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Electricity Access and Structural Transformation

Evidence from Brazil's Electrification

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Abstract

This study proposes a novel supply-side mechanism driving economic structural transformation: grid electrification. Increasing electricity availability affects the reallocation of inputs to more productive activities through generating higher returns and lowering entry costs in sectors with greater infrastructure intensity. The results of modeling and econometric analysis based on Brazil's historical data over the period 1970–2006 confirm that the manufacturing sector benefits the most in these two dimensions, followed by services and agriculture. The expansion of electricity infrastructure explains about 17 percent of this process and 32 percent of the observed increase in GDP per capita. Simulations of a multisector neoclassical growth model with heterogeneous firms help assessing the effectiveness of different electrification policies.

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Electricity Access and Structural Transformation: Evidence from Brazil's Electrification[*]

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1 Introduction

As Herrendorf et al. (2014), among many others, argue, the process of structural transformation, that is, the reallocation of inputs to more productive activities, is recognized as an important feature of successful economic development. Focusing particularly on the three largest sectors of the economy, we can further characterize this process as the reallocation of productive resources from agriculture to manufacturing and services, and later from agriculture and manufacturing to services.[1]

Access to public infrastructure services and, particularly, to modern electricity services is another important process that has recently gained a prominent place in the development economics literature. Electricity is as an important public good, and consequently improving electricity access in developing countries is a significant goal of the international community. The Sustainable Development Goals and the United Nations initiative Sustainable Energy for All (SE4All), for example, call for providing electricity to the 1.1 billion hitherto non-electrified people worldwide by 2030.

The economics literature has demonstrated that improved access to electricity positively affects employment (Dinkelman, 2011), industrial output (Rud, 2012), human development and housing values (Lipscomb et al., 2013, Lewis and Severnini, 2017), household income (Chakravorty et al., 2014), industrial and agricultural productivity (Fisher-Vanden et al., 2015, Allcott et al., 2016, Assunção et al., 2018), infant health (Lewis, 2018), and firms' entry and exit (Kassem, 2018).

However, our understanding of how improved electricity access interacts with the structural transformation process and affects national income levels is limited. To fill the gap, this paper assesses the significance of electricity access, and the different constraints that surround it, in the allocation of resources among sectors and in the formation and growth of

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[1] We adopt the definition of these three sectors based on Herrendorf et al.'s (2014) survey of the literature on structural transformation. In particular, the agriculture sector includes cultivation and breeding of animals, plants, and fungi. The services sector refers to the tertiary sector: financial, business, distribution and personnel services. Finally, the manufacturing sector captures all production activities that fall outside agriculture and services.

Gross Domestic Product (GDP) based on the experience of Brazil, one of the world's largest developing nations.

To achieve this goal, we develop a multisectoral general equilibrium model of unbalanced economic growth and then analyze it quantitatively.[2] In this framework, the three sectors – agriculture, manufacturing, and services – coexist within a closed economy, except for the capital market, which is open.[3] They experience exogenous sector-specific productivity growth. There are three main actors: firms, households and government. We deviate from the existing literature by introducing electricity infrastructure and heterogeneous firms. Electricity infrastructure is a complementary factor that increases the productivity of private inputs (Fisher-Vanden et al., 2015, Allcott et al., 2016, Assunção et al., 2018). Firms have plant-specific productivity and are free to enter and exit markets. We consider firm heterogeneity because, besides the standard complementarity between public and private capital shown in the earlier literature (Reinikka and Svensson, 2004), electricity access in our model affects fixed costs of operation. That is, the lack of electricity access can act as a barrier to the entry of firms into markets (Kassem, 2018). The size of the fixed costs also contributes to endogenously determine the average productivity level in each industry and affect input reallocation across sectors.

This second effect of electricity access to which we refer above is motivated by recent literature (see, e.g., Hopenhayn, 2016, for a review) that emphasizes the importance of firm size heterogeneity to explain total factor productivity (TFP) differences across nations. It is also motivated by the observation that some fixed operating costs such as payments, depreciation and maintenance for certain indivisible equipment depend on the quality of

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[2] The unbalanced growth feature of the model should not be perceived as a limitation or unnecessary complication. As Herrendorf et al. (2014) argue: "[in order to study the structural transformation process] focusing on frameworks that yield exact balanced growth is probably overly restrictive. The literature should instead focus on building models that can quantitatively account for the properties of structural transformation and in the process assess the importance of various economic mechanisms."

[3] The closed-economy assumption is common in the structural transformation literature. Openness in goods markets is introduced by some papers, like Uy et al. (2013), to accelerate the development of the manufacturing sector. In our case, the openness of capital markets simply implies that the interest rate is exogenous, and then the consumption side does not play any role in capital accumulation.

public utility networks. In many developing countries, the problem of deficient electricity supply is further exacerbated by financing constraints that prevent smoothing these fixed costs (Steinbuks, 2012). Electrification can lead to higher or lower operating costs. On the one hand, a lower need for supporting equipment like self-generating electricity machines will contribute to reduce them (Foster and Steinbuks, 2009, Steinbuks and Foster, 2010). On the other, improvements in electricity access are conducive to the technological progress that generates increasing returns, such as e.g., adoption of electric irrigation pumps in India (Rud, 2012), which contributes to raise those costs.

The quantitative analysis in our study is based on Brazilian data for the period 1970-2007, although the model simulations cover a slightly shorter time interval, 1970-2006, because we lose one observation when forming predictions. These data indicate that our analytical framework is well suited to examining the influence of electrification on structural transformation in Brazil. Unlike many developing countries, Brazil offers comparable data across sectors on gross value added, employment levels, and size and number of firms. The advances in electrification and the interconnection process in Brazil started as early as the 1960s, when high voltage transmission lines connected the Southeast states of São Paulo, Rio de Janeiro and Minas Gerais. The process accompanied the rapid pace of industrialization observed during the 1960s and 1970s, which required significant infrastructure investments. During 1970-2006, the value added shares of agriculture and manufacturing declined and that of services increased. As expected, these patterns are replicated by the sectoral employment shares. As regards firm size, the manufacturing sector has, on average, the largest firms, followed by the services sector, and the agriculture sector that has the smallest firms. The average establishment size remains relatively stable in the agriculture and services sectors and exhibits cyclical behavior in the manufacturing sector.[4]

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[4] The evidence on the relationship between a country's income per capita level and average firm size is not conclusive. For example, using data on the manufacturing sector, Alfaro et al. (2009) find that firm size decreases with the level of income across nations, and Laincz and Peretto (2006) report no trend in average firm employment in the U.S. More recent papers, such as Poschke (2017) and Bento and Restuccia (2017), on the contrary, document that average establishment size is positively correlated with GDP per capita in the cross-section of countries.

The analysis starts with econometric estimation based on municipality-level panel data using both OLS and IV methods. The IV employs the instrument constructed by Lipscomb et al. (2013) and its estimates suggest that a 1 percentage point increase in electricity access increases the share of services by 1.06-1.14 percentage points; whereas the shares of agriculture and manufacturing decline, respectively, by 0.65-0.7 and 0.42-0.43 percentage points. The theoretical model simulations further support the important role of advances in electricity on the structural transformation process, explaining 17 percent of this process for the Brazilian case during the period 1970-2006. The model, however, predicts that the growing public capital mainly favors the manufacturing sector, which is what the OLS findings imply. Interestingly, the theory is able to rationalize these two different econometric results and supply a clearer view of the effects.

The reason is that the role of electric power infrastructure arises through two channels. The first one, which is what the IV method mainly captures, runs through consumption and investment as a consequence of supply-side forces linked to the output production technologies. These supply-side effects accelerate the reallocation of production inputs towards services. More specifically, in the model, when sectors are complementary, their consumption and investment shares increase with the relative product price. Because manufacturing is the most energy intensive sector, and also the one that experiences the fastest decrease in fixed costs as electricity availability improves, the relative prices of primary and tertiary products grows with advances in electricity access, and hence the reallocation of resources towards those sectors (especially services) speeds up.

The second one, on the other hand, represents a demand-side channel that favors the growth of manufacturing and, to a lesser extent, the one of services, because the creation of infrastructure demands additional investment that comes mainly from the secondary sector. A further increase in the investment effort is allowed by the net reduction in fixed costs that the economy enjoys with electrification. Due to the large impact of investment on manufacturing, it is the second channel that dominates and the share of manufacturing is the one that benefits the most from the creation of electricity infrastructure. This last general equilibrium effect shows up in the OLS estimates.[5]

Based on our model simulations, the growth of electricity infrastructure explains 8.3, 28.0 and 10.4 percent of the total variation in the GVA shares of agriculture, manufacturing and services, respectively, observed in the Brazilian economy over the period 1970 to 2006, and is responsible for 32.3 percent of the growth observed in GDP. The predictions also provide a substantial role to changes in the sectoral wedges that determine the size of firms. More specifically, variation in sector-specific operating fixed costs that do not depend on electricity access explain 6.3, 14.4 and 5.5 percent of the Brazilian structural transformation process in the primary, secondary and tertiary activities, respectively. We also find that the increase in this component of the fixed costs prevented GDP from rising an additional 15.6 percent during the period 1970-2006. The remaining variation of the sectoral shares in the model is a consequence of changes in the sectoral TFP variable.

We also run some experiments that relate the model simulations to real-life policies. The first two consider the fall in the Brazilian GDP-share of public capital formation, which includes expenditures on expansion and maintenance of electricity infrastructure, from the average 3.28 percent observed in the 1970s and 1980s to the 0.9 percent observed during 1990-2007. We ask the question of what would have been the effect of maintaining the public-capital formation levels of 1970-1989 during the 1990s and 2000s. First, we achieve this counterfactual through a less partisan view of public spending that generates stronger policy incentives in favor of the public input. The result is an increase of the income share of manufacturing and declines in the shares of the other two production activities. There is also a substantial positive effect on total GDP and production levels. In particular, GDP per capita

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[5] This does not mean that OLS obtains less biased estimates than the IV. Notice that OLS suffers from omitted variable and simultaneity problems, and that these simultaneity concerns come from the potential positive influence that increases in output have on investment and public capital formation. Moreover, whereas the additional investment required to finance a better grid infrastructure should be attributed to the effects of electricity access, the increase in electricity capital induced by a higher GDP should not. Given that these two differentiated effects on investment are both demand driven, the IV estimate does not discriminate between them, and at the end, captures mainly the supply driven channel. This feature will prove useful during the model calibration.

and manufacturing output go up by 23.9 and 38.0 percent, respectively. Second, we study the case when the increase in public capital formation occurs due to the improvement in the management of public investment so that a larger fraction of public investment expenditures ends up converted in improved provision of electricity services. Compared to the previous scenario, the GVA sectoral shares change much less, because the same amount of investment goods can now generate stronger capital accumulation. The effects on GDP and sectoral production, though, remain substantial.

Third, we examine a variation in rent-seeking behavior of the central government directed to capture total output, which appears to have no effect on the paths of electricity access, sectoral GVA, and GDP per capita. This is because rent-seeking politicians prefer that the economy achieves the first-best so that they can extract the maximum amount of rent. Fourth, we investigate the effect of an increase in the effectiveness of electricity infrastructure in specific sectors. Even though this does not significantly affect income shares, it has a clear positive effect on the development process through a rise in the optimal electricity infrastructure stock. Finally, large negative effects on GDP per capita and a possible reduction in the size of the manufacturing sector are obtained in a scenario equivalent to a subsidization of electricity services that brings a decline in infrastructure investment, the result known as the infrastructure subsidy trap (McRae, 2015).

Our paper contributes to the extensive literature on the structural transformation by proposing a novel driving mechanism – the electricity infrastructure – that works through the supply side, and that directly affects both the productivity of private inputs and the firm's operating costs. Previous papers largely focus on two main channels of structural transformation. The first one is non-homotheticity of consumers' preferences, pioneered by Konsamut, Rebelo, and Xie (2001).[6] These authors build a neoclassical model of growth in which the income elasticity of demand is less than one for agricultural goods, equal to one for manufacturing goods, and greater than one for services. They are able to generate a

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[6] Similar demand-side channels are presented in Matsuyama (1992), Echevarria (1997), Laitner (2000), and Gollin et al. (2002), among others.

balanced growth that is consistent with observed structural change trends. The second one is the sector-biased technical change suggested by Baumol (1967) and, more recently, by Ngai and Pissarides (2007).[7] Ngai and Pissarides (2007) show that if there are two industries, one characterized by a larger TFP growth, hours of work increase in the stagnant sector if the two goods have a relatively large degree of complementarity; otherwise labor moves in the direction of the progressive sector.

Several papers propose alternative mechanisms of structural transformation. Caselli and Coleman (2001) assume that non-agriculture sectors are more skill intensive than the agriculture sector. Bar and Leukhina (2010) and Leukhina and Turnovsky (2016) investigate the effects of population size increases. Alvarez-Cuadrado et al. (2016) point out that relative sectoral output prices also depend on the elasticity of substitution between capital and labor. Uy et al. (2013) and Tegnier (2018), among others, study the effect of openness to international trade on the structural transformation.[8] Our paper is also closely related to Acemoglu and Guerrieri (2008), who study a model based on capital accumulation and constant returns to scale; like us, Acemoglu and Guerrieri offer a supply-side explanation of structural change that depends on sectoral capital-intensity differences. None of these studies considers the role of electricity access, or the role of firm size heterogeneity in the structural transformation process.[9]

Finally, another strand of the literature related to our work concentrates on the role of infrastructure costs on the spatial distribution of economic activity and income per capita. Herrendorf et al. (2012), for instance, study the effect of the transportation technology

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[7] Buera and Kaboski (2009) and Guillo et al. (2011) also provide support in favor of biased technical change. So does Alonso-Carrera et al. (2017) regarding the main driving force of the movement of labor out of agriculture; however, this last paper finds as well that the increase of labor employment in the service sector is mainly caused by demand-side income effects.

[8] In a recent contribution, Sposi et al. (2018) construct a multi-sector model of the structural transformation to perform a structural accounting decomposition exercise. They conclude that trade costs had a significant effect on the evolution of the sectoral labor shares in Hungary, Portugal and the Republic of Korea during the period 1970-2010.

[9] Bento and Restuccia (2018) study the allocation of resources between the manufacturing and services sectors in a model with firm-size heterogeneity. However, they focus on assessing the impact of the degree of misallocation. Put differently, they look at how the sectoral dispersion of firm sizes affects the sectoral shares, whereas we look at the effect of the evolution of the average size.

revolution on the spatial reallocation of labor between agriculture and manufacturing in the U.S. economy during the period 1840-1860. Another example is Karadiy and Korenz (2017), who quantify the impact of transport costs on sector location and productivity differences across OECD nations. They focus on a different type and role of infrastructure.[10]

The rest of the paper is organized as follows. The next section presents the model outline. Section 3 describes the Brazilian experience and data. Section 4 defends the model calibration and shows the results of the quantitative analysis and policy simulations. Section 5 concludes.

2 Analytical Framework

We consider an economy with three main actors: households, firms, and the government. There are three production sectors: agriculture, manufacturing, and services; manufactures are the numeraire. For simplicity, we assume that there is a free international movement of capital. All other markets are closed. Within all production activities, there is free entry and exit of heterogeneous firms. Firms pay fixed costs of entry and operation. If they decide to operate in the market, firms have access to a production technology that employs private capital, labor and public electricity infrastructure, which are assumed imperfect substitutes in the production process. The public input determines factor productivity and affects the fixed costs faced by firms. It is provided by rent-seeking politicians and is financed by lump-sum consumer taxes. The model variables and parameters are described in appendix A.

