

Infrastructure and income inequality: an application to the Brazilian case using hierarchical spatial autoregressive models

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ABSTRACT

Many scholars have highlighted the role of infrastructure in reducing income inequality. Developing economies present immense regional and income discrepancies, which are correlated with unequally distributed infrastructure in territorial and population terms. In this paper, we assess the effects of infrastructure supply on income inequality and verify whether these effects vary according to the infrastructure sector and its degree of quality and access in Brazil. The analysis is based on spatial hierarchical models. Results allow us to say that infrastructure correlates negatively with income inequality. Hence, policies aimed at improving infrastructure quality and expanding access are crucial for reducing income concentration.

KEYWORDS

Infrastructure; income inequality; Brazil; spatial econometrics; multilevel approach

JEL

H54; D31; C21; R11

1. INTRODUCTION

In a context of strong fiscal adjustment, economic stagnation and rising income inequality in many developing countries, many economists have pointed to investment in infrastructure as a key variable that can foster economic growth with a reduction in poverty and social inclusion (Ali & Pernia, 2003; Calderón & Servén, 2014). Previous studies have proven the importance of infrastructure as a promoter of economic growth through increasing productivity of production factors, improvements in competitiveness and trade, as well as its complementary effects in the formation of higher levels of private investment (Aschauer 1989, 2004; Calderón, Moral-Benito & Servén, 2014; Munnell, 1992). Nevertheless, the possible channels of transmission of infrastructure on income inequality are unclear.

From a theoretical perspective, an adequate infrastructure provides several positive social impacts that include, in addition to improving environmental conditions and energy use, better education and health conditions, access to public goods and services, equality and social inclusion. Finally, infrastructure is seen as a tool for structural change in the economy since it unites transversal advances in economic, environmental and social terms, generating a process of sustained economic and inclusive growth, thus benefiting the poorest part of the population (Sanchez et al., 2017; United Nations, 2016).

Empirical studies about that theme, however, are still very scarce, with substantial differences found in the main results.¹ While some conclusions point to a positive or null relationship between infrastructure and income inequality (Bajar & Rajeev, 2015; Makmuri, 2017; Mendoza, 2017), other researches indicate that infrastructure expansion is a key factor in reducing inequalities (Calderón & Chong, 2004; Calderón & Servén, 2004, 2010; Hooper et al., 2017; Makmuri, 2017; Raychaudhuri & De, 2010; Seneviratne & Sun, 2013). In addition to the scarcity of studies, many limitations can be noted in the existing literature. A first point concerns the variables used. Few studies take into account different aspects of infrastructure, such as supply, quality and access. Infrastructure supply indicators alone may say little about the impacts of infrastructure on issues such as inequality and poverty, since the expansion of these assets can be concentrated on richer and urbanized regions, not necessarily translating into greater supply for the poorest. Another issue that is not explicitly addressed in the literature on infrastructure and inequality concerns spatial issues. Theoretically speaking, infrastructure affects the choices of both firms and families, and since it is distributed asymmetrically between regions, it decisively influences agents' localization decisions such as migration, establishment of new companies, capital investment in different locations etc. (Ottaviano, 2008). Empirical studies on infrastructure and economic growth have proven the existence of such proximity spatial interactions (Arbués et al., 2015; Cosci & Mirra, 2017; Del Bo & Florio, 2008, 2012); however, although it is likely, it is unknown whether the same pattern of interaction can be observed for inequality.

The Brazilian case presents interesting peculiarities. We observe a setback of a long cycle of falling income inequality, which began at the end of the 1990s. In 2015, the country shows the first high in the Gini Index since the turn of the century. In addition to the worsening of inequality indicators, there is a sharp drop in infrastructure investment, which was around 1.5% of GDP in 2017 (ABDID, 2018), one of the lowest levels of infrastructure investment in the country history. While these investments exceeded 6% of GDP in the 1970s, the current ratio does not even cover the infrastructure losses that occur through depreciation. Decades of insufficient investment has contributed to a precarious current infrastructure in several aspects, which include insufficient supply, poor quality and limited population access in most sectors.

Another intriguing specificity of the Brazilian economy refers to the immense regional and income discrepancies.² In relation to the regional contrasts, there are large regional heterogeneities in general represented by an extremely poor and unequal North–Northeast region and a richer and more egalitarian Center–South region. Similarly, one can observe strong spatial autocorrelation patterns in the incidence of inequality in Brazilian states and municipalities (Silva & Leite, 2017), since more unequal municipalities perpetuate similar conditions in terms of poor infrastructure, low educational level, limited governmental technical capacity, poor quality of health etc., propagating a vicious cycle of transmission of these inequalities to their neighbors. The distinctions of income are also remarkable. In 2015, about 85% of the richer population was served with Internet service, while only 21% of the poorer population was covered by this same service. A similar situation is observed with regard to sewage, and there is still a considerable parcel of the poor population who are without access to treated water (Raiser et al., 2017).

In a context that includes immense spatial heterogeneities, as in the Brazilian case, are there any effects of infrastructure supply on income inequality? Do these effects vary according to the infrastructure sector and its degree of quality and access in a particular state or municipality? In order to answer these questions, a broad database of varied indicators for the transportation, power, telecommunications and sanitation sectors is elaborated. This paper tests, for the first time, many of these indicators. The inclusion of several sectoral infrastructure measures, which include supply, quality and access in the sectors analyzed, allow a more realistic and specific analysis of the effects of these sectors on income inequality. In this way, the existence of heterogeneous effects of the infrastructure itself can be verified. Another contribution of this study concerns the inclusion of spatial aspects in the econometric model. In this sense, the use of hierarchical and spatial models is proposed, which allows us to treat both spatial heterogeneity (data distributed at different levels, such as municipalities and states) and spatial autocorrelation (spatial proximity interactions). This is, to the best of our knowledge, the first study that empirically investigates the relationship between infrastructure and income inequality, taking into account spatial dependencies and heterogeneities, as well as infrastructure effects heterogeneities.

The paper is organized as follows. The next section presents the variables used in the study as well as their respective sources and treatment methods. The third section describes the methodologies utilized. The estimated results of infrastructure effects on income inequality, taking into account both spatial heterogeneity and spatial dependence through spatial hierarchical models, are reported in the fourth section. Finally, the conclusions of the work are made.

2. DATABASE AND INFRASTRUCTURE MEASUREMENT STRATEGY

Due to data limitations, the representative variables of supply and quality of the transport, energy and telephony sectors will be arranged in state aggregations. Toward the categories of sanitation and Internet and the access indicators representing electricity and telephony services, the aggregation is taken in municipal character. As it is possible that infrastructure investments take some time to mature and generate effects on economic development (Hooper et al., 2017; Makmuri, 2017), we sought to include previous years together with the year 2010. However, another limitation arising from the unavailability of data is related to the time at which data on infrastructure is available, period that varies according to the sector analyzed. To mitigate possible problems of discrepant observations or null values for some years, averages were calculated for the supply and quality variables for the period 2004–2010. Exceptions are given in the case of telecommunications, where data are available for the

2007–2010 period, and for infrastructure access variables, which, in turn, are for the year 2010. The data sample contains 5,426 observations.

In this way, the infrastructure variables were created following the national and international literature, considering the different sectors that make up the concept of infrastructure (Bajar & Rajeev, 2015; Calderón & Chong, 2004; Calderón & Servén, 2004, 2010; Chakamera & Alagidede, 2017; Makmuri, 2017; Straub & Hagiwara, 2010). Variables to represent the sectors of transportation, power, telecommunications and basic sanitation are captured. Then, the variables disaggregated by sectors are used to generate new measures in order to better describe the multidimensional aspect of infrastructure (Calderón & Servén, 2014). Therefore, indexes representing infrastructure supply, quality and access are created through Principal Component Analysis (PCA), which each one includes—whenever it is available—variables from all infrastructure sectors analyzed in this work.

Finally, we used the variables of supply, quality and access to create “hybrid” indexes of infrastructure, analyzed by sector and in aggregate form. It is assumed that quality can act as a burden that enhances (or limits) the effects of infrastructure supply on income inequality (Chakamera & Alagidede, 2017). Similarly, it is argued that access to infrastructure may weigh the relationship between infrastructure supply and income inequality, whereas this infrastructure can be allocated asymmetrically in the population. In this way, indices for the various sectors were created as the interaction of the supply variables with those of quality and access.

2.1 Infrastructure supply

The first group of representative infrastructure variables is related to their supply level. This type of variable captures the provision of a given infrastructure sector for a given state or municipality. In other words, it concerns the stock of power, transportation, telecommunications and sanitation that is offered for general use by the population.

In relation to the transportation sector, the natural logarithm of the total extension of paved and unpaved roads (km) divided by the state population is used as a proxy variable. To represent the power sector, the indicator residential energy consumption (GWh) *per capita* is used. Regarding telecommunication sector, two quantity variables are used.³ The first one represents Internet supply, being arranged by the natural logarithm of Internet accesses divided by the number of inhabitants of each municipality. The second measure consists in the natural logarithm of the sum of fixed and mobile telephony accesses divided by the number of state inhabitants. Municipal sanitation quantity is represented by the logarithm of the treated water volume distributed per day (m³) *per capita*, which is collected from the National Survey of Basic Sanitation for the year 2008 (IBGE, 2008).

2.2 Infrastructure quality

The second group of infrastructure variables seeks to capture the quality of the sectors, or their efficiency. In this sense, these measures represent the capacity of a given infrastructure to effectively provide the expected services, such as the moving of people with safety and speed, water with adequate conditions for people’s health etc. Given that none of the supply variables contain these characteristics, it is fundamental to include the indicators of infrastructure quality, since supply effects can be heterogeneous according to their efficiency (Calderón & Servén, 2010, 2014; Makmuri, 2017; Straub, 2011).

The transportation quality is represented by the percentage of total length of highways (km) classified as being in good and excellent condition. It is believed that the variable chosen in this study is adequate because, besides taking into account the paving of highways, it considers other qualitative issues related to road safety and conservation (CNT, 2018).

