Commuting Infrastructure in Fragmented Cities*

Olivia Bordeu†

December 29, 2023

Click here for the latest version.

Abstract

Cities are divided into local governments responsible for local commuting infrastructure that is used by both their residents and outsiders. In this paper, I study how metropolitan fragmentation affects the provision of commuting infrastructure and the 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 in their jurisdictions. In equilibrium, relative to a central metropolitan planner, municipalities underinvest in areas near their boundaries and overinvest in core areas away from the boundary. Infrastructure investment in fragmented cities results in higher cross-jurisdiction commuting costs, more dispersed employment, and more polycentric patterns of economic activity. Estimating the model using data from Santiago, Chile, I find substantial gains from centralizing investment decisions. Centralization increases aggregate infrastructure investment and population. More importantly, for a given amount of investment, centralization yields large welfare gains due solely to more efficient infrastructure allocation.

*I am grateful to my advisors Esteban Rossi-Hansberg, Erik Hurst, Jonathan Dingel, and Milena Almagro for their continued guidance, support, and encouragement. This paper also benefited from insightful comments from Rodrigo Adao, Felix Tintelnot, Rick Hornbeck, Robert Shimer, Daniel Sturm, Marta Santamaria, and other seminar participants at the University of Chicago and the CEP-Warwick Junior trade workshop. I thank George Colligan, Marcos Sorá, Santiago Franco, Pauline Mourot, Lucy Msall, Aleksei Oskolkov, Thomas Bourany, Jordan Rosenthal-Kay, Juanma Castro-Vincenzi, Sebastian Otero, and Nano Barahona for repeated feedback and discussions. All errors are my own.

†University of Chicago, Booth School of Business. obordeug@chicagobooth.edu.

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 infrastructure investment for transportation purposes. 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 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 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 municipal-

[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] If households are mobile, welfare benefits of local public goods will be capitalized into land values (Starrett, 1981).

ities. 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.

The theoretical framework has two core predictions about infrastructure misallocation in the decentralized equilibrium relative to centralized metropolitan planning. The first prediction is about the pattern of investment *within* municipalities, and the second prediction is about 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. 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

[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.

Chile. Santiago's metropolitan area is divided into 34 municipalities, and each has control over transportation planning within its own boundaries. Municipalities' two main sources of tax revenue, aside from transfers, 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.

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 collect data on travel speed across different locations in the city and combine these data with administrative data on traffic flows to estimate the congestion elasticity of travel times. Third, 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.

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 77% higher. In response to the new infrastructure, the city would be 5% larger in population, and welfare would be 2.3% 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

[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).

amount as in the decentralized equilibrium. By shifting infrastructure towards the locations that underinvest the most, the constrained metropolitan planner achieves 65% 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.

The municipalities with the biggest gains in net land value from centralization are the ones where poor households live today. Lower-income households are concentrated in municipalities in the south and west peripheries. These locations are far from the productive areas where jobs are located and are next to the municipalities that most underinvest in the baseline scenario. As a result, lower-income households commute farther and through areas with fewer roads than their higher-income counterparts. Therefore, lower-income households would benefit the most from the increased investment in the municipalities they must commute through to get to work.[5]

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. Another important benefit of decentralization is enhancing competition across governments, as households can "vote with their feet."[6]

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). An important related paper in this literature is Jannin and Sotura (2020). They are the first to 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.

[5]Note that the theoretical framework in this paper does not account for household income heterogeneity; therefore, the counterfactual analysis is not suitable to study how the income composition of municipalities would change in response to the new infrastructure.

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

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

In developing this model, I borrow and contribute to the literature on quantitative spatial economic model (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 quantitative 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 infrastructure 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.

Studying commuting flows presents an additional technical challenge compared to the flow of goods, especially in a network structure. A key result in Fajgelbaum and Schaal (2020) is that goods are transported through the network based on price differences. Producers will only opt to transport a particular good through a network link if the price gap between the link's endpoints justifies the transportation cost. In the context of urban commuting, individuals might travel to locations with lower wages or travel through areas with lower wages to access areas with higher wages. My paper contributes to this body of research by offering a framework that studies optimal commuting networks. This framework accounts for the more idiosyncratic travel behavior of commuters compared to the transportation of goods. Furthermore, I contribute by studying how political forces, such as decentralization, lead to suboptimal infrastructure networks.

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 sub-optimal 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). Baum-Snow (2007) and Brinkman and Lin (2022) document that highways resulted in central-city population decline, hurting inner cities and benefiting the suburbs.[7] 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 departmental 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.

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.

[7] Other related papers on this literature are Zárate (2020), Donaldson and Hornbeck (2016) and Hornbeck and Rotemberg (2019).

2 Model

This section presents the theoretical framework the paper. First, I describe the main ingredients of the model and define the equilibrium of the metropolitan area. Second, I use a simpler version of the model, a linear city, to illustrate the key economic forces of the model that drive the results of the theory. Then, I briefly discuss how the intuition and results from the linear city translate to the full network structure.

2.1 Environment

This section presents a general equilibrium model of a metropolitan area composed of multiple locations populated by households that choose where to live and work and commute between these locations. The metropolitan area is divided into local governments that optimally invest in commuting infrastructure to maximize their land value. The model provides a framework to study the equilibrium infrastructure and city structure as a function of the local governments' incentives and metropolitan political fragmentation.

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 j is endowed with a fixed supply of land for residential purposes, $\bar{H}_{Rj}$, and a fixed supply of land for production purposes, $\bar{H}_{Fj}$. 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.

Intuitively, we can think of the underlying graph as a metropolitan area composed of J city blocks, where geographically contiguous blocks are connected by an edge. Workers commute from their residency to their workplace through the network, traveling through multiple edges. Different city blocks and streets (edges) belong to different local governments.

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 a 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,[8]

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

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 in the metropolitan area. Finally, they choose a commuting route between their home and work locations.[9]

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 $\epsilon_{cij,r}(\nu)$.

[8] For a more detailed derivation of the firm's problem, see Appendix A.1.

[9] Households make these three decisions simultaneously.

These are drawn independently across households according to a Generalized Extreme Value (GEV) distribution:

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

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.[10] 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.[11] Before describing each in more detail, it is helpful to define the following indexes:

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

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

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:

[10] For a more detailed derivation of the household's problem, see Appendix A.2.

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

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

where U is given by equation (6) and is the expected utility of choosing to live in the metropolitan area. The better the expected utility of living in the metropolitan area relative to the outside option, the more people choose to live there. This model of population supply to the metropolitan area nests a closed-city model ($\mu = 0$) and a fully elastic city model ($\mu = \infty$).

