Gray Zones: Slums and Urban Structure in Developing Countries*

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Abstract

Slums are prevalent in many developing country cities and are a critical feature of their landscape. Slums are characterized by the lack of well defined property rights and by precarious public infrastructure, such as access to improved water and sanitation. However, they allow poor households to live in the city close to where they work and enjoy agglomeration externalities. We investigate how slums are formed and how different urban related policies affect the structure of a city. We build a dynamic spatial environment in which agents are heterogenous in their labor productivity and they endogenously choose where and the type of housing mode (formal or informal) they live. We fit the model such that key macro and micro level moments of the city of Sao Paulo in Brazil are matched. We then implement counterfactual exercises to assess the role of urban land use and transportation policies on the city landscape and welfare of their citizens. We show that some policies can have non-trivial effects. For instance, a fall in transportation costs rises the overall efficiency of the city, which attracts more households to the city. Immigration from rural households increases house prices and lead to a substantial rise in slums on the border of the city. We also show that given the land use in a city, slums can be persistent over time even when the city adopts urban policies to foster formal housing.

Keywords: Slums; Rural-Urban Migration; City Growth; Regulation; Transportation Policies.

J.E.L. codes: O18, O15, R52.

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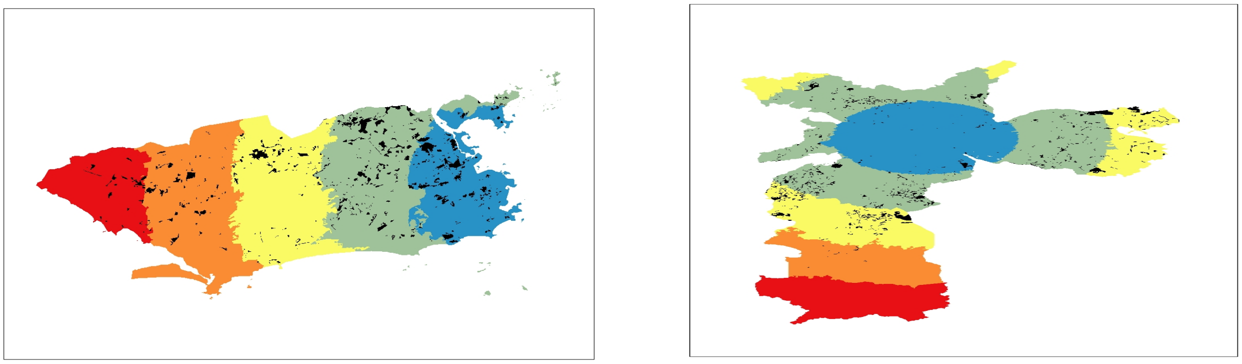

Figure 1: **Slums.** *Left Photo:* Rio de Janeiro, Brazil. *Right graph:* São Paulo, Brazil. Concentric Areas: Blue - Business Center District. Black shades are areas with slums

1 Introduction

Figure 1 displays the map of the city of Rio de Janeiro and the city of Sao Paulo in Brazil. Both cities are divided into 5 different areas, which differ in the distance to the Central Business District (CBD). The black shades are areas with slums. We can easily see that in both cities there are slums in almost all locations, including those very close to the CBD.

Slums are prevalent in many developing country cities and are a critical feature of their landscape. In parts of developing country cities, formal sector houses are adjacent to slums.[1] Evidence from the United Nations (2013) show that slum prevalence is highest in Sub-Saharan Africa – where about 62 percent of the urban population live in slums – but it is also present in a large scale in Western Asia (25 percent), South Asia (35 percent), and Latin America and the Caribbean (24 percent). Slums are also present at a smaller scale in cities in the developed world. For instance, some cities in the United States have also a large prevalence of slums, such as Hidalgo County in Texas, in which about 6.6 percent of the population are slum dwellers and live in the *colonias* with no proper water supply and secured land. Slums are characterized by the lack of well defined property rights and by precarious public infrastructure, such as access to improved water and sanitation.

We investigate how slums are formed and how different urban related policies affect the structure of a city. In order to guide our analysis, we construct a spatial dynamic general equilibrium model with endogenous location choice and housing type (formal and informal) choice. We consider a standard infinity horizon model in which heterogenous

[1]The Dharavi slum in Mumbai, India, where approximately one million people live, is just beside the Mumbai financial district; the textitFavela da Rocinha, where approximately 70 thousand people live, is only 3 km from Brazil's most expensive real state price, Leblon, and with a beautiful ocean view.

agents choose in each point in time where and in which type of housing to live. Locations are different by their distance to the Central Business District (CBD) and by local externalities. There are moving costs and agents are different in their labor productivity and endogenous net wealth.[2] Labor productivity is composed by two components: a permanent (skill) component and a transitory uninsurable component, in the spirit of Huggett (1993) and Aiyagari (1994).

The trade-off from choosing informal housing over formal housing is straightforward. Households choosing informal housing units do not reap all benefits from public goods and must protect the informal plot from property theft or eviction, but they dodge complying with building regulations and paying property tax. There is an opportunity cost to protect the informal plot as households must forgone labor income to spend part of their time protecting the plot. For each location in the city space the trade-off between formal and informal housing is present.

Given that we take into account rural-urban migration and the decision on where to live within a city, the model is able to explain important features of the urbanization process in developing countries. We calibrate and estimate the model parameters such that key macro and micro level moments of the city of Sao Paulo in Brazil are matched. Our model is consistent with main landscape features of this city. Richer households tend to live in formal housing units, near the city center, and surrounded by a greater availability of public goods. Poor households can also choose to live close to the city center but, in general, they afford that by living in slums. They can also live in the outskirts of the city in better housing but with larger commuting costs. Not all slum units are the same in our model because of the intensive margin of housing space consumption and difference in public goods from different locations. For the same location, formal housing rents are higher than informal housing ones (cf., Jimenez, 1984; Friedman, Jimenez, and Mayo, 1988). We also show that both formal and informal housing rents decrease as distance from the city center increases.