Regarding power quality, the natural logarithm of the ANEEL (National Electric Energy Agency) Consumer Satisfaction Index (IASC) will be used. This index allows evaluating the residential consumer satisfaction with the services rendered by the electric power distributors, capturing items such as: perceived quality; perceived value (cost-benefit ratio); overall satisfaction; confidence in the supplier; and fidelity. For those states that were served by more than one electric power distributor, simple arithmetic averages of distributors were calculated.

In relation to the telecommunication sector, two variables are used to capture Internet and telephony quality. The first one refers to the proportion of Internet accesses with speed above 512 Kbps, connection that are classified as non-slow speed. The choice of this variable followed the classification made by Swiss (2011). Telephony quality is represented by the Completed Originated Call Rate. In the telephony case, since the states are served by more than one provider, state averages of these rates were calculated.

To represent sanitation quality or, in this case, inefficiency, we use the proportion of hospitalizations from waterborne diseases. This variable captures qualitative aspects related to inefficiency in the treatment of water and sewage, with consequent implications on the number of hospitalizations due to diseases caused by sanitation quality.

2.3 Infrastructure access

The last range of variables used refers to that representing population access to infrastructure, all with municipal scope. Access, in the sense used in this work, is understood as the ability or the possibility that people have to utilize some infrastructure service.

In order to depict access to infrastructure, variables of the Demographic Census are collected. This survey allows us to evaluate household access to infrastructures. Then, household measures are aggregated at the municipal level. Regarding transportation sector, there are no available variables fulfilling the proposed requirements for this type of variable. Power access is represented by the percentage of households with electricity. Similarly, telecommunications access, reproduced here by telephone services, is represented by the percentage of households with access to fixed or mobile telephone. In turn, basic sanitation access is represented by the percentage of households with adequate water supply and sanitary sewage. Table C1 in Appendix C summarizes the infrastructure variables used.

2.4 Composite indices: an application of Principal Component Analysis (PCA)

The indexes are created by Principal Component Analysis according to infrastructure characteristic and its aggregation. Therefore, for the supply case two indices are calculated, one containing the state-level variables, and the other with the municipal level variables. The same is true for quality measures. In relation to access indicators, a single index is created in municipal aggregation. A full description of the method can be obtained in Dunteman (1989).

Table D1 in Appendix D describes the proportion of the variance and its accumulation with the different components for the indices created. In all cases, we chosen to use those components that had an eigenvalue greater than one, following the Kaiser's criterion (Kaiser, 1958). The indices are described in the equations below:

$$SIS = -0,283 * Otransp + 0,696 * Oenerg + 0,661 * Otelec2 \quad (1)$$

$$MIS = 0,707 * Osanea + 0,707 * Otelec1 \quad (2)$$

$$SIQ = 0,689 * Qtransp + 0,663 * Qenerg + 0,291 * Qtelec2 \quad (3)$$

$$MIQ = -0,707 * Qsanea + 0,707 * Qtelec1 \quad (4)$$

$$IAI = 0,503 * Asanea + 0,593 * Aenerg + 0,628 * Atelec \quad (5)$$

The first index created, named State Infrastructure Supply Index (SIS), condenses the information about power, telephony and transport state-level variables. According to equation 1, power and telephony indicators have a substantial weight in the index, with a positive sign. The second index, designed Municipal Infrastructure Supply Index (MIS), added information on sanitation and Internet provision indicators, which have the same positive weight in the composite index.

A similar procedure is implemented for quality measures, creating the State Infrastructure Quality Index (SIQ) and the Municipal Infrastructure Quality Index (MIQ), with the same sectors as the supply indexes. While in the municipal index the variables of sanitation inefficiency and Internet quality have the same weight, in the state index the variables that hold the highest weight are those linked to the transportation and power sectors.

Finally, the Infrastructure Access Index (IAI) synthesized information on the variables of access to electricity, telephony and sanitation. All variables had a significant influence on the index, in such a way that it represents well the access to infrastructure in the Brazilian municipalities. The composite indicators described in the equations above are used in the subsequent econometric analysis.

2.5 Hybrid indices: interactions between infrastructure characteristics

The hybrid indexes proposed in this paper seek to simultaneously capture the aggregate effects of access, quality and infrastructure supply indicators. When analyzing the links between infrastructure and income inequality, having only one supply indicator is insufficient. In addition, separate analysis of the effects of provision, access and quality, may not fully reveal the impact of the infrastructure, which is a great challenge in the causality test. Finally, no studies using a hybrid aggregate index that considers both the infrastructure stock and access were found, in such a way that it becomes a contribution of this study to test such interactions in the econometric models. Hybrid indices can be described as:

$$SSQ = SIS * SIQ \quad (6)$$

$$MSQ = MIS * MIQ \quad (7)$$

$$SSA = SIS * IAI \quad (8)$$

$$MSA = MIS * IAI \quad (9)$$

In equations 6 and 7 the interactive indices are described between supply and quality both at the state and municipal level, respectively. In relation to hybrid indicators of quantity and access, two indicators

were also created, both state and municipal level (equations 8 and 9, respectively). This choice was chosen due to the fact that the telephony and power sector have municipal access indicators, however, their supply is arranged by state. On the other hand, sanitation access and provision are given at the municipal level, and an interaction at this level is necessary. The same procedure is done for the disaggregated variables. The multiplication between supply and quality is named with the initials S (supply) and Q (quality) (example SQtransp to the transportation sector), while the interaction between supply and access is named with the initials S and A (access) (example OAenerg to the power sector).

2.6 Income inequality and control variables

In order to represent income inequality, we use “Ratio 10/40 (r1040),” a measure that compares the average per capita household income of the individuals belonging to the richest decile of the distribution, with the average per capita household income of the individuals belonging to the poorer two-fifths of people. The universe of individuals is limited to those who live in permanent private households.

The control variables are represented by the logarithm of the industrial value added per capita, the logarithm of the aggregate value of agriculture per capita, the logarithm of the value added of the services sector per capita, logarithm of the education human development index, logarithm of health human development index, formalization degree of employed persons, rate of infant mortality and the logarithm of total population. All control variables, as well as the dependent variable, are from the year 2010.⁵ Table C2 in Appendix C summarizes this group of variables, while Table C3 describes the descriptive statistics of the variables used in the work.

3. INFRASTRUCTURE EFFECTS ON INCOME INEQUALITY IN A REGIONAL APPROACH: THE HIERARCHICAL SPATIAL AUTOREGRESSIVE MODEL (HSAR)

Since spatial heterogeneities and dependencies patterns can coexist, it is necessary to treat these two types of problem together. A model that solves such difficulties is the hierarchical spatial autoregressive model (HSAR), proposed by Dong and Harris (2014). According to the authors, the purposes of HSAR are: i) to avoid the “ecological fallacy,” which occurs when transferring relations between variables on an aggregate scale for individuals; ii) to avoid the “atomistic fallacy,” when correlations between variables are investigated exclusively at individual level, without taking into account the context; iii) investigate and quantify contextual effects; and iv) provide better estimates of model parameters and their standard errors in the presence of group effects.

The motivation of Dong and Harris (2014) in HSAR elaboration was linked to the inability of conventional hierarchical models to deal with spatial issues that went beyond group heterogeneity. According to the authors, classical hierarchical models would be able to treat the so-called “vertical group dependence” (or spatial heterogeneity at the macro level), which occurs when lower level units are similar, since they absorb identical group effects. However, such models fail to treat the so-called “horizontal group dependence” (or spatial autocorrelation), characterized by interactions and spillovers that occur due to geographic proximity.

The HSAR model, by including the hierarchical data, provides more efficient and accurate estimates for the regression coefficients. In addition, it provides more correct estimates of the intensity of spatial interaction at the lower level, separating it from the measurement of regional effects, with which it can

be confused. In this sense, the HSAR model simultaneously integrates spatial autoregressive processes (SAR) for both the response variable and the upper level residues within a classical hierarchical approach. The key feature of the SAR process is that it allows the observed values of a dependent variable y in a particular locality to be directly dependent to the values observed in neighboring locations (or spatial lag of y), providing both specification and measurement of interaction effects (or spatial spillovers) (LeSage & Pace, 2009). HSAR model specification follows as:

$$y = \rho W y + X \beta + Z \gamma + \Delta \theta + \varepsilon \quad (10)$$

$$\theta = \lambda M \theta + u$$

$$\Delta = \begin{bmatrix} l_1 & 0 & \dots & 0 \\ 0 & l_2 & \dots & \vdots \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & l_j \end{bmatrix}$$

Where y is a column vector $N \times 1$ of the dependent variable values; ρ is the level 1 spatial autoregressive parameter; W is the spatial weights matrix at municipal level; X is a matrix $N \times K$ of independent variables at the level one; β is a matrix $K \times 1$ of regression coefficients at the municipal level; Z is an $N \times P$ matrix of level two variables; γ is the vector $P \times 1$ of corresponding coefficients of level two; Δ is a diagonal block matrix $N \times J$ with column vectors of ones; and ε is a level one random error term, distributed as $N(0, \sigma_\varepsilon^2)$.

The vector $J \times 1$ of level two residuals, $\theta[\theta_1, \theta_2, \dots, \theta_j]$, represents contextual random effects. The residuals u are distributed as $N(0, \sigma_u^2)$, and it is assumed that they are independent of ε . Similar to W , M is a normalized spatial weights matrix at level two, while the parameter λ measures the intensity of spatial interactions at state level. Finally, specified as a SAR process, the covariance matrix for θ is $cov(\theta) = \sigma_u^2 (B' B)^{-1}$, where $B = I_j - \lambda M$. As a consequence, the distribution of θ is multivariate normal, $\theta \sim N(0, \sigma_u^2 (B' B)^{-1})$.

The spatial multipliers ρ (Corrado & Fingleton, 2012) and λ indicate nothing more than that spatial dependence process can have causes such as: i) spatial externalities coming from explanatory variables; ii) spatial externalities coming from not observed factors; and iii) a feedback or diffusion effect on y ; in other words, some unobserved spatial factor that is captured in the error term. Since there are spatial interaction effects, a variation in some independent variable in municipality i has a direct effect on municipality i and an indirect effect on other municipalities. The same is true for a variation in a state-level independent variable. The direct, indirect and total effects calculation methods can be seen in Dong and Harris (2014). HSAR model estimation is implemented through a Bayesian simulation approach using Markov Chain Monte Carlo (MCMC) algorithms.

