Commuting Infrastructure in Fragmented Cities*

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Abstract

Cities are often divided into local governments, each responsible for their local commuting infrastructure used by local residents, workers, and outsiders. This paper examines how metropolitan fragmentation impacts the provision of commuting infrastructure and the spatial distribution of economic activity. I develop a quantitative spatial model in which municipalities compete for residents and workers by investing in commuting infrastructure to maximize net land value within their jurisdictions. In equilibrium, relative to a metropolitan planner, municipalities underinvest in areas near their boundaries and overinvest in areas away from the boundary. Central municipalities tend to underinvest more, as higher commuting costs encourage households to move closer to where they work, thereby increasing land values in central areas. Decentralized investment results in higher cross-jurisdiction commuting costs, dispersed employment, and more polycentric patterns of economic activity. I estimate the model using data from Santiago, Chile, and find substantial gains from centralizing investment decisions. Centralization allocates infrastructure more efficiently and increases aggregate expenditure on infrastructure.

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1 Introduction

Metropolitan areas are politically fragmented: in the OECD, the average city with more than 500,000 people is divided into 74 local municipalities (Brueckner & Selod, 2006). Although some cities coordinate city-wide public transportation services, this cooperation does not extend to all types of transportation infrastructure. Many decisions on local infrastructure, like roads, avenues, and bridges, are made by decentralized municipalities.

Many commuters live and work in different municipalities and, hence, rely on local infrastructure built by other municipalities. For example, in Santiago, Chile, 73% of commuters' trips span across municipalities, and 80% of the typical trip's travel time is spent in municipal infrastructure.[1] Since economic interactions in cities span across municipalities, how does failure to coordinate distort the optimal allocation of commuting infrastructure and aggregate welfare?

In this paper, I study how political decentralization affects the provision of local commuting infrastructure and, consequently, the distribution of population and employment within cities and welfare. To illustrate why decentralized investment decisions by municipalities can be inefficient, let's consider the following example: There are two municipalities, Downtown and Suburb, that make investments to maximize their their land value[2]. Downtown evaluates whether to build a new road to Suburb, expanding the commuting capacity between the two municipalities. The construction of such a road would lead to households adjusting their choices of where to live and work. On the one hand, Downtown could expect a decrease in its residential population as households choose to relocate to Suburb for more affordable housing, resulting in a decline in residential property values in Downtown. On the other hand, the improved connectivity with Suburb would attract more workers to Downtown due to easier commuting, thereby increasing its commercial property values. Downtown's decision to proceed with the road hinges on whether the overall change in land value in its jurisdiction outweighs the road's costs. However, if a hypothetical metropolitan government were to decide whether to build the road, it would consider not only the change in land value in Downtown but also the impact on residential and commercial land values in Suburb.

To formalize this intuition and evaluate the potential losses from decentralization, I develop a quantitative spatial model of the internal structure of a metropolitan area divided into

[1] In the U.S., there is significant commuting across jurisdictions. Monte, Redding, and Rossi-Hansberg (2018) document that in the median county in the year 2000, 39% of commuters work outside the county where they live. Moreover, most roads are municipal, and municipalities are typically smaller geographical units than counties.

[2] Maximizing land value in the model is consistent with maximizing tax revenue or maximizing a weighted sum of the wage-bill of residents and workers.

local municipalities that invest in infrastructure within their jurisdiction to maximize local land value net of building costs. The metropolitan area is embedded in a greater economy, where households choose whether to move into the city. Households also choose where to live and work within the city and commute between these locations through the network of infrastructure built by municipalities. Locations within the metropolitan area are heterogeneous in their productivity, residential amenities, and position within the network.[3] Municipal governments understand that improving infrastructure in a link in the network affects the distribution of residents and employment throughout the city. When deciding whether to invest in infrastructure, municipal governments evaluate whether the investment would result in more or fewer residents and workers in their jurisdiction and how these population shifts would affect its land value. However, municipal governments do not account for the benefits or costs to other jurisdictions.

I compare the equilibrium that arises under decentralized decision-making to the one that would result under a single metropolitan government maximizing total land value net of building costs across the metro area. This comparison yields two key predictions about infrastructure misallocation in the decentralized equilibrium. The first concerns the pattern of investment *within* municipalities, and the second concerns the overall level of investment *across* municipalities.

First, within their jurisdiction, municipalities underinvest in areas near their boundaries where additional infrastructure partly benefits the neighboring jurisdictions through households relocating outside their jurisdiction. A key prediction of the model is that infrastructure declines with proximity to the boundary and changes discontinuously at the boundary. Conversely, municipalities might overinvest in core locations, that is, locations away from the boundary.

Second, whether a municipality's overall level of investment is higher or lower relative to the optimum is a function of its productivity, its residential amenities, and its location relative to their neighboring jurisdictions. Municipalities that are central or more productive underinvest because higher commuting costs encourage households to live closer to their workplaces, which, in turn, drives up residential land values in those areas. Municipalities located on the periphery or with high residential amenities, on the other hand, tend to overinvest. Lower commuting costs allow residents to move farther from work and enjoy lower housing prices and better residential amenities, benefiting residential municipalities.

[3]Productivity, residential amenities, and position within the network are exogenous in the model. The position of a location within the network refers to its placement in the broader metropolitan area; some locations are more central or well-connected than others.

Finally, municipalities located between productive and residential municipalities underinvest the most. This underinvestment arises because, given their relative location to high-wage locations and high-amenity locations, investment in these areas results in the outflow of both workers and residents.

Given this pattern of infrastructure misallocation, decentralization leads to higher commuting costs across municipalities, dispersed employment, and shorter commutes. Employment is less concentrated in productive locations, and households tend to live closer to where they work, resulting in a more polycentric urban pattern. In the aggregate, the metropolitan area has a smaller total population and lower welfare.

To quantify the implications of decentralized infrastructure investment, I focus on Santiago in Chile. Santiago's metropolitan area is divided into 34 municipalities, and each has control over transportation planning within its own boundaries. Aside from transfers, municipalities' two main sources of tax revenue are property taxes and commercial permits.[4] Chile is otherwise a relatively centralized country. For example, the national government provides most public school funding in Chile, and students are not restricted to attending the public school of their municipality of residence. Furthermore, tax rates are uniform across municipalities and established by the national government. These characteristics allow me to focus on differences in commuting infrastructure among local municipalities.

To test the model's key predictions, I start by documenting a significant discontinuity in the density of roads at the border between municipalities. I also show that infrastructure increases with the distance to the border. Both these patterns are consistent with the forces in the model: municipalities' incentives to invest change discontinuously at the border, and the fraction of benefits captured by neighboring municipalities is larger close to the border.

The placement of municipal borders is endogenous. For example, borders might be more likely to be found in areas with higher building costs due to geographic features or may align with man-made structures, contributing to road density patterns. To address this issue, I analyze road density near a subset of borders characterized by smooth geographical features, meaning they do not follow natural landmarks such as rivers or ridges and do not coincide with highways. Moreover, this pattern of road density differences at jurisdictional borders is not specific to Santiago. For instance, Loumeau (2023) observes a similar trend in France, leveraging the geometrically designed borders from the French Revolution to address the problem of endogenous border placement.

[4] In 2012, on average, 41% of municipalities' income came from transfers between municipalities and from the national government. Out of their income raised from local taxes and permits, 37% comes from property taxes, and 39% comes from commercial permits (Bravo Rodríguez, 2014).

I then estimate the model's key parameters. First, following the standard approach in the literature, I use data on commuting flows between residential and work locations and travel time data to estimate the households' commuting parameters and the exogenous location characteristics, that is, productivity and amenities, that match the observed distribution of residents and employment. Second, I exploit the discontinuity in infrastructure at the border between municipalities to estimate the infrastructure elasticity of travel times. The infrastructure elasticity controls how travel times improve as a function of the density of roads in an area. Finally, I use publicly available data on the network of roads and information on travel times to construct the network of links between locations within the city and estimate the baseline infrastructure level in each link.

By assuming that local municipalities maximize aggregate land value within their jurisdiction, the model assumes that municipalities weigh benefits to their residents and benefits to their workers and firms according to the land share of utility and land share of production, respectively. I challenge this assumption and directly estimate the political weights of residents and workers in the data. I exploit the variation in road density at the boundary between municipalities to recover these political weights. Identification of these weights lies on the assumption that building costs are the same across municipality borders, implying that differences in road density are explained by differences in the value perceived by the municipality, captured either in the wage bill of their residents or the wage bill of their workers. Although I recover similar political weights to those implied by the land value objective function, the relative weight on residents is larger. This is consistent with the political context of Santiago, where residents and not workers vote for municipality majors.

With the estimated model, I quantify political decentralization's aggregate and local effects. I examine a counterfactual scenario where a metropolitan planner chooses the infrastructure for Santiago's entire network. The main result from this counterfactual exercise is that centralizing investment decisions would substantially increase investment: expenditure in infrastructure would be 44% to 60% higher, depending on the exact specification for the municipalities' objective function. In response to the new infrastructure, the city would be 1.9% to 2.4% larger in population, and welfare would be 1.4% to 1.7% higher. These results suggest there is aggregate underinvestment in the current fragmented equilibrium.

Importantly, the gains from centralizing are not only about building more but also about allocating the infrastructure more efficiently. To show this result, I consider a counterfactual scenario where a metropolitan planner chooses the infrastructure but is constrained to spending the same aggregate amount as in the decentralized equilibrium. By shifting infrastructure towards the locations that underinvest the most, the constrained metropolitan planner achieves roughly 30% of the aggregate gains in welfare and population from the unconstrained counterfactual without increasing the total amount of investment.

Some municipalities are worse off in the centralized counterfactuals; their aggregate land value net of building cost is lower. These municipalities have lower productivity and residential amenities relative to their neighboring areas. Hence, when infrastructure improvements occur within their jurisdiction, there is an outflow of residents towards the suburbs and workers towards the productive central municipalities. In the centralized equilibrium, these municipalities significantly boost their infrastructure investments, but the advantages largely accrue to their neighboring jurisdictions.

Related literature The benefits and costs of political decentralization have been widely studied, dating back to Tiebout (1956). Decentralization's key benefit is the efficient allocation of local public services in the presence of imperfect information or heterogeneous preferences for public goods (Wallis & Oates, 1988; Oates, 2005). Local governments can have better information about local conditions than central governments, enabling them to tailor services to residents' needs. Moreover, if households have heterogeneous preferences for public goods, they benefit from having a menu of options.[5]

The literature also highlights potential costs associated with decentralization. These include underinvestment when there are spillovers across jurisdictions, uncoordinated public investment, and increasing economic disparities across local governments (OECD, 2019). In order to account for these spillovers across jurisdictions, we usually need a model. Important related papers in this literature using analogous spatial models are Hsiao (2022) and Jannin and Sotura (2020). Hsiao (2022) studies the effect of democratization in healthcare infrastructure and highlights both the benefits and costs: On one hand, democratization reduces corruption through improved electoral accountability. On the other hand, spillover effects are less internalized as districts become more focused on their own constituents. Jannin and Sotura (2020) structurally quantify cross-jurisdiction spillovers from public goods by proposing a quantitative spatial model with jurisdictions, mobile households, and endogenous public good provision and applying it to the setting of French municipalities.

My contribution to this literature is to study decentralization's potential costs in the context of one public good with important economic spillovers: roads. I provide a rich quantitative model that captures the conflicting incentives between the different levels of government and allows me to quantify these costs. Moreover, I study the resulting misallocation of public

[5] Agrawal, Hoyt, and Wilson (2022) provide a great survey of the recent empirical and theoretical literature on local policy choice.

goods from decentralization, in addition to the aggregate welfare costs.

In developing this model, I borrow and contribute to the literature on quantitative spatial economics (Redding & Rossi-Hansberg, 2017). The theoretical framework presented in this paper has two blocks: First, given the infrastructure network, households' and firms' decisions determine the city's spatial equilibrium: where people live and work, wages, and land prices (e.g., Ahlfeldt et al. (2015)). Second, there is an optimal infrastructure block, where local governments choose infrastructure to maximize their land value.

My primary contribution to the literature on spatial economics is in the second block: developing a framework with endogenous commuting infrastructure built by non-cooperative municipalities. Moreover, the provided framework also contributes to the study of optimal commuting networks in spatial equilibrium, even in the case of a single planner.

I build upon recent papers studying optimal transport infrastructure for the trade of goods. Felbermayr and Tarasov (2022) study transportation infrastructure by non-cooperative planners focused on the international and intra-national trade of goods. Their analytical framework is a stylized linear geography with two countries, where they show that decentralizing transportation investments leads to underinvestment, particularly in border regions between countries. Further, Fajgelbaum and Schaal (2020) study optimal transport networks in spatial equilibrium. Their framework considers the complete network structure and is amenable to quantitative exercises.

Allen and Arkolakis (2022) propose a spatial framework with traffic congestion that allows the study of the benefits of infrastructure both in the context of commuting and trade of goods. With their framework, they can characterize the welfare benefits of improving any network segment. I build upon their model and contribute by studying the globally optimal infrastructure network rather than the marginal benefits of each segment.

This paper is inspired by the theoretical literature studying optimal urban structure in a circular city when there are externalities. Rossi-Hansberg (2004) studies the optimal allocation of land to business and residential use in cities with commuting and production externalities. Moreover, Solow (1973), Wheaton (1998), and others study land allocation to roads in models with congestion in commuting times. I contribute to this literature by studying the role of metropolitan political structure, how these political forces result in suboptimal road investment, and how these distortions affect the equilibrium urban structure. Moreover, although I illustrate the model forces with a linear city example, my framework can be applied to more complex network structures.

This project also relates to the large literature studying the impact of transportation infrastructure on economic activity and its spatial distribution—for example, Tsivanidis (2019). Particularly relevant to this paper, Baum-Snow (2007) and Brinkman and Lin (2022) document that highways resulted in central-city population decline, hurting inner cities and benefiting the suburbs. While this literature focuses on the effects of transportation investment on economic activity, it does not study the optimality of the infrastructure itself.

There is a separate literature studying the political economy of transport investment. Brueckner and Selod (2006) examine how the socially optimal transport system compares to the one chosen under the voting process. They show that the voting equilibrium can result in a transportation system that is slower and cheaper than the social optimum. Another example is Glaeser and Ponzetto (2018), which studies how voters' perceptions of different costs of transportation projects can distort the type of project chosen by politicians. Finally, the recent paper by Fajgelbaum et al. (2023) studies how politicians' preferences for redistribution and approval shape transportation policy in the context of California's High-Speed Rail. I contribute to this literature by studying the role of political decentralization relative to centralized infrastructure planning.

Finally, there is empirical evidence that aligns with the predictions of my model. Loumeau (2023) documents significant border effects in commuting flows, using quasi-experimental variation around French borders. The observed discontinuity in commuting flows at the border can be primarily explained by local transport networks not being integrated at these regional borders. He then uses a quantitative spatial model to evaluate the gains of integrating the commuting networks. My paper builds on this important study and contributes by endogenizing these border effects through a model of municipal optimal behavior.

The rest of the paper is organized as follows. Section 2 describes the theoretical framework, where I then illustrate the model's key economic forces using a linear city example. Section 3 describes the empirical context of Santiago, Chile, and discusses how the economic forces outlined in the theory manifest in the data. Section 4 details how I estimate the model's key parameters. Section 5 presents the counterfactual analysis, where I quantify the costs of decentralization by examining a counterfactual scenario involving a centralized Santiago. Section 6 concludes.

2 Model

This section presents the paper's theoretical framework, building closely on the urban model in Allen and Arkolakis (2022). I then introduce a simplified linear city version to illustrate the core economic forces driving the results, and briefly discuss how these insights extend to the full network structure.

2.1 Environment

This section presents a general equilibrium model of a metropolitan area made up of multiple locations. Households choose where to live and work and commute across locations. Local governments invest in commuting infrastructure to maximize land value. The model provides a framework to study how the structure of metropolitan governance, whether centralized or fragmented, shapes the city's equilibrium.

The metropolitan area is composed of J distinct locations, indexed by $j \in \mathcal{J} = \{1, ..., J\}$. Locations are arranged on a directed graph $(\mathcal{J}, \mathcal{E})$, where $\mathcal{E}$ is a set of edges (links) connecting pairs of locations in $\mathcal{J}$. For each location j, there exists a set $\mathcal{N}(j)$ of connected locations. Workers can only commute through connected locations and travel through multiple edges until they reach their destination.

Each location is endowed with a fixed supply of land for residential purposes and a fixed supply of land for production purposes. Furthermore, locations differ in their exogenous productivity and their residential amenities.

The metropolitan area is divided into a finite set of local governments $\mathcal{G}$. A local government g is defined as a set of locations, $\mathcal{J}^g$, and a set of edges, $\mathcal{E}^g$. Local governments only control the commuting infrastructure on the edges within their jurisdiction.

Notation Residential locations are indexed with i and work locations with j. Indices k and ℓ are used to discuss edges that connect location k to location ℓ. Therefore, a commuter will travel from their home location i (origin) to their work location j (destination) through a sequence of edges $k\ell \in \mathcal{E}$.

Variables with a bar, e.g., $\bar{A}_j$, are exogenous in the model. Variables without a bar are endogenous. Greek letters are preference or technology parameters.

2.1.1 Production

Perfectly competitive firms produce a freely traded numeraire good using labor and land with constant returns to scale technology. The output of a firm located in j is given by:

$$Y_j = \bar{A}_j \Big(\frac{L_{Fj}}{\beta}\Big)^{\beta} \Big(\frac{H_{Fj}}{1-\beta}\Big)^{1-\beta}, \tag{1}$$

where $\bar{A}_j$ is the exogenous productivity, L_{Fj} is labor, and H_{Fj} is land. Firms take local productivity and factor prices as given, where w_j is the wage paid in location j and $q_{\mathrm{F}j}$ is the rental price per unit of productive land in location j.

Productive land is in fixed supply, $\bar{H}_{\mathrm{F}j}$, and output in location j has diminishing marginal returns to local labor conditional on land. Hence, more people traveling to work at a location j puts downward pressure on wages in j. Local wages are given by:

$$w_j = \bar{A}_j \Big(\frac{\beta}{1-\beta} \frac{\bar{H}_{\mathrm{F}j}}{L_{Fj}} \Big)^{1-\beta}. \tag{2}$$

2.1.2 Households' preferences

Households are geographically mobile and make three discrete choices to maximize utility. First, they choose whether to live in the metropolitan area or the outside option: other cities in the country or the countryside. Then, conditional on choosing the metropolitan area, they choose where to live and work within the metropolitan area. Finally, they choose a commuting route between their home and work locations.

The preferences of a household ν that lives in the metropolitan area c, resides in location i, works in location j, and commutes via route $r \in \mathcal{R}_{ij}$ are defined over the consumption of the numeraire good, C_{ij}, residential land, H_{ij}, commuting costs, $\tau_{ij,r}$, residential amenities, $\bar{B}_i$, and idiosyncratic preferences, $\epsilon_{cij,r}(\nu)$, according to the Cobb Douglas form:

$$U_{cij,r}(\nu) = \frac{\bar{B}_i}{\tau_{ij,r}} \Big(\frac{C_{ij}}{\alpha} \Big)^{\alpha} \Big(\frac{H_{ij}}{1-\alpha} \Big)^{1-\alpha} \epsilon_{cij,r}(\nu). \tag{3}$$

The commuting cost $\tau_{ij,r}$ is a utility cost of commuting via route $r \in \mathcal{R}_{ij}$, where $\mathcal{R}_{ij}$ is the set of all possible routes between i and j. Households' idiosyncratic preferences are defined over the metropolitan area c, the residence-work pair ij, and the commuting route r, denoted $\epsilon_{cij,r}(\nu)$. These are drawn independently across households according to a Generalized Extreme Value (GEV) distribution:

$$G(\{\epsilon_{cij,r}\}) = \exp\Bigg(- \Bigg[\sum_c \Bigg(\sum_{ij \in \mathcal{J}^2} \Big(\sum_{r \in \mathcal{R}_{ij}} \epsilon_{cij,r}^{-\rho} \Big)^{-\frac{\theta}{\rho}} \Bigg)^{-\frac{\mu}{\theta}} \Bigg] \Bigg), \tag{4}$$

with $\mu < \theta < \rho$. The parameter μ captures the substitutability between the metropolitan area and the outside option, while θ shapes the substitutability across residence-work location pairs within the metropolitan area. The parameter ρ governs the substitutability across commuting routes. The $\mu < \theta < \rho$ condition implies that households can more easily substitute across commuting routes than across neighborhoods or work locations, which is easier than substituting across metropolitan areas.