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}. Given households' preference structure, the number of households that choose the residence-work pair ij is given by:

$$L_{ij} = \frac{\tau_{ij}^{-\theta} \left(\frac{\bar{B}_i}{q_{\mathrm{R}i}^{1-\alpha}} \right)^{\theta} w_j^{\theta}}{\sum_{od} \tau_{od}^{-\theta} \left(\frac{\bar{B}_o}{q_{Ro}^{1-\alpha}} \right)^{\theta} w_d^{\theta}} L. \tag{9}$$

Local labor supply is increasing in the nominal wage w_j, with elasticity θ. 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, a higher commuting cost results in fewer households selecting the ij option. Note that the denominator is the expected utility of choosing the metropolitan area, and the fraction represents the fraction of households that choose ij. Hence, we can write equation (9) as,

$$L_{ij} = \tau_{ij}^{-\theta} \left(\frac{\bar{B}_i}{q_{\mathrm{R}i}^{1-\alpha}} \right)^{\theta} w_j^{\theta} \frac{L}{U^{\theta}}. \tag{10}$$

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. We can also define the number of residents and number of workers in a location with

$$L_{Ri} = \sum_j L_{ij}, \quad L_{Fj} = \sum_i L_{ij}.$$

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 $k\ell$,

$$d_{k\ell} = \exp\Big(\kappa \underbrace{\bar{t}_{k\ell}\frac{Q_{k\ell}^{\sigma}}{\mathrm{I}_{k\ell}^{\xi}}}_{\text{Travel Time}}\Big). \tag{11}$$

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 depends on some exogenous edge characteristics, denoted by $\bar{t}_{k\ell}$. 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. Finally, time is 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

$$\tau_{ij,r} = \prod_{k\ell \in r} d_{k\ell}. \tag{12}$$

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

$$\tau = \left((\mathbf{I} - \mathbf{A})^{-1}\right)^{-\frac{1}{\rho}} \tag{13}$$

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 (13) 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

$$\pi_{ij}^{k\ell} \equiv \left(\frac{\tau_{ij}}{\tau_{ik} d_{k\ell} \tau_{\ell j}}\right)^{\rho}. \tag{14}$$

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 (14) according

to

$$Q_{k\ell} = \sum_{ij} L_{ij} \pi_{ij}^{k\ell}. \tag{15}$$

This expression illustrates the benefit of introducing idiosyncratic preferences over commuting routes, which greatly simplifies the numerical computation of the equilibrium. Suppose we did not have idiosyncratic preferences for 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), we make the problem more 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, namely,

$$q_{\mathrm{R}i} = \frac{1-\alpha}{\bar{H}_{\mathrm{R}i}} \sum_{j} L_{ij} w_j. \tag{16}$$

Similarly, for the commercial land market, we can equate the fixed land supply to firms' demand for land, namely,

$$q_{\mathrm{F}i} = \bar{A}_i \Big(\frac{1-\beta}{\beta} \frac{L_{Fi}}{\bar{H}_{\mathrm{F}i}} \Big)^{\beta}. \tag{17}$$

The price of residential land is increasing in the number of residents in a location, and the price of commercial land is increasing in the number of workers in a location. Hence, governments want to maximize their land value by investing in infrastructure to attract residents and workers.

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 $ij \in \mathcal{E}^g$, taking as given all the infrastructure investments by other governments, according to

$$\max_{\mathrm{I}_{ij} \in \mathcal{E}^g} \sum_{i \in \mathcal{J}^g} \{ q_{\mathrm{R}i} \bar{H}_{\mathrm{R}i} + q_{\mathrm{F}i} \bar{H}_{\mathrm{F}i} \} - \sum_{k\ell \in \mathcal{E}^g} \delta^{\mathrm{I}}_{k\ell} \mathrm{I}_{k\ell}, \tag{18}$$

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 living in ij in equation (9),

(iv) residential land market clearing, given by equation (16),

(v) commercial land market clearing, given by equation (17),

(vi) wages, as a function of equilibrium commercial land values,[12]

$$w_j = \left(\frac{\bar{A}_j}{q_{\mathrm{F}j}^{1-\beta}} \right)^{\frac{1}{\beta}} \quad \text{for all } j, \tag{19}$$

(vii) equilibrium traffic flows, given by equation (15),

(viii) bilateral commuting cost index, given by equation (13),

(ix) edge-level commuting costs, given by equation (11),

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

Municipalities maximize their economic surplus, defined as their land value net of the building costs of providing the infrastructure, subject to the equilibrium of the city given by households and firms' decisions. The equilibrium of the city acts as an implementability constraint on the governments' problem; they understand how people and firms respond to infrastructure and commuting costs.

In this setting, maximizing land value relates closely to maximizing total consumer surplus, defined as

$$\mathrm{CS}^g = \sum_{i \in \mathcal{J}^g} \omega^g_{Ri} L_{\mathrm{R}i} U + \sum_{j \in \mathcal{J}^g} \omega^g_{Fj} L_{\mathrm{F}j} U,$$

where ω^g_{Ri} and ω^g_{Fj} are the government g's social weights for residents in i and workers in j respectively. Maximizing land value implies assuming that the social weights of residents and workers are given by the marginal land value of an additional resident and an additional worker, respectively.[13] Note that in a standard optimal policy problem, when studying an optimal policy at the city or metropolitan level, we typically don't have to define how the government values

[12] It is more standard to express the equilibrium wages as a function of labor supply. However, it simplifies the exposition in the next section to express the wage as a function of the commercial land price, $q_{\mathrm{F}j}$. We want to keep track of just one price in the origin locations (residential land value) and one price in the destination locations (commercial land value).

$$w_j = \bar{A}_i \left(\frac{\beta}{1-\beta} \frac{\bar{H}_{\mathrm{F}i}}{L_{Fi}} \right)^{1-\beta} = \left(\frac{\bar{A}_j}{q_{\mathrm{F}j}^{1-\beta}} \right)^{\frac{1}{\beta}}$$

[13] Note that maximizing aggregate land value has a long tradition in urban economics, for example, as used in Kanemoto (1977),Wheaton (1998), and Rossi-Hansberg (2004), to name a few. This tradition arises from the Henry George theorem, where, under certain conditions, the welfare benefits of local public goods are capitalized into land values (Stiglitz, 1977; Starrett, 1981).

residents relative to workers because everyone works and lives in the city. Therefore, the population of residents and workers is the same. However, when dividing the metropolitan area into multiple local governments, the set of residents and set of workers at the municipality level are different; some people live and work in different municipalities.

We can also think of equation (18) as local governments maximizing land tax revenue, where the tax rate of productive land equals the tax rate of residential land. Moreover, the framework allows for more general objective functions for local governments, where we could allow for income tax based on workplace or other types of tax revenue.

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. This means that the governments "understand" the equilibrium forces of the city, including how quantities and prices of nodes outside its jurisdiction might affect prices and quantities within its jurisdiction. 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 municipality chooses its optimal infrastructure conditional on the infrastructure chosen by the other governments in the metropolitan area.

Centralized Planner (Metropolitan)

In the following sections, I compare the decentralized equilibrium, where each municipality optimizes the objective described in equation (18), to the centralized equilibrium, where a metropolitan planner chooses the infrastructure that maximizes economic surplus for the entire city. This implies that the metropolitan planner internalizes the full benefits and costs of its investments.