4. RESULTS AND DISCUSSION

The first practical step is to test the existence of global spatial autocorrelation using Global Moran's I statistic.⁶ As described in Table E1 in Appendix E, we can reject the null hypothesis that there is no spatial autocorrelation in all the variables analyzed, except for transportation supply and telephony quality. However, the Moran's I statistic is purely global, thus not allowing us to determine possible clusters and spatial outliers between the municipalities. Local measurements of spatial autocorrelation are more adequate for this type of inference. Figure 1 graphically depicts Local Moran's I statistic for

the income inequality measure. The map includes municipal values for the Moran Scatterplot that were statistically significant at the 5% level.

[Figure 1 here]

It can be seen from Figure 1 that there are clusters for income inequality. Without great details, Brazil can practically be divided in two. North and Northeast regions have large clusters of positive spatial autocorrelation highlighting high inequality areas, that is, municipalities with high inequality values surrounded by other municipalities also with high income disparities. South and Southeast regions, although to a lesser extent in relation to the North and Northeast, present sets of municipalities, in proximity, with low income inequality.

Before proceeding with spatial model estimations, we estimate the null conventional hierarchical model in order to analyze the importance of including a second (state) hierarchical level in the analysis. The value of intraclass correlation coefficient of 0.66 indicates the importance of modeling the variance between groups. In other words, about 66% of the variance of income inequality can be explained by the hierarchical structure of the data.⁷

Since spatial exploratory analysis indicated remarkable spatial dependence patterns in the analyzed variables and the null conventional multilevel model indicated the presence of group dependence, the next step of the work is the application of the spatial hierarchical model. According to the HSAR model estimates set out in Appendix G, both spatial parameters, ρ^8 and λ , are significant in all specifications, indicating the importance of considering neighborhood interactions at the lower (municipal) and upper (state) levels, respectively. Regarding the control variables, it can be observed that the formalization degree of workers, the level of educational and health human development, and industrial value added correlate negatively with income inequality. On the other hand, the larger the population of the municipality, the infant mortality rate and the value added in the service sector, the lower the personal income equality in the municipalities.

When we include the supply variables without any type of weighting (Table 1), it can be observed that only sanitation and telephony supply indicators correlate significantly with the municipal income inequality. The total effect of a 1% increase in the sanitation supply provides an income ratio of the richest 10% over the poorest 40% (r10/40) 0.149 times lower. This total effect comes from: i) direct impacts of sanitation expansion in the municipality in which it is done, where a 1% increase in the basic sanitation provision correlates directly with a ratio (10/40) 0.105 times lower; and ii) a feedback mechanism that spreads to neighboring municipalities and returns to the municipality itself, generating a return in terms of lower levels of income inequality of approximately 0.044. Similarly, a 1% expansion in the telephony state-level stock correlates with a “10/40 ratio”, on average, 6.93 times lower (with a direct impact of -4.878 and an indirect effect of -2,052).

[Table 1 here]

The Municipal Infrastructure Supply (MIS) Index also spreads significant effects on income concentration. The increase of 1% in the MIS negatively affects the income ratio by 0.375 units (-0.264 as direct impact and -0.111 via spatial interactions). Since MIS captures information on the Internet service and basic sanitation municipal supply, this result indicates that the expansion of these services is an important factor for municipalities to reach higher levels of income equality.

The results presented so far provide good evidence about infrastructure effects on inequality, which corroborate much of the related literature (Calderón & Chong, 2004; Calderón & Servén, 2004, 2010;

Raychaudhuri & De, 2010) where negative effects of infrastructure supply on personal income inequality were found. However, a more careful analysis encompasses the study of various infrastructure characteristics, such as its quality and access. Next, the supply variables are weighted for their respective quality, in order to capture possible heterogeneities in supply infrastructure effects on income concentration.

Table 2 shows the total, direct and indirect infrastructure supply effects weighted by its quality. Since we have included interactive variables between supply and quality, we have the supply term involved in two regression parameters (for example, $r1040 = \beta_1 * Ssanea + \beta_2 (Stransp * Qtransp)$). The marginal effect of an expansion in infrastructure supply can be obtained with the partial derivative $\frac{\partial r1040}{\partial Supply} = \beta_1 + \beta_2 * \overline{Quality}$, where $\overline{Quality}$ indicates the average value of a certain quality infrastructure indicator. The mean values used to calculate the marginal effects can be obtained in Table C3 in Appendix C.

With the proposed weighting, the results change considerably. Both parameters representing sanitation supply and quality were significant and had an expected signal. The total effect of a 1% increase in the logarithm of the distributed water volume *per capita*, given the average sanitation quality, negatively affects the inequality measure by 0.166 units. Quality, in this case, ponders the infrastructure provision in the sense that the greater the proportion of waterborne diseases in a given municipality, the less negative the infrastructure effects on inequality will be. This result was expected, since the returns of water and sewage provision may be higher in places with adequate treatment conditions. Since the poor may be more subject to precarious water and sewage treatment situations, expanding the sector in union with higher quality can guarantee more appropriate health conditions for the lower income group, as well as lower medicines and hospitalization expenses, perpetuating productivity gains to them and greater equality of income within the municipalities.

Regarding the transportation sector, we can note that while the supply coefficient remains non-significant, its interaction with quality is significant and has the negative sign. This result indicates that, given the existing level of transportation infrastructure, only expansion in conjunction with the improvement of this infrastructure is capable of providing lower levels of income inequality. The total effect of a 1% expansion in the highways supply, taking the average quality of the sector equal to 0.29, correlates with an appropriate income of the richest 10% being 1,975 times lower compared to the poorest 40%. The transportation quality helps to alleviate income inequality by increasing the region's comparative advantages for trade, the productivity of established businesses and the income of its workers. The reasonable explanation for this result would be that a better road network has a considerable distributional impact on household income. Since the lowest income layer in the population has a chance to access productive opportunities, their return access to better roads may be higher than the returns earned by high-income households.

[Table 2 here]

In relation to the power sector, the inclusion of the interaction between supply and quality has made the coefficient of the supply variable significant, as it occurs with the coefficient of interaction. The expansion of the state power supply, taking the average quality of the sector, negatively affects income inequality (total effect of -0.24). It is noted that power quality acts as a supply-weighting factor so that the higher the quality, the greater the returns from power stock expansion in terms of lower levels of income concentration. It is argued that a greater supply of infrastructure means little about income inequality, since it is not known whether the poorest localities and the poorest people are benefiting

more from this supply than the non-poor. In turn, energy infrastructure quality is represented by an index that takes into account residential consumer satisfaction issues, such as cost-benefit and quality of services provided. In this sense, while people are being served by an infrastructure with lower cost and higher quality, it is very likely that the poorest are the most benefited. This can occur because this parcel of population is the one most vulnerable to the payment of higher tariffs for power services, and also the one that suffers most from the loss of electrical appliances due to interruptions and poor quality of electricity supply services.

The parameter related to the interaction between municipal supply and quality infrastructure (MSQ) was statistically significant. Given the average quality of municipal infrastructure, a 1% increase in the Municipal Infrastructure Supply Index (MIS) affects income inequality in approximately -0.371 units. In this case, the importance of the expansion, with quality, of the services of sanitation and Internet is indicated. These findings corroborate some of the studies found in the literature (Calderón & Chong, 2004; Calderón & Servén, 2004, 2010; Seneviratne & Sun, 2013), in the sense that infrastructure quality plays an important role for localities to reach higher levels of income equality. In addition, the explanation given by Calderón and Chong (2004) that the quantitative link is stronger than the qualitative one is contradictory, since, in many cases, the beneficial infrastructure supply effect on lower levels of inequality seems to necessarily result from a joint expansion in terms of supply and quality.

The next step in the econometric analysis is to include the interactions between infrastructure supply and access. It is emphasized that the specifications set out in Table 3 are essential for the study of inequality that is conducted here, while capturing the infrastructure coverage/access effects, that is, the proportion of a certain population that, in fact, can receive the benefits of a particular infrastructure sector. Many of these indicators have not been tested in the literature, providing new evidence for the study about infrastructure and inequality.

All parameters, except for those related to sanitation access and the interaction between supply and state infrastructure access (SSA), are significant. Infrastructure supply has maintained its negative effect on income inequality. A peculiar result is found in the power sector case. The average effect of an increase of 1% in power supply, taking the average of access in the sector, on income inequality is 0.265. That is, it correlates with greater inequality. This initial effect, however, is weighted by people's access to electricity. The greater the access, the more the returns from infrastructure expansion tend to be negative, correlating with lower levels of income concentration. A particularity of the indicator of access to electricity should be mentioned. Even in 2010, the year of this indicator, the vast majority of the Brazilian population had electricity facilities, as observed by a maximum value of the indicator of population served of 100% and an average of 97%. The lowest values of this measure, with a minimum number of 27%, are found in municipalities with a high proportion of residents in rural and low-income areas, notably in the northern region of the country. The municipalities in the North of the country, in turn, have, in general, the highest indicators of income inequality. In this sense, it can be expected that the returns of an expansion in power infrastructure in these regions are still very high, while in "average" municipalities, in terms of access to energy, the effects are smaller.

[Table 3 here]

The negative returns of telephony on income inequality (-6,187), in turn, are reinforced by a greater population access to fixed or cellular telephone. The effects of telecommunication expansion on inequality are enhanced while more individuals have the means to use the services. Since there is ample telephony coverage in a given municipality, more people, including the poor, can benefit from

better productive opportunities, media, access to information and social interactions through telephony.