Workers choose among these options by trading off their idiosyncratic preferences, residential amenities, land prices, $q_{\mathrm{R}i}$, wages, w_j, and commuting costs. Given the preferences specified in equation (3), a household ν that lives in the city c, resides in location i, works in location j, and commutes via route $r \in \mathcal{R}_{ij}$ has the following indirect utility:

$$V_{cij,r}(\nu) = \frac{w_j}{\tau_{ij,r}} \frac{\bar{B}_i}{q_{\mathrm{R}i}^{1-\alpha}} \epsilon_{cij,r}(\nu). \tag{5}$$

The idiosyncratic preference structure in equation (4) results in a nested logit demand system, where the upper nest is across the metropolitan area and the countryside, the middle nest is across residence-work pairs within the metropolitan area, and the lower nest is across commuting routes.[6] Before describing each in more detail, it is helpful to define the following indexes:

$$U \equiv \Big[\sum_{ij} \tau_{ij}^{-\theta} \times \Big(\frac{\bar{B}_i}{q_{\mathrm{R}i}^{1-\alpha}} \Big)^{\theta} \times w_j^{\theta} \Big]^{\frac{1}{\theta}}, \tag{6}$$

$$\tau_{ij} \equiv \Big[\sum_{r \in \mathcal{R}_{ij}} \tau_{ij,r}^{-\rho} \Big]^{-\frac{1}{\rho}}, \tag{7}$$

where U represents the ex-ante expected utility of moving to the metropolitan area, and τ_{ij} represents the ex-ante expected commuting cost between i and j.

Upper nest: City choice Households choose whether to live in the metropolitan area or an outside option. The outside option is not explicitly modeled and is represented by a fixed exogenous utility value, $\bar{U}_o$. The country has a fixed aggregate population, $\bar{L}$, and given households' preference structure, the endogenous total population of the city is given by:

$$L = \frac{U^{\mu}}{U^{\mu} + \bar{U}_o^{\mu}} \bar{L}, \tag{8}$$

where U is given by equation (6) and is the expected utility of choosing to live in the metropolitan area. This model of population supply to the metropolitan area nests a closed-city model ($\mu = 0$) and a fully elastic city model ($\mu = \infty$).

[6] See Train (2009), chapter 4, for a more detailed discussion of the properties of the resulting demand system.

Middle nest: Choice of residence and work location Conditional on choosing to live in the metropolitan area, households choose where to live and where to work by observing amenities, $\bar{B}_i$, land prices, $q_{\mathrm{R}i}$, wages, w_j, and the expected commuting cost, τ_{ij}. We drop the subindex c for simplicity. Given households' preference structure, the number of households that choose the residence-work pair ij is given by:

$$L_{ij} = \tau_{ij}^{-\theta} \Big(\frac{\bar{B}_i}{q_{\mathrm{R}i}^{1-\alpha}} \Big)^{\theta} w_j^{\theta} \frac{L}{U^{\theta}}. \tag{9}$$

Local labor supply is increasing in the nominal wage w_j. Likewise, when there are better rent-adjusted amenities $(\frac{B_i}{q_{\mathrm{R}i}^{1-\alpha}})$, more households opt to reside in that location. On the other hand, higher commuting costs result in fewer households selecting the ij option. Moreover, the number of people choosing ij is a function of two endogenous aggregate variables: the expected utility of the city, U, and the total population of the city, L.

Lower nest: Routing Households choose their commuting route $r \in \mathcal{R}_{ij}$. A route r is defined as a sequence of edges in the network. I will start by describing how I model the costs of traveling through an individual edge, $k\ell$, where $\ell \in \mathcal{N}(k)$. Let $d_{k\ell}$ be the utility cost of traveling through the edge $k\ell$, given by:

$$d_{k\ell} = \exp\Big(\kappa \times \mathrm{time}_{k\ell}\Big), \quad \text{with } \mathrm{time}_{k\ell} = \bar{t}^0_{k\ell} + \bar{t}^1_{k\ell} \frac{Q^{\sigma}_{k\ell}}{\mathrm{I}^{\xi}_{k\ell}}. \tag{10}$$

Commuting costs are an exponential function of travel time, as in Ahlfeldt et al. (2015), where κ controls the disutility from commuting; a larger κ means that households strongly dislike commuting. Travel time is a function of some exogenous edge characteristics, denoted by $\bar{t}^0_{k\ell}$ and $\bar{t}^1_{k\ell}$[7]. For example, the slope of the terrain might make traveling through the edge slower. Travel time is increasing in the traffic flows, $Q_{k\ell}$, with a congestion elasticity σ, and decreasing in the level of infrastructure on the edge, $\mathrm{I}_{k\ell}$, with elasticity ξ. Traffic flows, $Q_{k\ell}$, and infrastructure investment, $\mathrm{I}_{k\ell}$, are endogenous outcomes resulting from the decisions of commuters and the local governments, respectively.

The total cost of traveling through a given route $r \in \mathcal{R}_{ij}$ is a function of the edge-level commuting costs and is given by:

$$\tau_{ij,r} = \prod_{k\ell \in r} d_{k\ell}. \tag{11}$$

[7]There is a minimum time needed to travel through (k, ℓ), $\bar{t}^0_{k\ell}$, which ensures that, even if there is no traffic flows, there is a maximum speed at which commuters can travel through an edge

Given households' preference structure for routes, we can derive the equilibrium expected commuting cost between i and j as a function of edge-level commuting costs, represented as a matrix. Following Allen and Arkolakis (2022), we can rewrite equation(7) as:

$$\tau = \left((\mathbf{I} - \mathbf{A})^{-1}\right)^{-\frac{1}{\rho}} \tag{12}$$

where $\mathbf{A} \equiv \left[d_{k\ell}^{-\rho}\right]$ is a matrix where the (k, ℓ) element is $d_{k\ell}^{-\rho}$. The resulting τ from equation (12) is a matrix where the (i, j) element is the expected bilateral commuting costs, τ_{ij}.

From this routing framework, we can derive helpful results that simplify the computation and study of the equilibrium. First, we define *link intensity* as the expected number of times in which the edge $k\ell$ is used by households that live in i and work in j, and is given by:

$$\pi_{ij}^{k\ell} \equiv \left(\frac{\tau_{ij}}{\tau_{ik} d_{k\ell} \tau_{\ell j}}\right)^{\rho}. \tag{13}$$

The intensity with which households of pair ij use the edge $k\ell$ is a function of the ratio between the expected cost between i and j, and the expected cost of traveling from i to the beginning of the edge, k, then through the edge, and then from ℓ to the destination j. Therefore, the more inconvenient the edge $k\ell$ is for households living in i and working in j, the fewer people use it.

Second, we can use this framework to describe the equilibrium traffic flows in the network. The total number of commuters flowing through edge $k\ell$ is a function of the number of households living in every pair ij in the metropolitan area and the link intensity given by equation (13) according to:

$$Q_{k\ell} = \sum_{ij} L_{ij} \pi_{ij}^{k\ell}. \tag{14}$$

This expression illustrates the benefit of introducing idiosyncratic preferences over commuting routes. Suppose we did not have idiosyncratic preferences over routes and instead had households choose the least-cost route. Then, when improving one edge in the network, we would have to re-compute the set of origins and destinations that use that edge. By smoothing the problem with this routing framework developed in Allen and Arkolakis (2022), the problem becomes more computationally tractable.

2.1.3 Land Market Clearing

In each location, there is a fixed supply of land for residential purposes, $\bar{H}_{\mathrm{R}i}$, and for productive purposes, $\bar{H}_{\mathrm{F}i}$. This implies two distinct land prices per location since agents cannot arbitrage across uses.

First, in the residential land market, we can derive the equilibrium rental price by equating the supply and demand of land:

$$q_{\mathrm{R}i} = \frac{1-\alpha}{\bar{H}_{\mathrm{R}i}} \sum_j L_{ij} w_j. \tag{15}$$

Similarly, for the commercial land market, we can equate the fixed land supply to firms' demand for land. As it will become clear in the following section, it is helpful to express the equilibrium commercial land value as a function of the wage bill:

$$q_{\mathrm{F}i} = \frac{1-\beta}{\beta} \frac{1}{\bar{H}_{\mathrm{F}i}} \sum_i L_{ij} w_j. \tag{16}$$

The price of residential land increases with the number of residents in a location, and the price of commercial land increases with the number of workers in a location. Improved commuting infrastructure increases market access, attracting residents and workers and, therefore, increasing land values.

2.1.4 Local Governments' Problem

There are G local governments. A local government $g \in \mathcal{G}$ is defined by a set of nodes $\mathcal{J}^g$ and a set of edges $\mathcal{E}^g$ under its jurisdiction. A government g chooses the infrastructure allocation I_{ij} for $ij \in \mathcal{E}^g$, according to:

$$\begin{aligned} \max_{\mathrm{I}_{ij} \in \mathcal{E}^g} \pi^g &\equiv \sum_{i \in \mathcal{J}^g} \{ q_{\mathrm{R}i} \bar{H}_{\mathrm{R}i} + q_{\mathrm{F}i} \bar{H}_{\mathrm{F}i} \} - \sum_{k\ell \in \mathcal{E}^g} \delta^{\mathrm{I}}_{k\ell} \mathrm{I}_{k\ell} \\ &= \sum_{ij} \left\{ \mathbb{1}[i \in \mathcal{J}^g] \underbrace{(1-\alpha)}_{\equiv \omega_{\mathrm{R}}} L_{ij} w_j + \mathbb{1}[j \in \mathcal{J}^g] \underbrace{\frac{1-\beta}{\beta}}_{\equiv \omega_{\mathrm{F}}} L_{ij} w_j \right\} - \sum_{k\ell \in \mathcal{E}^g} \delta^{\mathrm{I}}_{k\ell} \mathrm{I}_{k\ell}, \end{aligned} \tag{17}$$

subject to:

(i) expected utility, given by equation (6),

(ii) aggregate population, given by equation (8),

(iii) travel demand, given by the equilibrium number of households in ij in equation (9),

(iv) residential land market clearing, given by equation (15),

(v) wages, given by equation (2),

(vi) equilibrium traffic flows, given by equation (14),

(vii) bilateral commuting cost index, given by equation (12),

(viii) edge-level commuting costs, given by equation (10),

where $\delta^{\mathrm{I}}_{k\ell}$ is the building cost in the edge $k\ell$.

Municipalities maximize their economic surplus, defined as their aggregate land value, net of the building costs of building and maintaining the infrastructure, subject to the city's equilibrium given by households and firms' decisions.[8]

Municipalities weigh building costs against the perceived economic benefits of infrastructure, reflected in residential and commercial land values. The assumption that governments maximize aggregate land value has a long tradition in urban economics, as seen in Kanemoto (1977), Wheaton (1998), and Rossi-Hansberg (2004), among others. This approach is grounded in the idea that, under conditions like perfect household mobility, the welfare gains from local public goods are fully capitalized into land values (Stiglitz, 1977; Starrett, 1981). Using equations (15) and (16), we can rewrite the objective function as a weighted sum of residents' and workers' wage bills. Thus, by assuming municipalities maximize land value, I implicitly assume specific political weights: residents' wage bill is weighted by $\omega_{\mathrm{R}} = (1-\alpha)$ and workers' wage bill by $\omega_{\mathrm{F}} = (1-\beta)/\beta$.

Hence, this framework allows for more flexible objective functions.[9] For example, if the weights reflect tax rates, the objective becomes equivalent to maximizing tax revenue net of building costs. Specifically, if $\omega_{\mathrm{R}} = (1-\alpha)\tau_{\mathrm{P}}$, where τ_{P} is the property tax rate, and $\omega_{\mathrm{F}} = \tau_{\mathrm{W}}$, the income tax rate, then local governments maximize total tax revenue from residents' property taxes and workers' income taxes. Moreover, I also compare this objective to traditional welfare-based functions in the linear geography example.

The local government maximizes this objective subject to the implementability constraints, that is, internalizing how prices and quantities from the competitive equilibrium change as a function of the infrastructure. Finally, governments take the infrastructure investments of other governments, $\mathrm{I}_{k\ell}$ for $(k\ell) \in \mathcal{E}^{g'}$, as given. I focus on the Nash equilibrium: every

[8]Note that I model municipalities more as firms maximizing profits subject to demand than more standard models of governments, where governments maximize some social function subject to a budget constraint. In this setting, where decentralization might lead to overall under or over-investment, I allow total expenditure on roads to change. One way I like to think about this model is that the land value is the total tax revenue, and governments spend some fraction of this tax revenue on roads. Given this model, municipalities will only spend on improving roads if the increase in tax revenue derived from improving roads is larger than the expenditure.

[9]In the model quantification, I estimate these political weights directly from the data and compare counterfactual results under both objective functions.

municipality chooses its optimal infrastructure conditional on the infrastructure chosen by the other governments in the metropolitan area.

Centralized Planner (Metropolitan) I compare the decentralized (uncoordinated) equilibrium, where each municipality optimizes the objective described in equation (17), to the centralized equilibrium, where a metropolitan planner chooses the infrastructure that maximizes aggregate land value net of building costs for the entire city. This implies that the metropolitan planner internalizes the full benefits and costs of its investments.

Note that this framework doesn't account for metropolitan planners' shortcomings, such as information frictions, corruption, etc. Rather, I use the metropolitan planner as a point of reference to study the misallocation that arises from non-cooperative planning.

2.1.5 Equilibrium

Given the model's parameters, $\{\alpha, \beta, \theta, \rho, \mu, \kappa, \sigma, \xi\}$, the reservation utility of the economy, $\bar{U}_o$, the total population of the country, $\bar{L}$, and the exogenous location characteristics $\{\bar{A}_i, \bar{B}_i, \bar{H}_{\mathrm{R}i}, \bar{H}_{\mathrm{F}i}, \bar{t}^0_{k\ell}, \bar{t}^1_{k\ell}\}$, an equilibrium of the model satisfies the following nine sets of equations: households maximize utility (8 and 9), labor markets clear (2), land markets clear (15 and 16), traffic equilibrium holds (10, 12, and 14), governments maximize their land value net of building costs (17).

Note that governments own the land in this model. Local governments capture all the land value, pay for roads, and consume the remaining land value in the numeraire good. An alternative assumption is that the remaining land value is transferred back to residents as a wage subsidy. Appendix A.4.2 discusses this alternative model. All the results and forces described in the following section hold under this alternative model; however, the distortions from decentralization are amplified.

2.2 Illustrative Example: Linear City

This section illustrates the model's trade-offs using the simpler case of a linear geography.

Suppose the metropolitan area is a finite number of locations arranged in a line, where locations are indexed by the distance to the start of the line, x. Every location in the metropolitan area has equal amounts of land for production and housing and the same residential amenities. The only differences across locations are their exogenous productivity, $\bar{A}_x$, location in the network, x, and local government $g(x)$.

As an illustrative example, I study a metropolitan area where productivity is high at $x = 0$ and declines with distance. The metropolitan area is divided into two local municipalities: Downtown and Suburb. I illustrate this city in Figure 1. The red line represents the productivity for each location, and the dashed line is the boundary between the two municipalities. Amenities are the same everywhere and are represented by the green line. We can think of this metropolitan area as N locations on a road. The vertical dashed line signifies the boundary between the municipalities; half of the locations and the road are under the jurisdiction of one municipality, and the other half are under the jurisdiction of another. Municipalities invest in infrastructure and increase the width or quality of the road within their jurisdiction.

Figure 1: Linear city

Note: There are 100 locations for this example ($N = 100$).

For this example and every figure in this section, I chose the parameter values in Table A.1. I use the same parameter value as the estimated in the model quantification whenever possible. Importantly, in this example, municipalities maximize land value. Given the value in Table A.1, the implied political weights for residents and workers are the same: $\omega_{\mathrm{R}} = \omega_{\mathrm{F}} = 0.25$.

The only difference between this setting and the model outlined in the previous section is the routing problem. I simplify the households' routing decisions by assuming everyone takes the shortest path, that is, the straight line between the origin and the destination. This effectively removes the lower nest of the households' decisions. The equations that change given this simplification are the commuting costs and traffic flows:

$$\tau_{ij} = \prod_{k\ell} \mathbb{1}_{ij}^{k\ell} d_{k\ell}, \quad Q_{k\ell} = \sum_{ij} L_{ij} \mathbb{1}_{ij}^{k\ell},$$

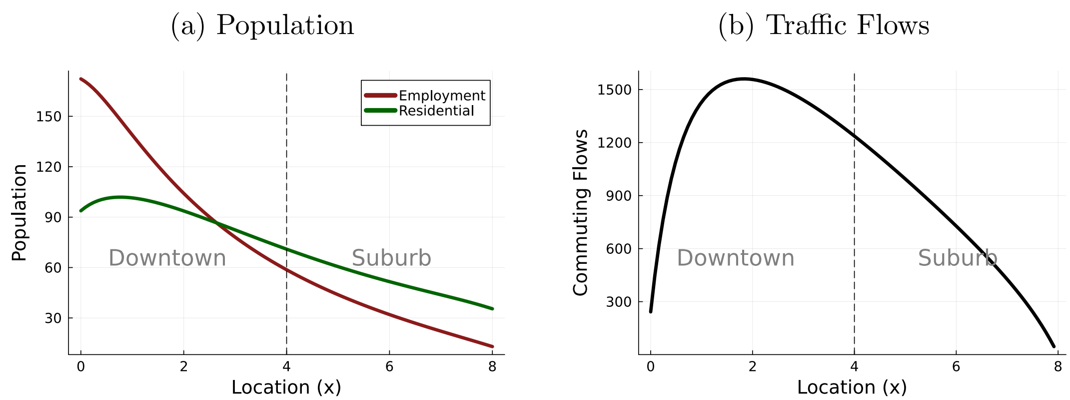
where $\mathbb{1}_{ij}^{k\ell}$ is an indicator function that takes the value 1 when the origin-destination ij uses the edge $k\ell$, and value 0 otherwise.[10]

Before shifting our attention to the optimal infrastructure in this linear city, describing the city's equilibrium for some fixed infrastructure level is helpful. Figure 2 shows the equilibrium population and traffic flows given some positive and uniform level of infrastructure

[10]The origin-destination ij will use the edge $k\ell$ if $i \leq k$ and $j \geq \ell$ or if $i \geq k$ and $j \leq k$.

everywhere in the line, $\mathrm{I}_{k\ell} = C$ for all $k\ell$. In equilibrium, employment is high in locations close to $x = 0$, where productivity is high. Even though residential amenities are the same everywhere, the residential population is also higher in downtown locations because of better access to jobs.[11] Net commuting flows to work travel towards $x = 0$. However, there are commuting flows in both directions, given the idiosyncratic preference shocks.

Figure 2: Equilibrium given constant $\mathrm{I}_{k\ell}$



Note: Commuters travel in both directions because of the idiosyncratic preference shocks for origin-destination pairs. Panel (b) plots the total commuting flows, the sum over both directions. However, most commuters travel towards $x = 0$, where wages are higher.

2.2.1 Optimal Infrastructure

In this stylized city example, I describe how decentralization distorts the distribution of commuting infrastructure. From the local governments' problem defined in Section 2.1.4, we solve for the optimal infrastructure, derived from equating the marginal value to the marginal cost of infrastructure:

$$\delta^{\mathrm{I}}_{k\ell} = \phi^{g}_{k\ell} \times \frac{\partial d_{k\ell}}{\partial \mathrm{I}_{k\ell}} / \frac{\partial d_{k\ell}}{\partial Q_{k\ell}} \implies \mathrm{I}^{g}_{k\ell} = -\frac{\xi}{\sigma} \frac{\phi^{g}_{k\ell} Q_{k\ell}}{\delta^{\mathrm{I}}_{k\ell}}, \tag{18}$$

where $\phi^{g}_{k\ell}$ is the Lagrange multiplier of constraint (14). This Lagrange multiplier is the marginal land value captured by the government g of an additional commuter in edge $k\ell$, given by the following equation:

$$-\phi^{g}_{k\ell} = \frac{\partial d_{k\ell}}{\partial Q_{k\ell}} \times \sum_{ij} -\lambda^{g}_{ij} \frac{\partial L_{ij}}{\partial d_{k\ell}}.$$

[11]Residential population declines slightly at $x = 0$ because there is nothing on the other side, so market access to jobs is better for $x \approx 0.5$ than exactly at $x = 0$.

First, additional commuters generate congestion externalities, increasing travel times for everyone using the link. Second, we have the indirect effects of changing travel times derived from the reorganization of economic activity in the city. Changing travel time in one edge, $d_{k\ell}$, will affect where people live and work. The Lagrange multiplier λ_{ij}^{g} is the multiplier on the travel demand constraint in equation (9), and it represents the marginal value for government g of an increase in L_{ij}.