It is worth noting that the solution to the metropolitan planner's problem is not the first-best because of the congestion externalities. I assume that the metropolitan planner can only control the infrastructure and can not implement other tools, such as congestion pricing.[14]

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 $\{\bar{A}_i, \bar{B}_i, \bar{H}_{\mathrm{R}i}, \bar{H}_{\mathrm{F}i}, \bar{t}_{k\ell}\}$, an equilibrium of the model satisfies the following 9 sets of equations: households maximize utility (8 and 9), labor markets clear (2), land markets clear (16 and 17), traffic equilibrium holds (11, 13, and 15), governments maximize land value net of building costs (18).

[14] In the context of Santiago, municipalities can not charge tolls on their local roads. Hence, I compare the decentralized equilibrium, where municipalities can only control the infrastructure, with a metropolitan planner that has the same policy tools as the municipalities, infrastructure investment, such that I can focus on the effect of the level of decision-making.

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.7 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.

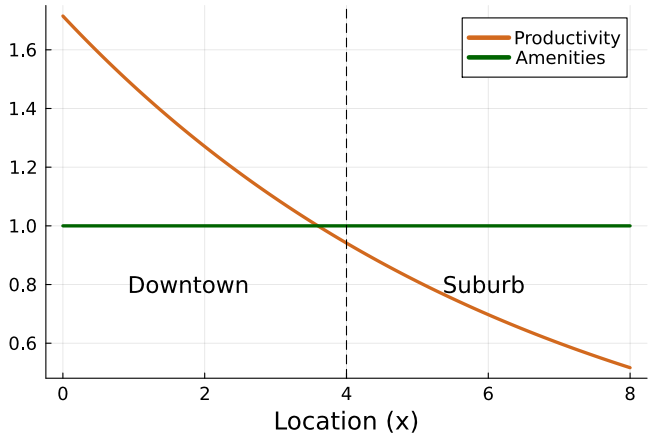
2.2 Illustrative Example: Linear City

This section uses the particular, simple case of a linear geography with common land and amenities to illustrate the model's trade-offs.

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, $\bar{A}_x$, their location x, and their 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 brown 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. Half of the locations and the road are under the jurisdiction of one municipality, and the other half under the other. Municipalities can 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 ($N = 100$).

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,

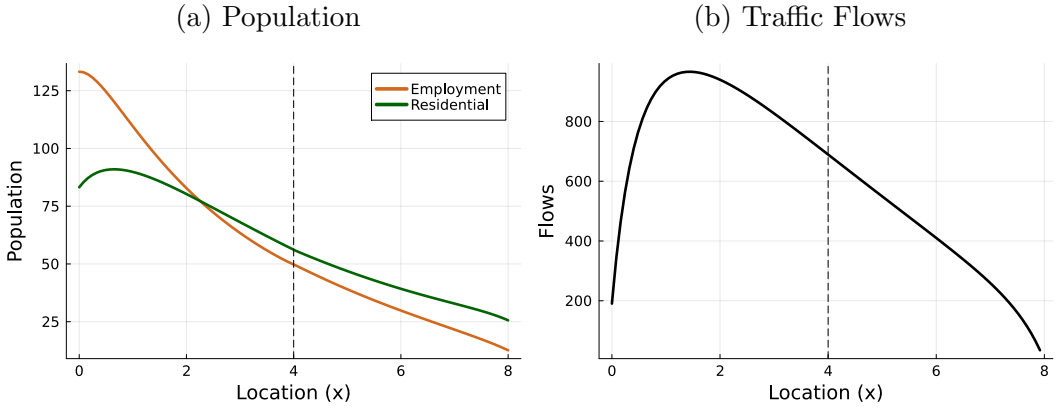
$$\tau_{ij} = \prod_{k\ell} \mathbb{1}_{ij}^{k\ell} d_{k\ell}, \tag{20}$$

$$Q_{k\ell} = \sum_{ij} L_{ij} \mathbb{1}_{ij}^{k\ell}, \tag{21}$$

where $\mathbb{1}_{ij}^{k\ell}$ is an indicator function that equals one when the origin-destination ij uses the edge $k\ell$.[15]

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 everywhere in the line, $\mathrm{I}_{k\ell} = C$ for all $k\ell$.[16] 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 closer to $x = 0$, because of better access to jobs.[17] 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.

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

[16] For this example and every figure in this section, I chose the parameter values in Table A.1.

[17] 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 $x = 0$.

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, I derive the following expression, which equates the marginal value to the marginal cost of infrastructure,

$$\frac{\partial d_{k\ell}}{\partial \mathrm{I}^g_{k\ell}} \sum_{ij} \lambda^g_{ij} \frac{\partial L_{ij}}{\partial d_{k\ell}} = \delta^{\mathrm{I}}_{k\ell}. \tag{22}$$

Infrastructure provides several benefits. First, we have the direct effect, $-\frac{\partial d_{k\ell}}{\partial \mathrm{I}_{k\ell}}$: more infrastructure translates into faster commute times. Second, we have the benefits from reorganizing economic activity in the city, $\sum_{ij} -\lambda^g_{ij} \frac{\partial L_{ij}}{\partial d_{k\ell}}$, which governments capture in land value. Changing travel time in one edge, $d_{k\ell}$, will affect where people live and work. The Lagrange multiplier λ^g_{ij} is the multiplier on the travel demand constraint in equation (9), and it represents the marginal land value for government g of an increase in L_{ij}. Namely, how much does land value in g's locations increase with one more household in ij?

The land 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 effects, employment effects, and congestion effects, as the following,

$$\sum_{ij} -\lambda^g_{ij} \frac{\partial L_{ij}}{\partial d_{k\ell}} = \underbrace{\sum_{ij} -\eta^g_{\mathrm{R}i} \frac{\partial q_{\mathrm{R}i}}{\partial L_{ij}} \frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Residential Force: } \equiv Q^g_{\mathrm{R}k\ell}} + \underbrace{\sum_{ij} -\eta^g_{\mathrm{F}j} \frac{\partial q_{\mathrm{F}j}}{\partial L_{ij}} \frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Employment Force: } \equiv Q^g_{\mathrm{F}k\ell}} + \underbrace{\sum_{ij} \sum_{rs} -\phi^g_{rs} \frac{\partial Q_{rs}}{\partial L_{ij}} \frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Congestion Force: } \equiv Q^g_{\mathrm{C}k\ell}}. \tag{23}$$

Residential and Employment Flows

First, the residential force, $Q^g_{\mathrm{R}k\ell}$, corresponds to all the changes to residential land value throughout the city from an improvement in the edge-level commuting cost $d_{k\ell}$, valued by the government g. Governments value these changes in residential land value according to the multiplier $\eta_{\mathrm{R}i}$; the Lagrange multiplier of constraint (16). We can think about these multipliers as government-specific weights for residential (origin) locations given by

$$\eta^g_{\mathrm{R}i} = \mathbb{1}[i \in \mathcal{J}^g] \bar{H}_{\mathrm{R}i} + \sum_{od} \lambda^g_{od} \frac{\partial L_{od}}{\partial q_{\mathrm{R}i}}. \tag{24}$$