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[10] There exists as well an important literature on the implications of public infrastructure (including electricity infrastructure) provision on economic growth and development. Going back at least to Barro (1990), theoretical models have analyzed the possible role of public capital in long-run economic growth. Contributions in this area include Glomm and Ravikumar (1994), Agénor (2010, 2012), and Rioja (2001), among others. Within an endogenous growth model, Felice (2016) studies the effect of public infrastructure on economic growth and the allocation of labor between a traditional and a modern sector. Other papers, like Chakraborty and Lahiri (2007) and Cubas (2018), try to quantify the impact of public capital on income differences across nations following a development accounting approach.

2.1 Households

The economy is composed of infinitely-lived individuals that show preferences defined over consumption of agricultural goods (c_a), manufacturing products (c_m), and services (c_s). They are endowed with *one* unit of time that is supplied inelastically as labor in exchange for a salary (w_t). They own equal shares in all firms that provide dividends from profits each period (d_t). The population is a mass of size one and remains constant.

The problem faced by a representative consumer is the following:

$$\underset{\{c_{it},b_{t+1}\}}{Max}\left\{\sum_{t=0}^{\infty}\rho^t ln(c_t)\right\} \tag{1}$$

where

$$c_t=\left[\omega_a^{\frac{1}{\varepsilon}}c_{at}^{\frac{\varepsilon-1}{\varepsilon}}+\omega_m^{\frac{1}{\varepsilon}}c_{mt}^{\frac{\varepsilon-1}{\varepsilon}}+(1-\omega_a-\omega_m)^{\frac{1}{\varepsilon}}c_{st}^{\frac{\varepsilon-1}{\varepsilon}}\right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{2}$$

subject to the budget constraint

$$w_t+d_t+b_t(1+r_t-\delta_k)-\tau_t=p_{at}c_{at}+c_{mt}+p_{st}c_{st}+b_{t+1}. \tag{3}$$

In the above problem, the parameter $\varepsilon\in(0,\infty)$ represents the elasticity of substitution between goods in consumption, ω_i weights the importance of sector i in the consumption bundle c_t, and ρ is the subjective discount factor. The prices p_{at} and p_{st} correspond to agricultural products and services, respectively, and are expressed in terms of manufacturing output. The consumer's stock of bonds in period t equals b_t, and provides a return given by the interest rate r_t minus the depreciation rate of private capital δ_k. Each individual pays lump-sum taxes τ_t to the government.

Taking prices exogenously, the solution to this problem results in the following optimality conditions for consumption:

$$\frac{P_{c,t+1}c_{t+1}}{P_c c_t}=\rho\left(1+r_{t+1}-\delta_k\right), \tag{4}$$

$$\frac{p_{it}c_{it}}{P_{ct}c_t} = \omega_i \left(\frac{p_{it}}{P_{ct}}\right)^{1-\varepsilon}; \tag{5}$$

where the exact CES price of the consumption bundle equals

$$P_{ct} = \left(\sum_{i=a,m,s} \omega_i p_{it}^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}. \tag{6}$$

Equations (4) and (5) represent the intertemporal and the intersectoral optimality conditions for consumption, respectively. The former defines the growth rate of total consumption expenditure as a function of the return to saving, that is, the interest rate net of depreciation discounted to take into account the time preference.[11] The latter expression, in turn, says that the share of sector i in total consumption expenditure depends on the weight ω_i and the relative price p_{it}/p_{ct}. More specifically, if the different consumption goods are complementary (i.e., $\varepsilon \in (0, 1)$), the consumption share of sector i rises with its relative price; the opposite is true when the goods are relative substitutes, $\varepsilon > 1$; finally, if ε equals one, the share is constant and equal to its exogenous weight in the consumption bundle.

2.2 Firms

There is free entry and exit of profit-maximizing firms in all markets. These markets are perfectly competitive. We consider an unlimited number of potential entrants. Entrants have highly idiosyncratic specialization and can operate in one and only one sector during their productive lives. Establishments can generate output in activity $i = a, m, s$ combining labor services l_i, private capital k_i, and electricity infrastructure G. The production technology at the firm level displays diminishing returns over private capital and labor. Electricity infrastructure is supplied free of charge by the government, and represents a non-rival good whose stock is used simultaneously by all firms.[12] Total factor productivity depends on a

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[11] This equation does not play any role in the solution of the model because the interest rate is assumed to be given by international markets. It will be used, however, in the calibration of the interest rate.

[12] We could relax this latter assumption and introduce congestion in the use of public goods, for example by dividing the stock of public capital G_t in expression (7) by the level of production $y_{it}(q)$. The main

sector-specific parameter A_i that grows at the exogenous gross rate Z_{A_i} and a plant-specific efficiency coefficient q. As in Ngai and Pissarides (2007), sector-biased technical change – that is, differences in the growth rate of A_i across sectors – will be one source of the structural transformation in our model.

More specifically, the amount of output $y_{it}(q)$ produced by a firm that operates in sector i at time t as a function of q is given by the following technology:

$$y_{it}(q) = A_{it} q \left(e_{it} G_t\right)^{\beta_i} \left[k_{it}(q)\right]^{\alpha} \left[l_{it}(q)\right]^{\gamma}, \qquad \alpha, \beta_i, \gamma \in (0,1); \qquad \alpha + \gamma < 1; \tag{7}$$

where β_i represents the intensity with which electricity infrastructure is used in sector i; whereas e_{it} is an exogenous sector-specific electricity infrastructure efficiency variable. The variable e_{it} captures the productivity of electricity infrastructure for the different sectors; it can be related to its type but also its location. For example, relatively low levels of public investment in irrigation systems and lack of proximity to electric grid in rural areas could mean a lower value of e_{at} compared to e_{mt}. This is different than the intensity with which irrigation systems are used in agriculture, which is clearly higher than in manufacturing.

Some of the assumptions made related to the role of electricity in the production function deserve some comment. First, electricity infrastructure enters equation (7) directly as an input. In this sense, we model electricity capital as a reduced form version of a mapping from electricity infrastructure through electricity use to productivity. Second, we suppose that the nature of G_t is non-rival. We make this assumption to avoid unnecessary modeling complications. In real life, electricity networks have some degree of rivalness because of congestion issues. We elaborate on the possible consequences of relaxing this assumption in footnote 12. Finally, electricity infrastructure (both grid and off-grid) in the real world is not always provided free of charge. For example, electricity access fees set by state-owned enterprises in many developing countries can be quite high (Golumbeanu and Barnes, 2013;

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consequence would be the division by $1 + \beta_i$ of the input shares (exponents) in the reduced-form production function. As we do not impose constant returns over private inputs, the calibration exercise should take care of this possible effect of congestion.

Blimpo et al., 2018). Even if electricity infrastructure provision is nominally free, there can be high shadow costs, such as long wait times to obtain a connection. In our model, these expenditures are captured, at least in part, by the fixed operation costs faced by firms, expression (18).

Knowing its production function, expression (7), a profit-maximizing firm with efficiency q rents capital and labor until input prices are equalized to the value of their marginal productivity. These first order conditions are given by:

$$w_t = p_{it}\gamma A_{it}q\left(e_{it}G_t\right)^{\beta_i}\left[k_{it}(q)\right]^{\alpha}\left[l_{it}(q)\right]^{\gamma-1}, \tag{8}$$

and

$$r_t = p_{it}\alpha A_{it}q\left(e_{it}G_t\right)^{\beta_i}\left[k_{it}(q)\right]^{\alpha-1}\left[l_{it}(q)\right]^{\gamma}. \tag{9}$$

Combining (7), (8) and (9) obtains that all firms will employ the same capital-labor ratios and that labor demand, capital demand and profits are a function of prices, total factor productivity and the electricity infrastructure efficiency level:

$$\frac{k_{it}(q)}{l_{it}(q)} = \frac{\alpha w_t}{\gamma r_t}, \tag{10}$$

$$l_{it}(q) = \left[p_{it}A_{it}q\left(e_{it}G_t\right)^{\beta_i}\left(\frac{\gamma}{w_t}\right)^{1-\alpha}\left(\frac{\alpha}{r_t}\right)^{\alpha}\right]^{\frac{1}{1-\alpha-\gamma}}, \tag{11}$$

$$k_{it}(q) = \left[p_{it}A_{it}q\left(e_{it}G_t\right)^{\beta_i}\left(\frac{\gamma}{w_t}\right)^{\gamma}\left(\frac{\alpha}{r_t}\right)^{1-\gamma}\right]^{\frac{1}{1-\alpha-\gamma}}, \tag{12}$$

and

$$\pi_{it}(q) = (1-\alpha-\gamma)\left[p_{it}A_{it}q\left(e_{it}G_t\right)^{\beta_i}\left(\frac{\gamma}{w_t}\right)^{\gamma}\left(\frac{\alpha}{r_t}\right)^{\alpha}\right]^{\frac{1}{1-\alpha-\gamma}}. \tag{13}$$

The last equality implies that the amount of profits $\pi_{it}(q)$ is a fraction $1-\alpha-\gamma$ of total production of a type-q firm in sector i at time t.

Firms build their stocks of physical capital borrowing saving to buy units from manufacturing and services that are combined according to the following CES technology:

$$x_t = \left[\mu_m^{\frac{1}{\nu}} x_{mt}^{\frac{\nu-1}{\nu}} + (1-\mu_m)^{\frac{1}{\nu}} x_{st}^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}; \tag{14}$$

where x_t represents investment at date t; x_{it} is the amount of sector-i products employed in capital formation; ν is the elasticity of substitution among investment products; and $\mu_i \in (0,1)$. This technology is based on the observation that over time, due to for instance the increasing importance of software, the service sector has increased very significantly its contribution to total investment. A consequence of this phenomenon is that, since year 2000, total investment in the US exceeds the size of the whole manufacturing sector.[13] It is straightforward to derive that the optimal demand of investment goods obey the following condition:

$$\frac{p_{it} x_{it}}{P_{xt} x_t} = \mu_i \left(\frac{p_{it}}{P_{xt}}\right)^{1-\nu}; \tag{15}$$

where the price of the investment bundle equals

$$P_{xt} = \left(\sum_{i=m,s} \mu_i \, p_{it}^{1-\nu}\right)^{\frac{1}{1-\nu}}. \tag{16}$$

As in the case of the consumption bundle, if the two investment goods are complementary (i.e., $\nu \in (0,1)$), the investment share of sector i goes up with its relative price; the opposite occurs when investment goods are substitutes (i.e., $\nu > 1$); if $\nu = 1$ then the shares are constant.

Following Restuccia and Rogerson (2008), we assume that establishments are heterogeneous in terms of their TFP due to the plant-level productivity parameter q drawn from a distribution with density function $h(q)$, and that draws are i.i.d. across entrants. In order to learn q in period t, the firm needs to pay an exogenous fixed cost F_{qt}. In addition, after knowing their type, firms that want to operate in market i must pay a second sector-specific

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[13] The share of the agriculture sector in total investment is not significant and thus ignored.

fixed cost F_{oit} that depends on the amount of electricity infrastructure in the economy. In particular,

$$F_{qt} = f_q A_{mt}^{\psi}, \tag{17}$$

and

$$F_{oit} = f_{oit} A_{mt}^{\psi} G_t^{\theta_i}; \tag{18}$$

where the parameters $\psi > 0$ and $\theta_i \gtrless 0$ affect the response of the fixed costs to technological change and the relative supply of public capital, respectively; f_q is a scaling parameter; and f_{oit} allows the fixed cost of operation to vary due to other sector-specific reasons. Variables F_{qt} and F_{oit} are expressed in units of manufacturing output. In addition, F_{qt} implicitly incorporates an insurance premium that covers firms that decide to enter but that eventually, due to a bad draw of q, cannot pay F_{qt} fully after production occurs.

Equations (17) and (18) imply that fixed costs depend on the economy's average technological level, captured by A_{mt}. Fixed costs will then increase with the level of development, a prediction consistent with the evidence presented by Bollard et al. (2016), among others. An example of F_{qt} is the cost of a market analysis intended to study the opportunities that the sector offers, and the strengths and weaknesses of the potential entrant within that market segment. Examples of F_{oit}, in turn, include any barrier to the operation that imposes a cost that varies with electricity infrastructure. We consider that $\theta_i \lesseqgtr 0$; that is, these costs can increase or decrease with G. They can rise, for example, if better electricity access induces technology upgrades that require higher operating costs. The fixed component of operating costs can be direct, like interest payments, depreciation, and maintenance of some indivisible equipment such as electricity self-generators and technology-specific physical capital, also permits, bribes and other indivisible administrative costs related to grid access. They can be as well indirect, due for example to power outages, that prevent production while they occur. For the sake of simplicity, we assume that firms mutate and every period need to rediscover their type; that is, both costs need to be paid every period after production takes place.[14]

Free entry means that establishments will enter the market if and only if expected profits are not lower than the up-front costs. This means that, before knowing its type, expected profits net of entry and operation costs in each sector i are reduced to zero. Therefore, the free entry condition can be stated as follows:

$$\int_0^\infty \left[\pi_{it}(q) - F_{oit}\right] h(q)\, dq - F_{qt} = 0; \tag{19}$$

In addition, after they know the type, firms will operate in a given period provided that they can obtain positive profits, which requires that their plant-specific productivity parameter q is greater than or equal to the threshold value $\hat{q}_{it}$ such that

$$\pi_{it}(\hat{q}_{it}) - F_{oit} = 0. \tag{20}$$

From free entry conditions (19), we can write output prices as

$$p_{it} = \frac{A_{mt}\left(e_{mt}G_t\right)^{\beta_m}}{A_{it}\left(e_{it}G_t\right)^{\beta_i}} \left(\frac{f_q + f_{oit}G_t^{\theta_i}}{f_q + f_{omt}G_t^{\theta_m}}\right)^{1-\alpha-\gamma}. \tag{21}$$

Unlike the more standard multisector models with Cobb-Douglas production functions, where output prices are fully pinned down by relative TFP, the price in our framework depends on the variables that affect the relative productivity of private inputs – namely, the sector-specific productivity and the efficiency level of electricity infrastructure – and on the relative size of fixed costs. A relatively less productive industry or a sector that faces higher relative fixed costs will charge a higher price. It is also easy to prove that a larger value of G_t will tend to increase p_{it} if $\beta_m > \beta_i$ due to the productivity effect (first quotient in the right-hand side of expression (21)), and if $f_{omt} > f_{oit}$ because of the fixed-costs effect (second term

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[14] The literature usually assumes that the entry cost F_{qt} is only paid in the period of entry; see, e.g., Restuccia and Rogerson (2008). We do not follow their approach to avoid keeping track of the productivity level of incumbents that entered the market in previous periods. This assumption should not have a significant effect on our results.

inside brackets in the right-hand side of (21)). Therefore, since the evolution of relative prices represents a main determinant of the structural transformation, public capital can be an important force in this process.