The value of reorganizing economic activity in the city and how the different governments capture it summarizes the main equilibrium forces of the model. To provide some insight into how local governments capture only fractions of the benefits and costs from their investments, I group the equilibrium forces into three groups: residential force, employment force, and congestion force, as the following:

$$\begin{aligned}\sum_{ij} -\lambda_{ij}^{g}\frac{\partial L_{ij}}{\partial d_{k\ell}} = & \underbrace{-\sum_{ij}\left(\omega_{\mathrm{R}}\mathbb{1}_{i}^{g} w_j + \eta_{\mathrm{R}i}^{g}\frac{\partial q_{\mathrm{R}i}}{\partial L_{ij}}\right)\frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Residential Force: } \equiv Q_{\mathrm{R}k\ell}^{g}} \underbrace{-\sum_{ij}\left(\omega_{\mathrm{F}}\mathbb{1}_{j}^{g} w_j + \eta_{\mathrm{F}j}^{g}\frac{\partial w_j}{\partial L_{ij}}\right)\frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Employment Force: } \equiv Q_{\mathrm{F}k\ell}^{g}} + \\ & \underbrace{\sum_{ij}\sum_{rs} -\phi_{rs}^{g}\frac{\partial Q_{rs}}{\partial L_{ij}}\frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Congestion Force: } \equiv Q_{\mathrm{C}k\ell}^{g}}.\end{aligned} \tag{19}$$

where $\mathbb{1}_{i}^{g} = \mathbb{1}[i \in \mathcal{J}^{g}]$.

At this point, defining the edge-level commuting elasticity of travel demand is helpful.[12] That is, the percentage change in the number of households living in i and working in j divided by the percentage reduction on the edge-level commuting cost, $d_{k\ell}$:

$$\varepsilon_{ij}^{k\ell} \equiv -\frac{\partial L_{ij}}{\partial d_{k\ell}} \times \frac{d_{k\ell}}{L_{ij}} = \theta\mathbb{1}_{ij}^{k\ell} - \frac{Q_{k\ell}}{L}\Big(\theta - \varepsilon_{L}\Big). \tag{20}$$

where ε_L is the elasticity of the aggregate metropolitan populations with respect to the ex-ante expected utility level, U[13]. The first term, $\theta\mathbb{1}_{ij}^{k\ell}$, is the direct effect. If the origin-destination ij uses the edge $k\ell$, then the commuting elasticity of travel demand is θ. The second term is the indirect effect. It arises from how changes to $d_{k\ell}$ affect the aggregate variables: the ex-ante expected utility of moving to the city, U, and the aggregate population of

[12]For a detailed derivation of this elasticity, see Appendix A.4.1.

[13]This elasticity is given by:

$$\varepsilon_L \equiv \frac{\partial L}{\partial U} \times \frac{U}{L} = \mu\left(1 - \frac{L}{\bar{L}}\right) > 0.$$

the city, L. Even for ij pairs that do not use the edge $k\ell$, travel demand changes because the denominator in equation (9) changes, and the aggregate population of the city, L, changes.

Note that the commuting elasticity of travel demand in equation (20) shows how by lowering the edge-level commuting costs, $d_{k\ell}$, municipalities can shift population away from origin-destination pairs that do not use the edge ($1_{ij}^{k\ell} = 0$) towards origin-destination pairs that do use it ($1_{ij}^{k\ell} = 1$). Their ability to move people away from locations that do not use the pair is increasing with the commuting flows, $Q_{k\ell}$. Hence, municipalities that control important edges, with large equilibrium commuting flows, have a higher ability to shift population throughout the city with their investments.

Residential and Employment Forces First, the residential force, $Q^g_{\mathrm{R}k\ell}$, corresponds to all the changes to residential value throughout the city from an improvement in the edge-level commuting cost $d_{k\ell}$, valued by the government g:

$$Q^g_{\mathrm{R}k\ell} = \sum_{ij} \left(\omega_{\mathrm{R}} \mathbb{1}^g_i w_j + \eta^g_{\mathrm{R}i} \frac{1-\alpha}{\bar{H}_{\mathrm{R}i}} w_j \right) \frac{L_{ij}}{d_{k\ell}} \varepsilon^{k\ell}_{ij}. \tag{21}$$

This force captures how governments value the changes in travel demand at their origin, that is, in the residential locations. Municipalities will value these changes in residential population, induced by changes to the commuting cost of edge $k\ell$, according to the terms in the parenthesis. First, they will value an increase in residential population directly if the residential location is within their jurisdiction, weighted by both the political residential weight, ω_{R} and the wage, w_j. Second, they internalize how a change in residential population will affect residential land prices and value these according to the multiplier $\eta_{\mathrm{R}i}$; the Lagrange multiplier of constraint (15). Note that governments internalize how changes in residential land prices affect their objective function, even when these changes are outside their jurisdiction. For example, they might benefit from an increase in housing prices in the neighboring municipality if that pushes residents to move to their locations or increases the market access to workers of their firms.

I name the second term in equation (19) employment force, $Q^g_{\mathrm{F}k\ell}$, which is the total employment value throughout the city from an improvement in the edge-level commuting cost $d_{k\ell}$, valued by government g. In the same spirit as in the residential force, this force captures how government g values changes in travel demand at their destination, that is, at the work locations:

$$Q^g_{\mathrm{F}k\ell} = \sum_{ij} \left(\omega_{\mathrm{F}} \mathbb{1}^g_j w_j - \eta^g_{\mathrm{F}i} \frac{1-\beta}{L_{\mathrm{F}j}} w_j \right) \frac{L_{ij}}{d_{k\ell}} \varepsilon^{k\ell}_{ij}. \tag{22}$$

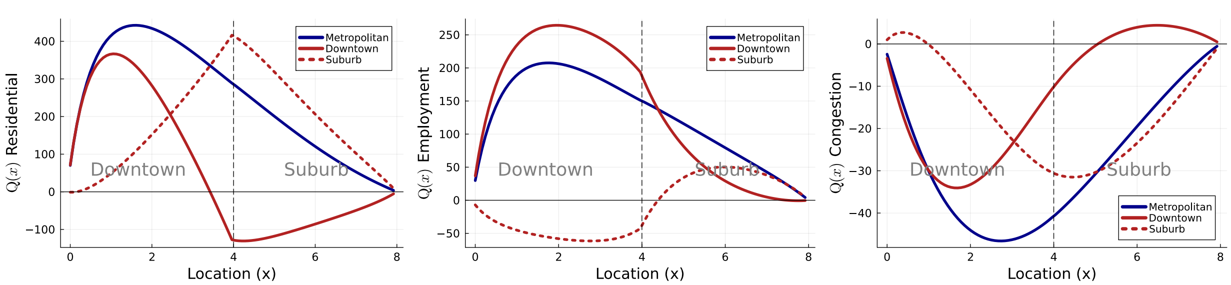
Governments value attracting workers to a location according to the term in the parenthesis. First, they will value directly an additional worker if the location is within their jurisdiction. Second, they internalize how a change in labor supply affects wages, which they value according to the Lagrange multiplier $\eta^g_{\mathrm{F}j}$. As in the residential force, municipalities internalize how changes to wages everywhere in the city will affect their objective function. For instance, an increase in labor supply outside their jurisdiction will depress wages, which will feed back to their residents who work in this location.

Equations (21) and (22) highlight how governments internalize both effects in locations within their jurisdiction and effects outside their jurisdiction through the spatial linkages given by population mobility and commuting. The multipliers ($\eta_{\mathrm{R}i}$ and $\eta_{\mathrm{F}j}$) can be positive or negative, depending on whether a price change in the location will increase or reduce the municipality's total land value.

Figure 3 shows the residential and employment forces from the perspective of the three governments. The blue lines represent the perspective of the metropolitan government, and the red lines represent the perspective of Downtown (solid) and Suburb (dotted). For example, for the residential force, the blue line represents the full residential land value derived from a marginal investment in the roads in that location. Then, the red lines are the residential force from the perspective of Downtown (solid) and Suburb (dotted). These lines sum up to the blue line: They represent how the residential value is divided between municipalities.

Figure 3: Residential, employment, and congestion values captured by local governments

(a) Residential force (b) Employment force (c) Congestion force



First, let's focus on the residential flows in Figure 3(a). On Downtown's side, investment in edges closer to the boundary mostly benefits commuters who reside in Suburb. Further, better infrastructure induces residents to move towards the periphery and enjoy lower residential land prices. This implies that, for most edges, Downtown only captures a small fraction of the residential land value gains as the distribution of residents shifts towards the periphery. Moreover, Downtown's residential force is negative at the boundary, implying that Downtown is losing residential land value by investing in these locations.

On the other hand, in suburban locations, the residential force is larger for Suburb than the metropolitan government. Suburb gains residents at the expense of Downtown's locations. The metropolitan planner, by contrast, internalizes that the increase in land value comes partly at the cost of reducing land value in other locations.

Consider the employment flows in Figure 3(b). In this case, most employment is concentrated in central locations, and better infrastructure allows for a shift towards more productive locations in the city's center. This implies the opposite pattern for the employment flows: Downtown gains commercial land value at the expense of commercial land value in suburban locations.

Congestion Force The third component in equation 19 is the congestion force, $Q^g_{Ck\ell}$, which captures the congestion costs associated with reshuffling traffic flows in the network and population growth of the city, as valued by the government g. Municipalities internalize how changes in $d_{k\ell}$ might divert traffic flows to their edges or away from their edges. These changes are valued according to the Lagrange multiplier ϕ^g_{rs}, associated with the constraint (14). The Lagrange multiplier captures how more traffic flows reduce land value for government g through travel time congestion for their residents and workers.

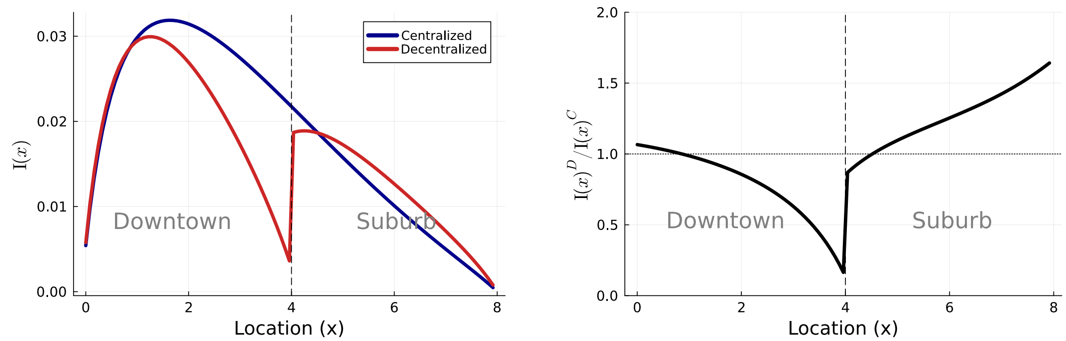
$$Q^g_{Ck\ell} = \sum_{ij} \left(\sum_{mn} \phi^g_{mn} \mathbb{1}^{mn}_{ij} \right) \frac{L_{ij}}{d_{k\ell}} \varepsilon^{k\ell}_{ij} \tag{23}$$

Figure 3(c) shows the congestion force from the perspective of the three governments. Investment in one edge might increase congestion for other municipalities, in which case the local government will internalize only a fraction of this cost. That is the case closer to the boundary, where the red lines are less negative than the blue line. On the other hand, investment might alleviate traffic in other municipalities, in which case the local government will internalize a higher cost than the metropolitan planner. That is the case for core locations around $x = 0$ and $x = 8$, where traffic flows are pushed inside the controlling municipality, alleviating traffic in the neighboring municipality.

Equilibrium Infrastructure Figure 4(a) shows the optimal infrastructure function for the centralized metropolitan planner (in blue) and for the decentralized equilibrium where each municipality chooses its investments (in red). Figure 4(b) shows the ratio of the decentralized infrastructure to the optimal metropolitan infrastructure. Values below one indicate underinvestment, and values above one indicate overinvestment. For this set of parameters, in equilibrium, local governments underinvest close to the boundary and overinvest away from the boundary. Further, if we look at the aggregate investment by municipality, defined as the sum of infrastructure across locations, Downtown underinvests overall, and Suburb overinvests.

Figure 4: Decentralized vs Centralized Infrastructure

(a) Optimal Infrastructure (b) Relative Infrastructure: I^g/I^*



This example illustrates the two main predictions of the model. First, the distortions *within* each municipality: Within a given municipality, relative to a metropolitan planner, local governments underinvest near the boundary and overinvest at their core locations. Second, we have the *level* distortions across municipalities: Taking the total investment at the municipality level, Downtown underinvests, and Surburb overinvests.

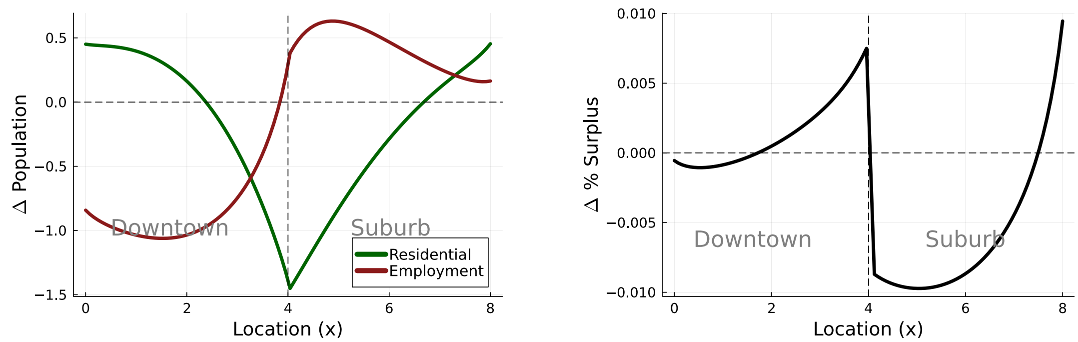
This second prediction about total investment across municipalities depends crucially on a couple of ingredients. First is the city's geography: municipalities' location in the network, productivity, and amenities. The comparative advantage of the different municipalities shapes their ability to attract residents or workers. Second is the relative size of the residential force relative to the employment force, that is, the value of attracting a resident relative to a worker. Note that in this example, the political weights of residents and workers are equal. However, the residential force still dominates. Partly, this is because additional labor supply depresses wages, decreasing the municipality's objective function. In a way, it is more "expensive" for municipalities to attract workers than residents.

City Structure Let us now shift our attention to the effects of decentralization on the city's equilibrium: where people live and work and the prices across these locations.

Figure 5(a) shows the change in the population distribution of both residents and workers. The residential population hollows out, shifting away from the border between municipalities where there is less infrastructure. Employment shifts towards the periphery and is less concentrated in downtown areas relative to the centralized equilibrium. Hence, decentralization makes cities less specialized, with a more mixed distribution of residents and employment. This is because municipalities underinvest near the boundaries, which results in higher cross-municipality commuting costs and the dispersal of employment across municipalities. Hence, the urban pattern is more polycentric in the decentralized equilibrium. Residents live closer to where they work, leading to shorter commutes. The shorter commutes and lower aggregate population make traffic flows smaller overall.

Figure 5: Changes to the city's equilibrium

(a) Δ in population (b) Δ in surplus



Note: The changes above compare the decentralized equilibrium relative to the centralized (metropolitan) one.

Figure 5(b) shows the percentage change of surplus across locations, where surplus is defined as land value minus building costs. Surplus losses are concentrated in Suburb. In this example, Downtown gains surplus at the expense of Suburb. Downtown benefits from decentralization, as it captures a larger share of the economic activity of the metropolitan area by increasing commuting costs and increasing the value of its comparative advantage for employment.

2.2.2 Discussion

This section discusses key assumptions of the model and features of the Nash equilibrium between municipalities, focusing in particular on the governments' objective function and the uniqueness of the equilibrium.

Objective function The model assumes that governments aim to maximize land value, or more broadly, a weighted sum of the wage bill of residents and workers. How does this compare to more traditional welfare-based objective functions?

We can modify the objective function in Equation (17) to instead reflect total welfare, expressed as:

$$\max_{\mathrm{I}ij \in \mathcal{E}^g} \pi = \sum ij \left\{ \mathbb{1}[i \in \mathcal{J}^g] \; \omega_{\mathrm{R}} L_{ij} U + \mathbb{1}[j \in \mathcal{J}^g] \omega_{\mathrm{F}} L_{ij} U \right\} - \sum_{k\ell \in \mathcal{E}^g} \delta^{\mathrm{I}}_{k\ell} \mathrm{I}_{k\ell}. \tag{24}$$

Under this specification, governments not only compete for residents and workers but also directly value the ex-ante utility.[14]

Another option is for governments to maximize total *real* wage rather than nominal wage bills. In this case, governments factor in the impact of infrastructure on residential land prices, local amenities, and commuting costs—not just on population and wages.[15] This amounts to maximizing total resident and worker' utility net of the idiosyncratic preference shock:

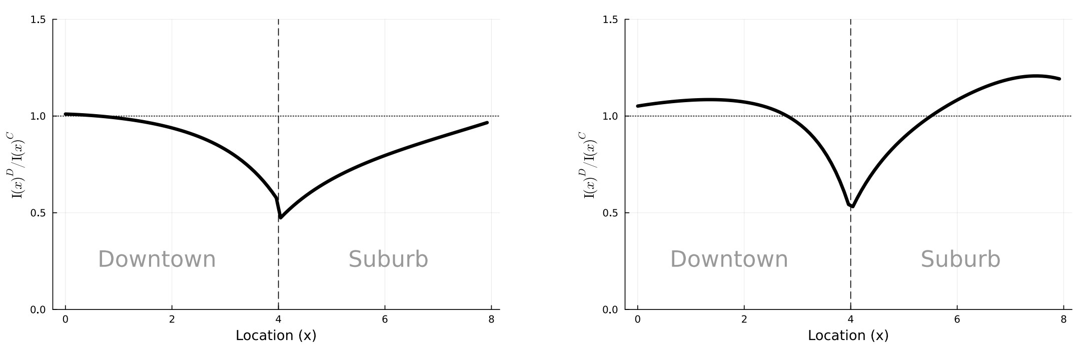
$$\max_{\mathrm{I}ij \in \mathcal{E}^g} \pi = \sum ij \left\{ \mathbb{1}[i \in \mathcal{J}^g] \; \omega_{\mathrm{R}} L_{ij} \frac{w_j \bar{B} i}{q\mathrm{R} i \tau_{ij}} + \mathbb{1}[j \in \mathcal{J}^g] \omega_{\mathrm{F}} L_{ij} \frac{w_j \bar{B} i}{q\mathrm{R} i \tau_{ij}} \right\} - \sum_{k\ell \in \mathcal{E}^g} \delta^{\mathrm{I}}_{k\ell} \mathrm{I}_{k\ell}. \tag{25}$$

Figure 7 illustrates the ratio of decentralized to optimal metropolitan infrastructure under both alternative objective functions. These results can be compared with the baseline findings shown in Figure 4(b).

Figure 6: Relative infrastructure under alternative objectives ($\omega_{\mathrm{R}} = \omega_{\mathrm{F}}$)

(a) Total Welfare

(b) Total Real Wages



These simulations use equal political weights for residents and workers, $\omega_{\mathrm{R}} = \omega_{\mathrm{F}}$. One key qualitative pattern persists: infrastructure investment declines near the municipal boundary.

[14]Note that if, alternatively, governments maximized utility itself ($\max U$), the decentralized equilibrium would coincide with the centralized planner's solution, eliminating any distortion from decentralization.

[15]Note that by maximizing the wage bill of residents and workers, governments already partially internalize residential costs and commuting costs through their effect on population.

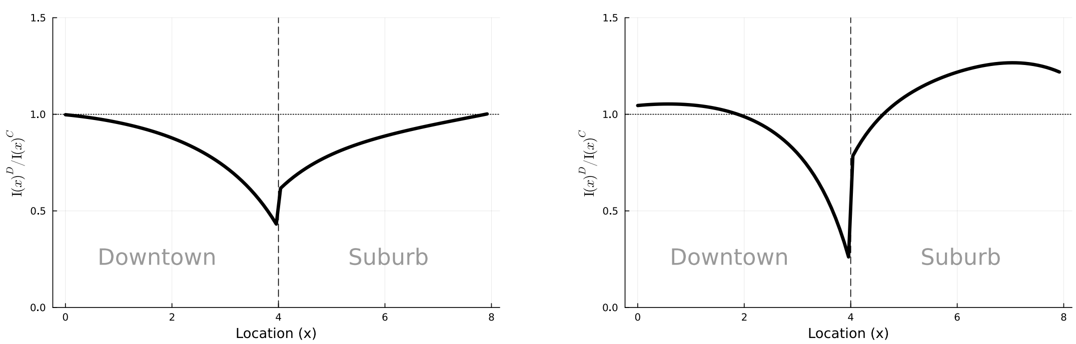
The main differences relative to the baseline are the reduced discontinuity at the boundary and a more symmetric investment pattern across municipalities.

