0.0142)	(0.0101)	(0.0113)
	Northern * Distance		0.0306***		0.0404**		-0.0149
			(0.0090)		(0.0201)		(0.0159)
	Log Population 1970	0.0361***	0.0363***				
		(0.0048)	(0.0048)				
	Log GDP 1970			-0.0791***	-0.0784***		
				(0.0088)	(0.0088)		
	Log GDP per capita 1970					-0.5193***	-0.5201***
						(0.0145)	(0.0145)
	R^2	0.3008	0.3030	0.1105	0.1115	0.3640	0.3641
1980-2000	Log Distance from Lines	-0.0288***	-0.0363***	-0.0499***	-0.0678***	-0.0349***	-0.0417***
		(0.0064)	(0.0077)	(0.0126)	(0.0153)	(0.0090)	(0.0109)
	Northern * Distance		0.0213*		0.0505**		0.0191
			(0.0124)		(0.0246)		(0.0175)
	Log Population 1980	0.0303***	0.0302***				
		(0.0050)	(0.0050)				
	Log GDP 1980			-0.1038***	-0.1040***		
				(0.0084)	(0.0084)		
	Log GDP per capita 1980					-0.5860***	-0.5859***
						(0.0138)	(0.0138)
	R^2	0.3273	0.3279	0.2057	0.2066	0.4677	0.4679
	Observations	3,644	3,644	3,644	3,644	3,644	3,644

Table A2 reports reduced form estimations of changes in population (col. 1 & 2), GDP (col. 3 & 4) and GDP per capita (col. 5 & 6) in municipality i and State s in 2000, estimated as a function of distance to the lines and a set of controls including state dummies, as well as the municipality distance to Brasília, Sao Paulo and the state capital, dummies for whether the Amazon intersects with the municipality, and whether the municipality is near the coast, and the municipality's area, and water, toilet and light access. The upper panel reports estimates of the 1970-2000 change in outcomes, the intermediate panel reports estimates of the 1970-1980 changes, and the lower panel reports estimates of the 1980-2000 changes. Standard errors clustered at the municipality level are in parentheses. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 3: A3 First Stage of full 2SLS

VARIABLES	Log State Capital Travel Cost	Log State Capital Travel Cost with North dummy
km of federal paved roads/area*distance	-46.8946***	-21.0440**
	(12.8050)	(9.2735)
km of state roads/area*distance	-2.5107	21.3469***
	(11.4583)	(6.2040)
km of municipal roads/area*distance	-0.2526	-2.6789***
	(1.4814)	(0.9479)
Northern * km of federal paved roads/area*distance		-7.4216
		(61.8975)
Northern * km of state roads/area*distance		-65.2038**
		(25.5943)
Northern * km of municipal roads/area*distance		10.6998***
		(1.7669)
Observations	10,914	10,914
R^2	0.2018	0.2091
Number of _ID	3,638	3,638
F Test all instruments significant	12.78	12.86
All prob>F	0	0

Table A3 reports the first stage of the two-stage least square estimations reported in Table 4. It estimates cost of access to the state capital in municipality i and State s and time t as a function of distance to the lines interacted with measures of the stocks in kilometers of federal, state, and municipal roads per squared-kilometers in State s at time t. Controls include municipality fixed effects, state-year dummies, as well as the municipalities average water, toilet and light access in each period t. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors double-clustered at the municipality and state-year level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 4: A4 Two Stage Least Squares: Population and GDP shares

	A			B		
	Urban Population Share			Female Population Share		
	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	OLS	2SLS	2SLS	OLS	2SLS	2SLS
Log Cost of Access to State Capital	0.1144	0.1188	0.0921	-0.0149***	-0.0403*	-0.0427
	(0.0697)	(0.2485)	(0.2603)	(0.0050)	(0.0224)	(0.0264)
Squared Log Cost of Access to State Capital	-0.0106*	-0.0165	-0.0145	0.0016***	0.0042**	0.0047**
	(0.0061)	(0.0190)	(0.0203)	(0.0005)	(0.0017)	(0.0018)
Northern * Log Cost of Access to State Capital			-0.4194			0.0315
			(0.5218)			(0.0603)
Northern * Squared Log Cost of Access to State Capital			0.0370			-0.0034
			(0.0400)			(0.0046)
Observations	10,914	10,914	10,914	10,914	10,914	10,914
R^2	0.8458			0.2873		
Number of _ID	3,638	3,638	3,638	3,638	3,638	3,638