Taking on-board the last expression, along with conditions (8) and (10), it is also easy to derive the relative labor allocations. Within sectors, labor is allocated exclusively based on the efficiency parameter q as follows:

$$\frac{l_{it}(q)}{l_{it}(q')} = \frac{q}{q'}, \quad for\ i = a, m, s. \tag{22}$$

Firms with a larger productivity parameter q will hire more labor and rent more capital. Across sectors, in turn, the relative labor allocation obeys:

$$\frac{l_{it}(q)}{l_{mt}(q)} = \left(\frac{f_q + f_{oit} G_t^{\theta_i}}{f_q + f_{omt} G_t^{\theta_i}} \right)^{1-\alpha-\gamma}. \tag{23}$$

for $i = a$, s. That is, across industries, variation in the hired amount of labor is exclusively driven by differences in fixed costs; sectors with lower fixed costs will have smaller firms on average.

The minimum plant-productivity level that justifies operation in sector i can be also easily obtained from (19) and (20) combining the free entry condition in manufacturing and the operation conditions. We obtain

$$\hat{q}_{it} = \left\{ \frac{E\left[q^{\frac{1}{1-\alpha-\gamma}} \right]}{1 + \frac{f_q}{f_{oit} G_t^{\theta_i}}} \right\}^{1-\alpha-\gamma}. \tag{24}$$

The expected value of $q^{\frac{1}{1-\alpha-\gamma}}$ ($E[q^{\frac{1}{1-\alpha-\gamma}} = \int_0^\infty q^{\frac{1}{1-\alpha-\gamma}} h(q)\, dq]$) and the fixed costs are its main determinants. To understand this, observe that the threshold value is related to the minimum firm-size that can survive in the market. A larger expected q makes fixed costs relatively less important in the entry decision and increases the size of the average firm. A larger sector-specific cost of operation, on the other hand, demands a larger size.

Finally, the profits that firms are able to obtain can be written as a function of the fixed costs and the plant productivity index, because the last two variables determine the firm's size. Combining equations (13) to (19) and (24) yields

$$\pi_{it}(q) = (1-\alpha-\gamma)\left(\frac{q}{\hat{q}_{it}}\right)^{\frac{1}{1-\alpha-\gamma}} F_{oit}. \tag{25}$$

Equation (25) implicitly reminds us that, at the minimum, firms' output must cover the fixed costs of operation. It also implies that profits before fixed costs depend on the ratio of the plant productivity level to its threshold value, $\hat{q}_{it}$. Therefore, to cover the entry costs F_{qt} and obtain strictly positive net profits, this ratio needs to be sufficiently larger than one.

2.3 Government

Consistent with the experiences of many developing countries, we assume that the public sector is an infinitely-lived institution composed of rent-seeking politicians that have their own preferences and do not optimally manage the economy. Politicians choose the amounts of rent capture, R_t, and the stock of electricity infrastructure, G_t, to maximize a welfare function that weighs the present value of consumers' utility and politicians' rent. In order to concentrate only on the variables that are under the direct control of the government – that is, R_t and G_t – we assume that the government makes decisions taking market allocations of other variables as given.

In particular, its problem can be written as follows:

$$\underset{\{R_t,G_{t+1}\}}{max}\left\{\varphi\, ln(R_t) + \sum_{t=0}^{\infty}\rho^t ln(c_t)\right\}; \tag{26}$$

where $\rho \in (0,1)$ is the time-preference coefficient; and $\varphi \geq 0$ weights the relative importance of rents. As a way to justify that equation (26) places value only on current rents extraction, we assume that politicians stay in the office for only one period; alternatively, we can think that politicians strongly believe that their corrupt behavior might not be sustainable in the near future.

The government's objective function (26) is maximized subject to the economy's feasibility condition:

$$\sum_{i=a,m,s} p_{it} Y_{it} = \sum_{i=a,m,s} N_{it} \left(F_{oit} + F_{qt} \right) + P_{ct} c_t L_t + I_{kt} + I_{gt} + R_t; \tag{27}$$

where N_{it} is the number of firms that produce output in sector i; I_{gt} and I_{kt} are investment in grid infrastructure (grid expansion and maintenance) and private capital, respectively; and Y_{it} is aggregate output in sector i, given by

$$Y_{it} = N_{it} \int_{\hat{q}_{it}}^{\infty} y_{it}(q) h(q) \, dq. \tag{28}$$

Equation (27) says that the total production (i.e., GDP) is allocated to pay for the fixed costs, consumption, investment, and rent capture. Observe that this equation also represents the government's budget constraint, because it implies that the amount paid by consumers as taxes τ_t – production less fixed costs, private investment, and consumption – is allocated between public capital formation and rent extraction.

Following Dabla-Norris et al. (2012), we assume that the government suffers from mismanagement of public investment. In particular, one unit of I_{gt} delivers $\xi < 1$ units of the electricity infrastructure value (e.g., due to local corruption, indolence, or lack of public management skills). In a similar vein as Tabellini and Alesina (1990), we also assume that because of its own preferences (or political ideology) the policy maker has a subjective valuation of the constructed grid that is the result of rescaling the actual electricity infrastructure investment using a parameter denoted by λ_t. This may be the case, for example, because access to electricity benefits both groups that support the government and groups that do not; but the government cares more about the former ones. Unlike ξ, the ideology parameter λ does not diminish the economic value of the electricity infrastructure accumulation obtained per unit of I_g. Observe that whereas a lower ξ tends to lead the economy toward too much public investment (with relatively small capital formation) due to the larger degree of mismanagement, a lower λ_t will tend to cause too little public investment due to the lack of incentives.

These considerations create a gap between the actual motion of aggregate grid infrastructure, and the subjective perception of the evolution of useful capital that the government takes into account to determine its optimal behavior. In particular, investment I_{gt} serves the maintenance and construction of infrastructure according to the following motion equation:

$$G_{t+1} = (1 - \delta_g)G_t + (1 + \mathbb{I}_\lambda \lambda_t)\xi I_{gt}; \tag{29}$$

where $\mathbb{I}_\lambda$ is an indicator that takes on one when the policy maker searches for the value of G_t that maximizes its objective function, and zero when determining the evolution of the stock of electricity infrastructure in the economy; and the parameter δ_g represents the depreciation rate of G_t.

The first order condition to the government's problem – given by expressions (26) to (29) – with respect to R_t predict that politicians' rents are a fraction φ of total aggregate consumption:

$$R_t = \varphi L_t P_{ct} c_t. \tag{30}$$

The first order condition with respect to G_{t+1} provides the intertemporal condition:

$$\frac{P_{ct+1}c_{t+1}}{P_{ct}c_t} = \frac{\rho(1+\lambda_t)\xi}{G_{t+1}} \sum_{i=a,m,s} \left(\beta_i p_{it+1} Y_{it+1} + N_{it+1}\theta_i F_{oit+1}\right) + \rho\left(1 - \delta_g\right). \tag{31}$$

Equation (31) gives the optimal evolution of total consumption expenditure from the government's viewpoint. Unlike in equation (4), where the consumer links intertemporal consumption to the return to saving, the policy maker in (31) relates consumption expenditure growth to the marginal return to investment in electricity grid. The return takes into account that a higher G_{t+1} increases private input productivity, reduces firms' fixed costs, and that not the whole amount of public investment translates into *productive* public capital due to either mismanagement or political ideology.

Putting together (4), (7), (8), (9), (19), (20), (28) and (31) yields

$$r_t - \delta_k = \frac{(1+\lambda_t)\xi}{G_t} \sum_{i=a,m,s} N_{it} \left\{ \beta_i \frac{\int_{\hat{q}_{it}}^{\infty} q^{\frac{1}{1-\alpha-\gamma}} h(q)}{(1-\alpha-\gamma) E\left[q^{\frac{1}{1-\alpha-\gamma}}\right]} \left(F_{qt} + F_{oit}\right) + \theta_i F_{oit} \right\} - \delta_g. \quad (32)$$

Equation (32) can be interpreted as a non-arbitrage condition: the government invests in electricity infrastructure until the return is the same as the one provided by the alternative type of investment. It is evident again that the stock of electricity infrastructure G_t affects the productivity of all firms in the economy, regardless of their sector, due to its non-rival nature. The productivity of electricity infrastructure is thus larger than the one perceived by the individual firm. It is also clear that a larger degree of mismanagement of public funds (a lower ξ) or a stronger politicians' preferences against public capital investment (a lower λ) both lead to a decrease in the formation of electricity infrastructure.

2.4 Market Clearing

To close the model we need to specify the market clearing conditions. In the labor market, the supply is given by the total population, normalized to one for simplicity, whereas firms' demand is derived from equation (8). Hence, labor market clearing requires:

$$\sum_{i=a,m,s} \left[p_{it} A_{it} \left(e_{it} G_t\right)^{\beta_i} \left(\frac{\gamma}{w_t}\right)^{1-\alpha} \left(\frac{\alpha}{r_t}\right)^{\alpha} \right]^{\frac{1}{1-\alpha-\gamma}} N_{it} \int_{\hat{q}_{it}}^{\infty} q^{\frac{1}{1-\alpha-\gamma}} h(q)\, dq = 1. \quad (33)$$

Let us now turn to the funds market. The amount of domestic saving available in the economy equals $b_{t+1} - b_t$. However, as capital markets are open, the supply of saving can be considered unlimited because of the small-open economy assumption. Therefore, from the supply side of the market the only relevant information that we need is the constant interest rate given by the rest of the world. The demand side at the firm level is given by equation (9), which implicitly pins down investment in private capital formation, I_{kt}. Starting from the motion equation of private capital, we can then write

$$K_{t+1} = (1-\delta_k)K_t + I_{kt}; \tag{34}$$

where K_t is the total stock of capital in the economy at t. It can be further disaggregated in

$$K_t = \sum_{i=a,m,s} \left[p_{it} A_{it} \left(e_{it} G_t\right)^{\beta_i} \left(\frac{\gamma}{w_t}\right)^{\gamma} \left(\frac{\alpha}{r_t}\right)^{1-\gamma} \right]^{\frac{1}{1-\alpha-\gamma}} N_{it} \int_{\hat{q}_{it}}^{\infty} q^{\frac{1}{1-\alpha-\gamma}} h(q)\, dq. \tag{35}$$

As regards product markets, we assume that policy makers capture rents from each sector in the same proportion as its share in the aggregate consumption expenditure. Market clearing then requires that production is allocated between private agents' consumption and firms' fixed costs in all sectors, and also to investment in manufacturing and services. We can write these conditions as follows:

$$p_{at} Y_{at} = (1+\varphi)\, p_{at} c_{at} + N_{at} \left(F_{oat} + F_{qt}\right); \tag{36}$$

and

$$p_{it} Y_{it} = (1+\varphi)\, p_{it} c_{it} + p_{it} x_{it} + N_{it} \left(F_{oit} + F_{qt}\right) \quad i = m, s; \tag{37}$$

where the consequences of I_{gt} on the economic value and actual motion of G_t are given by

$$G_{t+1} = (1-\delta_g)G_t + \xi I_{gt}, \tag{38}$$

and total investment needs to be allocated between private and public capital, $P_{xt} x_t = I_{kt} + I_{gt}$.

2.5 Equilibrium

We are focusing on a decentralized small open economy with public sector intervention that takes the world's interest rate r_t as given. An equilibrium in this model economy is defined as the value of wages w_t, output prices p_{it}, consumption c_{it}, investments x_{it}, private input allocations $l_{it}(q)$ and $k_{it}(q)$, infrastructure provision G_t, operation thresholds $\hat{q}_{it}$, number of firms N_{it}, and politicians' rents R_t so that, given input and output prices, consumers maximize utility, firms maximize profits, and the government maximizes its welfare function, and where prices are the solution to the free entry and market clearing conditions.

A useful transformation to study the dynamics of this economy is writing the capital-to-labor ratio, expression (10), in terms of aggregate capital as follows:

$$K_t = \frac{\alpha w_t}{\gamma r_t}; \tag{39}$$

recall that the size of the labor supply is normalized to one. Expression (39) allows for constructing a solvable equation system that only depends on sectoral variables.

More specifically, for a predetermined stock of electricity infrastructure and an interest rate given by the international market, free entry condition (19) for the manufacturing sector pins down the equilibrium wage rate, and then (39) determines the stock of private capital. Output prices and plant-productivity thresholds are given by (21) and (24), respectively. Incorporating (5), (6), (15) and (16) into the market clearing conditions makes equations (33) and (36) deliver expressions for the number of firms in each industry. Finally, motion equations (34) and (38), market clearing condition in manufacturing (37) and the public-investment optimality condition, equation (32), solve for the optimal consumption and investment values.

The above method of solution provides all economy-wide and sectoral equilibrium values of the endogenous variables. Rents extracted by politicians can be recovered from (30). At the firm level, the capital and labor allocations are obtained from equations (10), (11), (22) and (23).

3 Electricity Access and Structural Transformation in Brazil

We employ the model to study the relationship between structural transformation and electricity infrastructure formation guided by the experience of one of the largest developing nations, Brazil. Unlike many developing countries, Brazil offers a good quality, regionally and sectorally disaggregated historical data on both public infrastructure and structural transformation variables that can be used to calibrate our model. The data we use comes from the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística*, IBGE), the Institute of Applied Economic Research (*Instituto de Pesquisa Econômica Aplicada*, IPEA), and Geographic Information System of the Electric Sector (*Sistema de Informações Geográficas do Setor Elétrico*, SIGEL) of the Brazil National Electricity Regulatory Authority (*Agência Nacional de Energia Elétrica*, ANEEL). In this section, we first describe the process of electrification and the main features of the structural transformation in this Latin-American country. Later, we present results from a reduced-form econometric analysis to illustrate the causal effects of electricity access on the Brazilian structural transformation process.

3.1 The Brazilian Experience

Over the last century the country underwent massive electrification accompanied by the rapid structural transformation process. Advances in the electrification process in Brazil took place in the early 1960s, when high voltage transmission lines connected the Southeast states of São Paulo, Rio de Janeiro and Minas Gerais. The process accompanied the rapid pace of industrialization observed during the 1960s and 1970s, which required significant infrastructure investments. From 1963 to 1980, total electricity consumption increased from 22,618 gigawatt hours (GWh) to 112,055 GWh, with industrial users representing approximately 55% of total consumption. Residential electrification rates also rose sharply, with household access increasing from approximately 40% to 70% during the same period.

To meet the rapidly growing demand, the interconnection of the North-Northeast subsystems was implemented during the 1970s, and the interconnection of the South and Southeast subsystems was achieved in the beginning of the 1980s. The fiscal crisis of the 1980s, which eroded the government investment capacity, led to a long period of stagnation. The absence of investments, coupled with unfavorable hydrologic conditions, culminated in the power outage of 2002 and the subsequent rationing regime. This energy crisis reinforced the importance of further integrating the electric system, as the excess energy potential in the South subsystem could not be transmitted to minimize the power outage impacts in the rest of the country. In 2003, various transmission facilities started operating, consolidating the North-South and the South-Southeast interconnections. Nonetheless, the quality of Brazil's electricity infrastructure remains precarious. For example, the Global Competitiveness Report 2016-17 ranks Brazil's quality of electricity supply at 91st place out of 138 nations. This figure represents a significant decline compared to the 76th position achieved in 2013-14.