With the model fitted to the data we implement policy simulations to assess the role of changing regulation and transportation policies. We show that pro-urban growth policies can have unintended consequences as they may increase urban land values and change both tenure and location decisions. For instance, a reduction in transportation costs decreases the prevalence of slums close to the business district as improvements in road networks and public transportation are capitalized into housing prices. However, such

[2]Therefore, our model captures main trade-offs of the location decision, as described in Bilal and Rossi-Hansberg (2018).

policies can increase substantially slums in areas away from the business center district due to immigration of poor households from rural areas. As in Glaeser, Kahn, and Rappaport (2008), in our model better public transportation attracts relative poorer households from rural areas to the city. In general equilibrium, lower transportation costs reduce slum formation in the city center and induce slum formation in the outskirts by attract migrants willing to move to this more productive city. We show that this process is a long one.

The remainder of this paper is divided into five additional sections besides this introduction. The next section describes the related literature on the topic and places our contribution. Section 3 describes the model economy, which is used for quantitative analysis. Section 4 fits model parameters to be consistent with micro and macro level data from the the city of Sao Paulo. Section **??** provides the quantitative analysis to measure the spatial and dynamic effects of urban policies on slums. Section 6 contains concluding remarks.

2 Related Literature

Our research is related to a growing literature on how different urban related policies affect the structure of a city. As we analyze the location of households within a city, our model is close to the standard models of Alonso-Muth-Mills in urban economics (cf., Alonso, 1964; Muth, 1969; Mills, 1967). While there are a number of papers studying the location of agents with a focus on developed countries (mostly extensions of the AMM model, see Brueckner, Thisse, and Zenou (1999)), we contribute by explaining spatial patters in developing countries. We are, in particular, linked to Kopecky and Suen (2010) and Baum-Snow (2007), as they explore the quantitative implications of AMM-type of models. In sum, we differ from previous works using the AMM-type of model by introducing the household choice between living either in formal or informal housing sector in a dynamic and spatial setting.[3]

Close related to our question and approach are Cavalcanti, Da Mata, and Santos (2018) and Ferreira, Monge-Naranjo, and Pereira (2016). Our model extends the environment developed by Cavalcanti, Da Mata, and Santos (2018) in at least two important dimen-

[3]There is a related literature on urban squatting and informal housing that is not based on general equilibrium models with heterogenous agents. See, for instance, Field (2007) , Brueckner and Selod (2009), Brueckner (2013), Cai, Selod, and Steinbuks (2018), among others. There is also an empirical literature evaluating the effects of different urban policies (e.g., land titling and infrastructure upgrading) addressing slum problems on individual outcomes and urban growth. See for instance Lanjouw and Levy (2002), Field (2005), Field (2007), Di Tella, Galiani, and Schargrodsky (2007), Galiani and Schargrodsky (2010), among others.

sions. Our model is dynamic and the city has many locations,[4] while their environment is static and the city has only one uniform location. Those are important extensions since they allow us to study the spatial distribution of slums and the dynamics and persistent of slums when government policies and institutions are changed. In addition, by using a dynamic environment we can assess how policies affect the decision of households who are currently living in slums. The literature on slums has not paid proper attention to how policy actions will affect decisions of households who are currently living in slums. The literature has models of slum formation to assess how policies would have impacted the city compared to its counterfactual, without analysing the dynamics of such changes. Therefore, a policy simulation can generate a city with slum share of 5 percent compared to a share of 10 percent in the baseline city. While this might be informative, it is important to consider the transitional dynamics from the baseline to the counterfactual. Ferreira, Monge-Naranjo, and Pereira (2016) also abstract from the spatial dimension[5] and focus on a different questions than ours. They explore the dynamic interaction between skill formation and slums in an overlapping generations framework while we focus on how urban growth policies affect households' location and slums prevalence.[6]

3 The Model

Time horizon is infinite and discrete, such that $t = 0, 1, 2, ...$ There is a mass P of individuals who could live in the city. The city has $n = 1, ..., N$ locations that differ in their distance, $d_n \in \mathbf{D} = \{d_1, ..., d_N\}$, to the Central Business District (CBD) and in the area available for housing, $L_n \in \mathbf{L} = \{L_1, ..., L_N\}$. All households living in location n have the same road network and public transportation so that they all spend the same commuting cost to the central business district. We interpret this as a circular city with a fixed radius S such that $d_n = \frac{n}{N} S, n = 1, ..., N$, and the total land area of the city is $\mathbf{S} = \pi S^2$. The area at location n is

[4] Selod and Tobin (2018) introduce endogenous choice of property rights in the standard spatial urban land use model with formal and informal housing. They derive important analytical results and provide intuition on how slums are formed. Their model is static and their analysis is qualitative. Therefore, we see our paper as complementary to theirs.

[5] They assume three locations in their model: rural areas, slums and city centers. We also have rural areas in our model but in our framework informal and formal households compete to the same land area in the city.

[6] An interesting and related article is Henderson, Regan, and Venables (2018) who also explore the spatial dynamics of a city but focusing on the decision of developers to build when property rights in some areas of the city are not well defined. While they use a representative household to study analytically the decision of developers, our model is based on infinite lived heterogenous agents. They use data from Nairobi to estimate building parameters and to assess the effects of different urban policies in Nairobi.

$S_n = \frac{\pi S^2}{N^2}(2n-1)$, but only $L_n = \sigma_n S_n$ with $\sigma_n \in [0,1]$ is available for housing. Households differ by their labor productivity and they have the option to choose two types of housing tenure, i.e., formal or informal.

3.1 The Environment

Households. There is a continuum of households of measure P, each of whom with labor productivity z who can live in the city or in a rural area. Each household has one worker and occupies one housing unit, so that the number of people equals both the number of households and housing units.