The State Infrastructure Supply Index (SIS) has a direct impact on inequality (-2.63), so that the higher the state supply, the lower the levels of municipal income concentration tend to be. Finally, a 1% change in the Municipal Infrastructure Supply Index (MIS), taking the average of the Infrastructure Access Index (IAI), generates a negative effect of 0.52 on the “10/40 Ratio.” The results of the composite indices provide strong evidence that infrastructure affects inequality when more people actually access these infrastructures, rather than when such infrastructures have a greater degree of supply. In this sense, the theoretical argument made by Straub (2008) and Calderón and Servén (2014) is corroborated in that it is imperative to include variables of access and quality of infrastructure to better explain their relations with issues such as inequality and poverty.

The final procedure in the analysis of the HSAR models is to verify whether the infrastructure supply effects are maintained when all of its characteristics are included. The results of this specification are set out in Table 4. The results, in general, resemble those obtained in the access weighting in the previous subsection. Nevertheless, there are changes in the magnitude of infrastructure returns on income inequality.

At average levels of quality and access, the higher the infrastructure stocks, the smaller the municipal income disparities tend to be. The exception to this assertion is in the power sector, while supply expansion, on average, has positive effects on inequality. For comparative purposes, Table 5 describes the summary of the results of the HSAR models, showing the infrastructure supply returns of each interaction type.

[Table 4 here]

[Table 5 here]

A perceptible consensus concerns the role of infrastructure access. This characteristic correlates negatively with inequality in all sectors analyzed, confirming its fundamental role in ensuring egalitarian use conditions of essential basic services such as water, sewage, Internet and electricity. In general, it can be argued that the analysis of supply indicators, on its own, does little to say about the infrastructure effects on inequality, since only three in seven supply variables tested had their significant parameters. The inclusion of infrastructure quality and, especially, access make most of the parameters significant, indicating important heterogeneities of the infrastructure characteristics for the Brazilian case.

5. CONCLUSIONS

This work applies recent advances in hierarchical and spatial modeling econometric techniques to evaluate the infrastructure effects on income inequality in Brazil in 2010. A broad database representing infrastructure in Brazil, both at the municipal and state levels is developed. We include various infrastructure sectors and characteristics. It is argued that in the Brazilian case, the possible relations between infrastructure and inequality become much more complex due to their regional and income heterogeneities. In general, the North and Northeast regions have extremely poor conditions in terms of infrastructure supply, quality and coverage, while the South and Southeast regions and, to a lesser degree, the Midwest have better indicators. In addition, there is a considerable correlation between states and municipalities with better infrastructure and lower levels of inequality.

The results obtained in this work do not only point towards a negative correlation between infrastructure and income inequality, but also validate the theoretical and empirical concerns that analyze the spatial interactions and their importance in studies on infrastructure. They also provide practical warnings referring to representativeness of infrastructure variables, since there are important heterogeneities between its sectors and characteristics. Estimates obtained through hierarchical spatial models allow us to conclude that the infrastructure supply, with the exception of the power sector, contributes to lower levels of income concentration in the Brazilian municipalities. Some caveats, however, deserve attention. First, the inclusion of supply indicators alone gives weak evidence of the infrastructure effects on inequality, while most parameters were not significant. Only with the inclusion of quality and access weights, did we obtain the majority of significant parameters. The main results demonstrate that public infrastructure policies aimed at improving infrastructure quality and, essentially, expanding access are crucial for achieving lower levels of income concentration.

In order to understand the dynamic mechanisms of infrastructure interaction and income inequality in space and time, panel data models need to be specified and interpreted in future research. Due to the unavailability of data, this work was limited to cross-section analysis. In addition, we do not address possible problems of endogeneity between infrastructure and income inequality.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

NOTES

1. A more detailed empirical literature review can be found in Appendix A.
2. Figures B1, B2 and B3 and Table B1 in Appendix B show some of these regional and income discrepancies in terms of infrastructure in Brazil.
3. Both Internet and telephony indicators represent the physical or logical means by which a user is connected to a telecommunications network (ANATEL, 2012). Therefore, these indicators capture the telecommunications provision to the total population, including people and firms.
4. An eigenvalue smaller than one for a particular main component indicates that it has less information than an original variable alone, since after standardization, each variable has variance that equals the value 1. In this case, it would be better to use the original variables than composite indexes.
5. The variables used are available for municipal disaggregation only in the Demographic Census prepared by IBGE (2010). However, since most of the infrastructure variables used are not available for the period preceding to the year 2000, a temporal analysis was not feasible.

6. To create spatial lags, first-order queen type matrices are created for each hierarchical level. It is the most commonly matrix used in space econometric studies. Therefore, both W (municipal) and M (state) matrices are constructed by contiguity, where states/municipalities that have a common border are considered neighbors.

7. Classical hierarchical models estimates are presented in Appendix F (TABLE F1, F2, F3, F4) for comparison purposes. It is noteworthy that classical hierarchical models overestimate the state-level variance σ_u^2 , a fact that is expected if some contextual macro effect not observed is due to spatial interaction coming from geographic proximity (Dong et al., 2015).

8. For comparison modes, estimates were inserted from the conventional spatial model without hierarchical structure, the SAR model (TABLE H1, H2, H3, H4 in Appendix H). The adjustment indicators of the model, Pseudo R² and DIC, show that the HSAR is better than the classical SAR to explain the income inequality of the Brazilian municipalities. In addition, with respect to the parameter ρ , it seems to be overestimated in the SAR models, in comparison to the HSAR. This indicates that, at the municipal level, spatial dependence can be confused with macro contextual effects, which tends to generate misleading estimates in conventional SAR models (Dong & Harris, 2014).

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TABLES AND FIGURES

Table 1 - Direct, indirect and total impacts of infrastructure supply on income inequality (ratio 10/40).

Variable/ Impact	Direct	Indirect	Total
	Posterior Mean	Posterior Mean	Posterior Mean
<i>Ssanea</i>	-0.105* (0.038)	-0.044* (0.016)	-0.149* (0.054)
<i>Stransp</i>	0.731 (0.817)	0.308 (0.344)	1.039 (1.16)
<i>Senerg</i>	1.035 (1.776)	0.437 (0.749)	1.472 (2.525)
<i>Stelec2</i>	-4.878* (1.727)	-2.052* (0.726)	-6.93* (2.453)
<i>Stelec1</i>	0.087 (0.125)	0.037 (0.053)	0.124 (0.178)
<i>MIS</i>	-0.264* (0.127)	-0.111* (0.054)	-0.375* (0.181)
<i>SIS</i>	-1.154 (0.74)	-0.485 (0.311)	-1.639 (1.052)

Notes: (*) indicates statistically significant parameter in a 95% Credible Interval (CI), standard errors in parentheses.

Table 2 - Direct, indirect and total impacts of infrastructure supply and quality on income inequality (ratio 10/40).

Variable/ Impact	Direct	Indirect	Total
	Posterior Mean	Posterior Mean	Posterior Mean
<i>Ssanea</i>	-0.140* (0.042)	-0.059* (0.018)	-0.198* (0.06)
<i>SIsanea</i>	0.383* (0.179)	0.161* (0.075)	0.543* (0.254)
<i>Stransp</i>	0.60 (0.709)	0.254 (0.3)	0.854 (1.008)
<i>SQtransp</i>	-4.785* (2.635)	-2.024* (1.115)	-6.809* (3.749)
<i>Senerg</i>	33.312* (9.047)	14.087* (3.826)	47.399* (12.873)
<i>SQenerg</i>	-8.107* (2.231)	-3.428* (0.944)	-11.535* (3.175)
<i>Stelec2</i>	-2.39 (8.995)	-1.002 (3.77)	-3.392 (12.765)
<i>SQtelec2</i>	-0.036 (0.09)	-0.015 (0.038)	-0.051 (0.128)
<i>Stelec1</i>	0.096 (0.119)	0.04 (0.05)	0.136 (0.169)
<i>SQtelec1</i>	-0.055 (0.104)	-0.023 (0.044)	-0.079 (0.147)
<i>MIS</i>	-0.07 (0.167)	-0.029 (0.069)	-0.099 (0.236)
<i>MSQ</i>	-0.037* (0.021)	-0.016* (0.009)	-0.053* (0.029)
<i>SIS</i>	-3.805 (2.538)	-1.581 (1.055)	-5.387 (3.593)
<i>SSQ</i>	0.488 (0.594)	0.203 (0.247)	0.69 (0.84)

Notes: (*) indicates statistically significant parameter in a 95% CI, standard errors in parentheses.

Table 3 - Direct, indirect and total impacts of infrastructure supply and access on income inequality (ratio 10/40).

Variable/ Impact	Direct	Indirect	Total
	Posterior Mean	Posterior Mean	Posterior Mean
<i>Ssanea</i>	-0.114* (0.038)	-0.048* (0.016)	-0.161* (0.054)
<i>SAsanea</i>	0.053 (0.04)	0.022 (0.017)	0.076 (0.057)
<i>Senerg</i>	17.165* (0.877)	4.616* (0.236)	21.781* (1.113)
<i>SAenerg</i>	-0.174* (0.007)	-0.047* (0.002)	-0.221* (0.009)
<i>Stelec2</i>	-2.616* (1.265)	-1.035* (0.5)	-3.65* (1.765)
<i>Satelec2</i>	-2.331* (0.38)	-0.922* (0.15)	-3.253* (0.531)
<i>MIS</i>	3.19* (0.383)	1.145* (0.137)	4.335* (0.52)
<i>MSA</i>	-0.396* (0.043)	-0.142* (0.015)	-0.539* (0.058)
<i>SIS</i>	-1.934* (1.091)	-0.694* (0.391)	-2.629* (1.482)
<i>SSA</i>	0.182 (0.121)	0.065 (0.043)	0.248 (0.164)

Notes: (*) indicates statistically significant parameter in a 95% CI, standard errors in parentheses.

Table 4 - Direct, indirect and total impacts of infrastructure supply, quality and access on income inequality (ratio 10/40).