In line with our model, Brazil's poor electricity infrastructure status seems to be at least in part due to poor management of public investment.[15] As Amann et al. (2016), among many others, argue, this is related to Brazil's deficient regulatory governance that has deterred or delayed infrastructure investment. World Bank (2012) gives a clear example of lost public capital as a consequence of bureaucratic barriers: no less than 15% to 20% of the budgets of hydroelectric investment projects in Brazil are a consequence of environmental licensing costs. Corruption is also behind the low quality of regulatory governance, with a prominent case of the recent Eletrobrás contractors' scandal (U.S. Securities and Exchange Commission, 2018).[16]

To get a better idea of the evolution of the Brazilian electrification, the right panel in

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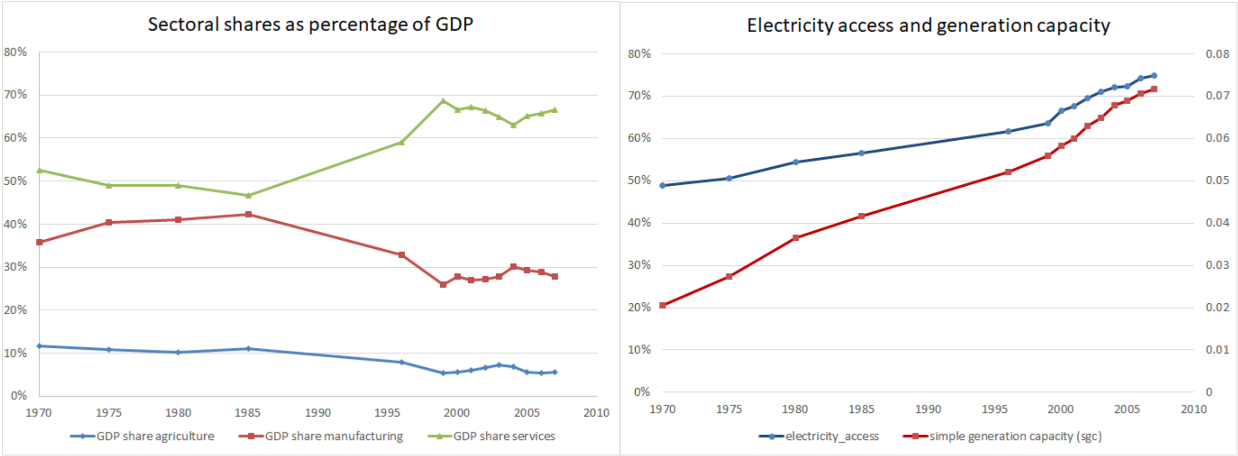
[15] Though public management issues are important, Brazil is not an extreme case of mismanagement according to the public investment efficiency index developed by Dabla-Norris et al. (2012). With an index of 3.12 out of 4, it ranks second within their sample of 71 low- and middle-income nations.

[16] Officers at Eletrobras Termonuclear S.A ("Eletronuclear"), Eletrobras's owned nuclear power generation subsidiary, engaged in an illicit bid-rigging and bribery scheme involving the construction of a nuclear power plant ("UTN Angra III") from approximately 2009 until 2015. These officers used their influence at Eletronuclear in favor of a bid-rigging scheme among certain private Brazilian construction companies.

Figure 1: Sectoral shares and electricity proxies in Brazil



Sectoral shares as percentage of GDP

Electricity access and generation capacity

Figure 1 presents the time series of the average electricity access and the average electricity generation capacity across municipalities; the time interval goes from 1970 to 2007. Electricity access is defined as the proportion of grid points in the municipality that are electrified in a given year. Generation capacity is, in turn, the amount of gigawatts (GW) supplied by power plants weighted by the inverse of the distance from each power plant to each municipality centroid. This second proxy tries to assess variations in the electricity supply available once a private agent is connected to the grid. We can see that both measures have increased steadily. Average electricity access went up from 48.9% in 1970 to 74.9% in 2007 (primary scale in panel), largely due to a massive electrification of the North East and Center West regions (see Appendix Figure A.1), and the average weighted electricity generation capacity (secondary scale) more than triples. In 1999 there is a clear acceleration in the electrification process. For example, the increase in average electricity access was about 0.5% per year before 1999, whereas this number became 1.4% after that year.

Let us now turn to the structural transformation process. The left panel in Figure 1 plots the shares in GVA of the three main sectors – agriculture, manufacturing, and services – supplied by IBGE. We see that, during the studied period, services experienced an increase from 52.6% to 66.7% in its value-added share, and the manufacturing sector a decline from 35.8% to 27.8%. The picture also shows the typical hump-shaped evolution of the manufacturing share, with an acceleration until the mid-1980s followed by a fall. Unlike in other nations, however, in the Brazilian case, this was accompanied by a U-shaped path of the share of services. The reason for this fall in the services share till the mid-1980s and later recovery was the unusual strength of the agriculture sector, whose share remained more of less stable around 11.6% until 1985, and then declined steadily reaching 5.5% in 2007.

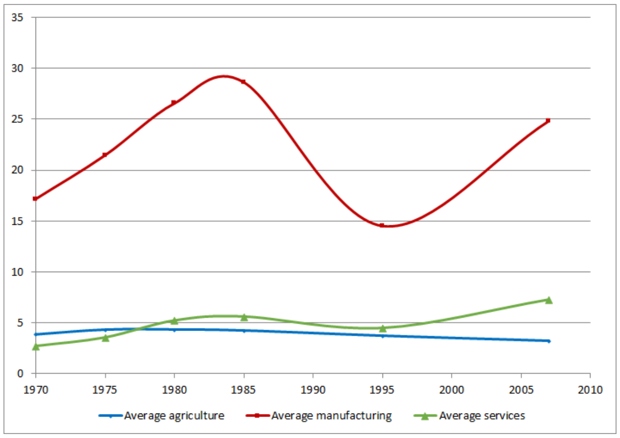
Another important component of the model, the size of firms, has also changed substantially during our sample period in Brazil. The number of occupied people per establishment at the municipal level can be constructed from data on occupied individuals and number of establishments in each sector collected by IBGE and published by IPEA for the years 1970, 1975, 1980, 1985 and 1995. We added average numbers at the national level for 2006 in agriculture and for 2007 in the other two sectors, reflecting information obtained from the agricultural census and different surveys in manufacturing (*Pesquisa Anual de Indústria*) and services (*Pesquisa Anual de Serviços* and the *Pesquisa Anual de Comércio*). These data sources include formal as well as informal employment.

Figure 2 plots the evolution of the mean number of employees per establishment in each sector. Starting from the late 1970s the agriculture sector becomes the one with the smallest average firm, followed by the services sector; the largest average establishment is located in the manufacturing sector. More specifically, the average for the period is 3.9 employees per plant in agriculture, 21.8 in industry, and 5.0 in services. That is, the average size of a firm in the services and the manufacturing sectors is 1.3 and 5.6 times larger than the one in agriculture, respectively. A closer examination of the chart also tells that over the period 1970 - 2007 the average size seems to evolve cyclically in the manufacturing sector, decline in agriculture and increase in services.

3.2 Econometric Analysis

We start now with the econometric analysis to establish the causal evidence of the effect of access to electricity on structural transformation. In the econometric analysis we use

Figure 2: Mean number of employees per firm



variation in electrification over the period 1970-2007 using Brazil municipality panel data. Specifically, we estimate the following regressions:

$$S_{Yjt} = \eta_j + \eta_t + \epsilon E_{jt} + \varphi' X + \varepsilon_{jt}, \tag{40}$$

where S_{Yjt} represents the shares of agriculture, industry, or services in the GVA in municipality j at time t, η_j is a municipality fixed effect, η_t is a time fixed effect, E_{jt} is the measure of electricity access defined as proportion of grid points in the municipality j that are electrified in period t, and X is the vector of the municipality control variables which include the municipality-level weighted electricity-generation capacity and population density. Table 1 shows the descriptive statistics for the data employed in estimating the regression model (40).

Estimating regression model (40) faces the standard concern that the evolution of grid infrastructure can be endogenous to unobserved factors affecting the structural transformation process, conditional on the time and year fixed-effects, and other control variables. This causes potential bias in the ordinary least squares (OLS) estimates. To remedy this potential endogeneity bias, we also estimate the regression model (40) with two stage least squares (2SLS), using the instrument developed by Lipscomb et al. (2013) and further refined in Assunção et al. (2018). The instrument takes advantage of the fact that hydropower accounts

Table 1: Sample Descriptive Statistics

Variable	N	Mean	St. Dev.	Min	Max
Electricity variables					
Electricity Access	69,521	0.654	0.442	0	1
Electricity Access Instrument	12,408	0.765	0.410	0	1
Generation Capacity, GW*	69,521	0.144	0.072	0.013	2.35
Economic variables					
GVA per capita, (BRL 1000)	54,830	3.840	7.156	0.085	830.7
GVA Share, Agriculture	69,521	0.306	0.210	0.000	0.971
GVA Share, Industry	69,521	0.168	0.157	0.000	1.000
GVA Share, Services	69,521	0.525	0.180	0.000	0.997
Demographic/Geographic					
Population Density, (people/km^2)	69,521	115.2	963.2	0.02	199,463

for the majority of electricity generation in Brazil, accounting for 65.8% of electricity generation in the country in 2016 (ANEEL, 2017). The power potential of a hydropower plant depends on local topological and hydrological characteristics, such as e.g., slope, elevation, and the amount of water available. These characteristics are plausibly exogenous to the local social and economic conditions that may be also correlated with the structural transformation process. As described in Lipscomb et al. (2013), there are three key steps to the construction of their instrument. First, each time period they calculate the budget for plants based on the actual construction of major dams across the entire country. Second, they calculate a cost factor that sorts potential locations by their geographic suitability. Finally, they apply the suitability predictions to the areas where hydropower plants were actually built. Using the predictions of estimated construction site for each dam, they generate a hypothetical transmission network that depends solely on topological and hydrological characteristics that is used as an instrumental variable.

Table 2 reports the estimation results. Columns 1 – 6 show respectively the OLS and IV estimates when the dependent variables are the natural logarithms of agriculture, industry

Table 2: Effects of Electricity Access on Structural Transformation

	Dependent variable:					
	GVA Share, Agriculture		GVA Share, Industry		GVA Share, Services	
	OLS	*IV*	*OLS*	*IV*	*OLS*	*IV*
	(1)	(2)	(3)	(4)	(5)	(6)
Electricity	-0.035^{***}	-0.704^{**}	0.066^{***}	-0.438^{**}	-0.031^{***}	1.143^{***}
Access	(0.006)	(0.289)	(0.009)	(0.199)	(0.008)	(0.388)
Population	0.072^{***}	0.0001	-0.042^{***}	0.003	-0.030^{***}	−0.004
Density, log	(0.007)	(0.011)	(0.012)	(0.008)	(0.011)	(0.014)
Generation	0.013^{***}	0.091^{***}	-0.017^{***}	0.039^{*}	0.004	-0.131^{***}
Capacity	(0.002)	(0.034)	(0.003)	(0.023)	(0.003)	(0.045)
Observations	69,521	12,408	69,521	12,408	69,521	12,408
R^2	0.881	0.001	0.887	0.0002	0.902	0.0002
Adjusted R^2	0.874	−0.333	0.881	−0.334	0.897	−0.334

Notes: *p<0.1; **p<0.05; ***p<0.01. Robust standard errors in parentheses. All regressions are weighted by municipal GVA and include municipality and time fixed effects.

and services shares in municipalities' GVA. We see that IV estimate suggests that a 1 percent increase in electricity access results in a 1.14 percentage point increase in share of services and a 0.7 and 0.43 percentage point decline in shares of agriculture and industry sectors, respectively. This result, significant at the 1 percent level, is of an order of magnitude larger in all sectors and comes with the opposite sign in manufacturing and services than the OLS estimate. The share of agriculture tends to increase and the shares of manufacturing and services in municipal GVA to decrease with the size of generation capacity. Perhaps counter intuitively, the share of agriculture in municipal GVA also tends to increase with population density, however this effect is marginally statistically significant.[17]

Table 3 shows the findings of the results sensitivity to the inclusion of municipal GVA per capita, accounting for potential non-linear effects (proxied by squared and cubic terms). All in all, the coefficients of the electricity access variable are little changed. The IV estimate suggests that a 1 percentage point increase in electricity access results in a 1.06 percentage point increase in share of services and a 0.65 and 0.42 percentage point decline in shares of agriculture and industry sectors, respectively. Table 3 also demonstrates that the structural transformation process is non-linear in the per capita GVA.

4 Quantitative Analysis

Next, we calibrate the model parameters and analyze the underlying drivers of the structural transformation process by simulating the model and running policy experiments.

4.1 Model Calibration

We first determine the parameters related to the household's behavior. We pick from the business cycle literature a standard value for the discount factor, $\rho = 0.96$. For the weights

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[17] These results differ from a recent study by de Faria et al., (2017), who find a decline in agricultural GDP following additions of hydro generation capacity. Their study, however, looks at the different temporal frame and, unlike this paper, does not account for grid expansion effects.

Table 3: Effects of Electricity Access on Structural Transformation (with additional controls)

	Dependent variable:					
	GVA Share, Agriculture		GVA Share, Industry		GVA Share, Services	
	OLS	*IV*	*OLS*	*IV*	*OLS*	*IV*
	(1)	(2)	(3)	(4)	(5)	(6)
Electricity Access	-0.035^{***}	-0.647^{**}	0.057^{***}	-0.418^{**}	-0.021^{**}	1.065^{***}
	(0.006)	(0.257)	(0.009)	(0.171)	(0.008)	(0.335)
GVA per capita, log	-0.120^{***}	0.065^{***}	0.135^{***}	0.067^{***}	-0.016	-0.133^{***}
	(0.008)	(0.011)	(0.016)	(0.007)	(0.015)	(0.014)
GVA per capita^2, log	0.026^{***}	-0.013^{**}	0.017^{**}	0.023^{***}	-0.042^{***}	-0.011
	(0.003)	(0.006)	(0.008)	(0.004)	(0.008)	(0.008)
GVA per capita^3, log	-0.002^{***}	-0.001	-0.005^{***}	-0.001	0.007^{***}	0.001
	(0.0004)	(0.002)	(0.001)	(0.001)	(0.001)	(0.003)
Population Density, log	0.062^{***}	0.014	-0.036^{***}	0.006	-0.026^{**}	-0.020
	(0.007)	(0.012)	(0.011)	(0.008)	(0.011)	(0.015)
Generation Capacity	0.191^{***}	0.927^{***}	-0.299^{**}	-0.010	0.107	-0.917^{***}
	(0.051)	(0.237)	(0.119)	(0.157)	(0.098)	(0.308)
Observations	54,830	12,408	54,830	12,408	54,830	12,408
R^2	0.881	0.004	0.898	0.020	0.911	0.017
Adjusted R^2	0.873	-0.330	0.891	-0.308	0.905	-0.311

Notes: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. Robust standard errors in parentheses. Regressions are weighted by municipal GVA and include municipality and time fixed effects.

of the different sectors in consumption, we choose values similar to other studies like Betts et al. (2017), $\omega_a = 0.07$, $\omega_m = 0.15$. The elasticity of substitution between consumption goods comes from Herrendorf et al. (2009). Using a value-added approach and the U.S. data these authors estimate $\varepsilon = 0.002$.

To obtain a value for the international interest rate, we follow a standard procedure by looking at the prediction given by the Euler equation for consumption assuming that aggregate consumption and output grow at the same constant rate.[18] If this is the case, condition (4) implies that

$$r_t = \frac{Z_{Y_m}}{\rho} - 1 + \delta_k; \tag{41}$$

where Z_{Y_m} is the rate at which these two variables grow. Equation (41) predicts that an interest rate net of depreciation of 6.79% is the one compatible with the 2.52% average annual growth rate of real GDP per capita for the Brazilian economy over the period 1970-2007 obtained fitting an exponential regression model to Penn World Tables data, version 8-0. The capital depreciation rates are the ones that generate an average investment share in gross fixed capital formation in Brazil for the period 1971-2007 of 0.194 – this number is calculated from the IBGE data. Applying the fact that estimated depreciation rates for public capital (including the electricity infrastructure) are usually about half those of private capital (see, e.g., Kamps 2006), we obtain $\delta_k = 0.0452$ and $\delta_g = 0.0226$.