Let us consider each term in equation (24) at a time. First, governments care directly about increasing residential land value in locations within their jurisdiction. Second, they value residential

price changes in every location (even outside their jurisdiction) through population responses. 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. By using equation (6), (8), (9), (16), and (20), the residential force can be expressed as weighted traffic *flows*, given by

$$Q^g_{\mathrm{R}k\ell} = \sum_{ij} L_{ij} \frac{\mathbb{1}^{k\ell}_{ij}}{d_{k\ell}} \underbrace{\left(\eta^g_{\mathrm{R}i} \theta \frac{1-\alpha}{\bar{H}_{\mathrm{R}i}} w_j - \frac{\theta - \varepsilon_L}{L} \sum_h \eta^g_{\mathrm{R}h} q_{\mathrm{R}h} \right)}_{\equiv \omega^g_{\mathrm{R}ij}}, \tag{25}$$

where ε_L is the elasticity of the aggregate metropolitan population with respect to the ex-ante expected utility level, U.[18] Recall that traffic flows are given by equation (21). Hence, the residential flows in (25) are the flow of commuters using $k\ell$, weighted by their marginal residential value for government g, $\omega^g_{\mathrm{R}ij}$. This weight is a function of the multipliers $\{\eta^g_{\mathrm{R}}\}$, wages, residential land values, and total population.[19]

I name the second term in equation (23) the employment force, $Q^g_{\mathrm{F}k\ell}$, which corresponds to all the changes to commercial land 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, government g values change to commercial land value according to the Lagrange multiplier $\eta_{\mathrm{F}j}$; the multiplier of constraint (17). These multipliers are government-specific weights for productive (destination) locations and are given by

$$\eta^g_{\mathrm{F}j} = \mathbb{1}[i \in \mathcal{J}^g] \bar{H}_{\mathrm{F}j} + \sum_{od} \lambda^g_{od} \frac{\partial L_{od}}{\partial w_j} \frac{\partial w_j}{\partial q_{\mathrm{F}j}} + \sum_o \eta^g_{Ro} \frac{\partial q_{Ro}}{\partial w_j} \frac{\partial w_j}{\partial q_{\mathrm{F}j}}. \tag{26}$$

Governments value attracting workers to a location because of the effect of labor supply on two prices: the commercial land value and the wage. For tractability, I express the wage in equation (19) as a function of the equilibrium commercial land value instead of labor supply. This transformation allows me to reduce the number of Lagrange multipliers I must keep track of. Hence, the multiplier in equation (26) represents the full valuation of changes in commercial land value, including the effects on wages.

Let us consider each term in equation (26) at a time. First, governments care directly about increasing commercial land value within their jurisdiction. Second, city commuters respond to wage movements in j, captured by the second term. Third, wage changes will also affect the residential

[18] This elasticity is given by

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

[19] For a detailed derivation and interpretation of the residential flows, see Appendix A.4.

land value in the origin location of those workers.[20] These two forces imply governments value destination locations outside their jurisdiction: governments can capture benefits from wage increases in other jurisdictions if that translates into higher residential land value in their jurisdiction, or they can value a wage decrease if that pushes workers to work in their locations.

Equations (24) and (26) 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. These weights ($\eta_{\mathrm{R}i}$ and $\eta_{\mathrm{F}j}$) can be positive or negative, depending on whether a price change in the location will increase or reduce total land value for government g.

We can also express the employment force as weighted traffic flows. By using equation (6), (8), (9), (17), and (20), the employment *flows* are given by,

$$Q^g_{\mathrm{F}k\ell} = \sum_{ij} L_{ij} \frac{\mathbb{1}^{k\ell}_{ij}}{d_{k\ell}} \underbrace{\left(\eta^g_{\mathrm{F}j} \theta \beta \frac{q_{\mathrm{F}j}}{L_{\mathrm{F}j}} w_j - \frac{\theta - \varepsilon_L}{L} \sum_h \beta \eta^g_{\mathrm{F}h} q_{\mathrm{F}h} \right)}_{\equiv \omega^g_{\mathrm{F}j}}. \tag{27}$$

The employment flows in (27) are the flow of commuters using $k\ell$, weighted by their marginal employment value for government g, $\omega^g_{\mathrm{F}j}$. This weight is a function of the multipliers $\{\eta^g_{\mathrm{F}}\}$, equilibrium commercial land value, and total population.[21]

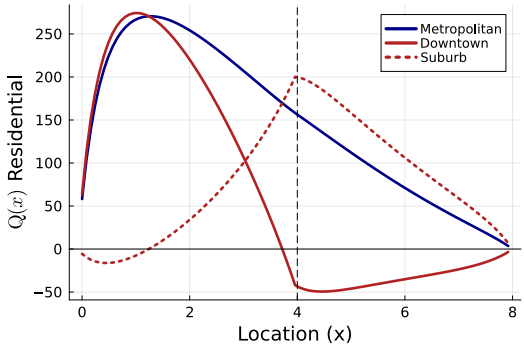
Figure 3 shows the residential and employment flows from the perspective of the three governments. The blue lines represent the perspective of the metropolitan government, and the red lines represent the perspective of Downtown (solid) and Suburb (dotted). For example, for the residential flows, the blue line represents the full land value from residents derived from a marginal investment in the roads in that location. Then, the red lines are the residential flows 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.

[20] Note the equation (26) is not symmetric to equation (24) because of the effect of wages on residential land value. The indirect effects captured in these destination weights, $\eta^g_{\mathrm{F}j}$, are twofold: wages affect residential land value in origin locations and population throughout the city. The residential weight, $\eta_{\mathrm{R}i}$, captures how movements in residential land value affect other locations only through population responses.

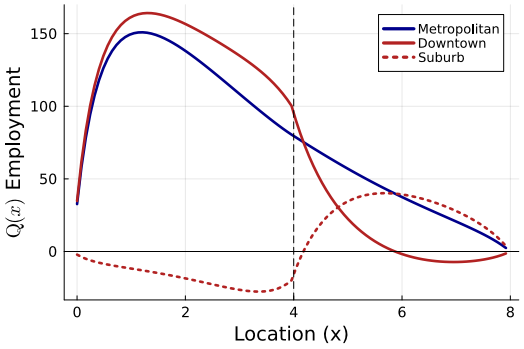
[21] For a detailed derivation and interpretation of the employment flows, see Appendix A.4.

Figure 3: Weighted flows by government

(a) Residential flows



(b) Employment flows



Note: These are constructed in the decentralized equilibrium, such that the sum of the red lines equals the blue line. We can interpret the red lines as how value is distributed between Downtown and Suburb.

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 flows are negative at the boundary, implying that Downtown is losing residential value by investing in these locations.

On the other hand, in suburban locations, the residential flows are larger for Suburb than the metropolitan government. Suburb gains residents and, in turn, land value 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 land value derived from employment at the expense of suburban locations.

Congestion Flows

The third component in equation 23 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 (15).[22] The Lagrange multiplier captures how more

[22] See Appendix A for this multiplier.

traffic flows reduce land value for government g through travel time congestion for their residents and workers.