There is a value $\bar{V}$ of living in a rural area and working in the agricultural sector. We assume that this value is independent of the productivity level z. Therefore, individuals will live in this city only if it is optimal to do so. Households who decide to live in the city have to choose their location in the city and their housing tenure type: formal or informal housing. They obtain utility over non-housing consumption (a homogeneous good c_t) and housing services (s_{jt}), where j equals F if formal housing and I if informal housing. The utility function is specified as

$$U = E_z\left[\sum_{t=0}^{\infty} \beta^t \left(\alpha \ln(c_t) + (1-\alpha)\ln(s_{jt}(d_n))\right)\right],\ \alpha,\ \beta \in (0,1),$$

Housing service flow (s_{jt}) entails housing space (h_t), public goods surrounding the housing unit ($G_t(d_n)$), and a parameter θ such that:

$$s_{jt} = \begin{cases} G_t(d_n)h_t & \text{if formal housing (j=F),} \\ \theta G_t(d_n)h_t & \text{if informal housing (j=I),} \end{cases}$$

where $\theta \in (0,1)$. The expression $\theta G_t(d_n)$ means that informal housing agents do not reap all the benefits from public goods provision within the city boundaries. The parameter θ may be seen as a congestion cost due to living in high density neighborhood (as is typically the case of slums).

Household's labor income is $w_t z_t$, where w_t is the wage rate per efficiency units of labor, and $z_t = exp(\iota_e e + \xi_t)$ is the labor productivity of the household with $\iota_e \geq 0$, where $e \in \{e_1, ..., e_E\}$ is a permanent component, which is time invariant, and ξ_t is a transitory component, which evolves accordingly to the following process:

$$\xi_{t+1} = \rho_{\xi}\xi_t + \epsilon_{t+1},\ \epsilon_{t+1} \sim iidN(0, \sigma_{\epsilon}^2), \tag{1}$$

In order to save on notation we will drop the subscript t and use the standard notation (prime - $'$) in dynamic programming to denote future variables. Each household has one unit of productive time and face a cost $\eta(d_n) = \eta_0 d_n^{\eta_1}$ in commuting time, where d_n is the location of the house of the household and η_0 and η_1 are parameters. A household allocates her income net of commuting cost $wz(1 - \eta(d_n))$ between non-housing consumption (c), and housing services (s_j). The two types of housing entail different costs. Only households in formal housing pay a property tax τ_p and a lump-sum fee χ associated with the cost of some public goods.

If a household decides to live in the informal sector, then they can evade property taxes, τ_p and lump-sum fee ϕ, but she incurs protection costs $\Psi(d_n, h) = \psi(d_n)h$, where $\psi(d_n) = \psi_0 d_n^{-\psi_1}$ with $\psi_0 > 0$ and $\psi_1 > 0$. Therefore protection costs are increasing with the size of the property h and the closer the house is to the central business district. Informal housing lacks property rights and is associated with insecurity due to exogenous risks of eviction and demolitions by the government. Therefore, if an agent chooses to dwell illegally, she will spend $1 - \eta(d_n) - \Psi(d_n, h)$ of her time working, i.e., informal housing agents allocate part of their time to protect their informal plot. This is a reduced form approach to represent the cost of informality which we assume to be decreasing with the distance to the business district. Therefore, on the border of the city the protection cost to live in a slum is lower than in locations closer to the business district. The implicit assumption is that if households living in informal housing do not spend time or resource in protecting their land, then they will be evicted. This implies that spending such time and resource are incentive compatible.

Households can change their house tenure and their location. But there are some moving costs. Let γ_F be the cost associated to move to a formal house and let γ_I be the cost incurred when moving to an informal house.[7] Denote a the amount of assets a household has at the beginning of a period and assume that houses are own by developers and households rent them out. The problem of developers will be fully described below. Let r be the net interest rate on assets, which is determined outside the city. Each household is described by their individual states: $\omega = (e, \xi, a, d, j)$ with $j \in \{F, I\}$. The value function

[7] In order to simplify the analysis, we assume that these moving costs are independent of the original type of house they are moving out. But clearly, this assumption could be relaxed

of a household represented by state $\omega = (e, \xi, a, d, F)$ is

$$V^F(e,\xi,a,d) = \max_{c,a',h,I_d^F,I_I^F} \{\alpha \ln(c) + (1-\alpha)\ln(G(d)h) + \tag{2}$$
$$\beta E_\xi[I_d^F V^F(e,\xi',a',d'_{-d}) + I_I^F V^I(e,\xi',a',d')] + (1 - I_d^F - I_I^F)V^F(e,\xi',a',d)]\},$$

subject to (1),

$$c + a' + (1+\tau_p)R_F(d)h + \chi + I_d^F\gamma_F + I_I^F\gamma_I = wexp(\iota_e e + \xi)(1-\eta(d)) + (1+r)a, \tag{3}$$

$$c, a', h \geq 0,\ I_d^F, I_I^F \in \{0,1\} \tag{4}$$

$$V^F(z,a,d) \geq \bar{V}. \tag{5}$$

Variable I_d^F and I_I^F indicates whether or not this household decided to move to a formal house in any other location and to an informal house in any location, respectively.

Similarly, a household represented by $\omega = (e, \xi, a, d, I)$ solves

$$V^I(e,\xi,a,d) = \max_{c,a',h,I_d^I,I_F^I} \{\alpha \ln(c) + (1-\alpha)\ln(\theta G(d)h) + \tag{6}$$
$$\beta E_\xi[I_d^I V^I(e,\xi',a',d'_{-d}) + I_F^I V^F(e,\xi',a',d')] + (1 - I_d^I - I_F^I)V^I(e,\xi',a',d)]\},$$

subject to (1),

$$c + a' + R_I(d)h + I_d^I\gamma_I + I_F^I\gamma_F = wexp(\iota_e e + \xi)(1-\eta(d) - \psi(d)h) + (1+r)a, \tag{7}$$

$$c, a', h \geq 0,\ I_d^I, I_F^I \in \{0,1\}, \tag{8}$$

$$V^I(z,a,d) \geq \bar{V}. \tag{9}$$

I_d^I denotes whether or not this household decided to move to a slum in another location and I_F^I indicates decision to move to a formal house in any location.