As we mentioned previously, not all investment comes from manufacturing because the service sector is an increasingly important component. Next, we search for the share of investment that needs to be assigned to each of these two sectors. Following Herrendorf et al. (2014), we allocate investment value added to each sector using constant shares. As these authors argue, the quantitative relevance of this assumption should be relatively small because total investment is a relatively small share of GDP. To estimate the share that we should attribute to services, we use input-output data for Brazil from the World Input-

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[18] Recall that this is not the case in our model of unbalanced growth. Nevertheless, we believe that this strategy is reasonable for the purpose of calibrating the interest rate.

Table 4: Benchmark model parameterization and targets

Variables / Parameters	Values	Criteria / Targets
ρ, ω_a, ω_m	0.96, 0.07, 0.15	Standard in literature
ε	0.002	Herrendorf et al. (2009)
r_t, z_{Am}	0.1131, 1.0085	GDPpc growth, Brazil, 1995-2013
α, γ	0.283, 0.567	Restuccia and Rogerson (2008)
β_a, β_m, β_s	0.045, 0.230, 0.108	Own estimates
θ_a, θ_m, θ_s	0.023, -0.103, 0.081	Own estimates
μ_m, μ_s	0.73, 0.27	Brazilian input-output tables, 2014
ν	0.18	Sposi (2012)
δ_k, δ_g	0.0452, 0.0226	Capital formation investment, Brazil, 1971-2007
A_{at}, A_{st}	Different values	Sectoral GVA shares, Brazil, 1970-2007
Mean	0.650, 1.486	
Average growth	0.0310, 0.028	
ξ	0.6204	Annual cost of corruption, Brazil, 2010
ψ	1.390	Own estimates
f_{oat}, f_{omt}, f_{ost}	Different values	Number of workers per firm in each sector
Mean	0.131, 0.702, 0.206	
Average growth	0.0100, 0.0287, 0.0495	
λ_t	Different values	Infrastructure stock, Brazil, 1970-2007
Mean	-0.834	
Average growth	0.0038	
e_i, A_{m1970}, f_q	1, 1, 0.1	Normalizations

Output Tables, 2016 release. In 2007 the share of manufacturing in fixed capital formation was about 73%. Then, we assign the remaining 27% to services. Given this information, we choose $\mu_m = 0.73$ and $\mu_s = 0.27$. The elasticity of substitution between sectors in investment-goods production is taken from Sposi (2012), who estimates a value of 0.18 for ν using data from the Republic of Korea.

On the production side, we adopt the values of Restuccia and Rogerson (2008) in a similar setting for the shares of private inputs; in particular, $\alpha = 0.283$ and $\gamma = 0.567$. Given that there are not available estimates of the impact of electricity access to output production at the sectoral level, we estimate them. Following the similar approach to the one explained in section 5.1, we perform an econometric analysis employing variation in electrification over the period 1970-1996 using Brazil municipality panel data on sectoral production, labor use and private capital, and municipal-level electricity availability. In particular, taking logs, we derive from equation (7) the following regression:

$$lnY_{jt} = \eta_j + gt + \beta\, lnG_{jt} + \alpha\, lnK_{jt} + \gamma\, lnL_{it} + \varepsilon_{jt}, \tag{42}$$

where Y_{jt}, K_{jt} and L_{it} represent the levels of production, private capital and labor in agriculture, industry or services in municipality j at time t; and η_j is a municipality fixed effect.

The proxy that we employ for G_{jt} is a combination of the electricity access and generation capacity indices described previously. In particular, we consider the fraction of electrified grid points (i.e., electricity access) multiplied by generation capacity. We call *grid capacity* to this compounded measure. The reason behind its choice is that electricity access has an upper bound equal to 1, which is somehow inconsistent with our definition of G_t, whereas generation capacity is not bounded above. A combination of the two then seems desirable.

We estimate (42) for each sector separately using the panel of Brazilian municipalities. The panel is shorter in the time dimension than in the previous regressions, because values for the stock of capital at the sectoral and municipal levels can be obtained from IPEA only for the years 1970, 1975 and 1980 for the manufacturing and services sectors, and for 1970, 1975, 1980 and 1985 for the agricultural sector. In addition, for agriculture, we use investment information for the years 1985 and 1996 also from IPEA to impute the capital stock in 1996.[19] As described previously, employment numbers were collected by IBGE and published by IPEA for the years 1970, 1975, 1980, 1985 and 1995. For the purpose of matching up the employment data with the data on capital stock, the agricultural employment in 1995 was used as a proxy for the agricultural employment in 1996.[20] In the IV regression, there

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[19] In particular, we created annual investment numbers between 1985 and 1996 by using linear interpolation, and then employed these interpolated investments, together with a depreciation rate of 7%, to bring the capital stock from 1985 forward to 1996.

[20] Although a central registry of formal employment contracts exists in Brazil, named Relação Anual de Informações Sociais (RAIS), we have chosen to use employment numbers from IBGE, which are based on a series of surveys conducted by IBGE. The reason is that the RAIS data may lack coverage of informal employment and the survey-based IBGE numbers are believed to reflect both formal and informal employment somewhat better.

is a further reduction in the number of observations because the Lipscomb et al.'s (2013) instrument is not available for the years 1975 and 1985.

The results using OLS and IV are presented in Table 5. We see that when we move from the OLS to the IV regressions, estimated values for electricity increase, although there is some reduction in the significance of the estimated coefficients. This reduction is in part due to the lower number of available observations. Nevertheless, we prefer the IV ones as they should be less biased. Coefficients for electricity remain significant in the manufacturing and services sectors. Capital and labor are highly significant in all cases. The Table also says that the estimated coefficients are compatible with the model assumption of decreasing returns over capital and labor. In sum, we choose $(\beta_a, \beta_m, \beta_s)$ equal to (0.045, 0.230, 0.108).

We follow a similar methodology to estimate the parameters θ_i and ψ. Equations (11), (13), (18) and (25) obtain

$$l_{it}(q) = \frac{\gamma}{w_t} \left(\frac{q}{\hat{q}_{it}} \right)^{\frac{1}{1-\alpha-\gamma}} f_{oit} A_{mt}^{\psi} G_t^{\theta_i}. \tag{43}$$

Employing GVA per capita (Ypc_{jt}) as a proxy for A_{mt}, we can then use this expression to derive the following regression to estimate the effect of capital-electricity infrastructure on the average number of employees in sector i at time t in municipality j ($\bar{l}_{jt}$):

$$ln\bar{l}_{jt} = \eta_j + \eta_t + \phi\, ln\, Ypc_{jt} + \theta\, lnG_{jt} + \varepsilon_{jt}; \tag{44}$$

The number of occupied people per establishment at the municipal level is available from IPEA for the years 1970, 1975, 1980, 1985 and 1995. These reflect information obtained in the agricultural census and in different surveys in manufacturing and services. These data sources include formal as well as informal employment. Employing the Brazilian municipality panel for those years, we again obtain estimates using OLS and IV results for each sector. In the IV estimation, we lose only 1975 and 1985 because the 1996 values of the instrument are assigned to year 1995.

Table 5: Production function estimation by sector

	Dependent variable:					
	GVA, Agriculture		GVA, Industry		GVA, Services	
	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Grid Capacity	0.003	0.045	0.020^{***}	0.230^{**}	0.008^{***}	0.108^{*}
	(0.004)	(0.108)	(0.004)	(0.106)	(0.001)	(0.063)
Labor	0.542^{***}	0.509^{***}	0.088^{***}	0.335^{***}	0.664^{***}	0.644^{***}
	(0.061)	(0.079)	(0.012)	(0.045)	(0.019)	(0.035)
Capital	0.500^{***}	0.422^{***}	0.344^{***}	0.238^{***}	0.242^{***}	0.211^{***}
	(0.037)	(0.055)	(0.044)	(0.016)	(0.017)	(0.024)
Observations	5,948	2,556	4,361	2,512	4,457	2,554
R^2	0.170	0.214	0.661	0.243	0.895	0.678
Adjusted R^2	0.167	0.207	0.659	0.237	0.894	0.676

Notes: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. The Lipscomb instrument is employed for grid capacity. Reported standard errors are robust. The amount 10^{-11} is added to all variables, which enter the regression in logs. Regressions are weighted by municipal GVA and include municipality fixed effects and a time trend.

Results are presented in Table 6. As in other papers in the literature (e.g., Bento and Restuccia, 2018), GDP per capita shows up always with a positive and significant coefficient. Weighting the estimated ϕs by the average share of the sector from 1970 to 2007, we obtain a mean GDP elasticity of the average number of employees (denoted by $\overline{\phi}$) equal to 0.217 and 0.208 in the OLS and IV cases, respectively.[21] Again, we prefer the IV estimate. We are, however, interested in the A_{mt} elasticity of firm size. From equation (13) that takes into account the induced effect of A_{mt} on the different inputs and equation (28), we can obtain ψ as $\overline{\phi}$ divided by $1 - \alpha - \gamma$, which implies $\psi = 1.390$.

Estimates for grid capacity in Table 6 are significant for agriculture and services with OLS but become insignificant with IV, which uses a much lower number of observations. Nonetheless, as above, we choose the IV estimates for the electricity-infrastructure elasticity of operating fixed costs, that is, $(\theta_a, \theta_m, \theta_s)$ equal (0.023, -0.103, 0.081). Observe that this means that the provision of electricity helps to reduce fixed costs in manufacturing but increases them in agriculture and services.[22]

During the simulations, we scale up grid capacity by a factor of 5.05 to generate an average GDP share of electricity infrastructure in Brazil from 1971 to 2007 of 1.81 percent;[23] this is calculated from estimates in Calderon and Serven (2017) and Frischtak (2017). These two sources also provide an average investment share in infrastructure as a fraction of GDP of 0.0382.[24] This last number can be used to calibrate the mismanagement parameter ξ as follows. According to FIESP (2010) the average annual cost of corruption in Brazil can be between 1.38 and 2.3 percent of the country's total GDP. Taking a conservative intermediate value of 1.45 percent, we estimate ξ to be equal to $1 - 0.0145/0.0382 = 0.6204$.

Some of the parameters are normalized. In particular, $e_i = 1$ for all i, $A_{m1970} = 1$, and

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[21] Bento and Restuccia (2018) find a larger elasticity of 0.3 in a wide cross-section of countries. They do not though disentangle the effects of electricity infrastructure.

[22] As will become clear, assuming that electricity infrastructure does not affect fixed costs would not have a significant impact on our main results.

[23] The rescaling of the electricity index should not have any impact on the results. Notice, for example, that the estimated elasticities are not affected, as the scaling factor would show up in the log regression in the intercept.

[24] Infrastructure include land transport, electricity, telecommunications, and water and sanitation.

Table 6: Grid capacity elasticity of fixed operating costs

	Dependent variable:					
	Employees per establishment, Agriculture		Employees per establishment, Industry		Employees per establishment, Services	
	OLS	*IV*	*OLS*	*IV*	*OLS*	*IV*
	(1)	(2)	(3)	(4)	(5)	(6)
Grid capacity	-0.003^{***}	0.023	0.027	-0.103	0.004^{***}	0.081
	(0.001)	(0.100)	(0.017)	(0.670)	(0.001)	(0.146)
GVA per capita	0.019^{*}	0.052^{**}	0.474^{***}	0.426^{***}	0.083^{***}	0.093^{***}
	(0.011)	(0.023)	(0.157)	(0.123)	(0.013)	(0.033)
Observations	5,948	2,556	5,815	2,512	5,943	2,554
R^2	0.728	0.755	0.394	0.644	0.802	0.610
Adjusted R^2	0.637	0.509	0.185	0.276	0.736	0.218

Notes: *p<0.1; **p<0.05; ***p<0.01. The Lipscomb instrument is employed for grid capacity. Reported standard errors are robust. The amount 10^{-11} is added to all variables, which enter the regression in logs. Regressions are weighted by municipal GVA and include municipality and time fixed effects.

$f_q = 0.1$. The first one, e_i, belongs to our main parameters of interest, because we want to know how changes in its value affect the model predictions. The last two, A_{m1970} and f_q, should not be important for our results, because their impact on output shares and the number of employees depends on their relative values with respect to other sectors and types of fixed costs, respectively.

The remaining parameters are allowed to vary from period to period so that the model exactly reproduces the values of some variables observed in the data from 1970 to 2007. More specifically, the manufacturing-sector productivity growth rate is chosen to obtain the Brazilian average growth rate of GDP per capita, 2.52 percent. This implies $z_{Am} = 1.0085$. In turn, the values of the sector-specific productivity parameters A_{at} and A_{st} deliver the value-added shares of the different industries. This calibration exercise gives average annual growth rates for TFP in agriculture and services of 3.10 and 0.28 percent, respectively. This estimated TFP growth across sectors agrees with the typical result in the literature, like in Herrendorf et al. (2015), which finds that agriculture is the activity that experiences the fastest growth, followed by manufacturing and services. The fixed cost parameters f_{oat}, f_{omt} and f_{ost} at each date are the ones that reproduce the average number of employees in our three big sectors. Finally, the value of the partisan parameter λ_t is allowed to vary so that the observed value of G_t becomes the optimal choice for the government. As expected, on average, the values of f_{oat}, f_{omt} and f_{ost} grow at positive rates (at 1.00, 2.87 and 4.95 percent annually, respectively), and so does the parameter λ_t (at 0.38 percent annually).[25]

4.2 Simulation Results

4.2.1 Model Baseline

We start by looking at the benchmark simulation, presented in Figure 3, with regards to sectoral value added shares (top left panel), the average number of workers per establishment

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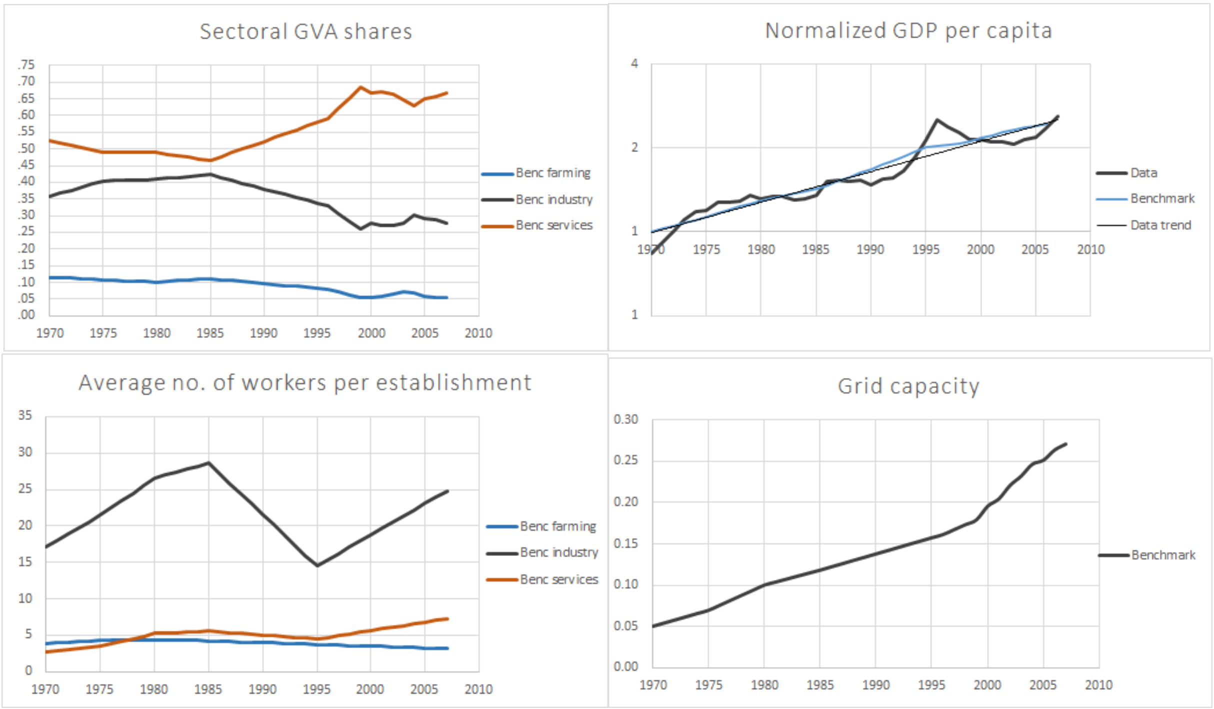
[25] The average growth rates reported correspond to 1970−2006, which is the period that we investigate with the model simulations.