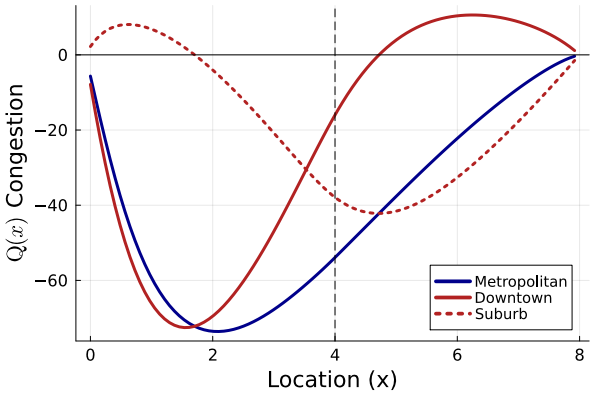
As with the residential and employment forces, we can rewrite the congestion force as weighted traffic flows. By using equation (6), (8), (9), (20), and (21), the congestion *flows* are given by,

$$Q^g_{\text{C}k\ell} = \sum_{ij} L_{ij} \frac{\mathbb{1}^{k\ell}_{ij}}{d_{k\ell}} \underbrace{\left(\sum_{rs} \phi^g_{rs} \left\{ \theta \pi^{rs}_{ij} - \frac{\theta - \varepsilon_L}{L} Q_{rs} \right\} \right)}_{\equiv \omega^g_{\text{C}ij}}. \tag{28}$$

The congestion flows in (27) are the flow of commuters using $k\ell$, weighted by their marginal congestion effect captured for government g, $\omega^g_{\text{C}ij}$. This weight is a function of the multipliers $\{\phi^g_{k\ell}\}$, equilibrium traffic flows, and total population.[23]

Figure 4 shows the congestion flows 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.

Figure 4: Congestion effect



Note: Constructed in the decentralized equilibrium, the sum of the red lines equals the blue line.

The congestion flows are generally negative from the metropolitan perspective because the aggregate population grows with more infrastructure, causing more congestion overall. From the perspective of each local government, these flows can be positive if investment diverts enough

[23] For a detailed derivation and interpretation of the congestion flows, see Appendix A.4.

traffic away from their locations. This generally happens in locations farther away from their boundaries, outside their jurisdiction.

Equilibrium Infrastructure

Taking equation (11), the first order condition in equation (22), and the weighted flows equations (25), (27), and (28), we can solve for the optimal infrastructure in edge kl controlled by government g as,

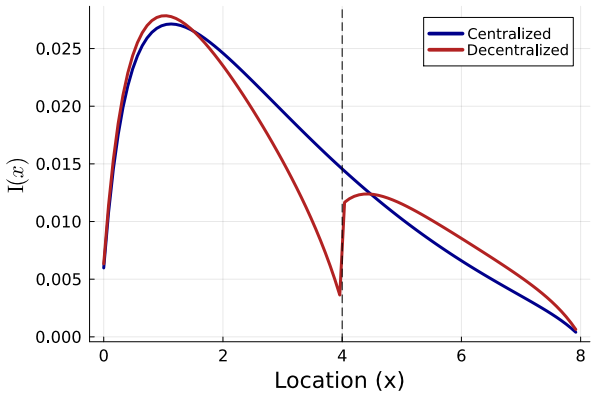
$$\mathrm{I}^g_{k\ell} = \left(\xi\kappa \frac{d_{k\ell}\bar{t}_{k\ell}Q^{\sigma}_{k\ell}}{\delta^{\mathrm{I}}_{k\ell}} \left[Q^g_{\mathrm{R}k\ell} + Q^g_{\mathrm{F}k\ell} + Q^g_{\mathrm{C}k\ell} \right] \right)^{\frac{1}{\xi+1}}. \tag{29}$$

Infrastructure is increasing in the equilibrium traffic flows, $Q_{k\ell}$, and increasing in the government-specific equilibrium weighted flows: the residential flows, $Q^g_{\mathrm{R}k\ell}$, employment flows, $Q^g_{\mathrm{F}k\ell}$, and congestion flows, $Q^g_{\mathrm{C}k\ell}$. Moreover, infrastructure is increasing in the infrastructure elasticity of travel times, ξ, increasing in the commuting parameter, κ, and decreasing in the building costs, $\delta^{\mathrm{I}}_{k\ell}$

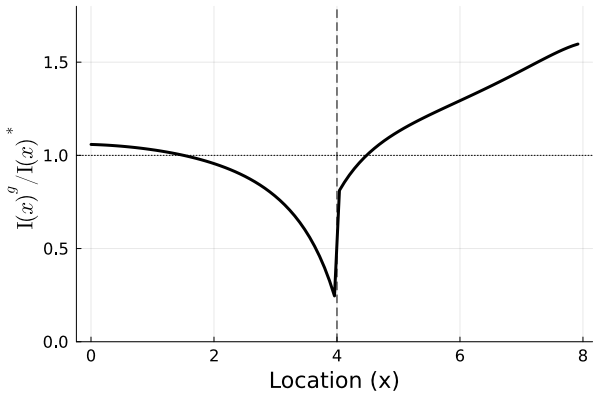
Figure 5(a) shows the optimal infrastructure function for the centralized metropolitan planner (in blue) and for the decentralized equilibrium where each municipality chooses its investments (in red). Figure 5(b) shows the ratio of the decentralized infrastructure to the optimal metropolitan infrastructure. 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 5: Decentralized vs Centralized Infrastructure

(a) Optimal Infrastructure



(b) Relative Infrastructure: $\mathrm{I}^g/\mathrm{I}^*$



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.[24] 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 two ingredients. First the land share of utility and production, as these affect how governments weigh residents versus workers. Second, the city's geography, that is, the distribution of exogenous productivity and residential amenities across space.

This second prediction about total investment across municipalities depends crucially on the size of the residential flows relative to the employment flows.[25] If the residential flows are larger, as in this case, Downtown tends to underinvest, and Suburb overinvests. If, instead, the employment flows were relatively larger, Downtown would underinvest less or even overinvest. The relative size of these forces is a function of the land shares of utility and production, and the distribution of exogenous productivity and residential amenities across space. In this example, there is dispersion in productivity and no dispersion in amenities, amplifying the size of the residential flows relative to the employment flow.

2.2.2 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.

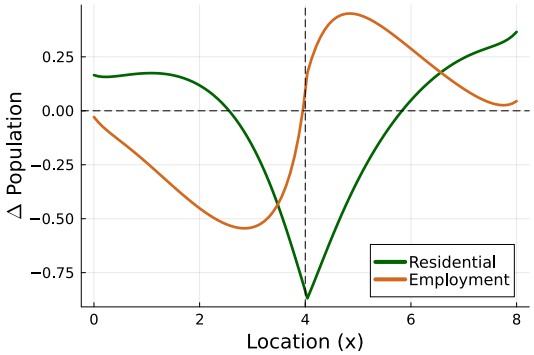
Figure 6(a) shows the change in the population distribution of both residents and workers. The residential population "hollows out," shifting away from the border between municipalities where there is less infrastructure. Employment shifts towards the periphery and is less concentrated in Downtown relative to the centralized equilibrium. Hence, decentralization makes cities less specialized, with a more mixed distribution of residents and employment. This follows from the municipalities underinvesting near the boundaries, which results in higher cross-municipality commuting costs and 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.

[24] Core locations are those farthest from the boundary.