Consumption Goods. The homogeneous non-housing consumption good is the economy's numeraire. There is a continuous of measure one absentee producers, each with access to the following production function $Y = BK^{v_1}N^{v_2}$ with $B > 0$ and $v_i \in (0,1)$ for $i = 1,2$, and $v_1 + v_2 < 1$. Firms rent capital and labor to solve

$$\pi = \max_{N,K}\{BK^{v_1}N^{v_2} - wN - (r+\delta)K\}.$$

The first-order conditions for K and N imply that

$$K(w) = \left(B \left(\frac{v_1}{r+\delta} \right)^{1-v_2} \left(\frac{v_2}{w} \right)^{v_2} \right)^{\frac{1}{1-v_1-v_2}}, \tag{10}$$

$$N(w) = \left(B \left(\frac{v_1}{r+\delta} \right)^{v_1} \left(\frac{v_2}{w} \right)^{1-v_1} \right)^{\frac{1}{1-v_1-v_2}}. \tag{11}$$

The above equations are the demand for capital and labor, respectively. Notice that Equation (11) implies that for a given interest rate r, the labor demand is negatively related to the wage rate w. Production of consumption good in the city is given by:

$$Y(w) = \left(B \left(\frac{v_1}{r+\delta} \right)^{v_1} \left(\frac{v_2}{w} \right)^{v_2} \right)^{\frac{1}{1-v_1-v_2}}.$$

Housing. Housing space is produced using land and capital. Land belongs to a group of absentee risk neutral landlords/developers. Land can also be allocate to agriculture production and the rental rate of land for agricultural production is r_a and it is determined outside the city. The technology to produce housing space is $\tilde{H}_j = A_j(\tilde{L}_j(d))^{\mu}(\tilde{K}_j(d))^{\phi}$, where $j \in \{F, I\}$, $\mu, \phi \in (0,1)$ and $\mu + \phi < 1$. The stock of housing space evolves according to:

$$\tilde{H}_j'(d) = A_j(\tilde{L}_j(d) + \tilde{l}_j(d))^{\mu}((1-\delta)\tilde{K}_j(d) + \tilde{x}_j(d))^{\phi},$$

where $\tilde{x}_j(d)$ corresponds to investment in structure and $\tilde{l}_j(d)$ denotes new land incorporated in the production of housing in sector j and location d. Notice that $\tilde{l}_j(d)$ can be negative and there is an adjustment cost such that developers have to pay $\kappa_j\tilde{l}_j(d)$ whenever new land is incorporated in the project or scrapped. Developers solve the following problem:

$$\begin{aligned}\Pi_j(\tilde{K}_j(d), \tilde{L}_j(d)) = \max_{\tilde{x}_j(d), \tilde{l}_j(d), \tilde{K}_j'(d), \tilde{L}_j'(d)} & \{R_j(d)A_j(\tilde{L}_j(d))^{\mu}(\tilde{K}_j(d))^{\phi} - \tilde{x}_j(d) - r_a\tilde{L}_j(d) \\ & -r_a\tilde{l}_j(d) - \kappa_j\tilde{l}_j(d) + \frac{1}{1+r}\Pi_j(\tilde{K}_j'(d), \tilde{L}_j'(d))\},\end{aligned} \tag{12}$$

subject to

$$\tilde{K}'_j(d) = (1-\delta)\tilde{K}_j(d) + \tilde{x}_j(d), \tag{13}$$
$$\tilde{L}'_j(d) = \tilde{L}_j(d) + \tilde{l}_j(d). \tag{14}$$

The first-order conditions with respect to $\tilde{l}_j(d)$ and $\tilde{x}_j(d)$ yield, respectively:

$$-r_a - \kappa_j + \frac{1}{1+r}\left(\frac{\partial \Pi_j(\tilde{K}'_j(d), \tilde{L}'_j(d))}{\partial \tilde{L}'_j(d)}\right) = 0, \tag{15}$$

$$-1 + \frac{1}{1+r}\left(\frac{\partial \Pi_j(\tilde{K}'_j(d), \tilde{L}'_j(d))}{\partial \tilde{K}'_j(d)}\right) \leq 0,\ \tilde{x}_j(d) \geq 0,\ \frac{\partial \Pi_j(\tilde{K}_j(d), \tilde{L}_j(d))}{\partial \tilde{K}_j(d)}\tilde{x}_j(d) = 0. \tag{16}$$

Using the envelope theorem, we have that

$$\frac{\partial \Pi_j(\tilde{K}_j(d), \tilde{L}_j(d))}{\partial \tilde{L}_j(d)} = R_j(d)\mu A_j(\tilde{L}_j(d))^{\mu-1}(\tilde{K}_j(d))^{\phi} - r_a, \tag{17}$$
$$\frac{\partial \Pi_j(\tilde{K}_j(d), \tilde{L}_j(d))}{\partial \tilde{K}_j(d)} = R_j(d)\phi A_j(\tilde{L}_j(d))^{\mu}(\tilde{K}_j(d))^{\phi-1}. \tag{18}$$

Given that these conditions are valid for all time periods, then:

$$\tilde{K}'_j(d) = \max\left[(1-\delta)\tilde{K}_j(d), \left(\left(\frac{\phi R'_j(d)A_j}{1+r}\right)^{1-\mu}\left(\frac{\mu R'_j(d)A_j}{(1+r)(r_a+\kappa_j)+r_a}\right)^{\mu}\right)^{\frac{1}{1-\mu-\phi}}\right], \tag{19}$$

$$\tilde{L}'_j(d) = \left(\frac{\mu R'_j(d)A_j}{(1+r)(r_a+\kappa_j)+r_a}\right)^{\frac{1}{1-\mu}} \tilde{K}'_j(d)^{\frac{\phi}{1-\mu}}. \tag{20}$$

Therefore, supply of housing type j in area d is:

$$\tilde{H}'_j(d; R'_j(d)) = A_j(\tilde{L}'_j(d; R'_j(d)))^{\mu}(\tilde{K}'_j(d; R'_j(d)))^{\phi}. \tag{21}$$

Recursive competitive equilibrium. At each point in time, agents differ from one another with respect to the vector of state variables $\omega = (e, \xi, a, d, j) \in \Omega$. Agents identified by their individual states ω, are distributed according to a probability measure λ defined on Ω, as follows. Let $(\Omega, \mathcal{F}(\Omega), \lambda)$ be a space of probability, where $\mathcal{F}(\Omega)$ is the Borel σ-algebra on Ω: for each $\zeta \subset \mathcal{F}(\Omega)$, $\lambda(\zeta)$ denotes the fraction of agents that are in ζ.