	C			D		
	Log GDP agriculture	Log GDP industry	Log GDP services	Prop. agriculture	Prop. industry	Prop. services
	(7)	(8)	(9)	(10)	(11)	(12)
VARIABLES	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS
Log Cost of Access to State Capital	-0.5529	-2.3078	-6.5013***	-0.5945	0.7936	-0.0254
	(1.7931)	(1.4019)	(0.8188)	(0.6728)	(0.5450)	(0.3883)
Squared Log Cost of Access to State Capital	0.0333	0.1370	0.5604***	0.0436	-0.0749	0.0144
	(0.1148)	(0.1107)	(0.0556)	(0.0530)	(0.0485)	(0.0223)
Northern * Log Cost of Access to State Capital	2.8666	7.9175**	7.6178***	0.3733	-0.3147	-0.5168
	(3.9704)	(3.2388)	(1.9455)	(1.0428)	(0.7131)	(0.9916)
Northern * Squared Log Cost of Access to State Capital	-0.2532	-0.7312***	-0.7301***	-0.0220	0.0279	0.0269
	(0.2996)	(0.2474)	(0.1442)	(0.0795)	(0.0563)	(0.0725)
Observations	10,901	10,908	10,914	10,914	10,914	10,914
R^2	0.4642			0.5807		
Number of _ID	3,635	3,638	3,638	3,638	3,638	3,638

Table A4 reports the second stage of two-stage least square estimations of urban population shares (panel A, col. 1 to 3), female population shares (panel B, col. 4 to 6), log sector GDP (panel C, col. 7 to 9), and sector GDP shares (panel D, col. 10 to 12) in municipality i, State s, and time t, estimated as a function of cost of access to the state capital and cost of access squared, using the command xtivreg2 (Schaffer, 2010). The Cost of access variables are instrumented using distance to the lines, interacted with measures of the stocks in kilometers of federal, state, and municipal roads per squared-kilometers in State s at time t (see first stage in A3). Controls include municipality fixed effects, state-year dummies, as well as the municipalities' average water, toilet and light access in each period t, partialled out for the estimation of the standard errors. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors double-clustered at the municipality and state-year level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 5: A5 Robustness: Time Interaction on Initial Water, Electricity and Toilet Access

	A		B		C	
	Log Population		Log GDP		Log GDP/cap	
VARIABLES	(1)	(2)	(1)	(2)	(1)	(2)
Log Cost of Access to State Capital	-4.8604***	-4.7769***	-4.7427***	-5.6393***	0.1177	-0.8623
	(0.9471)	(0.8248)	(1.2997)	(1.1136)	(0.9146)	(0.8005)
Squared Log Cost of Access to State Capital	0.4288***	0.4347***	0.4006***	0.4586***	-0.0282	0.0239
	(0.0628)	(0.0641)	(0.0795)	(0.0791)	(0.0514)	(0.0431)
Northern * Log Cost of Access to State Capital		6.9796***		8.4809***		1.5013
		(1.4238)		(2.0525)		(2.0098)
Northern * Squared Log Cost of Access to State Capital		-0.6509***		-0.7481***		-0.0972
		(0.1079)		(0.1558)		(0.1502)
Observations	10,914	10,914	10,914	10,914	10,914	10,914
Number of _ID	3,638	3,638	3,638	3,638	3,638	3,638

Table A5 reports the second stage of two-stage least square estimations of log population (panel A, col. 1 & 2), log GDP (panel B, col. 1 & 2) and log GDP per capita (panel C, col. 1 & 2) in municipality i, State s, and time t, estimated as a function of cost of access to the state capital and cost of access squared, using the command xtivreg2 (Schaffer, 2010). The Cost of access variables are instrumented using distance to the lines, interacted with measures of the stocks in kilometers of federal, state, and municipal roads per squared-kilometers in State s at time t (see first stage in the Appendix). Controls include municipality fixed effects, state-year dummies, municipalities' average water, toilet and light access in each period t, and a time interaction with initial municipality levels of water, electricity and toilet access, partialled out for the estimation of the standard errors. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors double-clustered at the municipality and state-year level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 6: A6 Robustness: Weighted Regresion (1/Area)