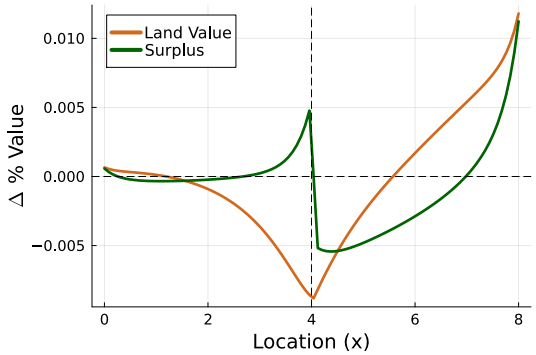
[25] Note that the congestion flows, for reasonable parameter values, are smaller in size than the benefits of infrastructure captured by the residential and employment flows.

Figure 6: Changes to the city's equilibrium

(a) Δ in population



(b) Δ in land value and surplus



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

Surplus losses are concentrated in Suburb. The periphery gains land value relative to the metropolitan equilibrium but loses overall surplus when accounting for the infrastructure building costs. Downtown gains a small amount of surplus. Figure 6(b) shows the percentage change of surplus and land value across space. In the decentralized equilibrium, Downtown loses land value but gains surplus thanks to the reduction in building costs.

2.3 From the linear geography to the full 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, $d_{k\ell}$.

This new term is grouped into the congestion force,

$$Q_{\mathrm{C}k\ell}^{g} = \sum_{ij}\sum_{rs} -\phi_{rs}^{g}\left(\frac{\partial L_{ij}}{\partial d_{k\ell}}\pi_{ij}^{rs} + L_{ij}\frac{\partial \pi_{ij}^{rs}}{\partial d_{k\ell}}\right) \tag{30}$$

Equation (29) changes to,

$$\mathrm{I}_{k\ell}^{g} = \xi\frac{d_{k\ell}}{\delta_{k\ell}^{\mathrm{I}}}\frac{\log d_{k\ell}}{1+\rho\sigma\log d_{k\ell}}\left(Q_{\mathrm{R}k\ell}^{g} + Q_{\mathrm{F}k\ell}^{g} + Q_{\mathrm{C}k\ell}^{g}\right), \tag{31}$$

where $Q^g_{\mathrm{R}k\ell}$ is given by equation (25). The residential and employment flows, $Q^g_{\mathrm{R}k\ell}$ and $Q^g_{\mathrm{F}k\ell}$, are given by equations (25) and (27), but replacing the indicator $\mathbb{1}^{k\ell}_{ij}$ for the link intensity $\pi^{k\ell}_{ij}$. For more details on how I solve the government's problem in the full network, see Appendix A.3.

3 Decentralization and Infrastructure in Santiago, Chile

I now describe how the forces described in the theory lead to the misallocation of infrastructure in the metropolitan area of Santiago, Chile. Santiago's metropolitan area is divided into 34 municipalities with autonomy over transportation planning within their jurisdiction, making it a good laboratory to study decentralization.

In this section, I first describe the data sources used for the empirical evidence and structural estimation. Then, I describe the city's political structure, commuting activity, and the distribution of economic activity. Finally, I show empirical support for the forces in the model by documenting the infrastructure pattern at the border between municipalities.

3.1 Data Sources

Travel survey

This paper uses Santiago's 2012 travel survey, *Encuesta Origen Destino de Viajes*, as the main data source. This survey data provides information on the daily trips of 60,000 individuals from 18,000 distinct households. This information includes the origin and destination of each trip, the purpose of the trip, the mode of travel, and the duration of the trip. The survey data also provides information about the individuals, such as wage and education level.

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.

I restrict the sample for two reasons. First, the locations outside the city's urban limit are more rural, larger in area, and with more dispersed population. Location within the city's urban limit are polygons of approximately 1 km side, and the locations outside are, on average, polygons of 4 km side. Second, these locations have more complicated geography, such as mountainous terrain. These characteristics make it harder to map these rural locations into nodes in the network and accurately measure their infrastructure. Moreover, since these locations are rural and outside the city's urban limits, there is no available information on floor space.

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.[26]

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 type of road includes categories such as motorway, residential, primary road, service road, etc.

I also combine this information with official government data on the road network 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.

Real-time traffic flows and speed data

Chile's Transportation and Communications Ministry collects real-time traffic data through automatic readers. These automatic readers count the number of cars traveling through a specific avenue or intersection in 15-minute intervals. They are located in 70 main traffic spots across nine municipalities in Santiago's metropolitan area.

I also collected real-time traffic speed data for those 70 locations using the Google Maps API. I recorded this information for six weeks, from August 1st to September 17th, 2022, a window of time for which the Ministry kindly agreed to share the data on traffic flows. I use the data on flows and speed for this set of locations to estimate the relationship between travel time and traffic flows.

[26] There is a five year gap between the data on land use and the travel survey. However, no major events or urban policies took place during that time window to think the land use would be significantly different in 2012. The one notable exception is the opening of a new subway line at the end of 2017 (line number 6). Still, since I use this data to calculate available floor space by purpose, it is unlikely that the supply of floorspace changed in one year from the opening of the subway.

3.2 Context: Santiago, Chile

Santiago is Chile's capital, as well as its industrial and financial center. The metropolitan area has a population of six million. In 2017, Santiago's GDP was comparable to that of Denver or San Diego in the United States.

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 to reside in the municipality to attend, 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 and avenues, bike lanes, and parking facilities. 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.1 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 are owned and maintained 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. Note that both

private cars and public buses use roads and surface infrastructure.

Santiago's economics, political, and natural geography

Geographically, the Metropolitan Region of Santiago is located in the central area of Chile. The region is nestled within a valley and is flanked by the Andes Mountains to the east. There is one important river that flows from its source in the Andes mountains onto the west and divides Santiago in two.

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.[27] The metropolitan government is responsible for the coordination, supervision, and inspection of regional public services. However, there are few coordination instruments 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 7: Build density and altitude

(a) Altitude

(b) Socio-economic status

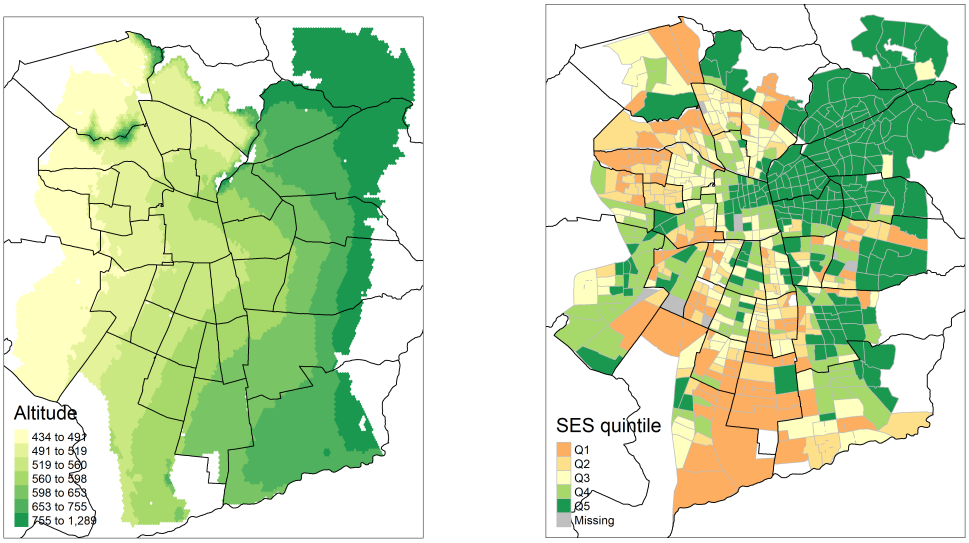


Figure 7(a) shows the altitude of different locations within the city in meters. The black lines correspond to the municipalities' borders. Note that there are important differences in altitude across city locations, with the altitude more than doubling from the west to the east. For this reason, I control for altitude and slope in the empirical analysis and estimation. Figure 7(b) shows the distribution of socio-economic quintiles in the city, calculated using the 2017 population census.