Given the asset distribution, λ, $Q(\omega,\zeta)$ induces the asset next period distribution λ' as follows. The function $Q(\omega,\zeta)$ determines the probability of an agent with state ω transiting to the set ζ. $Q(\omega,\zeta)$ depends on the agents' policy functions and on the exogenous stochastic process for ξ. Now, we have all the objects to characterize the stationary recursive competitive equilibrium. Households' optimal behavior was previously described in detail above as well as the problem of firms and developers. It remains, therefore, to characterize the market equilibrium conditions, the aggregate law of motion, and the government budget constraint. In each period, there are $3 + 2 \times N$ prices in this economy $(w, r, r_a, R_j(d))$ for $j \in \{F, I\}$. We have that r and r_a are determined outside the city. The equilibrium in the labor market requires:

$$\sum_{d\in\mathbf{D}} P \int_{\Omega} exp(\iota_e e + \xi) \left((1-\eta(d) - \psi(d)h(\omega))\mathbf{I}_{d,I} + (1-\eta(d))\mathbf{I}_{d,F}\right) = N(w), \tag{22}$$

where $\mathbf{I}_{d,j}(\omega)$ is an indicator function, which takes value 1 if household ω lives in area d in house type j.

The housing market is determined by demand and supply of housing in each location, such that:

$$P\int_{\Omega} \mathbf{I}_{d,j}(\omega)h(\omega)d\lambda = \tilde{H}_j(d; R_j(d)), \text{ for } j \in \{F, I\} \text{ and } d \in \{1, ..., N\},$$

In addition, the use of land in each location is constrained by the supply of land in each location:

$$\tilde{L}_F(d) + \tilde{L}_I(d) \leq L_d.$$

Finally, local public goods $G(d)$ are financed by a property tax rate (τ_p) and a lump-sum fee χ paid only by formal housing residents. We also assume that the local government runs a balanced budget and therefore

$$G(d) = P\int_{\Omega} \mathbf{I}_{d,F}(\tau_p R_F(d)(\omega)h(\omega) + \chi)d\lambda, \; d \in \{1, ..., N\}.$$

Given the decision rules of households, $\lambda(\omega)$ satisfies the following law of motion:

$$\lambda'(\zeta) = \int_{\Omega} Q(\omega,\zeta)d\lambda, \;\; \forall \zeta \subset \mathcal{F}(\Omega).$$

4 Model Fit

The model formalizes the mechanisms through which income, land use regulations, and other variables affect location choice and housing tenure choice. Now we want to determine the magnitude of those factors on slum formation. Since our model is one of a city, the parameters of the model are set to match relevant features of Sao Paulo city in 2010. We divide the city of Sao Paulo into 5 different areas.

We need to calibrate 31 parameters generated by the structure of the model. A formal calibration and estimation are in progress. We now solve a static version of the model that has 20 parameters represented by the following vector:

$$\xi = \{\lambda_0, \epsilon, \alpha, \gamma, \beta, \tau_p, P, S, v, r, B, \phi, \eta, \psi_0, \psi_1, \theta, \underline{h}, A_F, A_I, \bar{V}\}.$$

The values of the parameters of vector ξ were either selected from existing observations ("external calibration") or determined by a distance minimization procedure ("internal calibration" or estimation). Let ξ_{ext} be the partition of vector ξ containing eleven parameters to be (externally) calibrated and ξ_{int} be the partition of ξ with the additional nine unknown parameters to be estimated.

External Calibration. The vector to be determined by external calibration is given by

$$\xi_{ext} = \{\lambda_0, \epsilon, \alpha, \gamma, \beta, \tau_p, P, S, v, r, B\}.$$

Due to the shortage of empirical literature on slums, in particular applied to cities in Brazil, we had to select parameters directly from datasets to use in the calibration. The parameters of the external calibration are: two parameters for the distribution of labor productivity (λ_0 and ϵ), weight of housing consumption (α), weight of land and capital in housing production (γ and β, respectively)[8], property tax rate (τ_p), total population (P), city radius (S), labor share in the production of the consumption good (v), real interest rate (r), and city-level productivity (B). As we will calibrate the model for two cities in Brazil, most of the data sources are similar in the two cases and come from Brazil's Official Bureau of Statistics (IBGE).

One key aspect of the numerical exercise is the distribution of labor productivity ($\Upsilon(\lambda)$). In the calibration exercise, the distribution of abilities $\Upsilon(\lambda)$ is set to be a Pareto distribution in order to fit the empirical income distribution. We adjust the two parameters of the

[8] Recall that housing supply price-elasticity comes from γ and β.

income distribution to match moments from the income distribution of São Paulo and Rio de Janeiro in 2010, i.e., the artificial income data is set to match moments of the empirical income data. We use two income data moments from IBGE's 2010 Brazilian Population Census (see Appendix **??**) for this exercise: the *per capita* income of the poorest quintile of the population (proxy for λ_0) and the Gini index (proxy for ϵ). The estimated Pareto distribution provides the income distribution for the calibration exercise.

The weight of housing consumption in the utility function (α) is set at 0.21 to São Paulo and at 0.23 to Rio de Janeiro. These values stem from IBGE's Household Budget Survey, the main data source on the distribution of spending of Brazilian households.

As for housing production, we set the weight of land input (γ) to be equal to 0.25. The parameter γ can be rewritten as the share of land out of total output given the Cobb-Douglas production function of the developers. Construction companies listed on the São Paulo Stock Exchange display information on the price of land compared to the their total sales (both by construction unit and the total values). Production technology of developers varies because several factors influence the ratio of land prices to total sales, such as whether the land was bought directly or whether the company traded residential units for land. However, data from construction companies in São Paulo indicate that the target value for land price lies between 25% to 35% of the total output when it comes to residential units. Additionally, we set the weight of capital input (β) to be equal to 0.25 using data from IBGE's SINAPI (National Survey of Costs in Construction Sector).