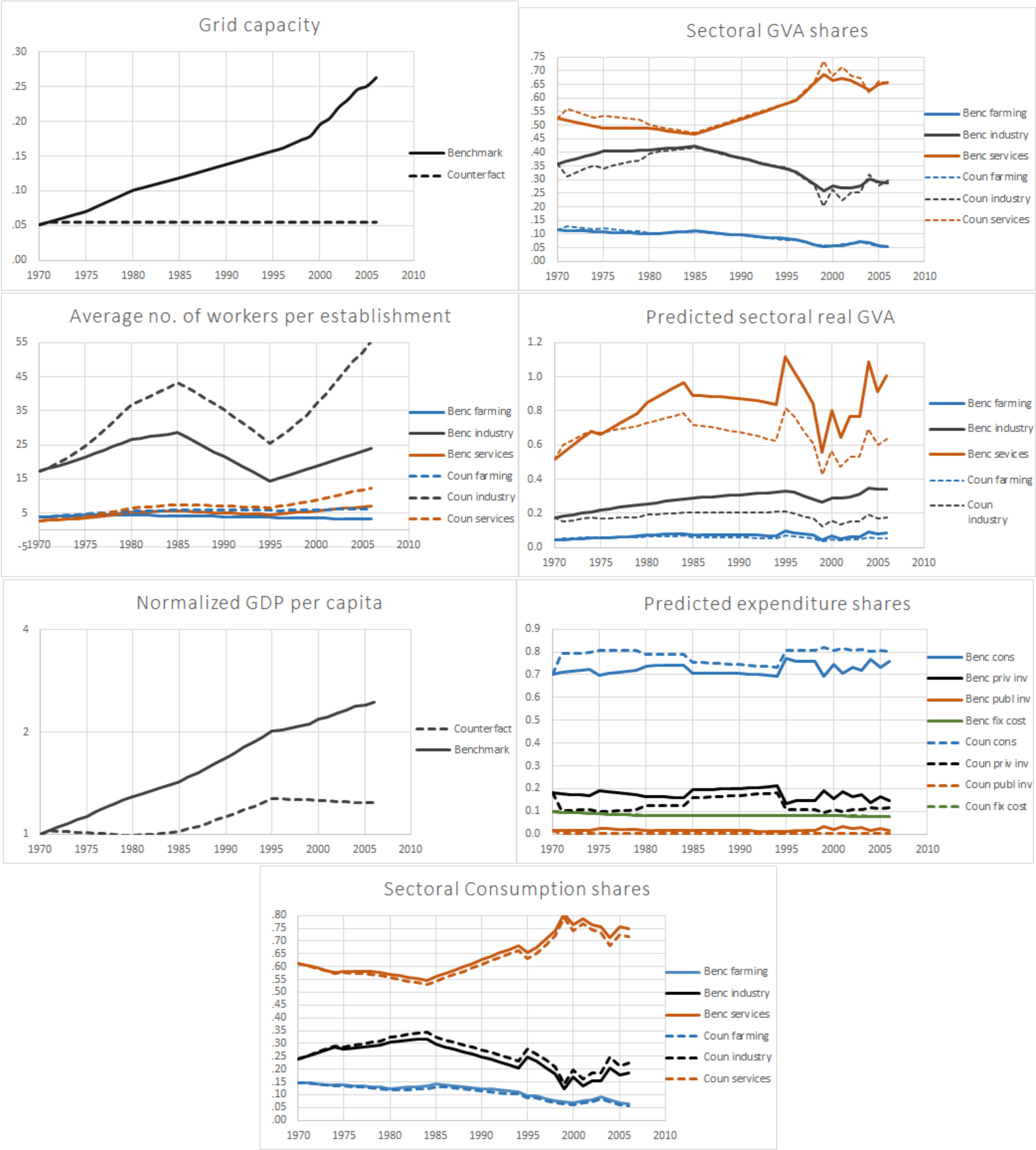
Figure 3: Benchmark simulations



in each sector (bottom left), the GDP levels (top right), and the public infrastructure stock proxy given by grid capacity (bottom right). Simulations go from 1970 to 2006. Year 2007 is lost because we need values of the different parameters at $t + 1$ to generate predictions for period t. By construction, the predictions exactly reproduce the Brazilian data with the exception of GDP. In the top right panel, we can see that what the benchmark GDP line reproduces is actually trend GDP. The only chart that deserves some comment is the one related to the electricity proxy. We can see in the bottom right panel that the grid capacity index follows a more or less linear trend with a significant break in year 2000. Between 1970 and 2000, its average annual growth equals 4.47 percent, whereas after year 2000 this rate rises to 5.66.

Our main objective is assessing the contribution of electricity infrastructure to the evolution of the different variables. Therefore, we next compare the model predictions when the value of G_t remains at its 1971 level to the benchmark simulation. We choose 1971 instead of 1970 so that the starting coordinates of the benchmark and counterfactual series coincide.

Figure 4: Comparative dynamics if G remains constant



Results are depicted in Figure 4. The top left panel shows that the counterfactual evolution of the electricity proxy indeed remains constant at the 1971 value, representing an average fall of 60 percent with respect to the benchmark case. The top right panel, in turn, shows the evolution of the sectoral GVA shares. We see that, in the absence of electricity infrastructure growth, the share of manufacturing would have been smaller and the ones of services and agriculture larger. The differences are larger in the initial and final periods, when the growth of electrification occurred at a faster speed.

Table 7 shows the average effect for the different scenarios analyzed in this section. The first column ("G_t fixed") considers the case when G_t remains at its 1971 level. It follows from the first three rows of Table 7 that the share of manufacturing falls, on average, by 1.74 percentage points, and the ones of services and agriculture increase by 1.59 and 0.15, respectively. Rows four to six inform about the goodness of fit of the counterfactual predictions compared to the observed values by providing the coefficient of determination (R^2). We see that the increase in electrification explains 8.3, 28.0 and 10.4 percent of the shares variation in agriculture, manufacturing and services, respectively. Weighting these percentages by the average share of each of the sectors, we conclude that the growth in electricity infrastructure is able to explain 17 percent of the observed structural transformation in Brazil from 1970 to 2006.

To understand the elements that contribute to these results, we first note that we have assigned values of 0.002 to ε and 0.18 to ν, thus meaning that the three sectors are complementary both in consumption and investment. Therefore, from equations (5) and (15), we know that an increase in the relative price of a product will result in raising the income share of that sector. Equation (21), in turn, informs that output prices depend on supply-side forces. More specifically, this expression implies that, according to our parameterization, TFP growth over the period 1970-2006 in Brazil pushed down, on average, the share of agriculture and the one of services, because their calibrated average TFP growth rate is higher and lower than in the manufacturing sector, respectively. In addition, the growth of the electricity infrastructure stock G_t, as a consequence of the relatively lower intensity of electricity infrastructure in services and in agricultural output production, shifts the structural transformation process towards these last two sectors. This effect can be observed, for example, in the bottom chart of Figure 4 that depicts the evolution of the sectoral consumption shares. We see that, in the absence of public infrastructure growth, the manufacturing share rises whereas the shares of the other two sectors shift down. The model predictions, in particular, imply that the consumption share rises 0.71 and 1.52 percentage points in agriculture and services, respectively, and declines 2.23 percentage points in manufacturing.

Second, the growth in the electricity infrastructure reduces fixed costs in manufacturing, but increases them in farming and services. This means that, ceteris paribus, the income share of the secondary sector will decrease as the public capital is accumulated as a less rapid increase in fixed costs in manufacturing increases the relative price in the other two sectors. Therefore, both supply-side effects that cause changes in relative prices push down the manufacturing share. This is precisely the qualitative effect that the IV estimates for electricity access in Tables 2 and 3 mainly capture, with the exception of agriculture. Hence, the electricity instrument tends to isolate the effect of the electricity-supply component on the sectoral production capacity and market-entry barriers.[26] Importantly, these findings reinforces the choice of the IV estimates made in the calibration section to assign values to the production-function and fixed-costs parameters.

A growing G_t also contributes to sectoral reallocations through the larger demand for investment goods induced by the grid construction. In this instance, the manufacturing share is the one that gains, because 73 percent of the total investment is supplied by the secondary

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[26] In Tables 2 and 3, the two electricity infrastructure proxies, electricity access and generation capacity, enter the regression separately, and electricity access is the only electricity proxy that is instrumented. Therefore, the access variable captures the supply-side channel, which benefits services, whereas the capacity variable captures the demand channel, which benefits manufacturing (as Table 2 suggests). In the simulation exercise, we combine them to get the G_t measure. Estimation results using (and instrumenting) electricity access times generation capacity as a single regressor are qualitatively similar to the ones obtained for electricity access, and in line with the supply-side implications of the production-function estimates in Table 5. The estimated IV coefficients are all strongly significant and imply that agriculture is the sector that experiences the largest gain, followed by services and manufacturing.

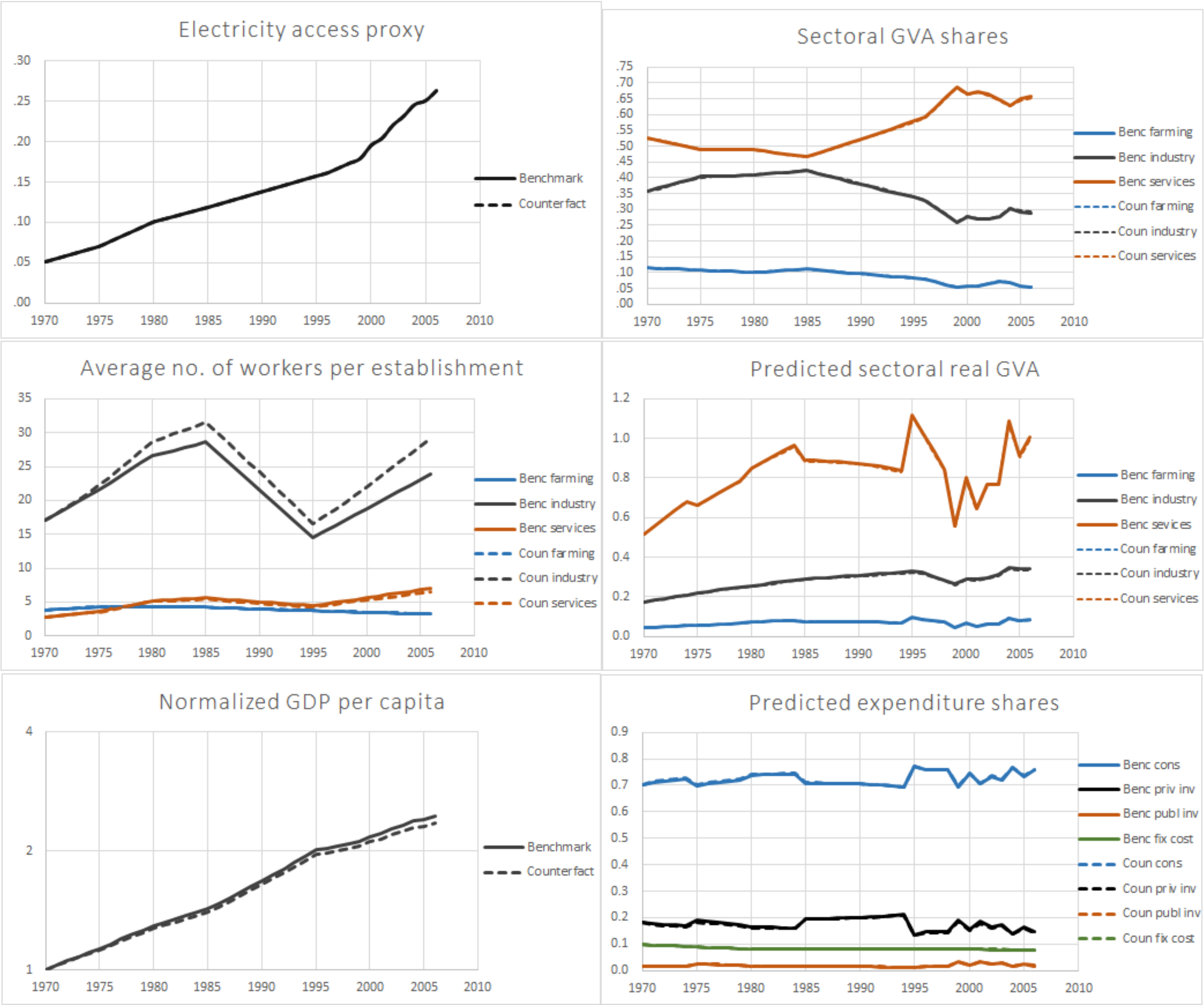
activity. Services also benefit but to a lesser extent (Figure 4). This is more evident during the periods of faster growth in the stock of electricity capital. Qualitatively, this is the general equilibrium effect captured by the OLS results in Tables 2 and 3. Quantitatively, the model simulations show a larger impact that the OLS estimates. This is, however, not surprising as the OLS estimates suffer from several well-known econometric problems.

Let us move now to the second row of panels in Figure 4. The left panel shows that the average number of employees increases in all industries by between 1.61 and 12.66 on average (see Table 7), with the largest increase in the manufacturing sector. Expression (43) implies that this change can be a consequence of wages, threshold productivity or grid capacity. However, the effect of the latter two factors move in opposite directions and partially offset one another. The one that dominates is the impact of wages, which fall by 23 percent when G_t does not change compared to the benchmark case, thus increasing the average size of firms. In the manufacturing sector, this effect is further amplified by the negative electricity-capital elasticity of firm size. The second row of the right panel shows the evolution of the real level of production by sector (i.e., the sectoral real gross value added). It is computed as the GVA share of the industry times GDP divided by the sector's relative price. It says that the decrease in infrastructure hurts production in all sectors, but specially the manufacturing one that falls by 34.08 percent; production in agriculture and services decrease by 17.26 and 19.40 percent, respectively.