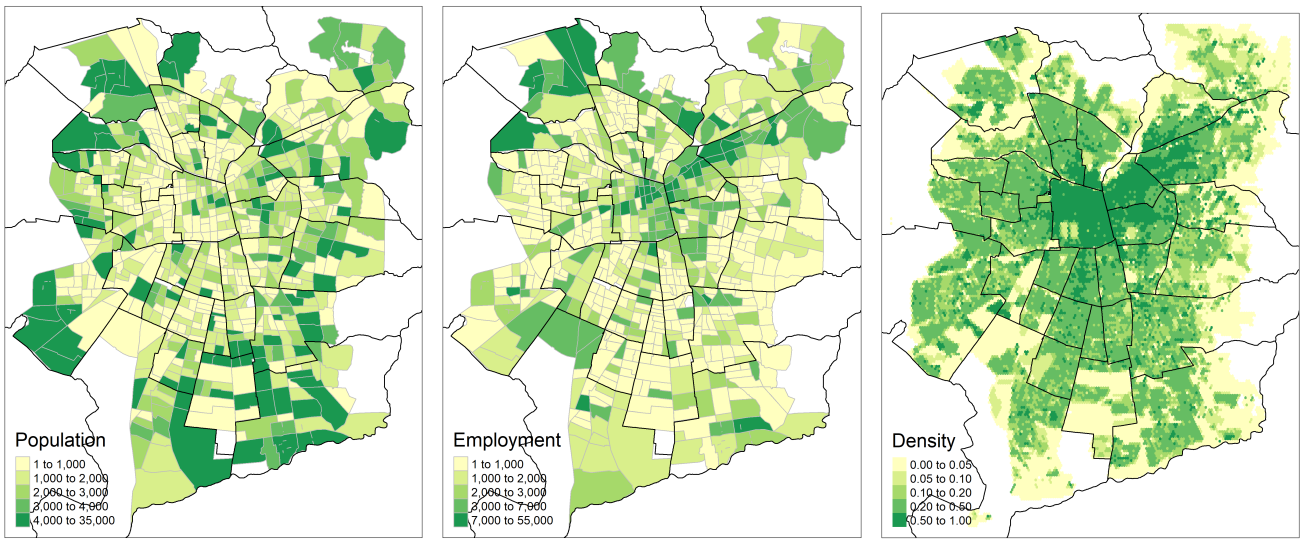
[27] Only 34 municipalities fall within Santiago's urban limit. The other municipalities in the region are more rural.

Richer households are concentrated in the city's northeast, towards the mountains. Lower-income households live primarily in the West.

Figure 8 shows the distribution of residents, workers, and urban density throughout the city. I calculated the distribution of residents and workers by location using the travel survey. 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 8(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 more dense at the center, where employment is high.

Figure 8: 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.

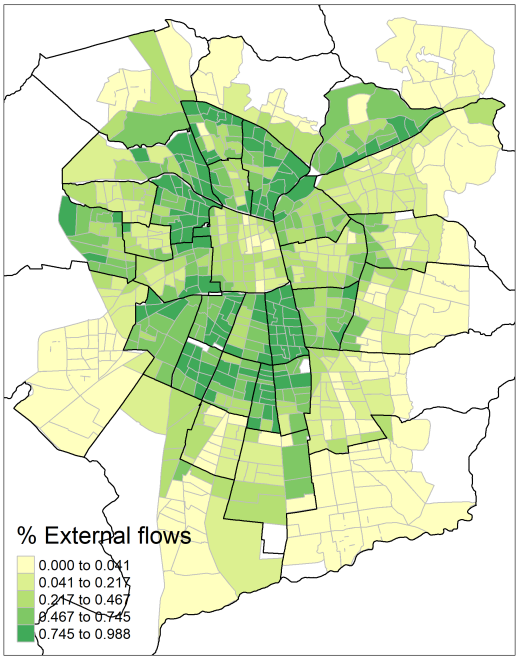
Santiago is a densely populated and compact urban center divided into municipalities. It is important to note that these municipalities do not function as separate, independent cities; rather, they collectively constitute a unified and cohesive metropolis. Figure 8 highlights that all municipalities 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.

Commuting interactions across municipalities

Roads are often used by residents or workers of other municipalities: more than 70% of commuters live and work in different municipalities. Moreover, I compute the fraction of external commuters, i.e., those who do not live or work in the 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. The municipality with the highest fraction of external commuters, San Joaquin, has an average of 85% external commuting flows. Figure 9 shows the distribution of external flows in space; external flows are concentrated in the ring of municipalities that connect residential locations to employment locations.

Figure 9: Fraction of external flows



Note: External flows are commuters that do not live or work in the municipality. Author's calculation based on travel survey data and Google Maps.

Connecting this empirical pattern to the forces in the model, the municipalities with a high fraction of external commuters have both low residential and employment forces relative to a metropolitan planner. Hence, they capture a small fraction of the value of any investment.

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.

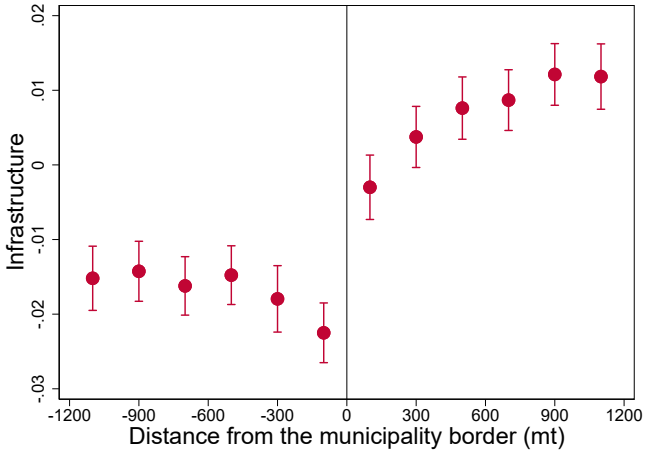
To document this fact, first, I construct a measure of infrastructure in space. I lay a grid of hexagonal cells over the area of the city; the grid cells have an area of 16 acres. Figure 10 shows one example of a border between municipalities. Black lines indicate the municipality boundaries and gray lines show the grid cells. 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, there are 81 municipality pairs that share a border. I exclude borders that coincide with geographical faults, such as rivers, resulting in a sample of 71 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.