	A		B		C	
	Log Population		Log GDP		Log GDP/cap	
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Log Cost of Access to State Capital	-3.5263***	-3.5599**	-3.2195***	-3.3994**	0.3068	0.1605
	(1.1042)	(1.4858)	(1.1667)	(1.3880)	(0.8569)	(0.9084)
Squared Log Cost of Access to State Capital	0.4173***	0.4153***	0.3695***	0.3779***	-0.0478	-0.0374
	(0.0750)	(0.0893)	(0.0746)	(0.0845)	(0.0561)	(0.0550)
Northern * Log Cost of Access to State Capital		0.6322		4.0385		3.4063
		(2.4914)		(2.5135)		(2.1723)
Northern * Squared Log Cost of Access to State Capital		-0.1513		-0.4776**		-0.3263*
		(0.1901)		(0.2051)		(0.1807)
Observations	10,914	10,914	10,914	10,914	10,914	10,914
Number of _ID	3,638	3,638	3,638	3,638	3,638	3,638

Table A6 reports the second stage of weighted two-stage least square estimations of log population (panel A, col. 1 & 2), log GDP (panel B, col. 1 & 2) and log GDP per capita (panel C, col. 1 & 2) in municipality i, State s, and time t, estimated as a function of cost of access to the state capital and cost of access squared, using the command xtivreg2 (Schaffer, 2010). The weights are the inverse of municipalities' area. The Cost of access variables are instrumented using distance to the lines, interacted with measures of the stocks in kilometers of federal, state, and municipal roads per squared-kilometers in State s at time t (see first stage in the Appendix). Controls include municipality fixed effects, state-year dummies, municipalities' average water, toilet and light access in each period t, and a time interaction with initial municipality levels of water, electricity and toilet access, partialled out for the estimation of the standard errors. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors double-clustered at the municipality and state-year level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 7: A7 First Stage using Access to São Paulo

VARIABLES	Log São Paulo Travel Cost (1)	São Paulo Travel Cost (2)
km of federal paved roads/area*distance	-56.3802***	-62.6948***
	(7.5875)	(8.3983)
km of state roads/area*distance	10.6428**	5.1613
	(4.8665)	(5.6349)
km of municipal roads/area*distance	1.3862	1.8183*
	(0.9539)	(1.0712)
Northern * km of federal paved roads/area*distance		17.1886
		(49.3896)
Northern * km of state roads/area*distance		6.8115
		(19.6505)
Northern * km of municipal roads/area*distance		-0.7331
		(1.3041)
Observations	10,932	10,932
R^2	0.3182	0.3197
Number of _ID	3,644	3,644
F Test all instruments significant	19.27	14.49
All prob>F	0	0

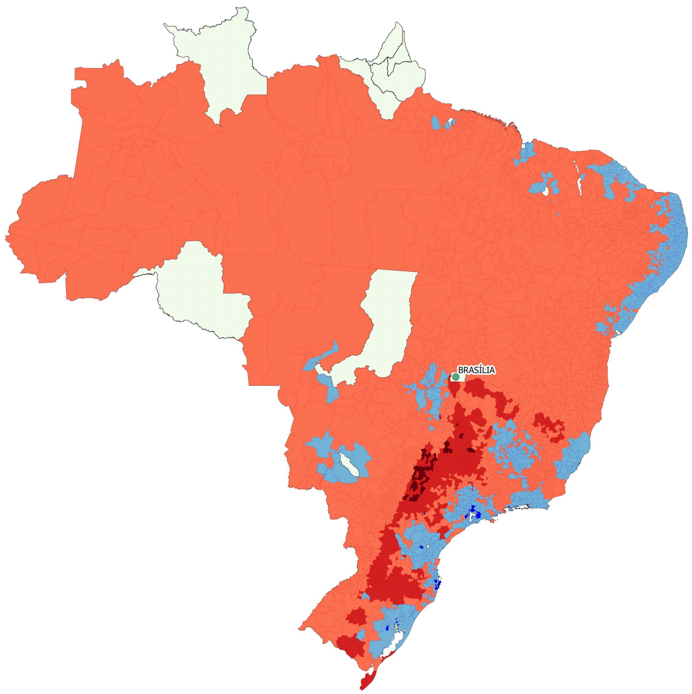
Table A7 reports the first stage of the two-stage least square estimations reported in Table A8. It estimates cost of access to Sao Paulo in municipality i and State s and time t as a function of distance to the lines interacted with measures of the stocks in kilometers of federal, state, and municipal roads per squared-kilometers in State s at time t. Controls include municipality fixed effects, state-year dummies, as well as the municipalities average water, toilet and light access in each period t. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors double-clustered at the municipality and state-year level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Table 8: A8 2SLS using Access to São Paulo