This difference arises because, under land value maximization, even with equal political weights, the objective function implicitly favors residents. Labor demand is downward sloping—attracting more workers suppresses wages—so attracting workers is effectively more "costly" than attracting residents.

If instead we assume $\omega_{\mathrm{R}} > \omega_{\mathrm{F}}$ in the alternative welfare objectives, the resulting investment pattern more closely resembles the land value maximization outcome.

Figure 7: Relative infrastructure under alternative objectives ($\omega_{\mathrm{R}} > \omega_{\mathrm{F}}$)

(a) Total Welfare (b) Total Real Wages



Uniqueness of the game One potential concern is whether the Nash equilibrium between the two municipalities—Downtown and Suburb—is unique. In this model, investments by the municipalities are strategic complements: the benefit of investing in one link increases with the level of investment in connected links.

I explore this issue numerically in Appendix A.4.3 and show that the equilibrium is unique in the linear geography case. The appendix computes best response functions by fixing one government's budget and solving for the other's optimal investment. The results indicate that the best responses are increasing but cross only once, implying uniqueness under the specific parameter values used. This result, however, does not guarantee uniqueness in all settings—for example, with different parameters, a larger number of municipalities, or a more complex network structure.

2.3 From the linear geography to the network

Now that I have illustrated the main economic forces of the model, I describe how we can extend these results to the full network structure. The main simplification of the linear geography concerned the routing problem. In the linear city, there is only one route between every origin and destination; however, there are multiple (countably infinite) routes in the full network.

Recall that $Q_{k\ell} = \sum_{ij} L_{ij}\pi_{ij}^{k\ell}$ in the network. In the linear geography, given the trivial routing problem, instead of $\pi_{ij}^{k\ell}$, we had the indicator $\mathbb{1}_{ij}^{k\ell}$. Hence, in the linear geography, the only effect of $d_{k\ell}$ on traffic flows was through the effect on the population, L_{ij}. However, changes to $d_{k\ell}$ in the full network also affect the routing decisions. Holding population L_{ij} fixed everywhere, commuters will adjust their routing decisions in response to a change in the travel time of one edge, $d_{k\ell}$.

In addition to the routing problem, I extend the travel technology model and divide the time to travel through edge $(k\ell)$ in two: the time in k and the time in ℓ. In addition, I allow for the infrastructure on the side of k to be different than on the side el ℓ. This extension is particularly relevant when $g(k) \neq g(\ell)$; when the location k belongs to a different municipality than location ℓ. Note that the investment in each side of the edge can still be "directional", in the sense that $\mathrm{I}_{k\ell}^{k}$ can be different than I_{kn}^{k}.

$$d_{k\ell} = \exp\left(\kappa \times \left\{\mathrm{time}_{k\ell}^{k} + \mathrm{time}_{k\ell}^{\ell}\right\}\right), \tag{26}$$

$$\mathrm{time}_{k\ell}^{k} = \bar{t}_{k\ell}^{0,k} + \bar{t}_{k\ell}^{1,k}\frac{Q_{k\ell}^{\sigma}}{(\mathrm{I}_{k\ell}^{k})^{\xi}} \tag{27}$$

In addition, I constraint the government's problem to $\mathrm{I}_{k\ell}^{k} = \mathrm{I}_{\ell k}^{k}$. Governments must choose the same infrastructure level in both directions of an edge. Note that this constraint does not imply that commuting costs are symmetric, $\tau_{ij} \neq \tau_{ji}$, as traffic flows and routing decisions can differ between one direction and the other.

Hence, in the quantitative version of the model, instead of equation (17), the optimal infrastructure must satisfy the following equation:

$$\mathrm{I}_{k\ell}^{k} = -\frac{\xi}{\sigma}\frac{1}{\delta_{k\ell}^{\mathrm{I},k}}\left(\phi_{k\ell}^{g(k)}Q_{k\ell}\frac{t_{k\ell}^{k}}{t_{k\ell}^{k} + t_{k\ell}^{\ell}} + \phi_{\ell k}^{g(k)}Q_{\ell k}\frac{t_{\ell k}^{k}}{t_{\ell k}^{k} + t_{\ell k}^{\ell}}\right), \tag{28}$$

where $t_{k\ell} \equiv \bar{t}_{k\ell}^{1,k}Q_{k\ell}^{\sigma}/(\mathrm{I}_{k\ell}^{k})^{\xi}$ is the variable travel time, which depends on the infrastructure level and traffic flows. The Lagrange multipliers, $\phi_{k\ell}^{g(k)}$ and $\phi_{\ell k}^{g(k)}$, are given by the solution to the system of equations described in Appendix A.3.

3 Decentralization and Infrastructure in Santiago, Chile

In this section, I study the forces outlined in the theory within the context of the Santiago metropolitan area in Chile. I use Santiago's setting both to provide evidence in support of the model and to quantify the misallocation of infrastructure resulting from non-cooperative governance in a real-world urban environment.

3.1 Data Sources

Travel survey Santiago's 2012 travel survey, *Encuesta Origen Destino de Viajes*, provides information on the daily trips of 60,000 individuals from 18,000 households. This information includes the origin and destination of each trip, the purpose of the trip, and the mode of travel, and the duration of the trip. The sample is representative at a granular geographic level, with 866 spatial units over 45 municipalities in the metropolitan region. I restrict the sample to 700 central locations in 34 municipalities. I define central locations as locations within the city's urban limit defined by Google Maps. Locations are, on average, 1 km squared. This sub-sample captures 80% of the work-related trips documented in the data and 83% of the city's residential population.

Land use and land prices I use a public database of real estate appraisals by the tax authority of Chile, *Servicio de Impuestos Internos* (SII), that has information on the assessed value of the property, floorspace, use, and address for each property in the country. I use data from 2018, the first year for which the data is public.

With this information, I can compute the available floor space for residential and business purposes for each location: $\bar{H}_{Ri}$ and $\bar{H}_{Fi}$ in the model. I construct the category of "business" by including land uses that employ people in urban areas: commercial, hotels, industry, offices, public administration, and hospitals. I exclude categories like storage, churches, and parking since these categories usually do not employ many people.

Infrastructure I use public data from Open Street Maps on the road network and road characteristics for the Santiago area. Open Street Maps records data on the type of road for each road segment and information on the number of lanes and width for some roads. The types of roads include categories such as motorway, residential, primary, service, and so on.

I also combined this information with official government data on the road network, which was documented in the 2017 census. Importantly, the government dataset includes information on who owns the road, the national or local government, but does not include information on the physical characteristics of roads, such as number of lanes.

3.2 Context: Santiago, Chile

Chile is a relatively centralized country. For example, public schools are managed by municipalities but are mainly financed by the central government. Some municipalities choose to complement the existing public school funding; however, households do not have municipality residents to attend the local public school, and residents do not get priority in admissions. Further, tax rates are determined by the national government and are the same across municipalities. These characteristics allow me to focus on commuting infrastructure without worrying about residential sorting patterns driven by differential tax rates or access to other public goods, such as schools. Having said that, there are some municipality-specific public goods that only residents can enjoy; for example, some municipalities offer subsidized gyms or additional security.

Municipalities in Santiago are responsible for building and maintaining surface infrastructure, such as local roads, avenues, and bike lanes. Larger infrastructure projects, such as highways and subways, are designed and built by the national government. Subways are mostly underground infrastructure, and highways are often located at the boundary between municipalities. Figure B.3 in the Appendix shows the city's distribution of large roads, including avenues and highways. Avenues are owned and maintained by the municipalities and drawn in blue. Highways owned by the national government and drawn in red.

Although national infrastructure, such as highways, is heavily used, most travel time is spent on municipal infrastructure. For the average commuting trip, 60% of the distance and 80% of the travel time takes place in municipal roads. I calculate this number by computing the shortest route for the trips observed in the travel survey and mapping each step to either municipal infrastructure or highways.

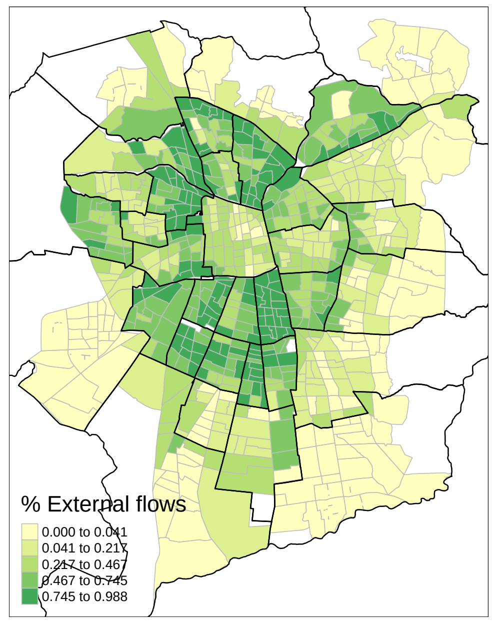
Most commuting in Santiago uses surface infrastructure rather than subways or trains. For instance, 31% of people commute using only their private car, but roughly 62% of trips use a car, bus, bike, taxi, or combination of these surface modes of transport. Nevertheless, the subway system is important and used for 22% of the trips. More than two-thirds of these subway trips also involve buses, bikes, or cars to connect to the subway system. Hence, most subway trips also involve local roads.

In the model estimation and counterfactual analysis, I focus on surface infrastructure, namely, roads. I don't model travel choices between using surface transportation or subway or trains. Hence, we can think about the model quantification and subsequent counterfactual analysis as capturing only the fraction of households and trips that use surface infrastructure. One important limitation of not modeling the substitution between surface infrastructure and subways is that the counterfactual results do not account for how the improved surface infrastructure would lead to households substituting away from the subway.

Santiago's economic and political context The region's political structure consists of 52 individual municipalities and a regional metropolitan government.

Publicly elected mayors lead municipalities, and the metropolitan government is led by a publicly elected governor.[16] The metropolitan government is responsible for coordinating, supervising, and inspecting regional public services. However, few coordination instruments exist for regional-municipal cooperation (Zegras & Gakenheimer, 2000). Even the current governor, Claudio Orrego, has been vocal about the important challenges related to the political fragmentation of the metropolitan area and the difficulties of enacting coordination (CitiesToBe, 2023).

Figure 8: Fraction of external flows



Note: External flows are commuters that do not live or work in the municipality.

Santiago is a densely populated and compact urban center divided into municipalities. It is important to note that these municipalities do not function as separate, independent cities; rather, they collectively constitute a unified and cohesive metropolis. In the Appendix, Figure B.2 highlights that all municipalities have both residents and employment. However, employment is more concentrated in a subset of municipalities. Moreover, although density is the highest at the central "business" municipalities, urban density is still high throughout the city's core. Importantly, urban density does not increase as a function of distance to the boundary between municipalities.

Commuting across municipalities Roads are often used by residents or workers of other municipalities: more than 70% of commuters live and work in different municipalities. I compute the fraction of external commuters, i.e., those who do not live or work in the

[16]Only 34 municipalities fall within Santiago's urban limit. The other municipalities in the region are more rural.

municipality building and maintaining the road. These commuters travel through the municipality, but both their origin and destination are in another jurisdiction. We can estimate the fraction of external commuters using the travel survey and Google Maps to compute the shortest path route: on an average road, 40% of commuters are external. However, this city-wide average hides significant heterogeneity in space. San Joaquin, the municipality with the highest fraction of external commuters, has an average of 85% external commuting flows. Figure 8 shows the distribution of external flows in space; external flows are concentrated in the ring of municipalities that connect residential locations to employment locations.

3.3 Local infrastructure at the border

One key prediction of the theory is that infrastructure changes discontinuously at the border and increases with distance to the border. This prediction is driven by two factors: First, municipalities' incentives change discontinuously at the border. Second, closer to the border, a larger fraction of the benefits from infrastructure are captured by neighboring locations, leading to less investment. In this section, I document a statistically significant jump and slope in the density of roads around the border between municipalities in Santiago.

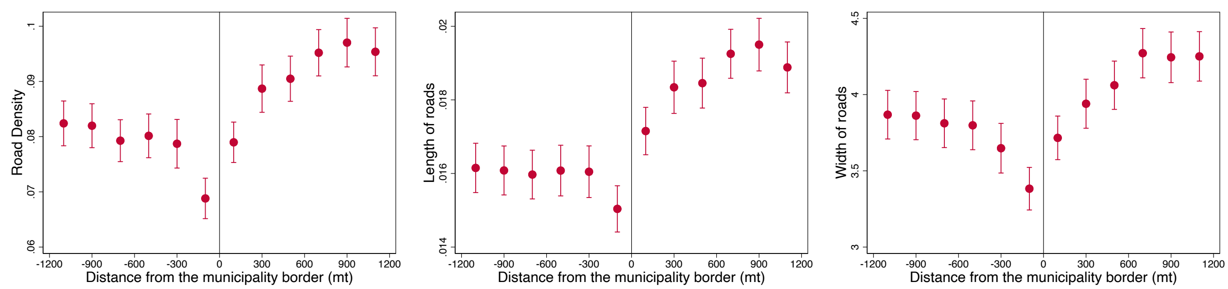
To document this fact, first, I construct a measure of infrastructure in space. I lay a grid of hexagonal cells over the area of the city; the grid cells have an area of 16 acres. In the following analysis, I focus on grid cells within a 1.2-kilometer (0.75-mile) window of the border. Within the metropolitan limits, 81 municipality pairs share a border. I exclude borders that coincide with geographical faults, such as rivers, and man-made barriers, such as highways, resulting in a sample of 44 border pairs. Within the grid cells, I define infrastructure as the percentage of area covered by roads. I calculate this as the sum of the road segments within the polygon, weighted by the width of each road, divided by the total area of the cell.

This exercise aims to test whether there is a systematic discontinuity in the density of roads around the border between municipalities. To visually show this, I order municipalities according to their relative *average* infrastructure. For two neighboring municipalities, A and B, I calculate the average road density of each municipality over the entire area around the border. Suppose the average density of A is larger than the average of its neighbor, municipality B. In that case, municipality A is ordered to the right of the border (positive distances), and municipality B is ordered to the left of the border (negative distances).

Figure 9(a) shows the resulting pattern. The dots indicate the average road density over 300-meter intervals around the border, with their 95% confidence intervals. We can see a significant jump at the border, and the infrastructure density is increasing with (absolute) distance to the border. This pattern is consistent with the model—both the jump and the slope. Closer to the border, a larger share of the benefits from infrastructures are captured by neighboring municipalities. We can compare the documented pattern with the pattern implied by the model in Figure 4(b).

Figure 9: Road pattern at the border between municipalities

(a) Road Density (b) Extensive margin: Length (c) Intensive margin: Width



Road density is defined as the sum of the road segmented within the polygon, weighted by the width of the road segment. We can think about the road segments and their length as the extensive margin: building new road segments. On the other hand, we can think about the width of a road segment as the intensive margin: enlarging an existing road. As shown in Figures 9(b) and 9(c), both the intensive and extensive margins show a similar pattern around the boundary. There are fewer road segments closer to the boundary and a discontinuity at the boundary. Moreover, roads tend to be less wide closer to the boundary, and there is also a discontinuity in width at the boundary.

I estimate the above discontinuity using a standard spatial regression discontinuity design, described in more detail in Appendix B.2. The estimated average jump at the border is 1.4pp, which can be interpreted as 1.4% more land allocated to roads and commuting infrastructure. The sample's average infrastructure is 9.9%; hence, the jump corresponds to roughly a 14% change in the infrastructure level, a relatively large change. Table B.1 shows the estimated discontinuity, including additional specifications with more flexible distance functions and different bandwidth sizes around the boundary.

Moreover, I describe how I select the set of borders and test for balance around the border for geographical characteristics such as slope and altitude and economic factors such as urban density. There are two important takeaways from the analysis in Appendix B.2: there are no apparent discontinuities in altitude, slope, or urban density at the boundary. More importantly, we might worry that either building costs are higher closer to the boundary or urban density is lower closer to the boundary, explaining why there is decreasing road density closer to the boundary. The terrain's slope and altitude do not increase closer to the boundary for the subset of boundaries used in this analysis. Finally, urban density is not lower around the boundary.

4 Model Quantification

This section explains how I either estimate or obtain values for all the model parameters. I follow the literature and leverage data on commuting patterns to estimate the commuting parameters and recover locations' productivity and amenities. Moreover, I combine the structure of the model with the observed pattern of road investment to estimate the municipalities' objective function parameters, that is, the political weights and the building costs. I exploit the discontinuity in road density at the boundary between municipalities to estimate the infrastructure elasticity and to inform my identification of the municipalities' political weights.

Land shares Two important parameters are the floor space share in production and the housing share in utility. In particular, when the objective function of the governments is maximizing land value, the land shares affect how local governments value residents relative to workers in their jurisdiction, ultimately affecting how much infrastructure is built and the degree of underinvestment.

I take the value for the land share in production from Tsivanidis (2019). He estimates $(1-\beta)=0.2$, by computing the share of floorspace in total costs across non-agricultural establishments in Bogotá, Colombia. This value is similar to the one estimated in Ahlfeldt et al. (2015). I calculate the housing share of utility, $(1-\alpha)$, from a household survey in Chile (CASEN), where people report spending on average 25% of their income in housing rent, $(1-\alpha)=0.25$.

Other preference parameters The other household preference parameters are the idiosyncratic preferences shape parameters of each nest, $\{\theta,\rho,\mu\}$, and the level of the disutility of commuting, κ. I take the shape parameter of the idiosyncratic preference shocks for residence-work pairs from the seminal work of Ahlfeldt et al. (2015), where they estimate $\theta=6.8$. This parameter is important in my framework because it controls the elasticity with which households substitute residential or work locations; that is, how much residents and workers reorganize in space in reaction to new infrastructure.

Then, with a value of θ at hand, I estimate the disutility of commuting parameter, κ, by exploiting equation (9). I estimate:

$$\ln L_{ij} = \alpha_i + \beta_j - \theta\kappa \text{Time}_{ij} + \epsilon_{ij}, \tag{29}$$

where I measure travel time, Time_{ij}, using the least cost path route travel time between every pair origin-destination computed by Google Maps. The data on travel demands, L_{ij}, comes from the bilateral commuting data in the travel survey. A large pair of locations have zero commuting flows. Hence, I estimate the above relationship with Poisson Pseudo Maximum Likelihood (Silva & Tenreyro, 2006). With this procedure, I estimate $\kappa = 0.01$. Notably, this is the same value estimated by Ahlfeldt et al. (2015).

Another important parameter is ρ, the routing idiosyncratic preference parameter. This parameter controls how elastic people's routing decisions are to changes in travel time in a given edge. Hence, it impacts how much traffic flows reorganize in the network in response to changes in the infrastructure. I set this parameter to $\rho = 80$. This value assures that I satisfy the conditions stated in Allen and Arkolakis (2022), mainly that the spectral radius of the matrix $\mathbb{A} \equiv [d_{k\ell}^{-\rho}]$ is less than one. My choice for ρ is significantly larger than the one used by Allen and Arkolakis (2022) ($\rho = 6.83$). Note that, as $\rho \to \infty$, the routing procedure converges to the least cost path route. Using a larger value of ρ implies that idiosyncratic noise plays a smaller role in households' routing decisions.

The parameter μ controls the substitutability across cities of the upper nest: it affects the variance of the idiosyncratic preference shocks between the city and other locations in the country, namely other cities or the countryside. Head and Mayer (2021) summarizes recent estimates of the elasticity of migration, values ranging from 0.5 to 3.2. I set $\mu = 2$, which is around the median estimate when restricting to studies of migration within countries.

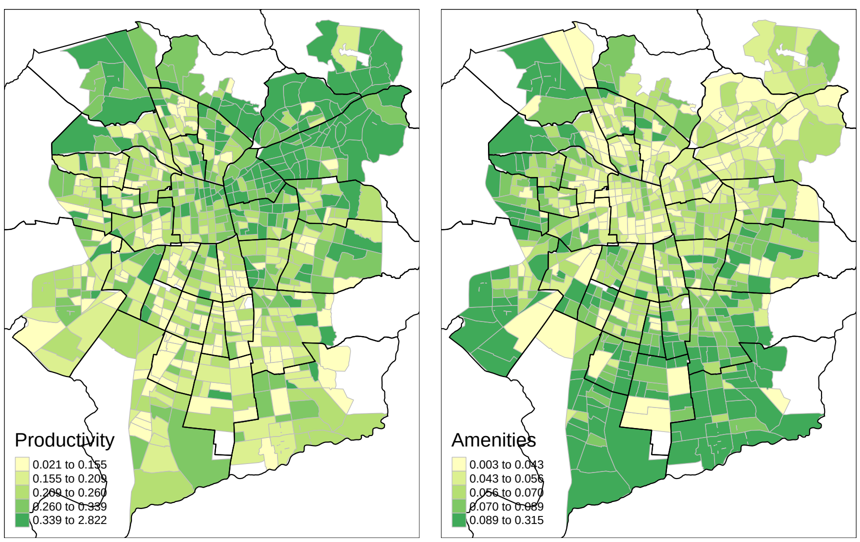
Exogenous locations characteristics From the tax authority's data on land use, I compute the available floorspace for residential purposes, $\bar{H}_{Ri}$, and for productive purposes, $\bar{H}_{Fi}$, for each location. Note that in the model, $\bar{H}_{Ri}$ and $\bar{H}_{Fi}$ are measures of land and not floor space. However, as the model doesn't include a housing construction sector, we can map land in the model to floor space in the data.