Variable/ Impact	Direct Posterior Mean	Indirect Posterior Mean	Total Posterior Mean
<i>Ssanea</i>	-0.147* (0.041)	-0.061* (0.017)	-0.208* (0.058)
<i>SIsanea</i>	0.374* (0.173)	0.156* (0.072)	0.53* (0.245)
<i>SAsanea</i>	0.047 (0.039)	0.020 (0.016)	0.067 (0.055)
<i>Senerg</i>	34.086* (6.658)	9.163* (1.79)	43.249* (8.448)
<i>SQenerg</i>	-4.032* (1.511)	-1.084* (0.406)	-5.116* (1.917)
<i>SAenerg</i>	-0.174* (0.007)	-0.047* (0.002)	-0.221* (0.009)
<i>Stelec2</i>	-2.215 (5.707)	-0.884 (2.278)	-3.100 (7.986)
<i>SQtelec2</i>	-0.010 (0.635)	-0.004 (0.253)	-0.014 (0.888)
<i>SAtelec2</i>	-2.322* (0.377)	-0.927* (0.15)	-3.249* (0.527)
<i>MIS</i>	3.234* (0.394)	1.158* (0.141)	4.392* (0.535)
<i>MSQ</i>	-0.018 (0.02)	-0.007 (0.007)	-0.025 (0.027)
<i>MSA</i>	-0.39* (0.043)	-0.14* (0.016)	-0.529* (0.059)
<i>SIS</i>	-4.357* (1.983)	-1.56* (0.71)	-5.917* (2.694)
<i>SSQ</i>	0.336 (0.232)	0.120 (0.083)	0.456 (0.315)
<i>SSA</i>	0.162 (0.127)	0.058 (0.045)	0.220 (0.172)

Notes: (*) indicates statistically significant parameter in a 95% CI, standard errors in parentheses.

Table 5 - Summary of results: Infrastructure supply returns on income inequality (ratio 10/40) as weighted (average marginal effects).

Variable/ weighting	Without weighting	Quality	Access	Quality & Access
Total impacts				
<i>Ssanea</i>	-0.149	-0.166	-0.161	-0.176
<i>Stransp</i>	ns	-1.975	-	-
<i>Senerg</i>	ns	-0.242	0.265	0.660
<i>Stelec2</i>	-6.930	ns	-6.187	-2.534
<i>Stelec1</i>	ns	ns	-	-
<i>SIS</i>	ns	ns	-2.629	-5.917
<i>MIS</i>	-0.375	-0.317	-0.523	-0.380
Direct impacts				
<i>Ssanea</i>	-0.105	-0.117	-0.114	-0.124
<i>Stransp</i>	ns	-1.388	-	-
<i>Senerg</i>	ns	-0.170	0.209	0.520
<i>Stelec2</i>	-4.878	ns	-4.434	-2.322
<i>Stelec1</i>	ns	ns	-	-
<i>SIS</i>	ns	ns	-1.934	-4.357
<i>MIS</i>	-0.264	-0.224	-0.385	-0.280
Indirect impacts				
<i>Ssanea</i>	-0.044	-0.049	-0.048	-0.052
<i>Stransp</i>	ns	-0.587	-	-
<i>Senerg</i>	ns	-0.072	0.056	0.140
<i>Stelec2</i>	-2.052	ns	-1.754	-0.927
<i>Stelec1</i>	ns	ns	-	-
<i>SIS</i>	ns	ns	-0.694	-1.560
<i>MIS</i>	-0.111	-0.093	-0.138	-0.100

Notes: (-) indicates that there is no indicator for the sector in question; (ns) indicates not significant.

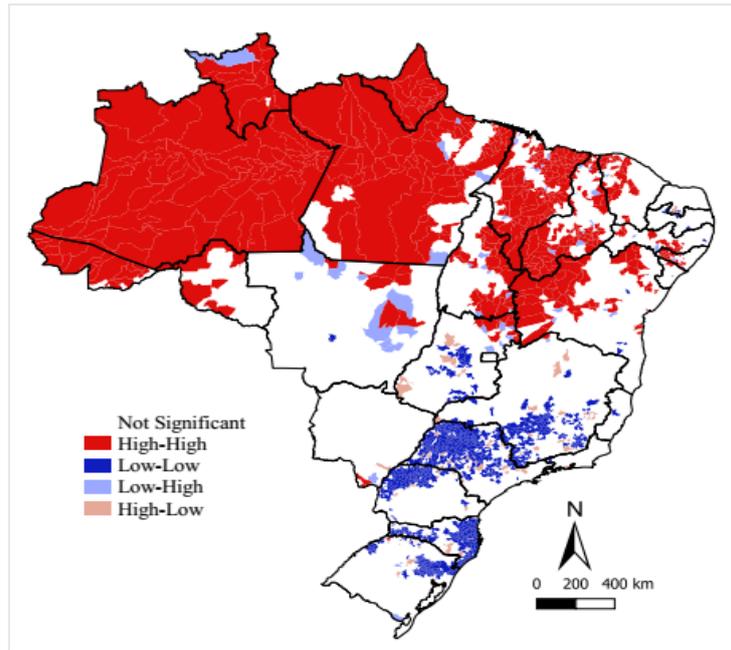


Figure 1 – Local Moran's I statistic for income inequality (r1040) in Brazil, 2010.

APPENDIX A

Table A1 - Empirical studies on infrastructure and income inequality.

Authors	Results	Geographic unit	Infrastructure sectors	Infrastructure Characteristics
Calderón & Chong (2004)	Infrastructure (-)	Countries	Power, Transportation and Telecommunications	Supply and Quality
Calderón & Servén (2004)	Infrastructure (-)	Countries	Power, Transportation, Telecommunications and Sanitation	Supply and Quality
Raychaudhuri & De (2010)	Infrastructure (-)	Countries (Asia)	Power, Transportation and Telecommunications	Supply and Quality
Calderón & Servén (2010a)	Infrastructure (-)	Countries	Power, Transportation, Telecommunications and Sanitation	Supply and Quality
Majumder (2012)	Power (+)	Regions (India)	Power, Transportation, Telecommunications and irrigation	Supply and Quality
Seneviratne & Sun (2013)	Infrastructure (-)	Countries	Power, Transportation and Telecommunications	Supply and Quality
Bajar & Rajeev (2015)	Power and Transportation (+); Telecommunications (-)	States (India)	Power, Transportation and Telecommunications	Supply
Hooper <i>et al.</i> (2017)	Infrastructure (-)	States (EUA)	Transportation	Supply and Quality
Makmuri (2017)	Rodovias and Telecommunications (+); Power and airports (-)	Provinces (Indonesia)	Power, Transportation and Telecommunications	Supply and Quality
Mendoza (2017)	Power (-); Transportation and Telecommunications (+); Sanitation (?)	Cities (China)	Power, Transportation e and Sanitation	Supply, Quality (Sanitation) and Access (Sanitation and internet)

Notes: (-) indicates that infrastructure effect is to reduce inequality; (+) indicates that infrastructure effect is to increase inequality; Infrastructure in the "Results" column indicates the use of the multidimensional approach, where the results take into account several sectors and measures.

APPENDIX B

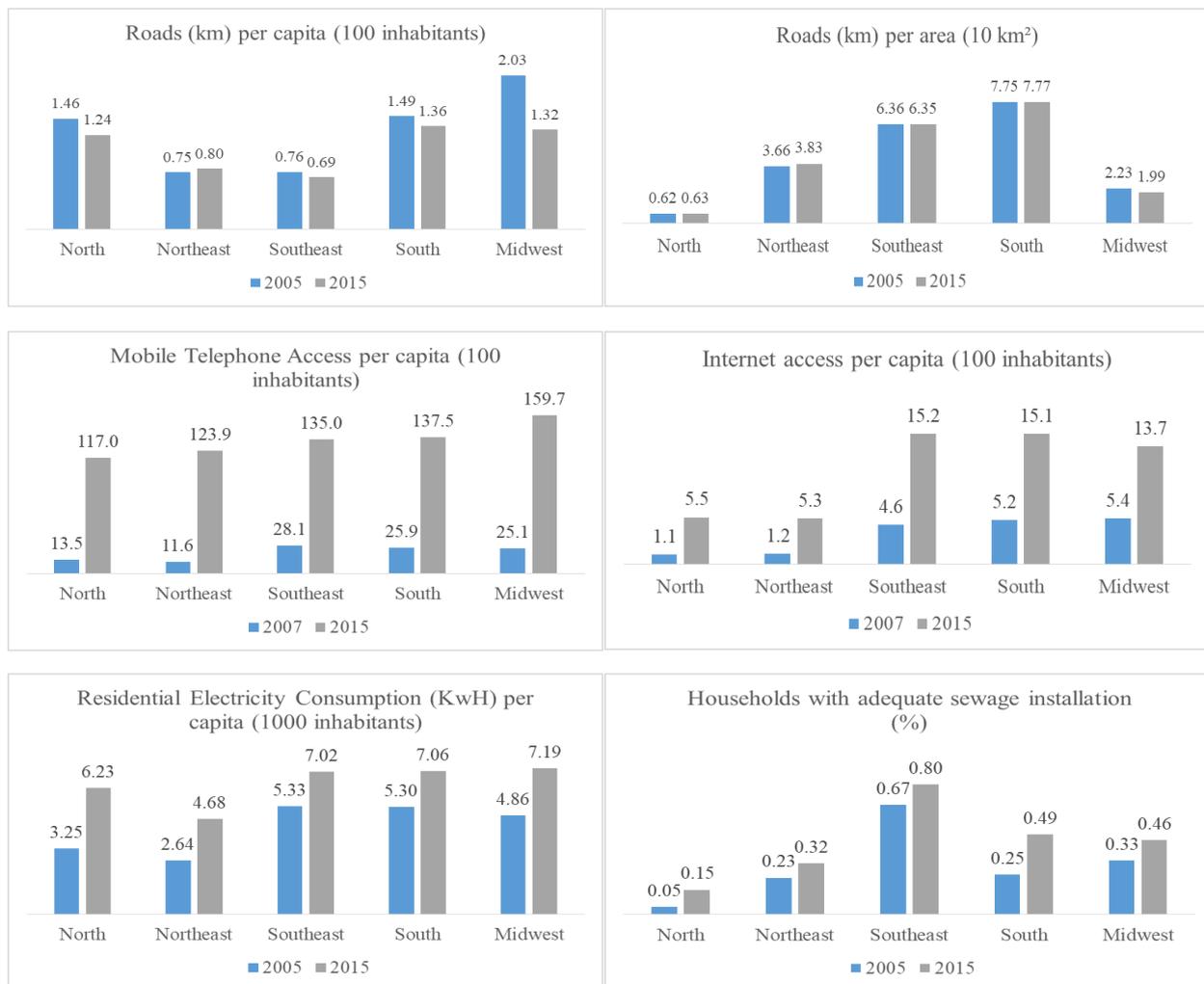


Figure B1 - Infrastructure supply indicators by Brazilian regions, 2015.