	A Log Population			B Log GDP			C Log GDP/cap		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	OLS	2SLS	2SLS	OLS	2SLS	2SLS	OLS	2SLS	2SLS
Log Cost of Access to Sao Paulo	-2.3277***	-4.2883***	-3.7200***	-1.8743***	-3.5797**	-3.4434**	0.4535	0.7086	0.2765
	(0.3707)	(1.0610)	(0.9160)	(0.5587)	(1.5634)	(1.4571)	(0.3685)	(1.2152)	(1.2140)
Squared Log Cost of Access to Sao Paulo	0.2004***	0.3591***	0.3315***	0.1438***	0.2996***	0.2948***	-0.0567*	-0.0595	-0.0367
	(0.0353)	(0.0644)	(0.0590)	(0.0517)	(0.0887)	(0.0837)	(0.0302)	(0.0679)	(0.0670)
Northern * Log Cost of Access to Sao Paulo			-43.4159			-37.0074			6.4085
			(27.8610)			(60.9103)			(38.3601)
Northern * Squared Log Cost of Access to Sao Paulo			2.6622			2.2722			-0.3900
			(1.7421)			(3.8178)			(2.4064)
Observations	10,932	10,932	10,932	10,932	10,932	10,932	10,932	10,932	10,932
R^2	0.4362			0.7364			0.7260		
Number of _ID	3,644	3,644	3,644	3,644	3,644	3,644	3,644	3,644	3,644

Table A8 reports the second stage of two-stage least square estimations of log population (col. 1 to 3), log GDP (col. 4 to 6) and log GDP per capita (col. 7 to 9) in municipality i, State s, and time t, estimated as a function of cost of access to Sao Paulo and cost of access squared, using the command xtivreg2 (Schaffer, 2010). The Cost of access variables are instrumented using distance to the lines, interacted with measures of the stocks in kilometers of federal, state, and municipal roads per squared-kilometers in State s at time t (see first stage in the Table A7). Controls include municipality fixed effects, state-year dummies, as well as the municipalities' average water, toilet and light access in each period t, partialled out for the estimation of the standard errors. The geographical unit used is IPEA's 1970 Minimal Comparable Areas (AMC 70-00), which covers 3,599 municipal areas, comparable at any point between 1970 and 2000. Standard errors double-clustered at the municipality and state-year level are in parentheses. Stars indicate statistical significance at the 1% (***), 5% (**), and 10% (*) level respectively.

Figure 1: A1: Marginal Effects of a fall in cost of access to the State Capital on GDP, using interaction on endpoint initial GDP