The two charts located in the third row of Figure 4 give information about the evolution of GDP (left panel) and the expenditure shares (right panel). The loss of the grid capacity reduces GDP by 32.31 percent. It also reduces private investment, because of the complementarity between the two types of capital. The result is that the expenditure shares that benefit are the ones of consumption and the fixed costs. In particular, the former rises by 6.04 and the latter by 0.09 percentage points. The private and public investment shares fall by 4.74 and 1.39 percentage points, respectively.

In the previous experiment, some public capital investment is directed to maintaining

Figure 5: Comparative dynamics when G_t does not affect fixed costs

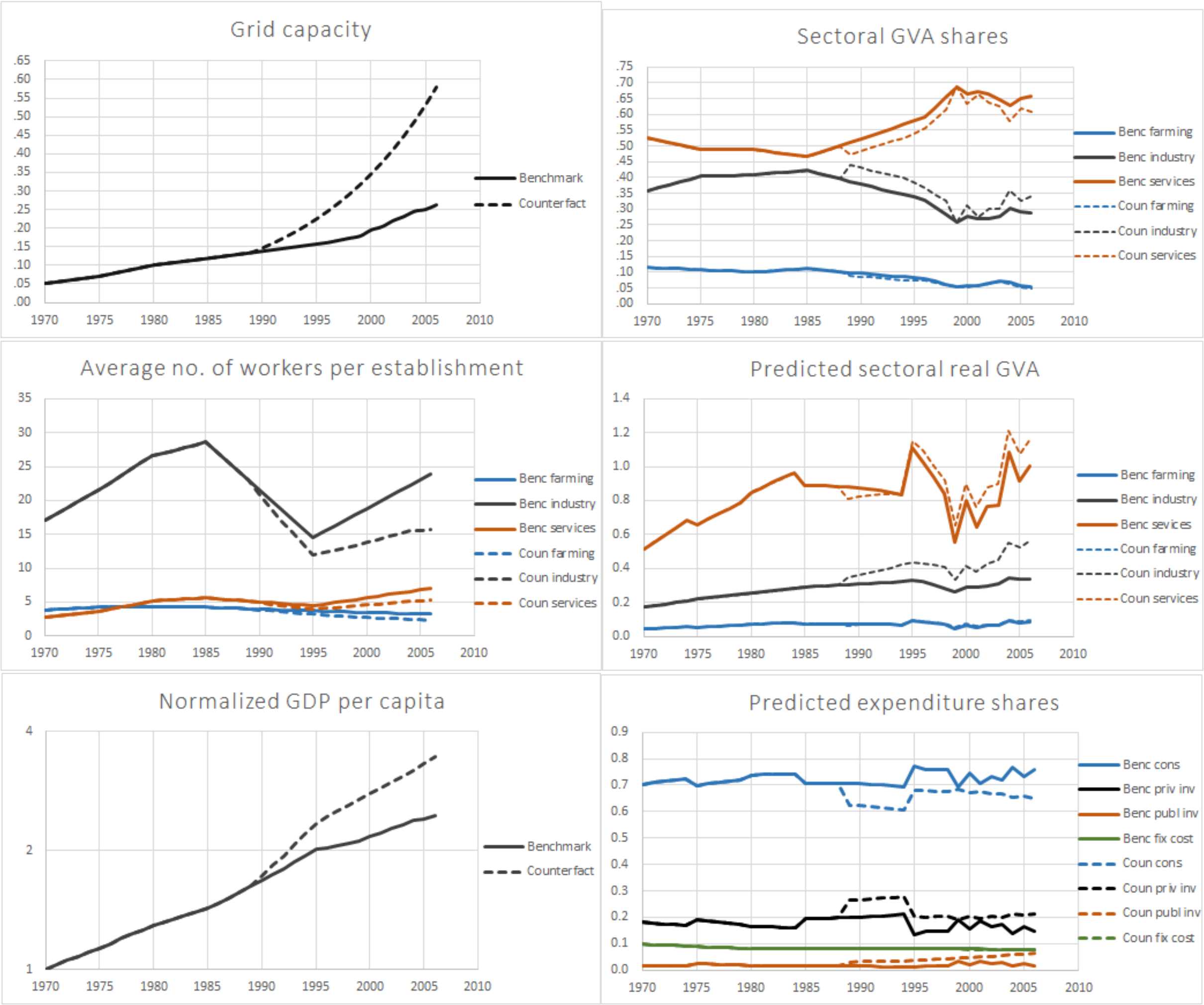


the electric grid and its capacity. An extreme case considers the evolution of the model variables when I_{gt} becomes zero, that is, when power infrastructure is not even maintained. The induced average decrease in G_t equals 72 percent of its benchmark values. Results are summarized in the second column of Table 7. The qualitative findings are, obviously, the same as before. However, the magnitudes are larger. We see (rows 4 to 6) that gross electricity investment now explains 13.8, 45.6 and 17.2 percent of the variation from 1970 to 2006 of the agricultural, manufacturing and services GVA shares, respectively. The decrease in GDP (row 10) rises to 42.98 percent. To better understand the contribution of G_t through its effect on fixed costs, we generate counterfactuals under the assumption that fixed costs are not affected by grid capacity, that is $G_t^{\theta_i} = G_{1970}^{\theta_i}$ for all t and i. Results are presented in Figure 5. The top left panel simply shows that the effect of grid capacity on output production remains the same in this experiment. Compared to the benchmark scenario, real production in the three sectors slightly falls (middle right chart) due to the small decline in private capital investment that the average increase in fixed costs generates. In particular, Table 7 says that real GVA (rows 11 to 13) declines by 0.43, 1.77 and 0.50 percent in the primary, secondary and tertiary sectors, respectively. However, the changes in relative prices greatly offset the effect on real production, and as a consequence, the variation in the GVA shares (top right chart) is negligible. Nevertheless, the decrease in private investment causes a fall in total GDP of 2.30 percent.

The number of workers (middle left panel in Figure 5) is significantly affected by the relative lack of variation of the fixed costs, especially in the manufacturing sector where we find 2.36 workers more per establishment compared to the benchmark case. Again, this is due to the change in the wage rate. Recall that the equilibrium wage is delivered by the free entry condition that equalizes profits to fixed costs. Because now fixed costs do not change with G_t, the wage rates does not need to go up with the use of grid capacity in production as much as before, which induces a larger size of firms in manufacturing and agriculture. In services, since $\theta_s > \theta_a > 0$, the effect that dominates is the lower fixed costs in this sector, which generates smaller firms. Finally, the shares of the different expenditure categories (bottom right chart) do not change much; only the one of private investment decreases, by 0.28 percentage points, mainly at the expense of consumption.

Even though the fixed-costs effect of G_t is not substantial, this does not mean that the evolution of fixed costs in the economy has not been important. Our calibration implies that these costs have been rising driven in part by the increase in the sector-specific parameters f_{oat}, f_{omt} and f_{ost}, which grew, on average, at rates 1.00, 2.87 and 4.95 percent annually, respectively. Recall that their calibrated values are the ones needed to reproduce the observed mean size of establishments in the different sectors. We next generate model simulations

Figure 6: Comparative dynamics if λ_t rises so that the I_{gt} share becomes 0.03



maintaining these parameters constant at their 1970 values. The fourth column ("f_{oit} fixed") of Table 7 gives the results of this exercise. The reported coefficients of determination (R^2) imply that the increase in these parameters can explain 6.3, 14.4, and 5.5 percent of the observed changes in the GVA shares of the primary, secondary and tertiary sectors, respectively. Furthermore, the Table reports as well that GDP would have been a 15.58 percent higher without their increase.

4.2.2 Policy Experiments

Our next task is running five policy experiments. The first two consider an acceleration of public capital formation. IBGE data imply that gross electricity infrastructure formation has decreased in Brazil from a 3.28 percent average share of GDP in the 1980s to an average of 0.9 percent for the period 1990 to 2007. As a consequence, as Calderón and Servén (2010) and Frischtak (2013) among others argue, Brazil's infrastructure investment has fallen in the past few decades below the levels shown by other Latin American and emerging nations such as Chile, China, and India. We now ask our model, what would have been the impact on the different sectors and the economy as a whole if Brazil had maintained the public-capital formation levels of the 1980s during the 1990s and 2000s? This would have implied an average investment in electricity infrastructure of 3.0 percent for the period 1970-2007.

We conduct two different experiments to achieve a stock of G_t similar to the one that the increase in the ratio of I_{gt} to GDP from 1.81 to 3.0 percent would deliver. In the first experiment (the "λ_t up" case), the rise comes as the result of stronger incentives to invest in grid capacity induced by an increase in the political ideology parameter λ_t. Put differently, the policy maker increases the public capital formation perceived as valuable by her supporting group. For this, starting from 1990, we increase each period the value of λ_t so that G_t rises at a constant rate that implies the desired average ratio I_{gt}/GDP of 0.03 for the whole period 1970-2006. All other parameters take on their benchmark numbers.

The results are in Figure 6 and the fourth column of Table 7. The Figure shows values of the different variables from 1970 to 2006. However, the quantities reported in the Table this time refer to the differences for the interval 1990-2006 – this will be the case in all the policy experiments. The bottom right panel depicts the different expenditure categories. We can see that the counterpart to the increase in the electricity infrastructure investment share is a decline in private consumption of 7.70 percentage points. The fixed cost share falls very little, namely by 0.07. Finally, the one for private investment increases by 5.22 percentage points triggered by the complementarity of the two capital goods.

The top left panel shows that the stock of G_t goes up by 70 percent on average as a consequence of the increase in λ_t, and the bottom left chart that this implies a sizable increase in GDP of 23.86 percent (see Table 7). In the middle left panel, in turn, we can observe the evolution of the average number of employees: this average clearly declines in all sectors, making firms become smaller as wages go up as a consequence of the faster public capital formation. The decrease is larger in manufacturing (4.15 workers), followed by services (0.87 employees) and agriculture (0.59 workers). Looking now at the GVA shares (top right panel), manufacturing is the sector that benefits the most: its share increases by 3.93 percentage points. Even though the services sector also benefits from additional investment, it suffers a decline of 3.36 percentage points in its income share due to the reduction in consumption. Agriculture is less affected by the change in consumption due to its lower weight and declines only by 0.57 percentage points.

The middle right panel in Figure 6 shows the evolution of the sectoral real gross value added. Manufacturing again displays the largest increase, at 38.02 percent. Agriculture and services also gain, although much smaller, at 2.86 and 7.65 percent, respectively. Observe that at the beginning of the 1990s, services actually experience a decline in real production. These results are driven by the same reasons as the changes in the shares explained in the previous paragraph.

The second experiment decreases the degree of investment mismanagement in the model economy. In particular, we increase the value of ξ from 0.62 to 0.84. As a result, the average level of G_t reaches 0.32 the same average level as in the last exercise when we changed the value of λ_t. Figure 7 and Table 7 (sixth column) show the simulation results. We can see in the top right panel that the impact of the increase in ξ on the sectoral income shares is now much smaller and go in the opposite direction than before. The reason is that the expenditure shares show little variation: the decrease in the degree of mismanagement increases incentives for public capital formation but reduces the needed amount of investment; both effects offset each other almost exactly. Consequently, manufacturing production increases less than in the λ_t exercise due to the much smaller rise in investment, and the services and agriculture shares go up more because the consumption-share decline is negligible.

More specifically, the bottom right panel of Figure 7 implies that the largest change in the expenditure share is displayed by consumption, whose share goes down by merely 0.21 percentage points (see Table 7), which is almost fully absorbed by the increase in the share of private investment. The income shares of agriculture and services increase, on average, by 0.28 and 0.71 percentage points, respectively, whereas that of manufacturing decreases by 0.99.

Therefore, the effect on the sectoral shares greatly differs compared to the λ_t-up case. To understand the logic, let us concentrate on the middle right panel of Figure 7 that shows the evolution of real production. Sectoral shares do not change much in nominal terms. However, if we abstract from prices and focus exclusively on the output units produced in each sector the picture changes substantially. The three sectors experience a significant increase: agriculture by 16.72 percent, manufacturing by 20.79 percent, and services by 17.14 percent. The additional capital formation, through differences in the β_is, do favor the manufacturing sector. However, the increase in manufacturing production is clearly smaller than in the λ_t-up exercise because capital investment rises by less (remember that manufacturing provides about 73 percent of all investment goods).

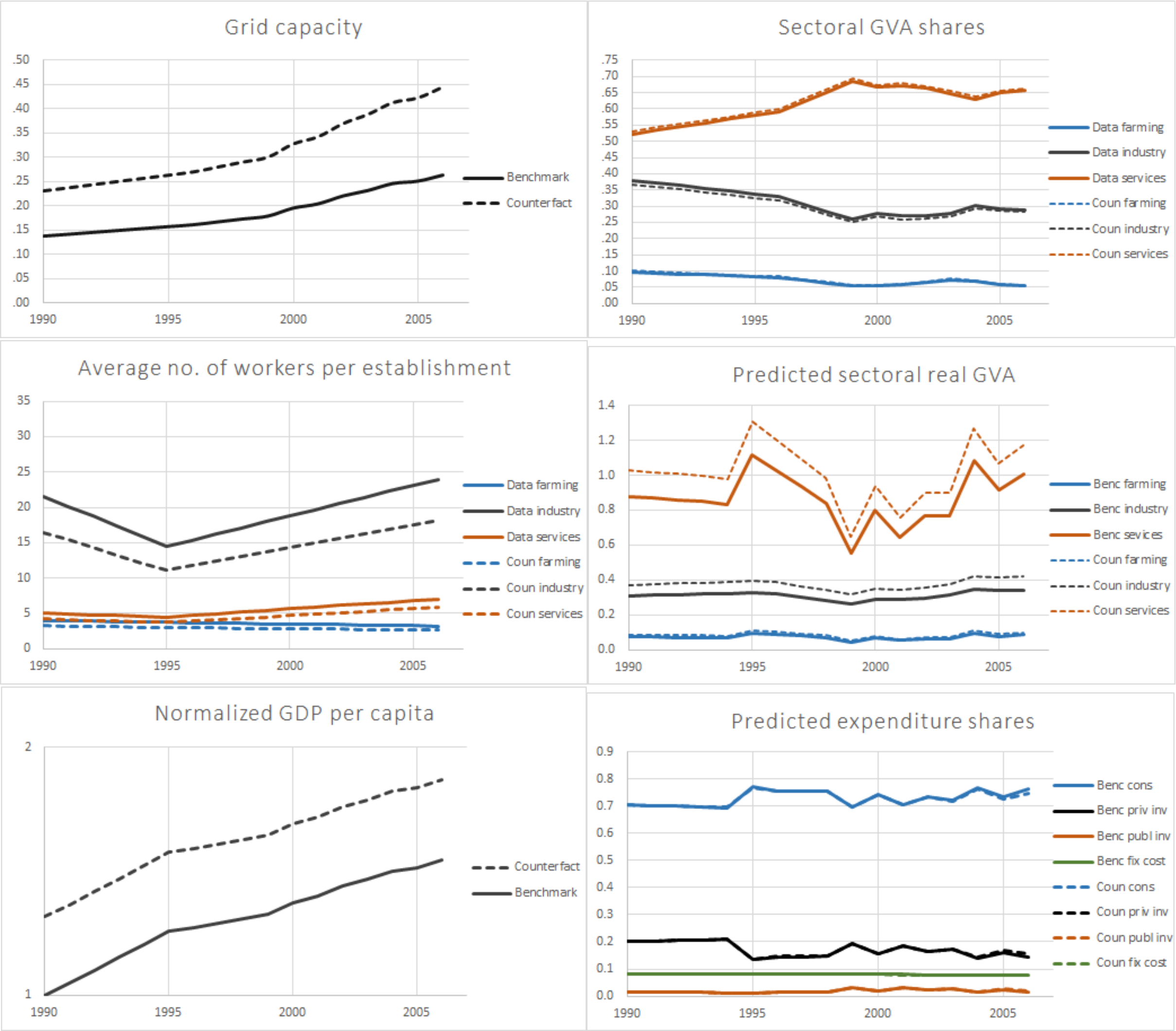
Other variables that do vary substantially as a result of the decrease in the degree of mismanagement include the average number of workers per firm (middle left panel) and the GDP level (bottom left). The additional capital formation causes an increase in the level of GDP of about 24.70%, very similar to what we found in the previous experiment. Finally, the average number of employees per establishment also falls significantly as a result of the increase in salaries: by 0.68 employees in agriculture, 4.54 in manufacturing, and 0.92 in services.