Sources: CNT (2017), ANEEL, ANATEL and IBGE.

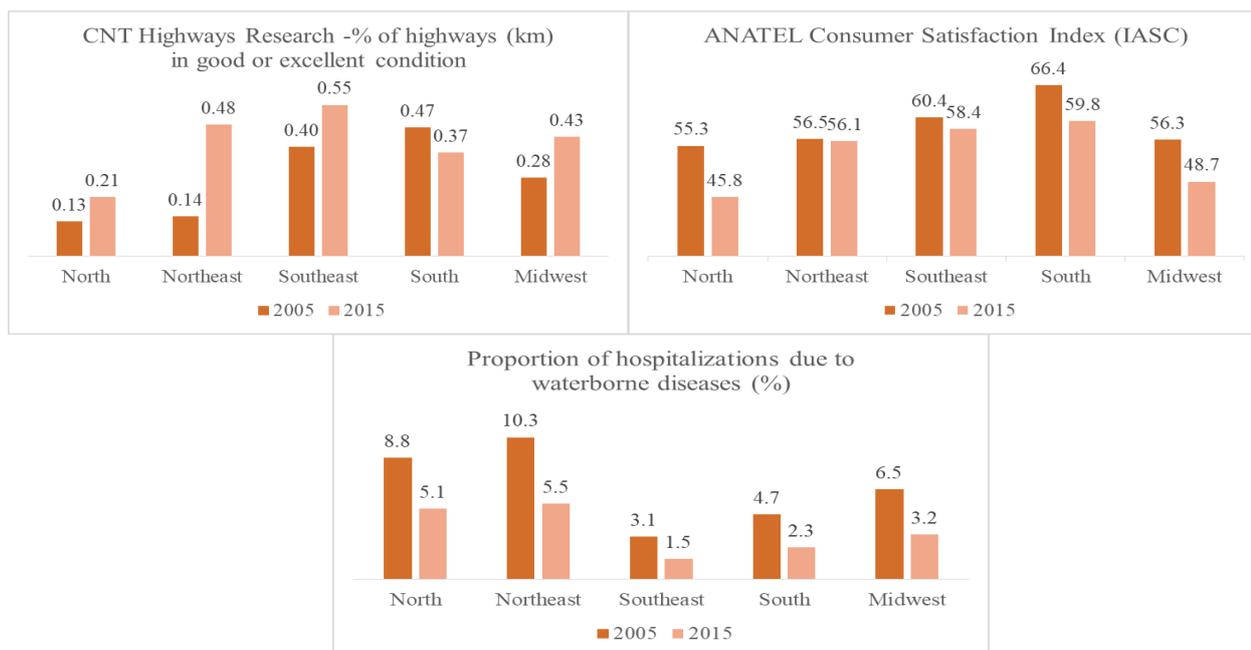


Figure B2 - Infrastructure quality indicators by Brazilian regions, 2015.
Source: CNT, ANATEL, ANEEL and DATASUS.

Table B1 – Infrastructure access by region, urban-rural population and income group (2015).

Division	Region	Electricity	Sewage	Water	Internet	Mobile
Regional	Northeast (NS)	98,3	49,0	31,0	11,2	78,2
	Southeast (SE)	100,0	58,3	92,2	43,9	95,5
	South	100,0	79,2	93,3	55,0	95,6
	Ratio (NE / South)	1,0	1,6	3,0	4,9	1,2
Rural-urban population	Rural population	98,0	4,9	31,0	11,2	78,3
	Other urban groups	100,0	58,3	93,4	43,9	95,6
	Metropolitan population	100,0	79,1	93,5	55,0	95,6
	Ratio (Rural/metropolitan population)	1,0	16,1	1,0	4,9	1,2
Income	40% poorer	99,4	42,3	75,5	21,1	90,7
	10% richer	99,9	79,2	94,0	84,8	98,6
	Ratio	1,0	1,9	1,3	4,0	1,1

Source: Raiser et al. (2017) via PNAD - National Survey of Household Sample, 2015, IBGE.

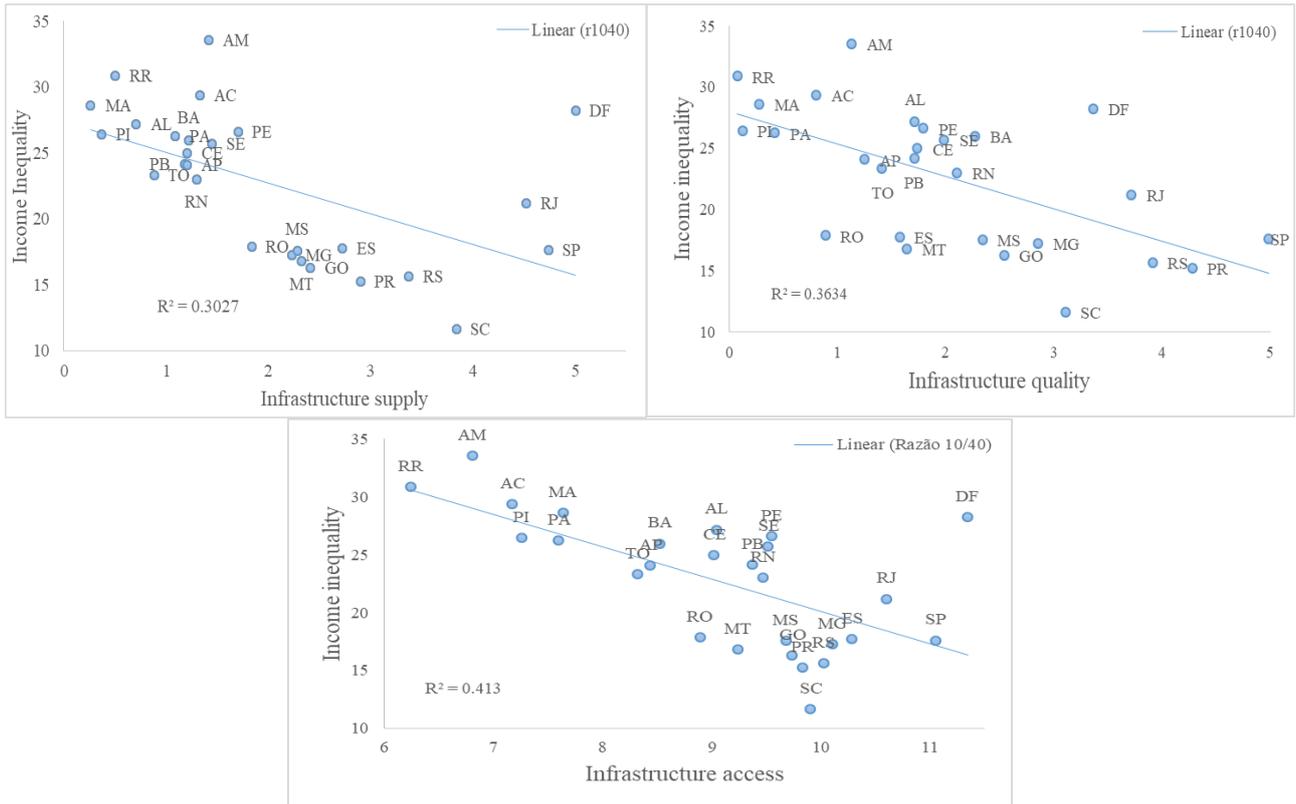


Figure B3 - Correlations between infrastructure and income inequality in Brazilian states.

APPENDIX D

Table D1 - Principal components: eigenvalues.

Indicator/ Component	Eigenvalue		
	Component 1	Component 2	Component 3
Supply (State)	1.30	0.98	0.58
Supply (Municipal)	1.15	0.81	-
Quality (Estadual)	1.26	0.97	0.68
Quality (Municipal)	1.07	0.92	-
Access	1.36	0.85	0.65

APPENDIX E

Table E1 – Global Moran’s I Statistics.

Variable	Moran’s I	Prob	Variável	Moran’s I	Prob
<i>Inequality</i>			<i>Municipal Infrastructure</i>		
<i>r1040</i>	0,446	0.00	<i>Ssanea</i>	0,203	0.00
			<i>Stelec1</i>	0,615	0.00
<i>Controls</i>			<i>Isanea</i>	0,586	0.00
<i>va_ind</i>	0,496	0.00	<i>Qtelec1</i>	0,284	0.00
<i>va_agro</i>	0,622	0.00	<i>Asanea</i>	0,739	0.00
<i>va_ser</i>	0,573	0.00	<i>Aenerg</i>	0,627	0.00
<i>idhm_e</i>	0,693	0.00	<i>Atelec</i>	0,752	0.00
<i>idhm_l</i>	0,737	0.00	<i>Municipal Infrastructure</i>		
<i>pformal</i>	0,773	0.00	<i>Stransp</i>	0,022	0.31
<i>mort</i>	0,740	0.00	<i>Senerg</i>	0,474	0.00
<i>pop</i>	0,336	0.00	<i>Stelec2</i>	0,576	0.00
			<i>Qtransp</i>	0,523	0.00
			<i>Qenerg</i>	0,522	0.00
			<i>Qtelec2</i>	0,071	0.19

APPENDIX F

Table F1 - Infrastructure supply effects on income inequality (Ratio 10/40) using classical hierarchical model.