The property tax rate (τ_p) equals 1% of the housing price in São Paulo. Note that τ_p multiplies *housing rents* (R_F) for formal households in the model, so it is necessary to calculate the "effective" property tax as of housing rents' values (instead of housing prices). For instance, a tax of 1% on housing prices is equivalent of a tax of 25% on rents, for a given interest rate of 4% per year.

Parameters P and S are set to one. We also need to stipulate the interest rate r, for which we use the national interest rate. Based on a 30 years average for Brazil, the interest rate is set to be 4% per annum in real terms. Parameter v is the labor share in the production of the consumption good. We set it equal to 0.6, which is consistent with the estimates provided by Gollin (2002). Given r and v, we choose productivity factor B such that the wage rate is equal to 1.

Internal Calibration. Due to the paucity of data, the additional nine parameters from vector ξ were found by minimizing the distance between the model and the data moments. Therefore, we find the nine parameters focusing on selected data moments (along the lines suggested by Hansen (1982)) instead of focusing on the entire distribution of the observed variables. Partition ξ_{int} is represented by

$$\xi_{int} = \{\phi, \eta, \psi_0, \psi_1, \theta, \underline{h}, A_F, A_I, \bar{V}\}.$$

The parameters of the internal calibration are: formal housing lump-sum fees ϕ, a parameter for transportation costs (η), two parameters for the protection costs function (ψ_0 and ψ_1), informality disutility θ, the minimum housing space $\underline{h}$, housing production parameters A_F and A_I, and reservation utility $\bar{V}$.[9] Internal calibration consists of estimating the parameters from ξ_{int} such that the model would match key statistics of the São Paulo's urbanization process.

We aim to match ten predictions of the model to their data counterparts. Tenure choice and housing rents are used as moments in the minimization procedure. Recall that the model is able to generate information on housing tenure choices (so we have the fraction of population in slums) and on housing rents (so we can construct the housing rent ratio between formal and informal housing units). We split each city into five concentric circles, such that we have ten moments, i.e., the fraction of population in slums and housing rent ratio in each circle. In order to create the slums' share, we verify the decision rule regarding housing tenure (represented by $\Omega(\lambda, d_n; \mathbf{o})$ in the model) for each agent and then aggregate it to create the slums share value. After verifying the optimal choices of each agent, it is also possible to retrieve information on housing rents.

We use a Method of Moments or Minimum Distance procedure to find the unknown parameters. The distance minimization procedure consists of finding the vector $\hat{\xi}_{int}$ that minimizes the distance between the model's prediction and the data. By carrying out this procedure, we aim to obtain parameter values which most closely reproduce key features of the data. The objective is to minimize the quadratic loss function of deviations of predicted moments from their empirical counterpart (weighted sum of squared errors of model moments and data moments). The model is overidentified, since the number of parameters in ξ_{int} is nine and the number of moments is ten. The nested fixed point algorithm used to compute the parameters has two loops: the inner loop computes the housing market equilibrium for all five concentric circles given each parameter value, while the outer loop searches for optimal parameter values.

Let $\mathcal{L}(\xi)$ be the quadratic loss function to be minimized, M_d be the vector of data

[9] Notice that it is difficult to obtain a measure of "minimum housing space" from the existing legislation, so the parameter $\underline{h}$ is obtained by the internal calibration.

moments, and $M_m(\xi)$ be the correspondent vector of model moments. Formally, we want to find a $\hat{\xi}_{int}$ such that

$$\hat{\xi}_{int} = arg \min_{\xi_{int}} \mathcal{L}(\xi) = arg \min_{\xi_{int}} \frac{1}{N}[M_m(\xi) - M_d]' W_N \frac{1}{N}[M_m(\xi) - M_d]. \tag{23}$$

where $M_m(\xi) - M_d$ is the orthogonality condition and W_N is a positive semi-definite weighting matrix. The matrix W_N converges in probability to W. It follows that $\hat{\xi}_{int}$ is a consistent and asymptotically normal estimator of ξ_{int}. In the analysis, we use an optimal weighting matrix W, which is given by the inverse of the variance-covariance matrix of the data moments[10] (S) , i.e., $W = S^{-1}$.

Notice that there is no formal proof that the parameters are identified from the chosen set of moments. However, the chosen moments are informative about the parameters to be estimated. All moments are important for the values of all parameters, but each parameter has more influence on a subset of the chosen moments. Specifically, minimum housing space ($\underline{h}$) highly influences slum share (recall Figure **??**), while protection costs (ψ_0) and informality disutility (θ) impact more on housing space consumption for informal housing (and thus the distribution of housing rent ratio).

Table 1 shows the value of the calibrated and estimated parameters. The internally-estimated parameters have the expected sign. The only parameter which its magnitude has a direct economic interpretation is ψ_0. Parameter θ is a utility-shifter and $\underline{h}$ is related to the concept of housing services (which enters the utility function as well) and a catch up of all variables which denoting housing regulations in the formal sector. Field (2007) estimates that in Peru no legal claim to property is associated with a reduction of 14% in total household working hours. Our estimate for São Paulo and Rio de Janeiro is that, for each housing space unit, the cost of informality is about XX% of disposable income.

5 Quantitative Analysis

In this section, we use our model to predict the impact of hypothetical policies on the location and formation of slums. We focus on hypothetical policies that makes formal housing market more accessible to the urban poor and improvements in road networks and public

[10] There are 10 moments, so the orthogonality condition is a 10x1 matrix and the weighting matrix is a 10x10 matrix. All five data moments are calculated from São Paulo's microdata. We computed data-moments variance-covariance matrix S directly from city-level variance-covariance information. The off-diagonal elements of the matrix S also come from the city-level information.