We next look at how the economy responds to changes in the degree of rent capture. This degree – proxied by the parameter φ – is a source of corruption in our model. However, unlike

Table 7: Differences in predicted values with respect to the benchmark case

Variable	G_t fixed	$I_{gt} = 0$	G_t fixed in fixed costs	f_{oit} fixed	λ_t up	$\xi = 0.84$	$\varphi = .1$	$e_m = 1.5$	$e_i = 1.25$ λ down
GVA share of agriculture (%)	0.15	0.19	0.03	0.14	−0.57	0.28	0.00	0.27	−1.07
GVA share of manufacturing (%)	−1.74	−2.42	0.11	0.65	3.93	−0.99	0.00	−1.82	5.71
GVA share of services (%)	1.59	2.22	−0.134	−0.78	−3.36	0.71	0.00	1.56	−4.65
GVA share of agriculture, R^2	0.917	0.862	1.000	0.937	—	—	—	—	—
GVA share of manufacturing, R^2	0.720	0.544	0.998	0.856	—	—	—	—	—
GVA share of services, R^2	0.896	0.828	0.999	0.945	—	—	—	—	—
Ave. no. of workers in agriculture	1.60	2.661	0.02	−1.22	−0.59	−0.68	0.00	−0.85	2.11
Ave. no. of workers in manufacturing	12.66	21.8	2.36	−10.69	−4.15	−4.54	0.00	−4.95	15.68
Ave. no. of workers in services	2.01	3.31	−0.19	−3.00	−0.87	−0.92	0.00	0.20	2.48
GDP percentage change	−32.31	−42.98	−2.30	15.58	23.86	24.70	0.00	31.61	−36.31
Agricultural output % change	−17.26	−23.92	−0.43	11.73	2.86	16.72	0.00	17.90	−33.46
Manufacturing output % change	−34.08	−45.05	−1.77	17.46	38.02	20.79	0.00	23.92	−25.53
Services output percentage change	−19.40	−26.63	−0.50	14.75	7.65	17.14	0.00	18.52	−32.15
Private consumption share (%)	6.04	8.76	0.20	−2.96	−7.70	−0.21	−6.64	−0.17	−4.96
Private investment share (%)	−4.74	−7.14	−0.28	1.71	5.22	0.19	0.00	0.15	5.31
Public investment share (%)	−1.39	−1.75	0.04	−0.23	2.55	0.04	0.00	0.01	−0.34
Fixed-costs share (%)	0.09	0.13	0.05	1.48	−0.07	−0.02	0.00	0.01	−0.01

Figure 7: Comparative dynamics if ξ increases to 0.84



changes in ξ (the other possible source of corruption), variations in φ are not distortionary of the economy's production capability. Table 7, column 7 shows results when φ rises from zero to 0.1. We see that the increase in rent-capture has no effect on the economy, except for the reduction in private consumption by 6.64 percentage points. Consistent with Shleifer and Vishny's (1993) theoretical model, under centralized corruption politicians realize that optimal government spending maximizes also their rents, and then the economy follows the first-best solution.

Next, we quantify the effect of an increase in the efficiency of electricity infrastructure in one of the industries, and in particular, an increase of 50 percent in e_m. Table 7, column 8 displays the simulation results. With the exception of the expenditure shares, all other variables vary significantly. The grid capacity index goes up by 29.3 percent. Real production goes up by 17.90 percent in agriculture, by 23.92 percent in manufacturing, and by 18.52 percent in services. Not surprisingly, the sector than benefits the most is the one in which efficiency increases. Nevertheless, the relative price of services and agriculture increase due to the greater efficiency of manufacturing, leading to a reduction in the GVA share of the latter sector by 1.82 percentage points. As previously, due to the rise in consumption levels, the share that goes up is the one of services that shows an average increase from 1990 to 2006 of 1.56 percentage points. Regarding the average number of workers, it falls in the primary and secondary sectors but increases in the tertiary one.

Finally, we try to assess how the subsidization of electricity infrastructure, a common practice in many developing nations such as e.g., India, Colombia, and many countries in Sub-Saharan Africa, can affect the industries and the economy. The issue that we face when running this experiment is that public capital services are freely distributed in our model economy. To circumvent this problem, we assume that firms allocate the same amount of resources to pay for electricity infrastructure regardless of the subsidy received. Concentrating the analyses on the implementation of a 20% subsidization rate, this implies that we can capture this policy action assuming that e_i goes up from 1 to 1.25 in all sectors.[27] The bad side of subsidies is that they can limit the capacity of the government to invest in electricity infrastructure. In our case, we suppose that the government collects a 20.0 percent less in revenues, and it also invests less by the same percentage in infrastructure spending. This is equivalent to decreasing the ratio of the electricity infrastructure formation to GDP until it equals 1.5 percent, which we achieve when we reduce the values of λ_t by 0.11.

Therefore, we have two opposing forces generated by electricity infrastructure subsidization. On the one hand, the larger e_i benefits the economy. On the other, a lower investment reduces the available stock of infrastructure, which hurts productivity and increases fixed costs. The results in Column 8 of Table 7 suggest that the negative effect dominates. During the sample period, GDP falls on average a 36.31 percent, and production levels also decline in all industries, 33.46 percent in the agriculture sector, 25.53 percent in the manufacturing sector, and 32.15 percent in the services sector. The variation in the average size of establishments is also substantial in all industries, plus 2.11 in agriculture, plus 15.68 in manufacturing, and plus 2.48 in services. Looking next to the expenditure shares, the ones of consumption and private investment experience a sizable change, -4.96 and 5.31 percentage points, respectively. Finally, the GVA share of manufacturing gains, rising by 5.71 percentage points, whereas the ones of agriculture and services decrease by 1.07 and 4.65, respectively. These results reinforce the significance of the infrastructure subsidy trap in developing countries (McRae, 2015).

5 Conclusion

This paper contributes to the understanding of the structural transformation process by: first, focusing on electricity infrastructure – a previously neglected mechanism; second, concentrating on the experience of Brazil, one of the largest developing nations; and third, assessing the

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[27] Observe that if 0.80 units of resources provide one unit of G_t, one unit of resources can buy 1.25 units of G_t.

impact of changes in the firm's operating fixed costs. The multisector model that we study combines elements of the economic growth and heterogeneous firms literatures. This framework considers the standard role of power infrastructure as an amplifier of the productivity of private inputs, but also its capacity to influence the fixed costs faced by firms.

Using Brazilian data on electricity access and generation capacity, sectoral GVA shares, investment expenditure shares, and differences in firm size across industries, our main result confirms that electricity infrastructure and changes in relative firm size are important driving mechanisms of the structural transformation. Our econometric estimates suggest that advances in electricity access mainly favor manufacturing in terms of productivity gains and entry-barriers reductions, followed by services and agriculture. Our model simulations, in turn, imply that the advances in grid access and capacity accelerate the process of the structural transformation (i.e., increase the share of services) through effects channeled by cross-sector differences in electricity intensity and entry costs, but help increase the share of the manufacturing sector through the increase in the required investment for capital formation.

Quantitatively, the model predicts that electricity infrastructure formation explains 17 percent of the observed structural transformation process in Brazil from 1970 to 2006. Fixed costs variations attributed to changes in electricity capital seem to have a small effect. However, changes in the total relative sectoral operating fixed-costs account for 8.8 percent of this process. The extreme case is manufacturing, where electricity formation and fixed-costs variations account together for 42.2 percent of the evolution of the GVA share. The model attributes the explanation of the remaining reallocations of resources across industries to the evolution of the relative sectoral TFP. In terms of GDP per capita, the electrification process is responsible for 32.3 percent of the observed increase, and the positive growth of the sector-specific fixed costs for a loss of 15.6 percent.

We also perform policy exercises to better understand the effectiveness of different electrification strategies. The first two relate to the Brazilian experience with partisan incentives and problems in regulatory governance that lead to lack of investment and mismanagement of public resources. We find that stronger incentives to invest in the electric grid have a significant impact on the evolution of the sectoral shares. In this scenario, the share of manufacturing increases and the ones of the other two production activities decline. On the contrary, a decrease in the degree of mismanagement has negligible effects on the weights of the different sectors in the economy. The reason is that the main driver of the sectoral GVA shares is the distribution of expenditure among the different sectors, regardless of whether or not this expenditure is mismanaged. Importantly, improvements in both the incentives to carry out electricity infrastructure investment and public management have a very significant positive effect on total GDP and production levels, especially in the manufacturing sector.

The third policy experiment analyzes the consequences of variations in the rent-seeking behavior of politicians that targets consumption units. We find no effect on the economy because politicians have incentives to pursue the first-best. Finally, we show that electricity-services subsidization practices of the type followed by nations like India, Colombia and many Sub-Saharan African countries, which limit the capacity of the government to invest in electricity infrastructure formation, can have a significant negative effect on GDP per capita and the share of the manufacturing sector in the economy.

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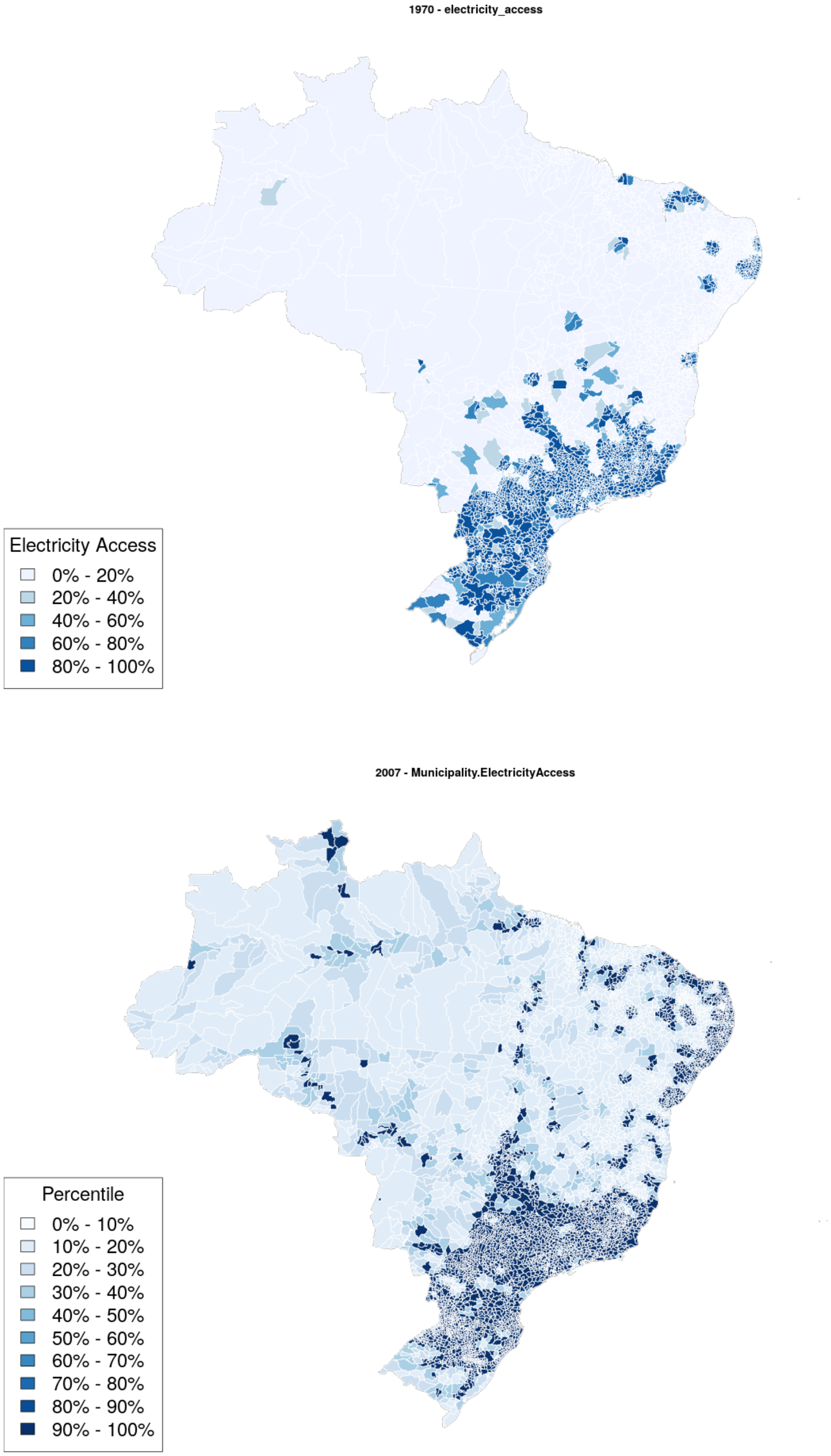
A Variables and parameters of the model

Endogenous variables	Exogenous variables and parameters
c_{it}: consumption of sector i products	A_{it}: technology level in sector i
c_t: consumption bundle	q: firm's productivity
w_t: wage rate	e_{it}: quality of public infrastructure in sector i
r_t: interst rate	ω_i: weight of sector i in consumption
b_t: consumer's stock of bonds	μ_i: weight of sector i in investment
τ_t: lump sum taxes per capita	ε: elasticity of substitution in consumption
p_{it}: price of sector-i products	ν: elasticity of substitution in investment
P_{ct}: consumption price incex	δ_k: depreciation rate of phisical capital
l_{it}: labor employed in sector i	δ_g: deprecitation rate of infrastructure
k_{it}: capital employed by sector i	α: share of capital in production
K_t: economy's capital stock	β_i: infrastructure share in sector-i production
y_{it}: firm's prodcution in sector i	γ: share of labor in production
Y_{it}: total production in sector i	f_q: entry cost parameter
F_{qt}: fixed cost of entry	f_{oi}: operation cost parameter in sector i
F_{oit}: fixed cost of operation in sector i	ψ: A_m elasticity of fixed costs
$\hat{q}_{it}$: productivity threshold in sector i	θ_i: G elasticity of fixed costs in sector i
π_{it}: firm's profits in sector i	φ: weight of rents in welfare function
d_t: dividents per consumer	ρ: subjective discount factor
I_{kt}: investment in physical capital	ξ: mismanagement parameter
I_{gt}: investment in public infrastructure	λ: policymaker's ideology parameter
G_t: stock of public infrastructure	
R_t: rents captured by polititians	
N_{it}: number of firms in sector i	

Figure A.1: Spatial path of electrication in Brazil, 1970 - 2007



source: Sistema de Informações Geográficas do Setor Elétrico