Variable/Sector	Null model		Sanitation		Transportation		Power		Internet		Telephony		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
<i>Constant</i>	19.27	2.04	46.44	51.84	38.25	52.44	43.44	52.21	43.58	52.24	58.90	51.90	41.89	51.89
<i>va_ind</i>			-0.454	0.133	-0.456	0.134	-0.456	0.134	-0.454	0.134	-0.461	0.134	-0.466	0.133
<i>va_agro</i>			-0.161 ^{ns}	0.103	-0.172	0.103	-0.172	0.103	-0.171	0.103	-0.166	0.103	-0.168	0.103
<i>va_ser</i>			2.355	0.293	2.312	0.293	2.313	0.293	2.296	0.302	2.326	0.293	2.449	0.296
<i>idhm_e</i>			-17.838	1.058	-18.152	1.055	-18.148	1.055	-18.192	1.073	-18.125	1.055	-17.655	1.068
<i>idhm_l</i>			8.399 ^{ns}	11.458	9.313 ^{ns}	11.469	9.345 ^{ns}	11.469	9.067 ^{ns}	11.534	9.939 ^{ns}	11.450	10.319 ^{ns}	11.460
<i>pformal</i>			-0.086	0.011	-0.086	0.011	-0.086	0.011	-0.086	0.011	-0.085	0.011	-0.084	0.011
<i>mort</i>			-0.058 ^{ns}	0.089	-0.050 ^{ns}	0.089	-0.050 ^{ns}	0.089	-0.051 ^{ns}	0.090	-0.049 ^{ns}	0.089	-0.049 ^{ns}	0.089
<i>pop</i>			0.977	0.135	0.930	0.134	0.927	0.134	0.921	0.139	0.925	0.134	1.010	0.137
Infrastructure														
<i>Ssanea</i>			-0.132	0.038										
<i>Stransp</i>					1.650 ^{ns}	3.160								
<i>Senerg</i>							-0.294 ^{ns}	1.326						
<i>Stelec1</i>									0.025 ^{ns}	0.126				
<i>Stelec2</i>											-6.140	1.694		
<i>SIS</i>													-2.478	1.354
<i>MIS</i>													-0.376	0.132
σ_u (state)	10.49		9.25		9.42		9.47		9.31		7.53		8.74	
σ_e (municipal)	7.54		7.17		7.17		7.17		7.17		7.17		7.17	
τ	0.66		0.62		0.63		0.64		0.63		0.52		0.60	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

Table F2 - Infrastructure supply and quality effects on income inequality (Ratio 10/40) using classic hierarchical model.

Variable/Sector	Sanitation		Transportation		Power		Telephony		Internet		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
<i>Ssanea</i>	-0.166	0.041										
<i>SIsanea</i>	0.366	0.176										
<i>Stransp</i>			2.751 ^{ns}	2.887								
<i>SQtransp</i>			-11.900	4.610								
<i>Senerg</i>					70.584	17.559						
<i>SQenerg</i>					-16.855	4.165						
<i>Stelec2</i>							-30.930 ^{ns}	23.664				
<i>SQtelec2</i>							0.329	0.314				
<i>Stelec1</i>									0.042 ^{ns}	0.127		
<i>SQtelec1</i>									-0.100 ^{ns}	0.104		
<i>SIS</i>											-2.103 ^{ns}	3.985
<i>MIS</i>											-0.155 ^{ns}	0.171
<i>SSQ</i>											-0.065 ^{ns}	0.838
<i>MSQ</i>											-0.042	0.021
σ_u (state)	9.25		8.47		7.40		7.53		9.28		8.92	
σ_e (municipal)	7.16		7.17		7.17		7.17		7.17		7.17	
τ	0.62		0.58		0.52		0.52		0.63		0.61	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

Table F3 – Infrastructure supply and access effects on income inequality (Ratio 10/40) using classical hierarchical model.

Variable/Sector	Sanitation		Power		Telephony		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
<i>Ssanea</i>	-0.137	0.039						
<i>SAsanea</i>	0.027 ^{ns}	0.039						
<i>Senerg</i>			18.438	1.019				
<i>SAenerg</i>			-0.192	0.007				
<i>Stelec2</i>					-3.612	1.714		
<i>SAtelec2</i>					-3.087	0.380		
<i>SIS</i>							-3.033	1.674
<i>MIS</i>							3.559	0.389
<i>SSA</i>							0.115 ^{ns}	0.126
<i>MSA</i>							-0.448	0.043
σ_u (state)	9.263		5.412		7.491		7.619	
σ_e (municipal)	7.167		6.711		7.132		7.024	
τ	0.63		0.39		0.52		0.54	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

Table F4 - Infrastructure supply, quality and access effects on income inequality (Ratio 10/40) using classical hierarchical model.

Variable/Sector	Sanitation		Power		Telephony		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
<i>Ssanea</i>	-0.170	0.042						
<i>SIsanea</i>	0.362	0.176						
<i>SAsanea</i>	0.024 ^{ns}	0.039						
<i>Senerg</i>			54.73	11.00				
<i>SQenerg</i>			-8.655	2.621				
<i>SAenerg</i>			-0.191	0.007				
<i>Stelec2</i>					-29.80 ^{ns}	23.476		
<i>SQtelec2</i>					0.348 ^{ns}	0.311		
<i>SAtelec2</i>					-3.090	0.380		
<i>SIS</i>							-2.785 ^{ns}	3.641
<i>MIS</i>							3.628	0.396
<i>SSQ</i>							-0.031 ^{ns}	0.734
<i>MSQ</i>							-0.020 ^{ns}	0.021
<i>SSA</i>							0.108 ^{ns}	0.127
<i>MSA</i>							-0.444	0.043
σ_u (state)	9.26		4.55		7.47		7.79	
σ_e (municipal)	7.17		6.71		7.13		7.02	
τ	0.63		0.32		0.52		0.55	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

APPENDIX G

Table G1 - Infrastructure supply effects on income inequality (10/40 ratio) using HSAR model.

Variable/Sector	Sanitation		Transportation		Power		Telephony		Internet		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
Variáveis de controle												
<i>Constante</i>	142.53	9.68	127.59	9.47	130.42	9.84	132.23	9.55	123.03	9.56	140.24	9.40
<i>va_ind</i>	-0.42	0.13	-0.43	0.13	-0.43	0.13	-0.43	0.13	-0.42	0.13	-0.44	0.13
<i>va_agro</i>	-0.07 ^{ns}	0.10	-0.09 ^{ns}	0.10	-0.08 ^{ns}	0.10	-0.07 ^{ns}	0.10	-0.08 ^{ns}	0.10	-0.08 ^{ns}	0.10
<i>va_ser</i>	2.10	0.28	2.08	0.28	2.05	0.28	2.06	0.29	2.01	0.30	2.16	0.29
<i>idhm_e</i>	-15.40	1.01	-15.62	1.01	-15.57	1.01	-15.54	1.04	-15.73	1.03	-15.23	1.04
<i>idhm_1</i>	-15.72	2.37	-15.86	2.76	-13.58	2.46	-10.21	2.68	-11.88	2.32	-15.05	2.33
<i>pformal</i>	-0.06	0.01	-0.06	0.01	-0.06	0.01	-0.06	0.01	-0.06	0.01	-0.06	0.01
<i>mort</i>	-0.24	0.03	-0.24	0.03	-0.23	0.03	-0.20	0.03	-0.21	0.03	-0.24	0.03
<i>pop</i>	0.90	0.13	0.86	0.13	0.87	0.13	0.87	0.13	0.84	0.13	0.92	0.13
Infrastructure												
<i>Ssanea</i>	-0.10	0.04										
<i>Sstransp</i>			1.39 ^{ns}	1.55								
<i>Senerg</i>					0.57 ^{ns}	0.97						
<i>Stelec2</i>							-5.12	1.81				
<i>Stelec1</i>									0.08 ^{ns}	0.12		
<i>SIS</i>											-1.78 ^{ns}	1.14
<i>MIS</i>											-0.26	0.13
Spatial parameters												
ρ	0.31	0.02	0.31	0.02	0.31	0.02	0.31	0.02	0.31	0.02	0.31	0.02
λ	0.53	0.20	0.80	0.20	0.61	0.18	0.62	0.19	0.55	0.20	0.44	0.20
Random effects												
σ_e^2 (municipal)	31.65	11.90	31.25	12.44	29.90	11.64	19.16	7.53	29.96	11.78	30.04	11.41
σ_u^2 (state)	48.25	0.93	48.31	0.95	48.27	0.93	48.33	0.93	48.27	0.93	48.29	0.94
Model adjustment indicators												
<i>Deviance information criterion (DIC)</i>	52249.27		52262.95		52251.74		52260.65		52255.43		52251.17	
<i>Log likelihood</i>	-26124.98		-26132.30		-26126.54		-26130.85		-26128.01		-26126.21	
<i>Pseudo R²</i>	0.39		0.39		0.39		0.39		0.39		0.39	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

Table G2 – Infrastructure supply and quality effects on income inequality (ratio 10/40) using HSAR model.

Variable/Sector	Sanitation		Transportation		Power		Telephony		Internet		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
<i>Ssanea</i>	-0.136	0.041										
<i>Slsanea</i>	0.371	0.174										
<i>Sstransp</i>			1.690 ^{ns}	1.995								
<i>SQtransp</i>			-6.994	3.851								
<i>Senerg</i>					30.275	8.222						
<i>SQenerg</i>					-7.137	1.964						
<i>Stelec2</i>							-1.973 ^{ns}	7.425				
<i>SQtelec2</i>							-0.039 ^{ns}	0.099				
<i>Stelec1</i>									0.100 ^{ns}	0.124		
<i>SQtelec1</i>									-0.055 ^{ns}	0.103		
<i>MIS</i>											-0.069 ^{ns}	0.164
<i>MSQ</i>											-0.037	0.020
<i>SIS</i>											-3.735 ^{ns}	2.491
<i>SSQ</i>											0.479 ^{ns}	0.583
ρ	0.310	0.018	0.311	0.018	0.312	0.018	0.308	0.018	0.310	0.0181	0.308	0.018
λ	0.555	0.213	0.417	0.232	0.289	0.268	0.661	0.189	0.564	0.193	0.516	0.193
σ_e^2 (municipal)	32.1	11.8	31.3	12.4	28.4	10.2	19.6	7.88	30.4	11.9	29.8	11.7
σ_u^2 (state)	48.2	0.94	48.3	0.94	48.2	0.93	48.3	0.93	48.2	0.94	48.2	0.93
<i>DIC</i>	52238.13		52256.60		52261.79		52260.980		52258.42		52247.940	
<i>Log likelihood</i>	-26119.53		-26128.87		-26131.27		-26131.150		-26129.51		-26124.300	
<i>Pseudo R²</i>	0.392		0.391		0.390		0.390		0.390		0.392	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

Table G3 - Infrastructure supply and access effects on income inequality (ratio 10/40) using HSAR model.