I follow the standard inversion approach in the literature, described in (Redding & Rossi-Hansberg, 2017), to estimate the exogenous productivity and amenities, $\{\bar{A}_i, \bar{B}_i\}_{i \in \mathcal{J}}$. I exploit the gravity equation implied by the model and the data on population and employment by location in the travel survey. That is, given a matrix of τ_{ij} and a value for θ, there is a unique vector of wages, $\{w_j\}$, that rationalizes the observed distribution of employment,

$\{L_{Fj}\}$, and of population $\{L_{Ri}\}$. Once I invert the vector of wages, I can recover the implied productivity using equation 2. Similarly, given τ_{ij}, the vector of wages, w_j, and the population distribution, I can calculate the implied residential amenity that rationalizes the observed residential population.

Figure 10 shows the resulting distribution of productivity and residential amenities. Locations close to the center of the city and in the northeast have higher productivity, which is consistent with the pattern of employment. Amenities are higher in the peripheral locations in the south and southwest. This is because these areas are highly populated, although they are relatively far from jobs. Hence, the model rationalizes through higher residential amenities. In reality, these areas are quite poor (see Figure B.1(b)).

Figure 10: Exogenous amenities and productivity



Note that the variance of productivity in space is much larger than the variance in residential amenities: $\mathbb{V}\mathrm{ar}(\bar{A}_i)/\mathbb{V}\mathrm{ar}(\bar{B}_i) \approx 68$. The variance in productivity and amenities in space is important for the implications of decentralization: First, it affects the size of spillovers and, therefore, the degree of underinvestment. Second, it increases the comparative advantage of some municipalities relative to others, allowing them to capture a larger fraction of the city's population by underproviding infrastructure and ultimately benefiting from decentralization.

Travel technology Travel time in an edge (k, ℓ) is given by equation (10). The two important parameters of this function are the congestion elasticity, σ, and the infrastructure elasticity, ξ. The value of the congestion elasticity will affect the size of the congestion externalities. Traffic congestion dampens the benefits of additional infrastructure and amplifies the distortions of decentralization through the indirect congestion force— municipalities fail to internalize the effect of their investments in traffic flows outside their jurisdiction.

I take the value of σ, the congestion elasticity, from Akbar and Duranton (2017). In Bogota, Colombia, they estimate traffic congestion elasticities of travel time between 0 and 0.4, depending on the level of traffic. I take their average elasticity and set $\sigma = 0.06$.

I estimate the infrastructure elasticity, ξ, by exploiting the discontinuity in infrastructure at the border between municipalities documented in Section 3.3. In the same sample of grid cells around the municipality borders, I construct a measure of travel speed using Open Street Maps and a random set of origin and destination points within each grid cell. See Appendix B.4.2 for more detail on the measurement of speed and estimation.

Figure B.9 shows the discontinuity in infrastructure and the corresponding discontinuity in speed. Using this variation, I estimate $\xi = 0.11$ by running a regression between log-speed and log-infrastructure, where I instrument log infrastructure with the municipality border.

In the Appendix B.4.1, I describe in detail how I construct the network of edges and how I combine data, estimated parameters, and the model to invert the edge-level exogenous characteristics, $\bar{t}^0_{k\ell}$ and $\bar{t}^1_{k\ell}$. Further, I describe how I incorporate the highways and other national infrastructure into the quantification and the municipalities' problem.

Municipalities' objective function Consider municipalities' objective function described in equation (17). Instead of assuming that $\omega_{\mathrm{R}} = (1-\alpha)$ and $\omega_{\mathrm{F}} = (1-\beta)/\beta$, the political weights implied by maximizing land value, we can estimate the political weights that best rationalize the observed road density in Santiago.

To estimate these weights directly from the data, I take the set of edges $(k\ell)$ such that $g(k) \neq g(\ell)$, that is, the edges that cross municipality boundaries. I assume the building costs at each side of the boundary are the same, that is, $\delta^{\mathrm{I},k}_{k\ell} = \delta^{\mathrm{I},\ell}_{k\ell}$. By combining this assumption and equation (28), I derive the following moment condition:

$$\frac{I^k_{k\ell}}{I^\ell_{k\ell}} = \frac{\phi^{g(k)}_{k\ell} Q_{k\ell} \frac{t^k_{k\ell}}{t^k_{k\ell}+t^\ell_{k\ell}} + \phi^{g(k)}_{\ell k} Q_{\ell k} \frac{t^k_{\ell k}}{t^k_{\ell k}+t^\ell_{\ell k}}}{\phi^{g(\ell)}_{k\ell} Q_{k\ell} \frac{t^\ell_{k\ell}}{t^k_{k\ell}+t^\ell_{k\ell}} + \phi^{g(\ell)}_{\ell k} Q_{\ell k} \frac{t^\ell_{\ell k}}{t^k_{\ell k}+t^\ell_{\ell k}}}, \quad \forall \quad k,\ell : g(k) \neq g(\ell). \tag{30}$$

I can observe the left-hand side of this equation directly in the data. The right-hand side combines data, estimated parameters, and easy-to-calculate objects, such as $Q_{k\ell}$. The only parameter that directly depends on the political weights are the traffic flow lagrange multipliers, $\phi^g_{k\ell}(k) = \phi^{g(k)}_{k\ell}(\omega_{\mathrm{R}}, \omega_{\mathrm{F}})$

Following a similar approach to Section 3.3, since the key identification assumption is that the building costs are the same across the boundary, I restrict the set of edges to those at borders with smooth geographical characteristics and borders that do not coincide with a highway. The 44 borders contain 222 edges, providing 222 moments to estimate the two political weights.

Minimizing the average distance for this set of moments means the estimated weights are $\omega_{\mathrm{R}} = 0.25$ and $\omega_{\mathrm{F}} = 0.21$. Note that these values are not too far off the land value implied weights, $\omega_{\mathrm{R}} = \omega_{\mathrm{F}} = 0.25$, which is reassuring. However, the data implied weights give relatively more weight to residents. This is consistent with the political context in Chile, where residents and not workers vote for the local mayors who lead the municipalities.

For more discussion on the type of variation that identifies these parameters, in Appendix B.3, I provide suggestive evidence that local governments prioritize building infrastructure in areas that benefit their own residents and workers. I show there is a positive and statistically significant correlation between road density and the fraction of commuting flows that are local residents and/or workers, controlling for overall traffic flows. We can interpret this correlation as the following: for areas with similar overall traffic flows and building costs and within the same municipality, there is more road density in areas where a larger fraction of commuters are residents. In turn, there is more road density in areas where a larger fraction of commuters are workers.

Building costs With all the estimated parameters, location characteristics, and edge characteristics, I use the structure of the model to obtain the infrastructure building costs. I use equation (28) and reorganize it as:

$$\underbrace{\delta^{\mathrm{I},k}_{k\ell}}_{\text{Building costs}} = \underbrace{-\frac{\xi}{\sigma}\frac{1}{\mathrm{I}^k_{k\ell}}\left(\phi^{g(k)}_{k\ell} Q_{k\ell}\frac{t^k_{k\ell}}{t^k_{k\ell}+t^\ell_{k\ell}} + \phi^{g(k)}_{\ell k} Q_{\ell k}\frac{t^k_{\ell k}}{t^k_{\ell k}+t^\ell_{\ell k}}\right)}_{\text{Data + Estimated parameters + Model inversion}}.$$

I use the observed infrastructure in the data as $\mathrm{I}^k_{k\ell}$. That implies that the recovered building costs are such that the model perfectly matches the observed infrastructure in the baseline. We can think about these building costs as capturing not only traditional building costs but also any additional characteristic of an edge (link) that explains the level of infrastructure beyond the forces of the model. For example, suppose there is low road density in an area of the city because it is a protected area (for historical preservation, environmental considerations, etc). In that case, I rationalize the observed low infrastructure level through high building costs.

Note that the Lagrange multipliers, $\phi_{k\ell}^{g(k)}$ and $\phi_{\ell k}^{g(k)}$, are a function of the political weights, ω_{R} and ω_{F}. So, depending on whether I am assuming land value maximization or the flexible weights implied by the data, the recovered building costs differ.

5 Centralizing Santiago

Using the estimated model, I consider two counterfactual scenarios where all infrastructure is decided by a metropolitan planner that maximizes the aggregate surplus of the city. In one counterfactual, I allow the metropolitan planner to increase or decrease the aggregate expenditure (budget). In the second one, I restrict the planner to spend the same budget as in the baseline decentralized equilibrium. I refer to this counterfactual as the constrained centralized. By comparing the current decentralized equilibrium to these counterfactual ones, we can evaluate the infrastructure misallocation and welfare losses generated by the political decentralization of Santiago.[17]

For each of these counterfactuals, I compare the results under two alternative objective functions for the municipal governments: maximizing land value or maximizing the sum of their residents and workers' wage bill, using the political weights estimated from the data.

Table 1: Objective Function Specification

Specification	Residents' Weight (ω_{R})	Workers' Weight (ω_{F})
Land Value	0.25	0.25
Flexible Weights	0.25	0.21

Table 2 shows changes to the aggregate variables of the model in the centralized counterfactuals relative to the baseline decentralized equilibrium for both objective functions. In the centralized equilibrium, the aggregate infrastructure expenditure increases between 44% and 60% depending on the objective function, implying significant overall underinvestment in the baseline. By construction, aggregate expenditure stays the same in the constrained centralized equilibrium.

[17] I compute the counterfactuals using the procedure described in Appendix A.5.

Table 2: Aggregate effects (%)

	Centralized		Constrained Centralized	
Variable	Land Value	Flexible Weights	Land Value	Flexible Weights
Population	1.9	2.4	0.7	0.8
Welfare	1.4	1.7	0.4	0.5
Surplus	1.6	1.7	1.4	1.4
Expenditure in infrastructure	44	60	0	0
Average commuting costs	0.3	0.1	0.6	0.6

In the centralized counterfactual, even after the significant increase in infrastructure, overall commuting costs increase slightly (less than 1%). This is due to the congestion forces, paired with the rise in population and reorganization of economic activity. As illustrated in the linear city, a higher concentration of employment in productive locations in the centralized equilibrium leads to larger commutes and more traffic flows overall. This feature of the model is consistent with the fundamental law of traffic congestion: increased provision of transportation infrastructure induces more demand and, therefore, does not necessarily relieve congestion.

Comparing the results across different objective functions, note that the aggregate gains of centralizing are larger when using the flexible weight specification. Recall that the residential and employment forces usually go in opposite directions (see Figures 3(a) and 3(b)). Depending on whether a municipality has a comparative advantage for employment or residential purposes, they trade off residential gains against employment losses, or vice versa, when making investment decisions. Since the flexible weights estimated in the data assign a smaller weight to workers than the weights implied by land value, in the flexible weights model, there are larger distortions due to decentralization.

The constrained counterfactuals, conditioned on the baseline budget, achieve roughly one-third of the aggregate benefits of centralization without increasing total expenditures. By reallocating investment toward municipalities with the greatest underinvestment, we can enhance connectivity and boost the city's overall welfare and land value.

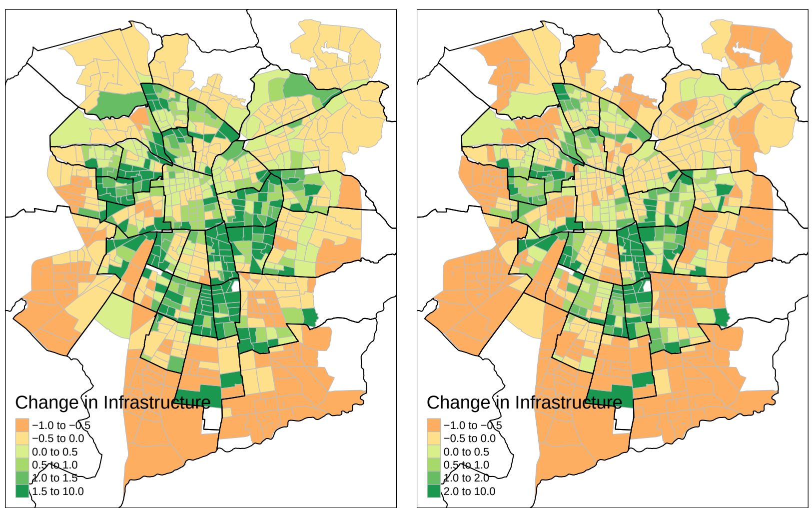
The aggregate effects on population relative to welfare are determined by the elasticity of the population supply to the metropolitan area. This elasticity is controlled by the preference shape parameter of the upper nest, μ. As aggregate infrastructure expenditure increases 44% to 60% in the centralized counterfactual or is better allocated in the constrained counterfactual, the gains in welfare are partially arbitraged away by more households moving into the metropolitan area from the countryside.

5.1 Effects in space

Figure 11 shows the spatial distribution of changes to commuting infrastructure relative to the baseline. In these figures, I plot the case where municipalities maximize land value.[18] Panel (a) shows the centralized counterfactual. The metropolitan planner invests more towards the city's center and less in the periphery than the baseline. The largest increases are concentrated in a ring around the central municipality. A large fraction of commuters in these locations are passing through: they live in the residential municipalities to the southwest of the city and commute to the core and northeast of the city (see Figure 8). Panel (b) shows the constrained centralized counterfactual, where we shift infrastructure from the periphery and central locations towards the inner ring, where there is more underinvestment in the baseline. This increase comes at the expense of a decrease in infrastructure in other locations, highlighted by the higher number of locations in red relative to the left panel.

Figure 11: Changes to the city's infrastructure - Land value maximization

(a) Centralized (b) Constrained centralized



Note: In these figures, I show the increase relative to the baseline (decentralized) equilibrium. The change in infrastructure is calculated as $\Delta \mathrm{I}_{k\ell} = \frac{\mathrm{I}^{C}_{k\ell} - \mathrm{I}^{g}_{k\ell}}{\mathrm{I}^{g}_{k\ell}}$.

Figure 12(a) shows the average increase in infrastructure as a function of the distance to the city's center. At the city's periphery, the metropolitan planner reduces the amount of infrastructure, aligning with the results in the linear geography example in Figure 4(b). Im-

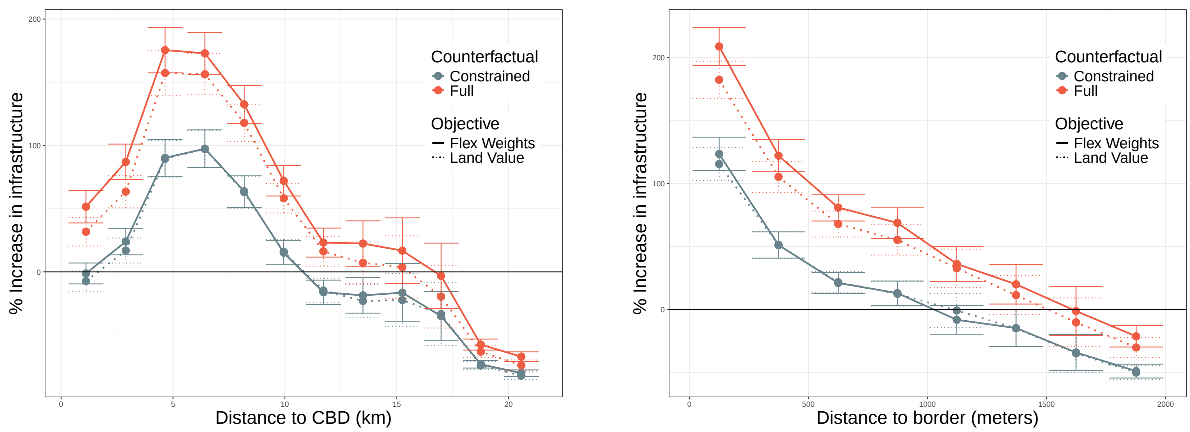
[18]The patterns are qualitatively the same in the specification where municipalities maximize residents' and workers' wage bills with flexible weights.

portantly, the metropolitan planner substantially increases infrastructure at the ring around the city's center, effectively improving the connection between residential and employment areas of the city.

Figure 12(b) shows the average increase in infrastructure as a function of the distance to the municipalities' boundary. There are larger increases in infrastructure in edges closer to the boundary with neighboring municipalities.

Figure 12: Changes to the city's infrastructure as a function of distance

(a) Distance to CBD (b) Distance to border



Note: Distance to the city's center is calculated as distance to *Plaza de Armas*, the main square in the downtown municipality.

We can study the economic forces that explain the pattern of increase (and decrease) in infrastructure shown in Figure 11 by comparing the residential and employment forces defined in Section 2.2.1 under both equilibria.

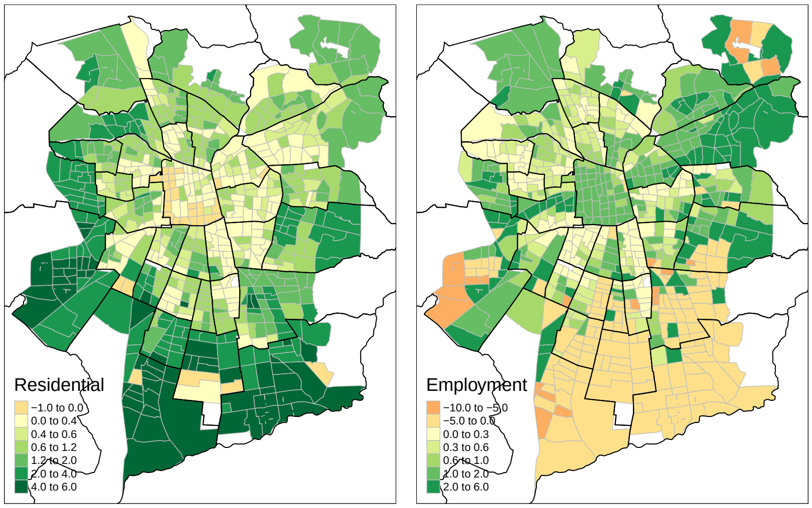
Figure 13(a) shows the ratio between the residential force in the decentralized equilibrium and the residential force in the centralized equilibrium. Figure 13(b) shows the ratio between the employment force in the decentralized equilibrium and the employment force in the centralized equilibrium. We can think of these relative forces as taking the ratio between the red and blue lines in Figure 3 in the linear city, that is, the fraction of the total residential or employment land value benefits internalized by the municipality.

With this in mind, values smaller than one imply that locations outside the municipality capture some fraction of the benefits or costs. Values larger than one imply that the municipality increases its value by more than the city as a whole, i.e., the increase in land value is at the expense of value in other locations. Negative values imply that the location loses value in this dimension. For example, the central municipality has negative residential values: additional infrastructure would translate into a loss in residents and land value for this municipality.

Figure 13: Relative residential and employment values

(a) Residential force

(b) Employment force



Note: Relative flows are defined as $\frac{Q_{\mathrm{R}}^{D}}{Q_{\mathrm{R}}^{C}}$. The centralized flows are computed in the baseline equilibrium, i.e., with the empirical population distribution, but using the weights implied by the metropolitan planner.

Let us focus first on the residential force in Figure 13(a). Areas around the city's center have low relative residential values, even negative values; other municipalities capture a large fraction of the residential investment value in these locations. Improving its infrastructure causes residents to move from the city's center towards peripheral areas with lower housing prices and better amenities. On the other hand, the periphery, especially the city's southwest, has large relative residential flows (higher than one). Investment in these locations increases residents and land value for these municipalities at the expense of residents in other jurisdictions.

Focusing now on the employment force in Figure 13(b), the central and eastern municipalities (areas with high exogenous productivity) have high relative employment values (higher than one). Investing in infrastructure in these areas allows employment to concentrate in these productive locations, and these governments capture more land value at the expense of locations outside.