Table 1: **Estimation of the Model: Parameters for Sao Paulo (SP) city**

External Calibration			
Parameter	Description	Values	Source
λ_0, ϵ	Labor productivity distribution	666, 1.33	PNAD survey
α_c	Preferences: Weight of consumption	0.55	POF survey
α_h	Preferences: Weight of housing service	0.21	POF survey
γ	Housing: Weight of land input	0.47	Construction Companies
β	Housing: Weight of capital input	0.25	SINAPE
τ_p	Government: Property tax rate[1]	25%	City Councils
r	Real interest rate	4%	Central Bank of Brazil
v	Capital share in production	0.40	Gollin (2002)
B	Total Factor Productivity	0.746	Normalized such that $w = 1$
$\underline{h}$	Minimum lot size	0.03	55% of average LS
Internal Calibration			
Parameter	Description	Value	Target
η_n	Transportation cost parameter	0,0.14,0.63,0.88,0.94	distribution of individuals
ψ_n	Protection cost parameter	66,39,11,0.27,0	distribution of informal housing
θ	Housing Informality Disutility	0.92	Aggregate share of informal housing
A_F/A_I	Housing production parameters	1.65	Average relative price
$\bar{V}$	Reservation utility	0.11	Average population density

Notes. Eleven parameters were chosen via external calibration. Other parameters were estimated via a distance minimization procedure (internal calibration).

[1] Equivalent to 1% of the housing price in São Paulo.

Table 2: **Results: Model vs Data**

	Total	Area 1	Area 2	Area 3	Area 4	Area 5
Share of informal housing						
Data	9.86%	2.65%	13.50%	14.25%	7.40%	0.00%
Model	9.70%	2.71%	13.55%	14.25%	7.71%	0.00%
Share of individuals						
Data		30.12%	48.41%	20.64%	0.79%	0.04%
Model		30.13%	48.43%	20.65%	0.80%	0.00%
Share of housing						
Data		34.36%	46.30%	18.61%	0.70%	0.03%
Model		35.56%	43.60%	18.61%	2.22%	0.00%
Formal/Informal rent						
Data		1.98	1.54	1.11	1.29	0.00
Model		2.02	1.13	1.01	1.30	0.00
Income per capita						
Data		R$ 2032	R$ 859	R$ 463	R$ 372	R$ 332
Model		R$ 2415	R$ 819	R$ 321	R$ 210	0
Population density						
Data		10880	10339	7395	531	22
Model		11040	10776	8486	736	0

transportation. By and large, policies towards slums are classified under the umbrella of "slum upgrading" interventions. Upgrading projects include a wide range of interventions. Typical interventions include a bundle of land titling, provision of basic infrastructure (e.g., water, electricity, and public lighting), construction of facilities (schools, health posts), and home improvement. In the simulations, we focus on a somewhat broader set of interventions that we split into two categories: apart from slum upgrading interventions, we also study the effects of policies that decrease barriers to formalization. The simulated policies have significant impact on the city so as to interfere with housing prices (our economy-wide outcome) as is typically the case of large-scale interventions. In fact, our simulations highlight the importance of considering general equilibrium effects of programs with universal coverage. In the present analysis, policies on slums impact the housing market of the entire city and thus influence housing prices within the city boundaries. Therefore, one must consider the effect on housing prices when analyzing the impacts from large-scale interventions.

We simulate here three policies (we plan to decompose the effects and implement more policy simulations): reduction in formalization costs, relaxation of urban regulations, and improvements in road networks. Results are presented on table 3. We first discuss the simulation of a reduction of property taxation. The comparative statics point out that this will actually increase the amount of slums dwellers in general equilibrium. The quantitative exercise shows by how much. According to Table 3, a reduction of property tax τ_p by half would increase informal housing by roughly 0.6 percentage point. This unintended consequence is due to a reduction in public infrastructure, which reduces the benefits of formal housing. The second simulation is associated with a relaxation of urban regulations. The intuition is to reduce the "regulation bundle", which means a (concomitant or separate) relaxation of selected building constraints (minimum lot size, height control, frontage, etc). The relaxation of regulation has great impact on reducing slums. A 50% reduction in the "regulation bundle" generates a decline of approximately 20% in the share of slums and effects are stronger in areas away from the business center district. Finally, we reduce uniformly transportation costs in 20%. This has a strong effect on the share of slums, since this share increases by about 40%. This is explained mainly by the inflow of immigrants from rural area to the city. Notice that the share of slums decreases close to the business district but it increases substantially on the areas which are away from the center of the city.

6 Concluding Remarks

Slums are prevalent in many developing country cities and are a critical feature of their landscape. We investigate how slums are formed and how different urban related policies affect the structure of a city. We build a dynamic spatial environment in which agents are heterogenous in their labor productivity and they endogenously choose where and the type of housing mode (formal or informal) they live. We fit the model such that key macro and micro level moments of the city of Sao Paulo in Brazil are matched. We then implement counterfactual exercises to assess the role of urban land use and transportation policies on the city landscape and welfare of their citizens. We show that some policies can have non-trivial effects. For instance, a fall in transportation costs rises the overall efficiency of the city, which attracts more households to the city. Immigration from rural households increases house prices and lead to a substantial rise in slums on the border of the city. We also show that given the land use in a city, slums can be persistent over time even when the city adopts urban policies to foster formal housing.