Variable/Sector	Sanitation		Power		Telephony		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
<i>Ssanea</i>	-0.111	0.037						
<i>SAsanea</i>	0.050 ^{ns}	0.037						
<i>Senerg</i>			17.190	0.879				
<i>SAenerg</i>			-0.173	0.007				
<i>Stelec2</i>					-3.279	1.585		
<i>SAtelec2</i>					-2.280	0.372		
<i>MIS</i>							3.146	0.377
<i>MSA</i>							-0.391	0.042
<i>SIS</i>							-2.642	1.489
<i>SSA</i>							0.180 ^{ns}	0.120
ρ	0.310	0.019	0.220	0.018	0.298	0.019	0.275	0.018
λ	0.574	0.194	0.468	0.225	0.577	0.190	0.541	0.209
σ_e^2 (municipal)	30.85	11.48	12.41	4.72	20.22	8.02	22.99	8.59
σ_u^2 (state)	48.21	0.92	43.67	0.84	48.02	0.92	47.04	0.90
<i>DIC</i>	52241.660		51132.240		52192.370		51960.090	
<i>Log likelihood</i>	-26121.250		-25566.560		-26096.430		-25980.690	
<i>Pseudo R²</i>	0.391		0.465		0.397		0.417	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

Table G4 - Infrastructure supply, quality and access effects on income inequality (ratio 10/40): spatial hierarchical model (HSAR).

Variable/Sector	Sanitation		Power		Telephony		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
<i>Ssanea</i>	-0.145	0.040						
<i>SIsanea</i>	0.369	0.171						
<i>SAsanea</i>	0.046 ^{ns}	0.038						
<i>Senerg</i>			35.499	6.934				
<i>SQenerg</i>			-4.483	1.680				
<i>SAenerg</i>			-0.172	0.007				
<i>Stelec2</i>					-3.027 ^{ns}	7.798		
<i>SQtelec2</i>					-0.002 ^{ns}	0.109		
<i>SAtelec2</i>					-2.269	0.368		
<i>MIS</i>							3.178	0.387
<i>MSQ</i>							-0.018 ^{ns}	0.020
<i>MSA</i>							-0.383	0.043
<i>SIS</i>							-4.573	2.082
<i>SSQ</i>							0.543 ^{ns}	0.374
<i>SSA</i>							0.155 ^{ns}	0.121
ρ	0.309	0.018	0.219	0.018	0.298	0.018	0.273	0.018
λ	0.611	0.194	0.056	0.303	0.586	0.199	0.590	0.182
σ_e^2 (municipal)	32.09	11.69	11.61	4.33	20.12	7.93	24.33	9.65
σ_u^2 (state)	48.18	0.91	43.67	0.85	48.01	0.92	47.03	0.89
<i>DIC</i>	52224.360		51132.010		52191.290		51953.320	
<i>Log likelihood</i>	-26112.570		-25566.210		-26096.400		-25977.290	
<i>Pseudo R²</i>	0.392		0.465		0.397		0.418	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

APPENDIX H

Table H1 - Infrastructure supply effects on income inequality (Ratio 10/40) using SAR model.

Variable/Sector	Sanitation		Transportation		Power		Telephony		Internet		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
Control variables												
<i>Constante</i>	138.817	9.521	125.255	9.319	127.000	9.489	128.181	9.238	120.141	9.398	136.747	9.614
<i>va_ind</i>	-0.278	0.128	-0.266	0.130	-0.258	0.133	-0.373	0.129	-0.272	0.128	-0.322	0.129
<i>va_agro</i>	0.214	0.092	0.210	0.090	0.215	0.089	0.276	0.090	0.223	0.090	0.237	0.090
<i>va_ser</i>	1.404	0.281	1.289	0.280	1.269	0.284	1.586	0.284	1.344	0.291	1.601	0.283
<i>idhm_e</i>	-12.923	0.947	-13.404	0.946	-13.568	0.995	-12.655	0.948	-13.225	0.978	-12.312	0.985
<i>idhm_l</i>	-19.353	2.240	-16.611	2.210	-16.653	2.233	-15.883	2.203	-15.278	2.233	-19.219	2.240
<i>pformal</i>	-0.062	0.009	-0.062	0.010	-0.066	0.010	-0.043	0.010	-0.062	0.010	-0.052	0.010
<i>mort</i>	-0.228	0.023	-0.209	0.024	-0.207	0.024	-0.267	0.025	-0.205	0.024	-0.248	0.024
<i>pop</i>	1.259	0.115	1.261	0.116	1.241	0.116	1.052	0.119	1.247	0.118	1.264	0.115
Infrastructure												
<i>Ssanea</i>	-0.166	0.036										
<i>Sstransp</i>			0.406	0.230								
<i>Senerg</i>					0.091 ^{ns}	0.102						
<i>Stelec2</i>							-1.687	0.247				
<i>Stelec1</i>									-0.078 ^{ns}	0.114		
<i>SIS</i>											-0.267	0.121
<i>MIS</i>											-0.483	0.122
Spatial parameter												
ρ	0.502	0.014	0.507	0.014	0.509	0.014	0.483	0.015	0.507	0.014	0.498	0.014
Model adjustment indicators												
<i>DIC</i>	53052.8		53075.4		53082.5		53019.5		53081.2		53056.9	
<i>Log likelihood</i>	-26527.7		-26539.1		-26541.9		-26511.0		-26542.3		-26529.7	
<i>Pseudo R²</i>	0.24		0.23		0.23		0.26		0.23		0.24	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

Table H2 - Infrastructure supply and quality effects on income inequality (Ratio 10/40) using SAR model.

Variable/Sector	Sanitation		Transportation		Power		Telephony		Internet		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
<i>Ssanea</i>	-0.207	0.038										
<i>SIsanea</i>	0.495	0.159										
<i>Sstransp</i>			0.403	0.230								
<i>SQtransp</i>			-0.160 ^{ns}	0.312								
<i>Senerg</i>					15.086	1.672						
<i>SQenerg</i>					-3.573	0.398						
<i>Stelec2</i>							1.753 ^{ns}	1.951				
<i>SQtelec2</i>							-0.046	0.026				
<i>Stelec1</i>									-0.043 ^{ns}	0.117		
<i>SQtelec1</i>									-0.105 ^{ns}	0.092		
<i>SIS</i>											-1.269	0.303
<i>MIS</i>											-0.225 ^{ns}	0.167
<i>SSQ</i>											0.186	0.049
<i>MSQ</i>											-0.044	0.020
ρ	0.500	0.014	0.508	0.014	0.474	0.015	0.485	0.015	0.507	0.014	0.493	0.015
<i>DIC</i>	53035.5		53085.6		52983.5		53010.1		53084.1		53022.7	
<i>Log likelihood</i>	-26519.2		-26543.4		-26493.4		-26505.6		-26543.0		-26513.0	
<i>Pseudo R²</i>	0.24		0.23		0.27		0.26		0.23		0.25	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

Table H3 - Infrastructure supply and access effects on income inequality (Ratio 10/40) using SAR model.

Variable/Sector	Sanitation		Power		Telephony		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
<i>Ssanea</i>	-0.159	0.037						
<i>SAsanea</i>	-0.027 ^{ns}	0.027						
<i>Senerg</i>			17.656	0.623				
<i>SAenerg</i>			-0.178	0.006				
<i>Stelec2</i>					-0.208 ^{ns}	0.365		
<i>SAtelec2</i>					-1.820	0.338		
<i>SIS</i>							-4.642	0.750
<i>MIS</i>							3.735	0.293
<i>SSA</i>							0.492	0.075
<i>MSA</i>							-0.480	0.030
<i>p</i>	0.503	0.015	0.340	0.016	0.476	0.015	0.429	0.015
<i>DIC</i>	53034.4		51650.5		52963.7		52597.9	
<i>Log likelihood</i>	-26518.7		-25826.2		-26483.1		-26300.2	
<i>Pseudo R²</i>	0.24		0.40		0.26		0.31	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.

Table H4 - Infrastructure supply, quality and access effects on income inequality (Ratio 10/40) using SAR model.

Variable/Sector	Sanitation		Power		Telephony		Infrastructure	
	Estim.	SE	Estim.	SE	Estim.	SE	Estim.	SE
<i>Ssanea</i>	-0.202	0.040						
<i>SIsanea</i>	0.481	0.159						
<i>SAsanea</i>	-0.016 ^{ns}	0.027						
<i>Senerg</i>			22.782	1.614				
<i>SQenerg</i>			-1.313	0.383				
<i>SAenerg</i>			-0.175	0.006				
<i>Stelec2</i>					2.315 ^{ns}	1.958		
<i>SQtelec2</i>					-0.034 ^{ns}	0.026		
<i>SAtelec2</i>					-1.784	0.348		
<i>SIS</i>							-4.071	0.802
<i>MIS</i>							3.775	0.331
<i>SSQ</i>							0.070 ^{ns}	0.059
<i>MSQ</i>							-0.040	0.019
<i>SSA</i>							0.398	0.095
<i>MSA</i>							-0.459	0.034
<i>p</i>	0.500	0.014	0.329	0.016	0.476	0.015	0.429	0.015
<i>DIC</i>	53027.3		51639.3		52964.8		52593.9	
<i>Log likelihood</i>	-26515.3		-25820.4		-26483.6		-26298.3	
<i>Pseudo R²</i>	0.24		0.41		0.26		0.32	

Notes: Estim., Estimates; SE, standard error; ns indicates not significant.