Note that the governments with the highest level of underinvestment in the baseline equilibrium are the governments with low relative residential and employment values.[19] These

[19]We can see a government's overall level of underinvestment in Figure 14(b). This figure shows the

governments have low productivity and residential amenities relative to their neighboring jurisdictions. The benefits from infrastructure in these municipalities are mostly captured by their neighbors, as more people can travel to the work-intensive municipalities, and more households can move to the high-amenity peripheral locations.

Underinvestment is not as acute in governments that enjoy either a productive or residential advantage, where this advantage can arise from their location within the city (central or peripheral) or from their productivity and amenities. This is because the residential and employment forces go in different directions for these jurisdictions. When a productive municipality invests in roads, it loses residents and does not capture the full residential benefit of that investment. However, it gains employment at the expense of employment in other areas. It captures more than the total productive benefit of the investment, as it "steals" some business from other areas. This employment force then compensates for the loss of residential value,

Population and Employment As in the line geography example, in the centralized equilibrium, the employment shifts towards the productive areas within the city and becomes more concentrated. The residential population shifts towards areas with high amenities in the periphery. Hence, the city becomes more specialized: employment is more concentrated in productive locations, and residents are more concentrated in high-amenity locations, leading to longer commutes. Appendix B.5, Figure B.10 map the changes to population and employment in space in the counterfactual scenario relative to the baseline equilibrium.

Winners and Losers of Decentralization We now compute the differences in aggregate surplus by municipality: the change in their land value minus the infrastructure building costs in the centralized equilibrium relative to the decentralized equilibrium. This comparison allows us to study which municipalities currently benefit from decentralization and, therefore, might oppose a more centralized infrastructure planning strategy. For this analysis, I focus on the full centralized counterfactual, where the budget and aggregate investment adjust. I focus on the specification where municipalities maximize land value, as it is easier to interpret.

Figure 14(a) shows the difference in surplus, and Figure 14(b) shows the difference in aggregate infrastructure expenditure by municipality. We can see that the peripheral municipalities in the south benefit the most from centralization. These municipalities don't increase

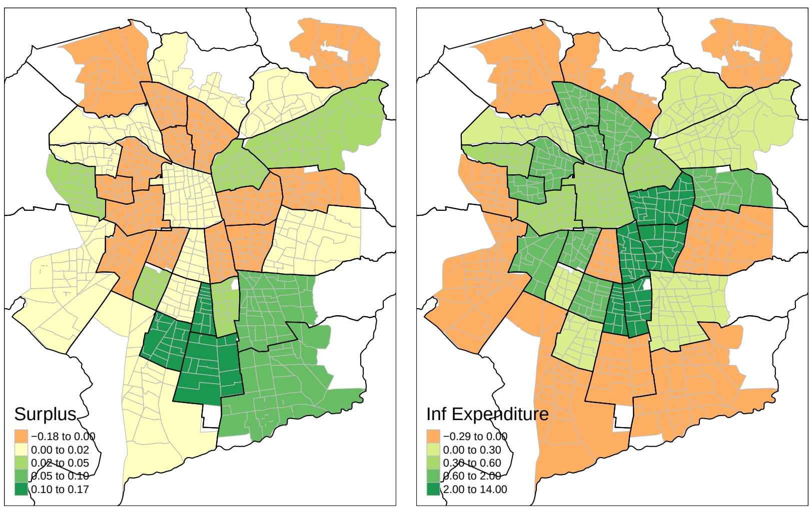
overall increase in expenditure by municipality in the full centralized counterfactual. The municipalities in the ring around the core increase their expenditure the most and, therefore, are the ones that underinvest the most in the decentralized equilibrium.

their investment as much as those in the inner ring but benefit from the improved market access to the work locations. Similarly, the municipalities in the northeast benefit from the improved market access to workers, which raised their productive land prices.

The municipalities in orange are the ones that benefit from decentralization and are losing surplus in this counterfactual metropolitan scenario. Intuitively, the worse-off municipalities coincide with those with some of the highest underinvestment in the baseline. They have to increase their expenditure significantly in the counterfactual, but most of the benefit is captured by other jurisdictions.

Figure 14: Full counterfactual, change in surplus and expenditure

(a) Change in surplus (b) Change in expenditure



Note: This figures plot the counterfactual with land value maximization.

In this framework, I do not account for key shortcomings of centralization, such as information frictions or heterogeneous preferences for public goods. As a result, centralization always appears more efficient than decentralization. Nonetheless, this analysis sheds light on the trade-offs between centralized and fragmented cities. In a decentralized city, the city is smaller in population and more polycentric, with residents living closer to their workplaces and experiencing shorter commutes. As illustrated in Figure 14(a), certain neighborhoods—particularly those near employment centers—derive significant benefits from this arrangement. These areas are typically home to middle- and higher-income households who can afford to live closer to work.

Conversely, neighborhoods in the city's south, farthest from employment centers, gain more from centralization. These peripheral areas are often inhabited by lower-income households.

While my analysis does not explicitly incorporate income differences among households or their spatial sorting, the distribution of surplus gains indicates a negative correlation with income: lower-income households benefit more from centralization than higher-income ones. Investigating the implications of political fragmentation for inequality presents a compelling avenue for future research, though it lies beyond the scope of this paper.

6 Conclusion

This paper studies how political decentralization can lead to misallocation in infrastructure investment. I propose a quantitative spatial model of a metropolitan area where local governments invest in commuting infrastructure to maximize their land value. In equilibrium, local governments underinvest in areas near their boundaries, where a large fraction of the benefits from infrastructure accrues to locations outside their jurisdiction. Local governments overinvest in areas where they can increase their land value at the expense of land value in other jurisdictions. Moreover, the under-provision of infrastructure around the boundary leads to employment dispersion and residents moving closer to their work locations. This shift in the population distribution translates into lower overall commuting flows, lower aggregate population, and lower aggregate welfare.

This paper aimed to take an initial step toward understanding how local government incentives can lead to infrastructure misallocation. However, it raises several intriguing questions that remain unresolved. For instance, in the counterfactual analysis, the municipalities that most benefit from centralization are also the most economically disadvantaged. Moreover, households income might interact with municipalities' incentives to build roads. Municipalities might want to attract higher-income households and deter lower-income households from moving in not only through the level of investment, but through the type of infrastructure (transit vs roads). This prompts a critical question: what are the implications of decentralization for urban inequality?

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A Theory Appendix

In this section, I go through the derivations of the main model presented in the paper.

A.1 Firms' problem

Firms located in j faces the following problem:

$$\max_{L_{\mathrm{F}j}, H_{\mathrm{F}j}} \bar{A}_j \left(\frac{L_{\mathrm{F}j}}{\beta}\right)^{\beta} \left(\frac{H_{\mathrm{F}j}}{1-\beta}\right)^{1-\beta} - w_j L_{\mathrm{F}j} - q_{\mathrm{F}j} H_{\mathrm{F}j}.$$

From the first-order conditions, we can derive the inverse demand functions,

$$w_j = \bar{A}_j \left(\frac{\beta}{1-\beta} \frac{H_{\mathrm{F}j}}{L_{\mathrm{F}j}}\right)^{1-\beta}, \quad q_{\mathrm{F}j} = \bar{A}_j \left(\frac{1-\beta}{\beta} \frac{L_{\mathrm{F}j}}{H_{\mathrm{F}j}}\right)^{\beta}.$$

A.2 Households' problem

Households are geographically mobile and have preferences according to equation (6), where the idiosyncratic preferences are described by equation (4). The face a budget constraint,

$$C_{ij} + q_{\mathrm{R}i} \leq w_j$$

From the first-order conditions, conditional on choosing to live in the metropolitan area, live and work in ij, and the commuting route r, the optimal consumption decisions are given by,

$$C_{ij} = \alpha w_j, \quad H_{ij} = (1-\alpha) \frac{w_j}{q_{\mathrm{R}i}}.$$

By replacing these optimal consumption equations back to equation (6), we get equation (5).

A.3 Governments' problem

In this section, I show how I derive the optimal infrastructure from the government's problem. Then, I show how we can separate the government-specific forces behind the optimal infrastructure into the three effects described in the main text: residential, employment, and congestion. Finally, I'll show how we can interpret these as traffic flows weighted by government-specific weights.

First, government g's Lagrangian is given by:

$$
\begin{aligned}
\mathcal{L} = & \sum_{ij} \left\{ \omega_{\mathrm{R}} \mathbb{1}[i \in \mathcal{J}^g] L_{ij} w_j + \omega_{\mathrm{F}} \mathbb{1}[j \in \mathcal{J}^g] L_{ij} w_j \right\} - \sum_{k\ell} \mathbb{1}[(k,\ell) \in \mathcal{E}^g] \delta^{\mathrm{I}}_{k\ell} \mathrm{I}_{k\ell} - \\
& \sum_{ij} \lambda^g_{ij} \Big[L_{ij} - \tau_{ij}^{-\theta} \Big(\frac{\bar{B}_i}{q_{\mathrm{R}i}^{1-\alpha}} \Big)^{\theta} w_j^{\theta} \frac{L}{U^{\theta}} \Big] - \sum_i \eta^g_{\mathrm{F}i} \Big[w_i - \bar{A}_i \left(\frac{\beta}{1-\beta} \frac{H_{\mathrm{F}i}}{\sum_j L_{ji}} \right)^{1-\beta} \Big] - \\
& \sum_i \eta^g_{\mathrm{R}i} \Big[q_{\mathrm{R}i} - \frac{(1-\alpha)}{\bar{H}_{\mathrm{R}i}} \sum_j L_{ij} w_j \Big] - \sum_{ij} \gamma^g_{ij} \Big[\tau_{ij} - \Big((\mathbf{I} - \mathbf{A})^{-1} \Big)^{-\frac{1}{\rho}} \Big] - \\
& \sum_{k\ell} \epsilon^g_{k\ell} \Big[d_{k\ell} - \exp \Big(\kappa \Big\{ \bar{t}^{0,k}_{k\ell} + \bar{t}^{1,k}_{k\ell} \frac{Q^{\sigma}_{k\ell}}{(\mathrm{I}^k_{k\ell})^{\xi}} + \bar{t}^{0,\ell}_{k\ell} + \bar{t}^{1,\ell}_{k\ell} \frac{Q^{\sigma}_{k\ell}}{(\mathrm{I}^{\ell}_{k\ell})^{\xi}} \Big\} \Big) \Big] - \\
& \sum_{k\ell} \phi^g_{k\ell} \Big[Q_{kl} - \sum_{ij} L_{ij} \Big(\frac{\tau_{ij}}{\tau_{ik} d_{k\ell} \tau_{\ell j}} \Big)^{\rho} \Big] - \\
& \upsilon^g_L \Big[L - \frac{U^{\mu}}{U^{\mu} + \bar{U}^{\mu}_o} \bar{L}_c \Big] - \upsilon^g_U \Big[U - \Big(\sum_{ij} \tau_{ij}^{-\theta} \Big(\frac{\bar{B}_i}{q_{\mathrm{R}i}^{1-\alpha}} \Big)^{\theta} (w_j)^{\theta} \Big)^{\frac{1}{\theta}} \Big] - \iota_{k\ell} \left[\mathrm{I}^k_{k\ell} - \mathrm{I}^{\ell}_{\ell k} \right]
\end{aligned}
$$

We can simplify the system of first-order conditions to the following system of $2 \times N + E$ system, where N is the number of locations and E is the number of edges.

$$
[q_{\mathrm{R}i}] : \eta^g_{\mathrm{R}i} = -\frac{(1-\alpha)}{q_{\mathrm{R}i}} \left(\theta \sum_j \lambda^g_{ij} L_{ij} - \frac{L_{\mathrm{R}i}}{L} (\theta - \varepsilon_L) \sum_{od} \lambda^g_{od} L_{od} \right) \tag{A.1}
$$

$$
[w_j] : \eta^g_{\mathrm{F}j} = \sum_i \left\{ \omega_{\mathrm{R}} \mathbb{1}[i \in \mathcal{J}^g] L_{ij} + \omega_{\mathrm{F}} \mathbb{1}[j \in \mathcal{J}^g] L_{ij} \right\} + \tag{A.2}
$$

$$
\frac{1}{w_j} \left(\theta \sum_i \lambda^g_{ij} L_{ij} + \sum_i \eta^g_{\mathrm{R}i} \frac{1-\alpha}{\bar{H}_{\mathrm{R}i}} L_{ij} w_j - \frac{L_{\mathrm{F}j}}{L} (\theta - \varepsilon_L) \sum_{od} \lambda^g_{od} L_{od} \right) \tag{A.3}
$$

$$
[d_{k\ell}] : \phi^g_{k\ell} Q_{k\ell} = \Big(\frac{1}{\sigma (t^k_{k\ell} + t^{\ell}_{k\ell})} + \rho \Big)^{-1} \sum_{ij} \gamma^g_{ij} \tau_{ij} \Big(\frac{\tau_{ij}}{\tau_{ik} d_{k\ell} \tau_{\ell k}} \Big)^{\rho} \tag{A.4}
$$

where:

$$
\begin{aligned}
\lambda^g_{ij} &= \omega_{\mathrm{R}} \mathbb{1}[i \in \mathcal{J}^g] w_j + \omega_{\mathrm{F}} \mathbb{1}[j \in \mathcal{J}^g] w_j + \eta^g_{\mathrm{R}i} \frac{1-\alpha}{\bar{H}_{\mathrm{R}i}} w_j - \eta_{\mathrm{F}j} \frac{1-\beta}{L_{\mathrm{F}j}} w_j + \sum_{k\ell} \phi^g_{k\ell} \Big(\frac{\tau_{ij}}{\tau_{ik} t_{k\ell} \tau_{\ell j}} \Big)^{\rho} \\
\gamma^g_{ij} &= -\frac{L_{ij}}{\tau_{ij}} \left(\theta \lambda^g_{ij} - \frac{(\theta - \varepsilon_L)}{L} \sum_{od} \lambda^g_{od} L_{od} \right) + \frac{\rho}{\tau_{ij}} \sum_{k\ell} \phi^g_{k\ell} L_{ij} \pi^{k\ell}_{ij} - \\
&\quad \frac{\rho}{\tau_{ij}} \sum_{\ell} \phi^g_{j\ell} \sum_m L_{im} \pi^{j\ell}_{im} - \frac{\rho}{\tau_{ij}} \sum_k \phi^g_{ki} \sum_m L_{mj} \pi^{ki}_{mj} \\
t^k_{k\ell} &= \kappa \bar{t}^{1,k}_{k\ell} \frac{Q^{\sigma}_{k\ell}}{(\mathrm{I}^k_{k\ell})^{\xi}} \\
\varepsilon_L &\equiv \mu \Big(1 - \frac{L}{\bar{L}_c} \Big) \quad = \frac{\partial L}{\partial U} \times \frac{U}{L}
\end{aligned}
$$

where the optimal infrastructure is given by:

$$
\mathrm{I}^k_{k\ell} = -\frac{\xi}{\sigma} \frac{1}{\delta^{\mathrm{I},k}_{k\ell}} \left(\phi^{g(k)}_{k\ell} Q_{k\ell} \frac{t^k_{k\ell}}{t^k_{k\ell} + t^{\ell}_{k\ell}} + \phi^{g(k)}_{\ell k} Q_{\ell k} \frac{t^k_{\ell k}}{t^k_{\ell k} + t^{\ell}_{\ell k}} \right),
$$

Residential, employment, and congestion forces Similar to the linear geography, we can express optimal infrastructure as a function of the residential, employment, and congestion forces. This decomposition entails just a re-writing of the equations above, but I believe it helps understand the forces behind the misallocation in infrastructure.

First, let us derive the edge-level commuting elasticity of travel demand, where we explicitly take into account the effect on the aggregates, L and U, holding the other prices, $q_{\mathrm{R}i}$ and w_j, fixed.

$$
\begin{aligned}
\varepsilon^{k\ell}_{ij} &\equiv -\frac{\partial L_{ij}}{\partial d_{k\ell}} \frac{d_{k\ell}}{L_{ij}} \\
&= -\frac{d_{k\ell}}{L_{ij}} \sum_{mn} \frac{\partial L_{ij}}{\partial \tau_{mn}} \frac{\partial \tau_{mn}}{\partial d_{k\ell}} \\
&= -\frac{d_{k\ell}}{L_{ij}} \left(\theta \frac{L_{ij}}{\tau_{ij}} \frac{\partial \tau_{ij}}{\partial d_{k\ell}} + \theta \frac{L_{ij}}{U} \sum_{mn} \frac{\partial U}{\partial \tau_{mn}} \frac{\partial \tau_{mn}}{\partial d_{k\ell}} - \frac{L_{ij}}{L} \frac{\partial L}{\partial U} \sum_{mn} \frac{\partial U}{\partial \tau_{mn}} \frac{\partial \tau_{mn}}{\partial d_{k\ell}} \right) \\
&= \theta \pi^{k\ell}_{ij} - \frac{Q_{k\ell}}{L} (\theta - \varepsilon_L)
\end{aligned}
$$

Where I used that:

$$
\frac{\partial \tau_{mn}}{\partial d_{k\ell}} = \frac{\tau_{mn}}{d_{k\ell}} \pi^{k\ell}_{ij}
$$

With this in mind, we can rewrite the main input into equation 28, $\phi_{k\ell}^{g(k)} \times Q_{k\ell}$, as a function of the residential, employment, and congestion forces:

$$\phi_{k\ell}^{g(k)} \times Q_{k\ell} = -\Big(\frac{1}{\sigma(t_{k\ell}^{k} + t_{k\ell}^{\ell})} + \rho\Big)^{-1} (Q_{\mathrm{R}k\ell}^{g} + Q_{\mathrm{F}k\ell}^{g} + Q_{\mathrm{C}k\ell}^{g})$$

With:

$$\begin{aligned}
Q_{\mathrm{R}k\ell}^{g} &= \sum_{ij} \left(\omega_{\mathrm{R}} \mathbb{1}_{i}^{g} w_j + \eta_{\mathrm{R}i}^{g} \frac{1-\alpha}{\bar{H}_{\mathrm{R}i}} w_j\right) \frac{L_{ij}}{d_{k\ell}} \varepsilon_{ij}^{k\ell} \\
Q_{\mathrm{F}k\ell}^{g} &= \sum_{ij} \left(\omega_{\mathrm{F}} \mathbb{1}_{j}^{g} w_j - \eta_{\mathrm{F}i}^{g} \frac{1-\beta}{L_{\mathrm{F}j}} w_j\right) \frac{L_{ij}}{d_{k\ell}} \varepsilon_{ij}^{k\ell} \\
Q_{\mathrm{C}k\ell}^{g} &= \sum_{ij} \left(\sum_{mn} \phi_{mn}^{g} \mathbb{1}_{ij}^{mn}\right) \frac{L_{ij}}{d_{k\ell}} \varepsilon_{ij}^{k\ell} - \rho \sum_{ij} \pi_{ij}^{k\ell} \Bigg(\sum_{mn} \phi_{mn}^{g} L_{ij} \pi_{ij}^{mn} - \\
&\quad \sum_{\ell} \phi_{j\ell}^{g} \sum_{m} L_{im} \pi_{im}^{j\ell} - \sum_{k} \phi_{ki}^{g} \sum_{m} L_{mj} \pi_{mj}^{ki} \Bigg)
\end{aligned}$$

Note that the residential and employment forces are the same as in the main text, in the linear geography example, in equations (21) and (22). On the other hand, the congestion force becomes more complicated. In particular, the additional terms capture how changes to the edge-level commuting costs, $d_{k\ell}$, affect the link intensity, $\pi_{ij}^{k\ell}$. In turn, the effect on link intensity will affect the routing decisions, and so I group these terms with the congestion force.

A.4 Linear City

For the linear city example in the main text, I model productivity as follows:

$$\bar{A}_x = \frac{e^{-\delta x}}{\sum_i e^{-\delta i}}.$$

With this function, productivity always averages one in the metropolitan area. The δ parameter controls how more productive central locations are than peripheral locations, but the mean is always one.