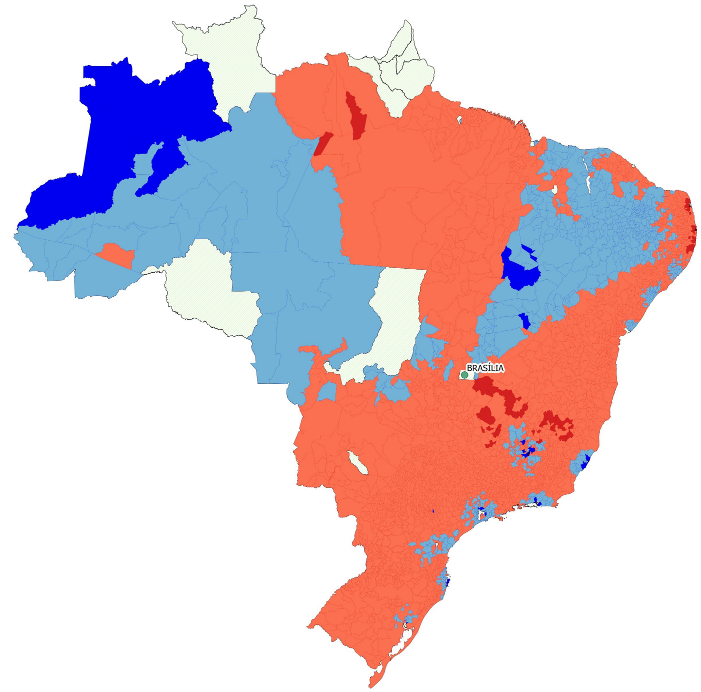
Deeper blues represent a stronger positive impact on GDP,

ie. a fall in travel costs to State Capital results in higher GDP.

Deeper reds represent a stronger negative impact.

Map constructed using estimates from Table 4.

Figure 2: A2: Marginal Effects of a fall in cost of access to the State Capital on GDP, using interaction on endpoint initial water access proportions



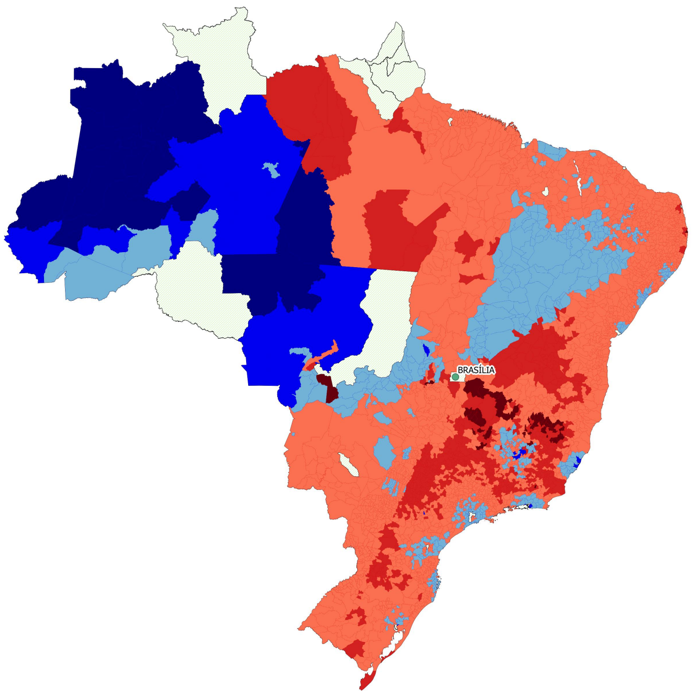
Deeper blues represent a stronger positive impact on GDP,

ie. a fall in travel costs to State Capital results in higher GDP.

Deeper reds represent a stronger negative impact.

Map constructed using estimates from Table 4.

Figure 3: A3: Marginal Effects of a fall in cost of access to the State Capital on GDP, using interaction on endpoint initial schooling levels



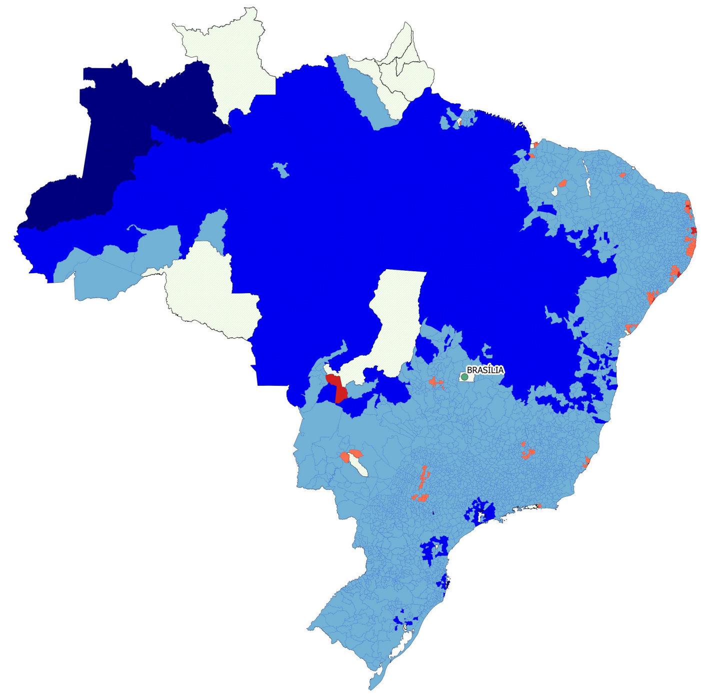
Deeper blues represent a stronger positive impact on GDP,