Table 3: Policy Simulations: Macro Effects

	Data	Baseline	Reducing property tax by half			Reducing minimum lot size by 10%			Reducing transportation in 20%			Increasing average income by 20%		
			(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
G	100	100	55.72	100	55.85	101.52	100	100.43	99.16	100	97.19	120.69	100	119.84
Share of informal housing														
Total	9.86	9.70	7.43	8.10	8.20	7.97	7.96	6.02	15.42	15.43	9.50	10.59	10.18	7.76
Area 1	2.65	2.71	2.03	2.22	2.23	2.15	2.12	1.51	1.88	1.87	0.75	2.80	2.72	2.08
Area 2	13.50	13.55	10.87	11.33	11.38	11.36	11.36	9.56	11.96	11.94	8.21	13.74	13.62	11.90
Area 3	14.25	14.25	10.49	12.01	12.10	12.04	12.04	6.49	17.18	17.21	7.31	15.38	14.92	9.58
Area 4	7.40	7.71	0.00	6.05	8.59	0.00	0.00	0.00	46.98	47.02	27.59	29.93	20.25	0.00
Area 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100	100	100	0.00	0.00	0.00
Share of individuals														
Area 1	30.12	30.13	30.60	30.33	30.31	30.13	30.12	30.76	24.85	24.82	27.27	29.56	29.66	30.55
Area 2	48.41	48.43	48.58	48.22	48.19	48.66	48.68	49.41	40.72	40.49	43.96	47.96	48.19	49.29
Area 3	20.64	20.65	20.40	20.65	20.63	20.72	20.73	19.76	19.60	19.64	19.13	20.77	20.73	19.95
Area 4	0.79	0.80	0.42	0.80	0.88	0.50	0.47	0.07	8.29	8.30	6.36	1.70	1.42	0.21
Area 5	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.56	6.55	3.17	0.00	0.00	0.00
out	62.50	62.51	63.14	62.56	62.50	60.76	60.78	62.50	56.67	56.66	62.50	60.24	60.49	62.50
Share of housing														
Area 1	34.36	35.56	35.79	35.61	35.60	35.83	35.85	36.38	31.93	31.91	32.76	35.42	35.43	35.97
Area 2	46.30	43.60	43.73	43.53	43.50	43.60	43.64	44.17	39.48	39.47	40.30	43.34	43.41	44.02
Area 3	18.61	18.61	18.61	18.64	18.61	18.59	18.60	18.36	18.13	18.16	17.94	18.58	18.55	18.48
Area 4	0.70	2.22	1.86	2.21	2.29	1.98	1.90	1.09	6.54	6.55	6.03	2.66	2.60	1.52
Area 5	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.92	3.91	2.97	0.00	0.00	0.00
Formal/Informal rent														
Area 1	1.98	2.02	2.26	2.19	2.18	2.22	2.22	2.55	2.34	2.34	3.33	2.00	2.01	2.24
Area 2	1.54	1.13	1.24	1.22	1.22	1.22	1.22	1.30	1.19	1.19	1.38	1.13	1.13	1.19
Area 3	1.11	1.01	1.16	1.09	1.08	1.09	1.09	1.41	0.92	0.92	1.35	0.97	0.99	1.20
Area 4	1.29	1.30	1.67	1.42	1.24	1.64	1.62	0.41	0.53	0.53	0.73	0.70	0.84	1.13
Area 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Notes. The table presents four policy simulations. Reduction of formalization costs is a reduction of the parameter η by half. MLS reductions means a reduction of 10% in $\underline{h}$. In the infrastructure upgrading we set θ equals to 1. Titling means reducing the value of the parameter ψ by half.

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A Data Sources and Definitions

The Brazilian Population Censuses (1960 to 2010) and Brazil's National Household Survey (PNAD – Pesquisa Nacional por Amostra de Domicílios) provided the majority of the data used to estimate the model. While the population censuses take place every decade, the PNAD survey is conducted every year (except in the census years). Both the Census and PNAD are carried out by IBGE (Brazilian Bureau of Statistics). The Population Census provides information on total population, rural population, urban population, slums, and slum dwellers. Annual income level and income inequality (measured by the Gini coefficient) stem from PNAD. The price index used to create real income data was the INPC (National Consumer Price Index) from IBGE.

A.1 Slums Data in Brazil

In Brazil, the only nationwide source of city-level slums data is the Brazilian Bureau of Statistics (IBGE) Population Census. The censuses classify whether the housing unit is considered an "aglomerado subnormal" (subnormal agglomeration). "Aglomerados Subnormais" classification includes both irregular and illegal units. The most recent data on slums is from the 2010 Population Census, in which Brazil had 11,425,644 people living in slums (6.01% of the total population). There were 3,224,529 housing units classified as subnormal agglomerations (5.61% of the total housing units). Slum data from the 2010 Census are not directly comparable with that of other censuses because of a methodological change (IBGE (2011)).

An issue with the census data is that they tend to underestimate the real number of slum dwellers in the country: one can see this pattern by verifying the number of slums according to other sources. Another concern is that the local government is in charge of defining whether a housing block is classified as subnormal. Another issue is the definition of a subnormal agglomeration itself as it must contain at least 50 housing units together. Other sources define a slum if two or more housing units lack public services and lack land titling. São Paulo has several small-scale slums (the opposite happens in Rio de Janeiro), and that explains part of the underestimated census numbers for São Paulo. Information on the number of slum dwellers in the municipality of São Paulo shows the evolution of slums as well as the issues regarding the measurement of slums in Brazil. Table 4 shows the number of people in slums in São Paulo according to different sources. In 1973, there were only over 71,000 people living in slums, by 1987 roughly 780,000 people were living in slums, and by 2010 there were almost 1.3 million people in slums.

Table 4: Population living in slums - São Paulo

Source	Year	# Pop. in slums	% Pop. in slums
Cadastro e Censo de Favelas	1973	71,840	1.06%
	1975	117,237	1.60%
	1987	812,764	8.90%
Eletropaulo	1980	594,525	7.00%
FIPE	1993	1,901,892	19,80%
CEM	1991	891,673	9.24%
	2000	1,160,590	11.12%
IBGE Population Census	1980	335,334	4.07%
	1991	711,050	7,46%
	1996	749,318	7,60%
	2000	932,628	8.92%
	2010	1,280,400	11.42%

Notes. "Cadastro and Censo de Favelas" was done by the city council of São Paulo. CEM stands for "Centro de Estudos da Metrópole". In 1996, there was a population count conducted by IBGE.

Table 5: Population in Brazil: 1950-2010

Year	Urban population	Rural population	Total population
1950	36.2%	63.8%	51,944,397
1960	44.7%	55.3%	70,070,457
1970	55.9%	44.1%	93,139,037
1980	67.6%	32.4%	118,562,549
1991	75.6%	24.4%	149,094,266
2000	81.2%	18.8%	171,279,882
2010	84.4%	15.6%	190,755,799

Notes. IBGE, Population Censuses 1950-2010.