Table A.1: Parameter values

Parameter	Description	Value
$(1-\alpha)$	Land share of utility	0.25
$(1-\beta)$	Land share of production	0.20
$\bar{U}_o$	Reservation utility	1
δ	Productivity dispersion	0.15
σ	Congestion elasticity	0.06
ξ	Infrastructure elasticity	0.11
θ	Commuting elasticity	6.8
μ	Migration elasticity	4

A.4.1 Edge-level commuting elasticity of travel demand

Let us derive the partial derivative of L_{ij}, where we explicitly take into account the effect on the aggregates, L and U, holding the other prices, $q_{\mathrm{R}i}$ and w_j, fixed.

$$\begin{aligned}
\frac{\partial L_{ij}}{\partial d_{k\ell}} &= \sum_{mn} \frac{\partial L_{ij}}{\partial \tau_{mn}} \frac{\partial \tau_{mn}}{\partial d_{k\ell}} \\
&= -\theta \frac{L_{ij}}{\tau_{ij}} \frac{\partial \tau_{ij}}{\partial d_{k\ell}} - \theta \frac{L_{ij}}{U} \sum_{mn} \frac{\partial U}{\partial \tau_{mn}} \frac{\partial \tau_{mn}}{\partial d_{k\ell}} + \frac{L_{ij}}{L} \frac{\partial L}{\partial U} \sum_{mn} \frac{\partial U}{\partial \tau_{mn}} \frac{\partial \tau_{mn}}{\partial d_{k\ell}} \\
&= -\frac{L_{ij}}{d_{k\ell}} \left(\theta 1_{ij}^{k\ell} - \frac{Q_{k\ell}}{L} (\theta - \varepsilon_L) \right)
\end{aligned}$$

where I used the fact that $\frac{\partial \tau_{mn}}{\partial d_{k\ell}} = \frac{\tau_{mn}}{d_{k\ell}} 1_{mn}^{k\ell}$.

Then, the edge-level commuting elasticity of travel demand is given by,

$$\begin{aligned}
\varepsilon_{ij}^{k\ell} &\equiv -\frac{\partial L_{ij}}{\partial d_{k\ell}} \frac{d_{k\ell}}{L_{ij}} \\
&= \theta 1_{ij}^{k\ell} - \frac{Q_{k\ell}}{L} (\theta - \varepsilon_L)
\end{aligned}$$

A.4.2 Land value transfers

In the main model specification, local governments own the land. They capture all the land value of the locations within their jurisdiction, pay for infrastructure, and consume the remaining land value in the numeraire good. Hence, we can consider their objective function in equation (17) as the governments' consumption.

Another alternative is transferring the remaining land value (after paying for the roads) as a wage subsidy back to households. That is, consider the following transfer

$$\pi = \frac{\sum_i \{q_{\mathrm{R}i}\bar{H}_{\mathrm{R}i} + q_{\mathrm{F}i}\bar{H}_{\mathrm{F}i}\} - \sum_{k\ell} \delta^{\mathrm{I}}_{k\ell}\mathrm{I}_{k\ell}}{\sum_{ij} L_{ij} w_j}. \tag{A.5}$$

Note that the remaining land rents are pooled at the metropolitan area level, not at the local government level, such that all households receive the same subsidy. A government-specific subsidy would introduce an additional incentive for households to reside in "rich" municipalities (municipalities with higher land value), distorting the population distribution.

Given the above subsidy, households employed in location j would have income $y_j = (1 + \pi)w_j$. That would affect the following equations:

$$q_{\mathrm{R}i} = \frac{1-\alpha}{\bar{H}_{\mathrm{R}i}} \sum_j L_{ij} y_j,$$

$$L_{ij} = \tau_{ij}^{-\theta} \left(\frac{\bar{B}_i}{q_{\mathrm{R}i}^{1-\alpha}} \right)^{\theta} y_j^{\theta} \frac{L}{U^{\theta}},$$

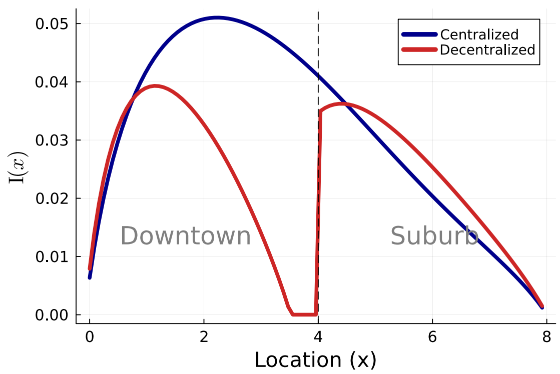
$$U = \left(\sum_{ij} \tau_{ij}^{-\theta} \left(\frac{\bar{B}_i}{q_{\mathrm{R}i}^{1-\alpha}} \right)^{\theta} y_j^{\theta} \right)^{\frac{1}{\theta}}.$$

I solve the government's problem and consider the two equilibria, centralized and decentralized, given this wage subsidy from land value. Note that local governments take into account equation (A.5) when solving their optimal investment problem.

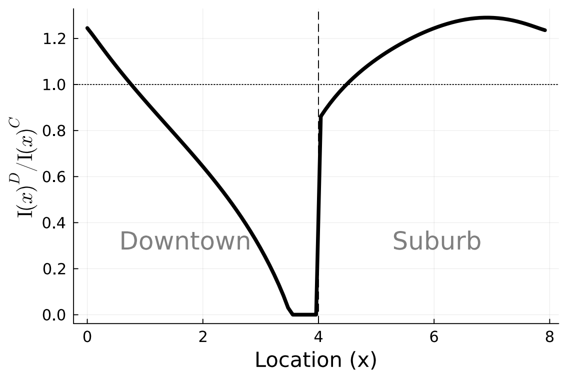
Figure A.1 shows the optimal investment with these land value transfers. I am using the same parameter values as in the linear city example in the main text. Note that the distortions from decentralization are amplified given the land transfers. First, these subsidies increase the implicit weight placed on attracting residents relative to workers, amplifying the underinvestment in Downtown locations and the overinvestment of the Suburb. Second, there is now a "cost exporting" incentive, driving the overinvestment of Suburb. Increasing road expenditure reduces the wage subsidy for everyone, but Downtown has a larger share of residents than the Suburb and, therefore, absorbs more of the infrastructure cost.

Figure A.1: Decentralized vs Centralized Infrastructure

(a) Optimal Infrastructure



(b) Relative Infrastructure: I^g/I^*



A.4.3 Uniqueness of Nash Equilibrium

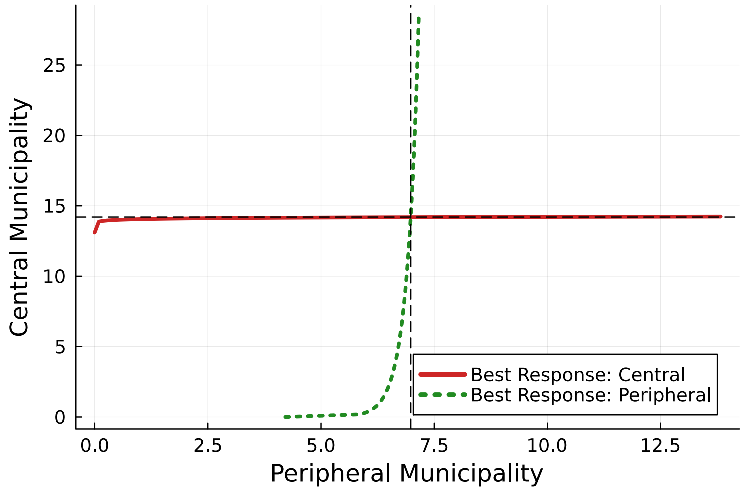
One potential concern is whether the Nash equilibrium between the two municipalities—Downtown and Suburb—is unique. In this model, investments by the municipalities are strategic complements: the benefit of investing in one link increases with the level of investment in connected links. An extreme illustration is a bridge shared by two jurisdictions, with each responsible for one half. Investment in one half is worthless if the other half is not built.

I explore this issue numerically in the linear geography setting. Specifically, I solve the problem defined in Section 2.1.4, constraining one government (denoted f) to a fixed budget B^f. Government f allocates this budget optimally within its jurisdiction but cannot spend more or less than B^f. I then compute the best response of government g as a function of B^f:

$$I^g_{k\ell} = I^g_{k\ell}\left(B^f\right)$$

Figure A.2 plots total road investment by government g in response to government f's total spending. As expected, the best response function is increasing, consistent with investment complementarity. However, the complementarity is weak enough to produce a single crossing, indicating a unique equilibrium in this case.

Figure A.2: Best response functions



This single-crossing result depends on ruling out zero investment on any link by imposing a lower bound $\mathrm{I}k\ell > \underline{\mathrm{I}}$. Intuitively, this assumes that even if no formal investment occurs, individuals can still cross—e.g., by walking—so the commuting cost $dk\ell$ remains finite. This eliminates multiplicity at municipal borders. Note, however, that Figure A.2 shows aggregate investment, not just investment at the border.

A.5 Computation Algorithm

To compute the equilibrium of the economy, both in the centralized and decentralized scenario, I use the following procedure, summarized in pseudo-code as follows:

1. Given a city equilibrium $\mathbf{x} = \{L_{ij}, q_{\mathrm{R}i}, q_{\mathrm{F}j}, Q_{k\ell}, d_{k\ell}\}$, I compute the Lagrange multipliers $\lambda = \{\eta_{\mathrm{R}i}, \eta_{\mathrm{F}j}, \phi_{k\ell}\}$: This implies inverting a linear system of equations of size $2N + E$, where N is the number of locations and E is the number of edges. The system of equations is given by equations (A.1), (A.3), and (A.4).[20]

2. Given $\mathbf{x}$ and λ, I compute the optimal infrastructure $\mathrm{I}^g_{k\ell}$ using equation (28).

3. Given the new network of infrastructure $\mathrm{I}^g_{k\ell}$, I compute the equilibrium of the city $\mathbf{x}$: I solve for $\mathbf{x}$ by solving a non-linear system of equations given by equations (6), (8), (9), (12), (13), (14), (15), and (2).

In the decentralized case, I compute step 1 for every government and recover λ^g, for $g \in \mathcal{G}$. One useful property of how I partition the problem in the procedure above is that λ^g

[20]Note that given $\mathbf{x}$, this is a linear system of Lagrange multipliers, so it is computationally fast to solve.

depends on other governments' decisions only through $\mathbf{x}$ and is not a function of $\lambda^{g'}$ directly. Therefore, I can independently solve the linear system of equations for each government.

B Empirical Appendix

B.1 Santiago's economic, geographic, and political context

In this section, I provide additional information about Santiago's context. Including exogenous characteristics, such as altitude, and endogenous characteristics, such as the distribution of population and employment, socio-economic status in space, and urban density.

Figure B.1(a) shows the altitude of different locations within the city in meters. The black lines correspond to the municipalities' borders. Note that there are important differences in altitude across city locations, with the altitude more than doubling from the west to the east. For this reason, I control for altitude and slope in the empirical analysis and estimation. Figure B.1(b) shows the distribution of socio-economic quintiles in the city, calculated using the 2017 population census. Richer households are concentrated in the city's northeast, towards the mountains. Lower-income households live primarily in the West.

Figure B.1: Build density and altitude

(a) Altitude

(b) Socio-economic status

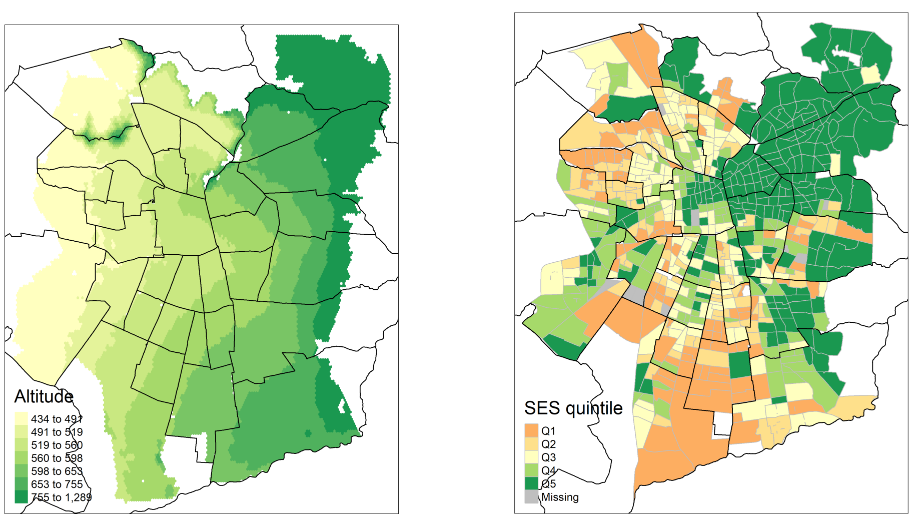
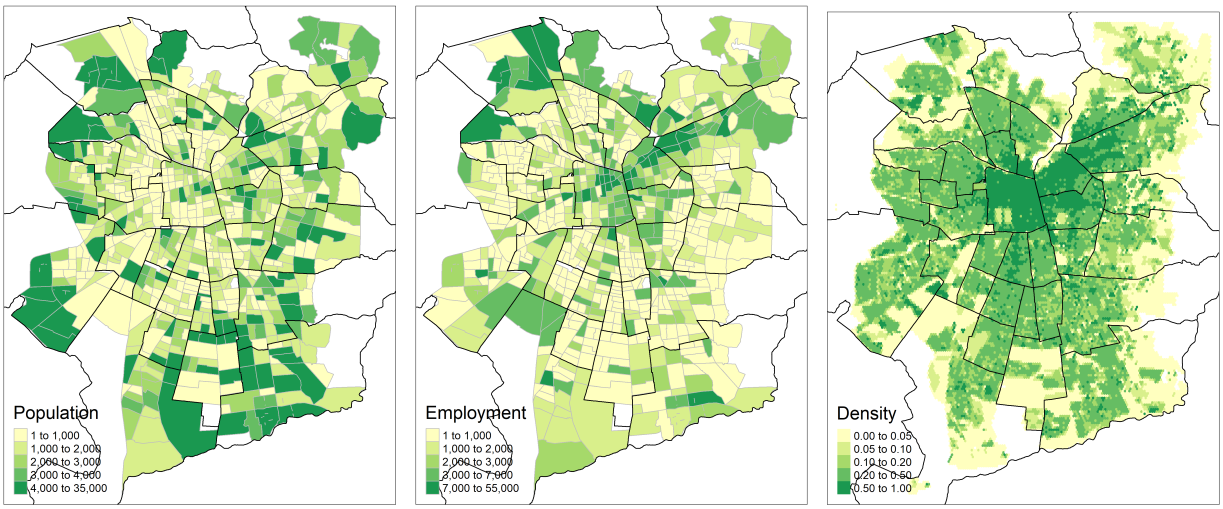


Figure B.2 shows the distribution of residents, workers, and urban density throughout the city. Using the travel survey, I calculated the distribution of residents and workers by location. Residents live everywhere in the city and are more concentrated in the periphery of the city. Employment is more concentrated than the residential population, located in the city center and the north of the city. Figure B.2(c) is the urban density, defined as total floor space over land area. Hence, this figure shows urban density both from commercial and residential floor space. As usual, the city is denser at the center, where employment is high.

Figure B.2: Santiago's metropolitan area economic geography

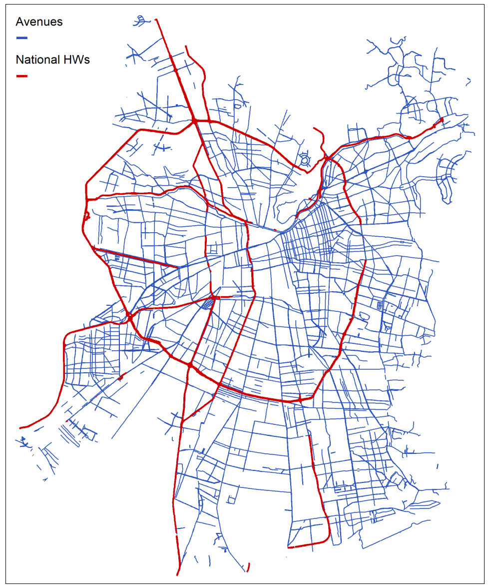
(a) Residential Population (b) Employment (c) Urban Density



Note: The darker black lines correspond to the municipalities' borders. The smaller geographical units inside are the Origin-Destination survey locations.

Figure B.3 shows the distribution of roads by ownership. In red, I plot the highways which are paid and managed by the national government. In blue, I plot the main avenues managed by local municipalities. Most of large roads are municipal, 83% of avenues or highways are under municipal management. If we expand the analysis to all roads, 96% of all road segments are managed by municipalities.

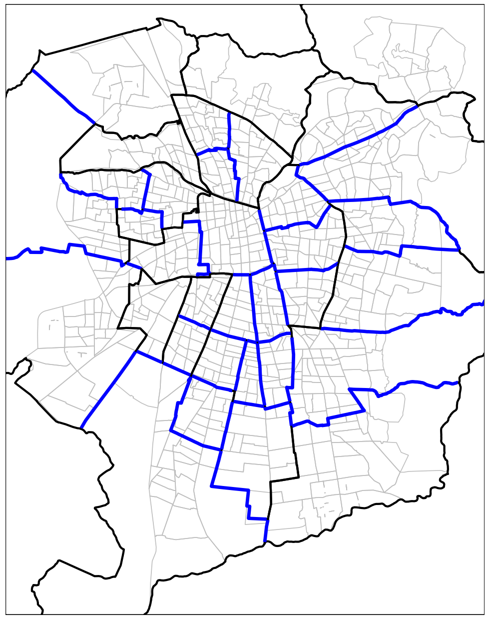
Figure B.3: Santiago's road network



B.2 Discontinuity in infrastructure

This section explains how I construct the investment pattern at the boundary documented in Figure 9(a). First, boundaries between municipalities are not exogenous. Hence, we might worry that boundaries tend to coincide with geographical faults such as waterways and mountains and that these geographical characteristics affect infrastructure through building costs. With this concern in mind, I select a subset of 44 borderlines with smooth geographical characteristics that do not coincide with a highway. The resulting set of borders is shown in the following figure:

Figure B.4: Selected Borders



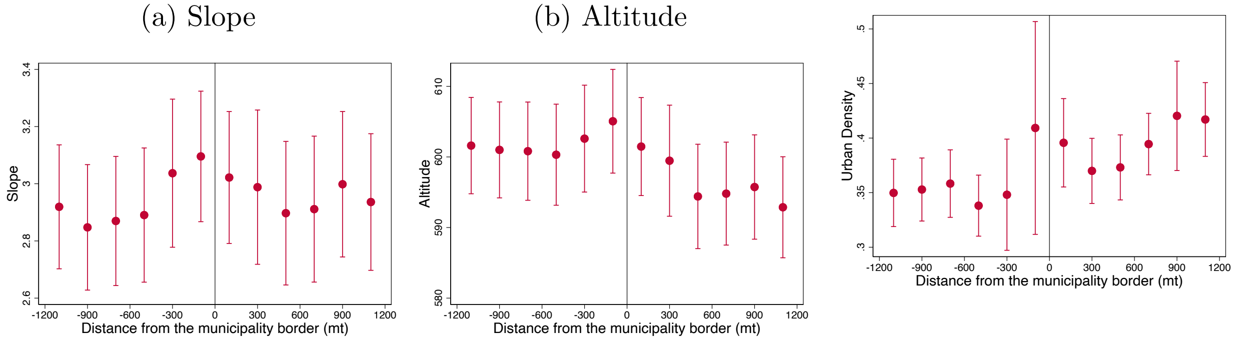
Note: In black, I plot the municipality boundaries. In blue, I plot the selected borders.

Finally, for this sample of borders, I consider whether exogenous characteristics of the terrain, such as slope or altitude, vary systematically around the border. For example, if borders tend to coincide with either high or low-altitude points, we would expect the slope to increase closer to the border. The following figure shows that there are no clear patterns in slope or altitude around the boundary and that there is no discontinuity in these variables.

In Figure B.5(c), I plot an endogenous variable, urban density, defined as total floor space over area. There is no clear discontinuity in urban density at the boundary between municipalities, but, more importantly, urban density is not increasing as a function of distance to the boundary. This fact is important: declining urban density (and therefore demand) closer to the boundary does not explain why road density is lower closer to the boundary.

Figure B.5: Balance at the border

(a) Slope (b) Altitude (c) Urban Density



To estimate the size of the jump and slope at the border between municipalities, I run the following regression:

$$\mathrm{I}_i = \beta \mathbb{1}(\text{Distance}_i > 0) + \gamma \text{Distance}_i + \mu \text{Distance}_i \times \mathbb{1}(\text{Distance}_i > 0) + \beta X_i^{\text{Geo}} + \delta_{B(i)} + \epsilon_i$$

where i denotes an individual location, in this case, grid cell i. I control for distance to the border, allowing the slope to vary on each side of the border. As it is clear in Figure 9(a), the slope is increasing the absolute value of the distance to the border. Finally, I control for border (municipality-pair) fixed effects and for the terrain's slope and altitude.

I also run the above regression allowing for a quadratic function of distance, where I also interact the quadratic term with the border dummy. Table B.1 shows the estimated discontinuity. Note that I vary the bandwidth size around the border, where the first two columns are estimated with a bandwidth of 1.2 km (0.75 miles) around the border, and the third and fourth columns use half the bandwidth: 0.6 km (0.37 miles). The average jump varies between 1pp and 1.5pp more road density. The sample's average infrastructure is 0.1; that is, roughly 10% of land allocated to roads. Hence, the estimated jump corresponds to approximately a 10 to 15% change in the infrastructure level.