ie. a fall in travel costs to State Capital results in higher GDP.

Deeper reds represent a stronger negative impact.

Map constructed using estimates from Table 4.

Figure 4: A4: Marginal Effects of a fall in cost of access to the State Capital on GDP, using interaction on endpoint initial manufacturing to services ratio



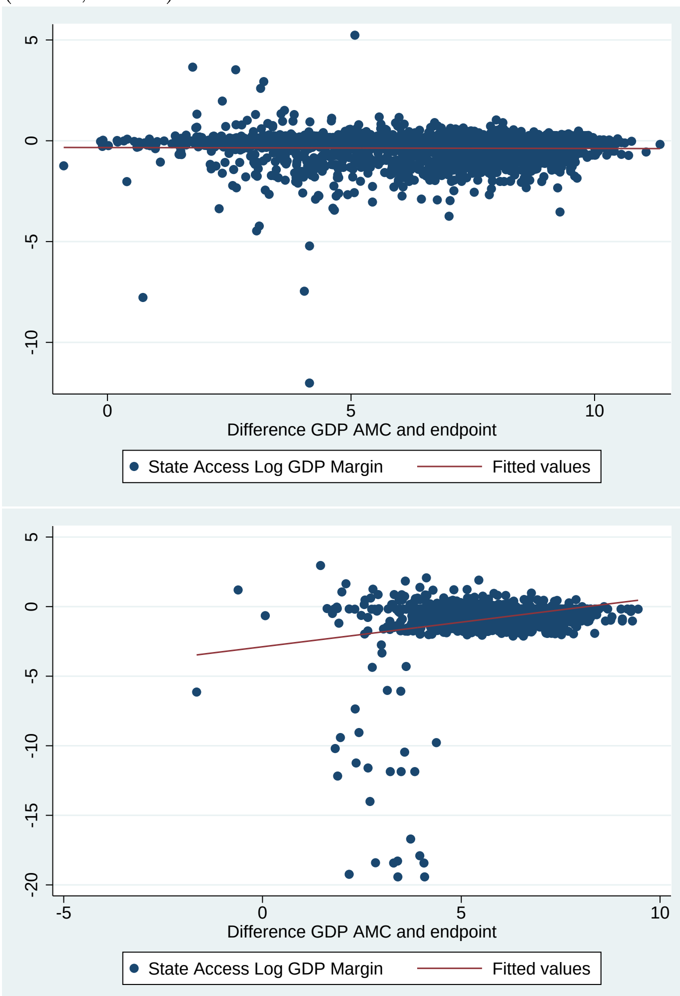
Deeper blues represent a stronger positive impact on GDP,

ie. a fall in travel costs to State Capital results in higher GDP.

Deeper reds represent a stronger negative impact.