Table B.1: Discontinuity in infrastructure at the border

	<1200 mt		<600 mt	
	(1)	(2)	(3)	(4)
	Linear	Quadratic	Linear	Quadratic
$\mathbb{1}$(Distance>0)	0.0138***	0.0105*	0.0149***	0.0102
	(0.00376)	(0.00575)	(0.00528)	(0.00931)
N	13013	13013	6614	6614
Border FE	Yes	Yes	Yes	Yes

Standard errors in parentheses

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

B.3 Testing local government's incentives in the data

In this section, I provide evidence suggesting that local governments prioritize building infrastructure in areas that benefit their own residents and workers. That is, for areas with similar total traffic flows and other observable characteristics, there is more infrastructure (road density) in locations where the traffic flows are primarily composed of the municipality's own residents and workers.

Following a similar approach to Section 3.3, where I document the discontinuity in infrastructure at the border between municipalities, I construct a measure of infrastructure, traffic flows, residential flows, and employment flows in space. The spatial units are given by a grid of hexagonal cells over the city's area. With this grid structure in mind, let us define the following local flows.

- *Residential flows:* Commuters traveling through grid k located in municipality g, that are residents of g.

$$Q^g_{\mathrm{R}k} = \sum_{ij} \mathbb{1}^k_{ij} L_{ij} \mathbb{1}[i \in \mathcal{J}^g]$$

- *Employment flows:* Commuters traveling through grid k located in municipality g, that work in locations within g.

$$Q^g_{\mathrm{F}k} = \sum_{ij} \mathbb{1}^k_{ij} L_{ij} \mathbb{1}[j \in \mathcal{J}^g]$$

- *Total traffic flows:* All commuters traveling through grid k.

$$Q_k = \sum_{ij} \mathbb{1}_{ij}^k L_{ij}$$

These residential and employment traffic flows are a simpler parallel of the residential and employment forces defined in the model. Instead of weighing each commuter by the full government-specific marginal value implied by the model, I only account for whether they live or work within the government providing the road.

We observe travel demand from residence i to the work location j, L_{ij}, in the data directly from the travel survey. I use the same sample of locations used to estimate the model parameters: the 700 central locations within the city's urban limit. The indicator function, $\mathbb{1}_{ij}^k$, indicates whether the origin-destination ij travels through the grid cell k. I construct this indicator by calculating the real network's least-cost path route using Open Street Maps. Locations in the travel survey are, on average, polygons of roughly 1 km by 1 km. Naturally, the shortest route might differ depending on where the trip starts or ends within these polygons. Hence, to capture a more realistic commuting pattern, for each pair of origin-destination with $L_{ij} > 0$, I take a sample of 10 random points within the polygons where the sample uses the census population at the block level as weights.

With all these ingredients, I can construct total traffic flows and residential and employment flows from the municipality's perspective that controls grid cell k. I also construct a measure of infrastructure in the data, following the same approach as in Section 3.3, defining infrastructure as the percentage of area covered by roads. That is the sum of the road segments within the polygon, weighted by the width of each road, divided by the total area of the cell.

The main objective of this analysis is to test my assumption about the objective function of local governments, that is, to determine whether municipalities build more infrastructure in locations with higher residential and employment flows. However, there are important empirical challenges when taking this prediction to the data. The main one is that traffic flows are endogenous to the infrastructure, i.e., infrastructure and commuting flows have a simultaneity issue: municipalities build more infrastructure where there are more traffic flows, and, in turn, more infrastructure leads to more traffic flows.

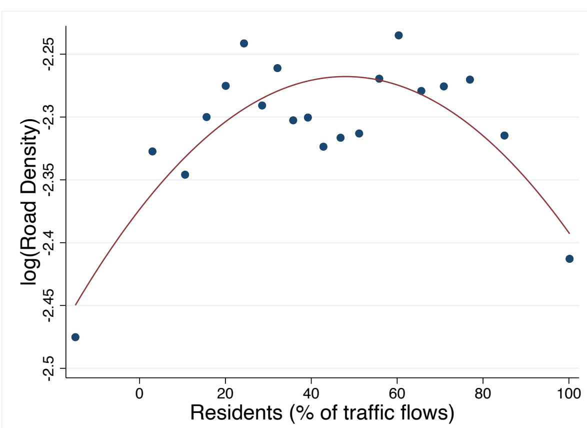
To address this concern, I control for overall log traffic flows. If we think about traffic flows as demand and infrastructure as supply, the idea is to compare locations with similar overall demand levels. However, supply can be different if it responds to the composition of the demand. The municipality invests in roads that are strategic for their own residents or firms, but households are indifferent to who built the road.

A second concern is differences in building costs, which are unobserved. To address this concern, similar to Section 3.3, I again focus on the area around the boundary between municipalities, and I consider only the boundaries that have smooth geographical features and do not coincide with a highway. This approach assumes that the building costs are the same at both sides of the border. Moreover, in the following analysis I control for border fixed-effects to account for differences in buildings costs across borders. Finally, I also control for municipality fixed-effects to account for any municipality-specific differences in overall infrastructure, such as differences in budgets, zoning plans, etc.

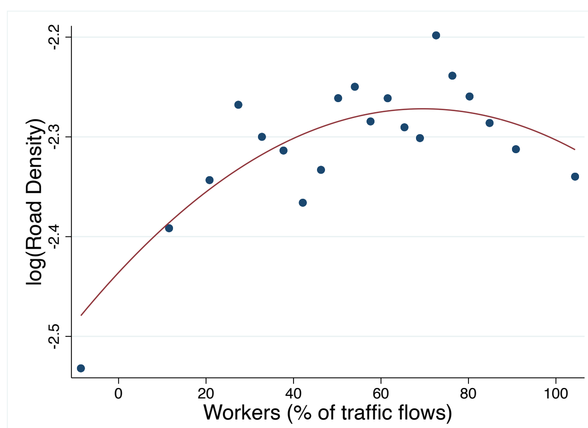
Figure B.6 shows the relationship between infrastructure and local flows in the data. On the left, Figure B.6(a) shows the relationship between log-road density and the percentage of commuters who are residents. There is an inverted U-shape relationship between the residential flows and road density, where road density declines for areas with a majority of local residents. However, this decline would be explained by the demand for small residential roads, used solely by the local residents to access bigger avenues and primary roads. On the right, Figure B.6(b) shows the relationship between log-road density and the percentage of commuters who are workers. This figure shows a positive correlation between the two variables.

Figure B.6: Infrastructure and local flows

(a) % of commuters who are residents



(b) % of commuters who are workers



Note: These bin-scatters include border and municipality fixed-effects.

Table B.2 shows the magnitude of these correlations, controlling for log traffic flows, border and municipality fixed-effects. Focusing first on column (1), we can see a positive and statistically significant correlation between the fraction of local commuters (residents and workers) and local road density. However, the correlation is much stronger for the fraction of commuters who are workers than the fraction who are residents. This result is consistent with the inverted U-shape pattern documented in Figure B.6(a). In column (2), I drop the areas where more than 90% of the commuters are residents, and we can see that then the coefficients for the residential fraction and the employment fraction are similar in size.

Table B.2: Infrastructure and local flows

	(1) log(Road Density) *Full Sample*	(2) log(Road Density) *Fraction Residential < 90%*
log(Traffic Flows)	0.175***	0.177***
	(0.00342)	(0.00359)
Residential Fraction	0.0537***	0.214***
	(0.0200)	(0.0232)
Employment Fraction	0.179***	0.194***
	(0.0207)	(0.0222)
N	10142	8783
Border FE	Yes	Yes
Municipality FE	Yes	Yes

Standard errors in parentheses

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

We can interpret this correlation as the following: for areas with similar overall traffic flows and building costs and within the same municipality, there is more road density in areas where a larger fraction of commuters are residents. In turn, there is more road density in areas where a larger fraction of commuters are workers.

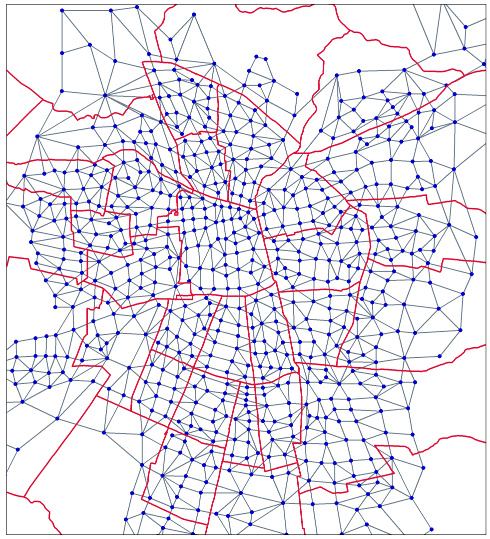
B.4 Estimation of the model's parameters

B.4.1 Building the network

I build the network of edges using the shapefiles for the 700 locations from the travel survey. Locations that neighbor each other are connected by an edge in the network. I exclude neighbors that only touch in one point (for example, two squares that touch in a vertex rather than sharing a border). Figure B.7 shows the resulting network of locations and their connections (edges).

The resulting network is composed of 700 nodes and 3442 directed edges.

Figure B.7: Network of nodes and edges



B.4.2 Estimating the infrastructure elasticity, ξ

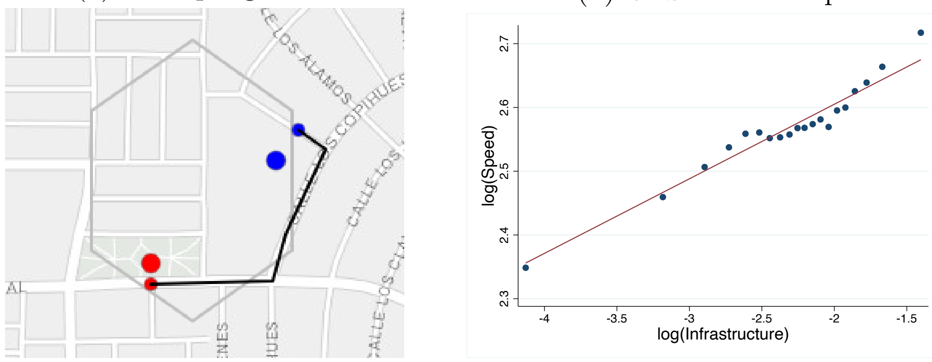
I estimate the infrastructure elasticity, ξ, by estimating the effect of more infrastructure on travel speed. I exploit the discontinuity in infrastructure at the border between municipalities as a plausibly exogenous variation on the amount of infrastructure and estimate the effect of that shift in infrastructure on average commuting speed. I use the same set of borders as in the discontinuity in infrastructure analysis described in Appendix B.2.

The identifying assumptions behind this strategy are that unobserved omitted variables that might affect infrastructure and speed are continuous at the border. Second, the exclusion restriction for the instrument of crossing the border has to hold; that is, crossing the border only affects the speed of travel through the available infrastructure.

I compute speed using the same grid of hexagonal polygons used to calculate infrastructure in space. For each grid cell, I take a random sample of origin and destination points within the polygon and then use Open Street Map to calculate the travel time and distance between these two points in the road network. Finally, I add the walking time and distance from the origin and destination to the road network, assuming a walking speed of 4.5 km/hr.

Figure B.8(a) shows an example of a grid cell. The larger red and blue dots show the original random origin and destination points. The smaller dots are the closest points in the road network to the origin and destination. Open Street Maps provides the distance and time of traveling through the road network, highlighted in black. Finally, I add the walking time and distance to adjust for the fact that the original origin and destination are not in the road network.

(a) Example grid cell (b) OLS relationship



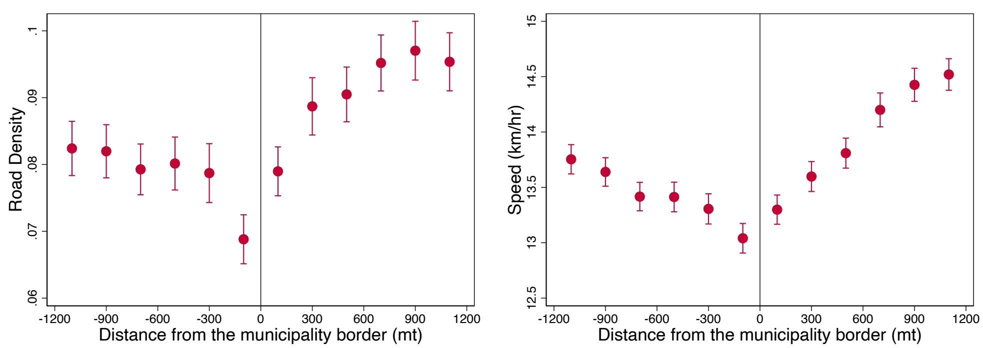
Note: In (b), I control for log(Flows), urban density, slope, and altitude.

Figure B.8(b) shows the OLS relationship in the sample of grid cells between the infrastructure, defined as the percentage of the area allocated to commuting infrastructure, and the speed calculated according to the above procedure.

Now, with a set of speed measurements for every grid cell in the 1.2 km buffer around the municipality borders, we can use the discontinuity in infrastructure at the border and relate that jump to the difference in speed around the border.

Figure B.9: Discontinuity at the border

(a) Infrastructure (b) Speed



I estimate ξ through the following 2SLS strategy

$$\begin{aligned}\text{First stage: } & \log(\text{Infrastructure}_i) = \alpha \mathbb{1}(\text{Distance}_i) + f(\text{Distance}_i) + \beta X_i^{\text{Geo}} + \epsilon \\ \text{Second stage: } & \log(\text{Speed}_i) = \xi \widehat{\log(\text{Infrastructure}_i)} + f(\text{Distance}_i) + \gamma X_i^{\text{Geo}} + \epsilon\end{aligned}$$

where $\widehat{\log(\text{Infrastructure}_i)}$ is the predicted value from the first stage. I control for a linear function of distance to the border, where I allow for different slopes on each side. I also control for geographical characteristics of the terrain, such as slope, altitude, and urban density. Intuitively, we are running a regression of log speed on log infrastructure, where we are instrumenting infrastructure using the municipality border.[21]

Table B.3 shows the results for different distance functions.

Table B.3: Spatial Regression Discontinuity

	OLS	IV		
	(1)	(2)	(3)	(4)
	<1200 mt	<1200 mt	<1000 mt	<800 mt
log(Infrastructure)	0.155***	0.0913**	0.106***	0.119***
	(0.00161)	(0.0365)	(0.0397)	(0.0424)
N	113848	113848	94490	75740
Border FE				

Standard errors in parentheses

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

B.4.3 Inverting edge's characteristics

In this section, I describe how I parametrize and estimate the characteristics of an edge on the network that affect travel times. First, I reformulate equation (27) as a function of the edge's length and the inverse speed. Hence, we can think about traffic flows, infrastructure, and exogenous characteristics as independent of the length of the edge. For example, we can

[21] I weigh the observations using the grid cell's areas. I intersect the grid cells with the government boundaries. Therefore, some grid cells at the boundary are smaller in size.

think about infrastructure as the density or width of roads.

$$\begin{aligned}\text{time}^k_{k\ell} &= \bar{t}^{0,k}_{k\ell} + \bar{t}^{1,k}_{k\ell}\frac{Q^\sigma_{k\ell}}{(\mathrm{I}^k_{k\ell})^\xi}\\ &= \text{length}^k_{k\ell} \times \left(\tilde{t}^{0,k} + \tilde{t}^{1,k}_{k\ell}\frac{Q^\sigma_{k\ell}}{(\mathrm{I}^k_{k\ell})^\xi}\right)\end{aligned}$$

First, I use the Google Maps API to calculate the travel time for each edge during peak hours on a weekday. Through this procedure, I get a measurement of $\{\text{time}^k_{k\ell}, \text{time}^\ell_{k\ell}\}$ for every $k\ell$. Since I already have values for ξ and σ at hand, in order to invert the edge characteristics, $\tilde{t}^{0,k}_{k\ell}$ and $\tilde{t}^{1,k}_{k\ell}$, I need measurements of infrastructure, $\mathrm{I}_{k\ell}$, and traffic flows, $Q_{k\ell}$.

For every edge, I compute a proxy for the current infrastructure level, $\mathrm{I}_{k\ell}$, by using the information on the Open Street Maps road network. Similarly to how I approximate infrastructure to show the patterns of road density around the border, I take a buffer around the connecting line between the two centroids of the neighboring polygons and calculate the percentage of land allocated to commuting infrastructure in that buffer. Since I divide each edge (k, ℓ) in two, the half on the side of k and the half on the side of ℓ, I measure two road densities for each edge.

For every edge, I measure two types of infrastructure: national and municipal. Let $\bar{\mathrm{I}}^k_{k\ell}$ be the road density in k's side of edge (k, ℓ) provided (funded and maintained) by the national government. In the counterfactual analysis, I take this infrastructure as given, that is, it affects households' travel times, but it does not enter into the municipality's expenditure. We can rewrite travel times as:

$$\text{time}^k_{k\ell} = \text{length}^k_{k\ell} \times \left(\tilde{t}^{0,k} + \tilde{t}^{1,k}_{k\ell}\frac{Q^\sigma_{k\ell}}{(\bar{\mathrm{I}}^k_{k\ell} + \mathrm{I}^k_{k\ell})^\xi}\right)$$

That is, national and municipal infrastructure are perfect substitutes from the perspective of travel times. I don't observe traffic flows directly in every edge. I proxy for traffic flows by using the travel demand data from the travel survey, L_{ij}, and the edge-intensity implied by the model. The edge intensity, $\pi^{k\ell}_{ij}$, I construct using the observed edge-level travel times from Google Maps, κ, and ρ, according to,

$$d_{k\ell} = \exp\left(\kappa\left\{\text{time}^k_{k\ell} + \text{time}^\ell_{k\ell}\right\}\right), \quad \tau_{ij}^{-\rho} = (\mathbf{I} - \mathbf{A})^{-1},$$

where $\mathbf{A} \equiv [d^{-\rho}_{k\ell}]$.

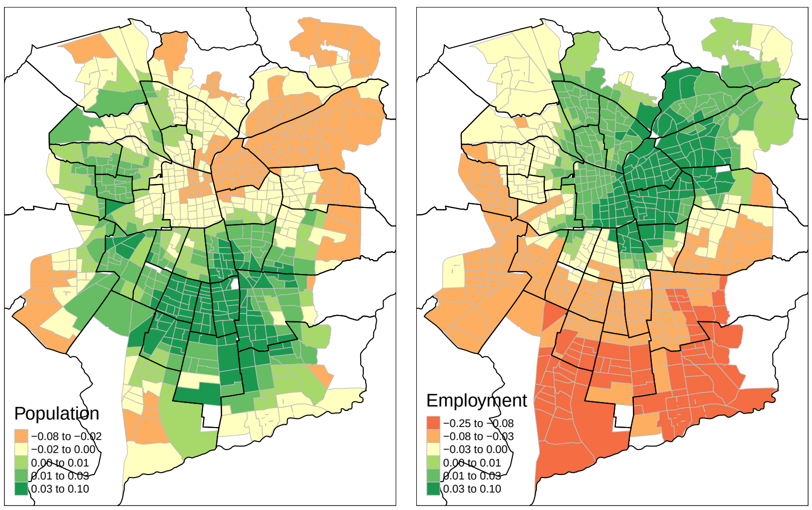
I calibrate the value of $\tilde{t}^{0,k}_{k\ell} = \tilde{t}^0$, that is, a minimum inverse speed that is constant across edges. I set $\tilde{t}^0 = 1/2000$, which implies a maximum speed of 120 km/hr. With this value of $\tilde{t}^0$, then the exogenous speed shifter, $\bar{t}_{k\ell}$, is such that I perfectly match the observed travel times. That is,

$$\tilde{t}^{1,k}_{k\ell} = \left(\frac{\text{time}^k_{k\ell}}{\text{length}^k_{k\ell}} - \tilde{t}^0\right) \frac{(\bar{\mathrm{I}}^k_{k\ell} + \mathrm{I}^k_{k\ell})^\xi}{Q^\sigma_{k\ell}}.$$

B.5 Counterfactual Analysis

Figure B.10: Constrained + Land value counterfactual: Changes to the city's population

(a) Residents (b) Employment



Note: These figures show the increase relative to the baseline (decentralized) equilibrium. For example, the change in residents is calculated as $\Delta L_{\mathrm{R}i} = \frac{L^C_{\mathrm{R}i} - L^g_{\mathrm{R}i}}{L^g_{\mathrm{R}i}}$.