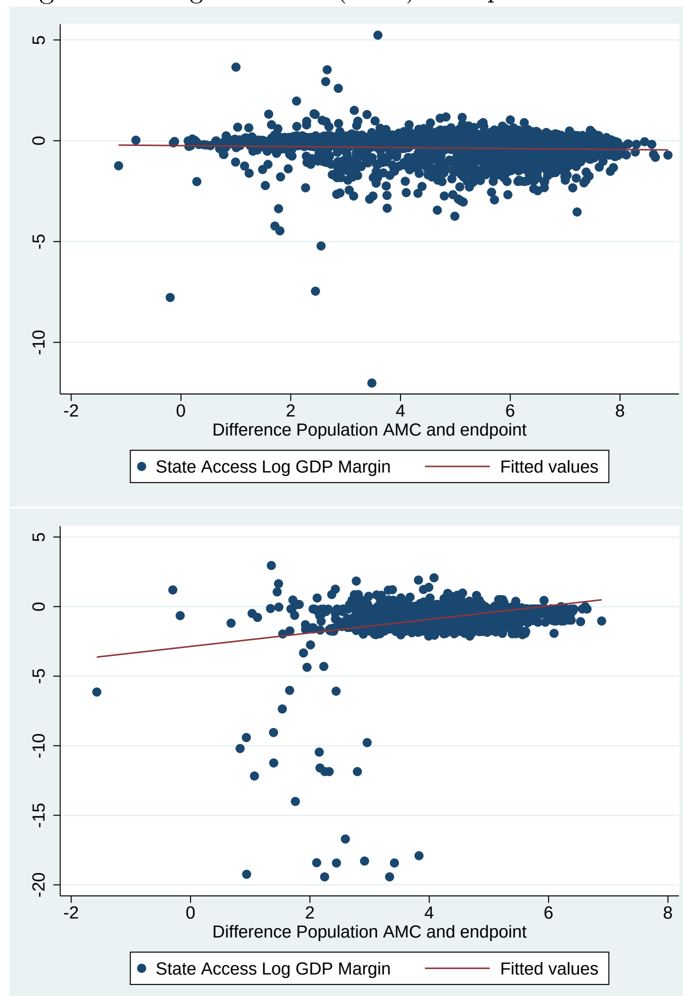
Map constructed using estimates from Table 4.

Figure 5: A5 Marginal Effects (GDP) on GDP differences (South, North)



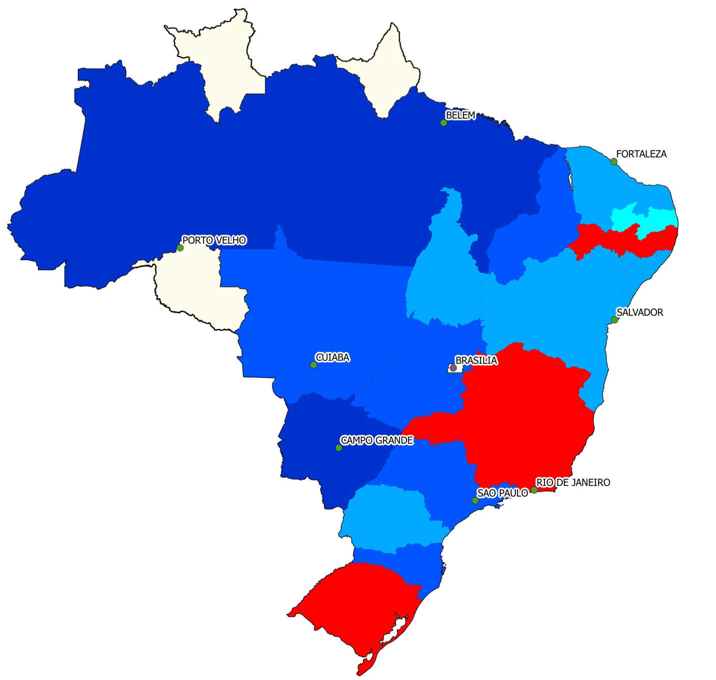
Marginal effects of a change in cost of access on GDP, against the difference in GDP between AMC and endpoint. Negative values occur when a fall in costs of access results in higher population levels.

Figure 6: Marginal Effects (GDP) on Population differences



Marginal effects of a change in cost of access on GDP, against the difference in population between AMC and endpoint. Negative values occur when a fall in costs of access results in higher population levels.

Figure 7: State level GDP per capita impacts of road improvements, as ratio of actual GDP per capita growth 1970-2000



Impact on fall in costs of access on GDP/cap as a ratio of actual change

calculated using marginal effects derived from Table 4

Deeper blues represent higher proportion of GDP/cap explained by road improvements.

Reds represent states where GDP per capita was reduced by road placement.

Appendix References

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