Figure 10: Example of one border between municipalities

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. In Figure 10, that would be the average road density in the area to the north of the border for one municipality and the average road density in the area to the south of the border for the other municipality. 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 11 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 clearly 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 5(b).

Figure 11: Pattern of road density at the border



Note: The y-axis shows the infrastructure residual after controlling for border fixed effects, slope, and altitude.

I estimate the above discontinuity using a standard spatial regression discontinuity design, described in more detail in Appendix B.2.1. The estimated average jump at the border is 1.8pp, which can be interpreted as 1.8% more land allocated to roads and commuting infrastructure. The sample's average infrastructure is 9.9%; hence, the jump corresponds to roughly a 17% change in the infrastructure level, a fairly large change. Table 1 shows the estimated discontinuity and slopes with distance. In the Appendix, I also provide robustness 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.

Table 1: Estimated discontinuity and slope

	Infrastructure
	(1)
	Linear
𝟙(Distance>0)	0.0175***
	(0.0055)
abs(Distance)	0.0100*
	(0.0054)
𝟙(Distance>0) × abs(Distance)	0.0098
	(0.0078)
N	7938
Border FE	Yes

Standard errors in parentheses, clustered by border.
Includes controls for terrain's slope and altitude.
Bandwidth size: 1.2 km from the border.
* p<0.10, ** p<0.05, *** p<0.01

We might worry that the ordering of municipalities around the border according to their relative average infrastructure is driving the discontinuity. To address this concern, I compare the estimated discontinuity with one estimated from placebo municipalities. To do so, I partition the area of Santiago into 30 random artificial municipalities. One example partition is shown in Figure B.3. Then, using the new placebo boundaries, I estimate both the discontinuity in infrastructure and the slope (as a function of absolute distance) using the same ordering and estimating procedure

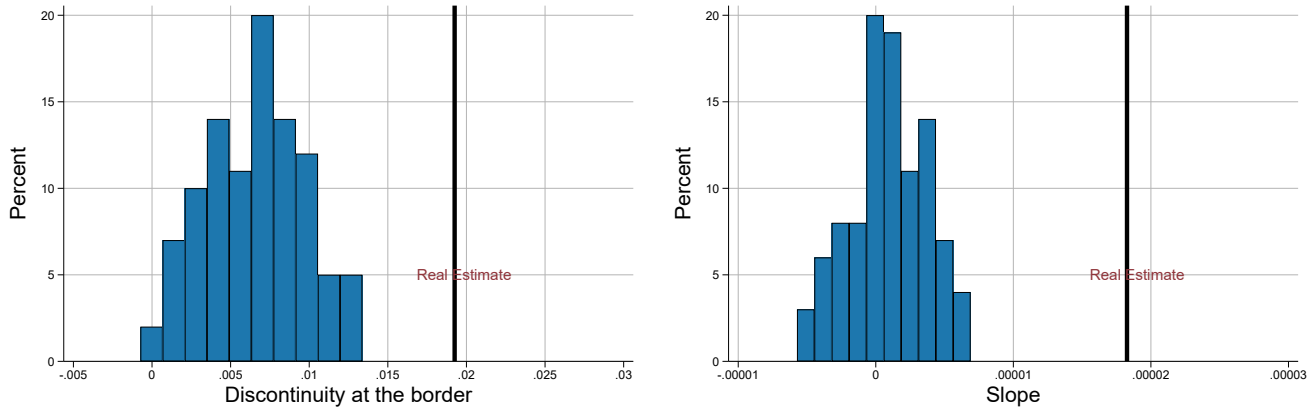
described above.

I repeat this exercise 100 times and plot the estimated border discontinuities and slope distribution. Figure 12 shows the histogram of the placebo estimates, compared to the "real" estimate using the true boundaries, highlighted with the bold black vertical line.

Note that the distribution of placebo discontinuities is not centered at zero. The ordering procedure, where I place the neighbor with relatively higher infrastructure on the positive side of the border, leads to positive jumps at the border. However, the estimated placebo discontinuities are always smaller than the real estimates, suggesting that it is unlikely that the pattern in Figure 11 is driven by the ordering procedure.

Figure 12: Placebo Analysis

(a) Histogram: Discontinuities at the border (b) Histogram: Slope with absolute distance (mts)



Note: These plots show the histogram of placebo estimates across the 100 sets of artificial municipalities. The bold vertical lines indicate the real estimates derived from the true municipality borders.

To recap, I document a investment pattern consistent with coordination failure and in line with the model's predictions: first, municipalities invest less near their boundaries. Second, there is a discontinuity in the density of roads at the boundary between municipalities.

4 Model Quantification

This section explains how I either estimate or obtain values for all the model parameters. In particular, I use detailed data on speed, roads, and traffic flows to estimate the parameters of the travel time function. I leverage data on commuting patterns to estimate the commuting parameter, transforming travel times into utility commuting costs. I use the structure of the model to recover productivity, amenities, and building costs. Moreover, I describe how I transform the data of locations and roads into a network of nodes and edges.

Land shares

Two important parameters are the floor space share in production and the housing share in utility. 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 Pérez Pérez, Vial Lecaros, and Zárate (2022). They estimate $\theta = 8.2$ in the context of Santiago.[28] 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).[29] I estimate

$$\ln L_{ij} = \alpha_i + \beta_j - \theta\kappa \text{Time}_{ij} + \epsilon_{ij}, \tag{32}$$

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 $\kappa = 0.008$. Comparing the implied $\theta\kappa$ This value is slightly smaller but similar to the one estimated by Ahlfeldt et al. (2015) ($\kappa = 0.01$).

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.

[28] They estimate this parameter following Ahlfeldt et al. (2015), by matching the standard deviation of the log wage distribution in the data. Moreover, they use the 2002 wave of data from the same travel survey used in this paper. Their model of household preferences is consistent with my model.

[29] Note that commuting costs, τ, are an exponential function of travel time. So when I take logs in equation 9, we get log commuters as a function of travel time.

Hence, it impacts how much traffic flows reorganize in the network in response to changes in the infrastructure. I set this parameter to $\rho = 150$. 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) ($\rho = 6.83$).[30] Note that, as $\rho \to \infty$, the routing procedure converges to the least cost path route. Hence, using a large value of ρ implies that idiosyncratic noise plays a small 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. From the nested preferences structure, we know that $\mu < \theta$, which implies that households' idiosyncratic preferences play a larger role when choosing among cities than among neighborhoods within the city. Monte, Redding, and Rossi-Hansberg (2018) estimate the heterogeneity in location preferences across counties in the U.S. They estimate $\mu = 3.3$, and their model of household preferences is consistent with mine.

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. Figure B.2 shows the distribution of floorspace by purpose in the city. 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

$$\bar{A}_j = w_j \left(\frac{1-\beta}{\beta} \frac{L_{Fj}}{\bar{H}_{Fj}} \right)^{1-\beta} \quad \forall j.$$

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 distribution, namely,

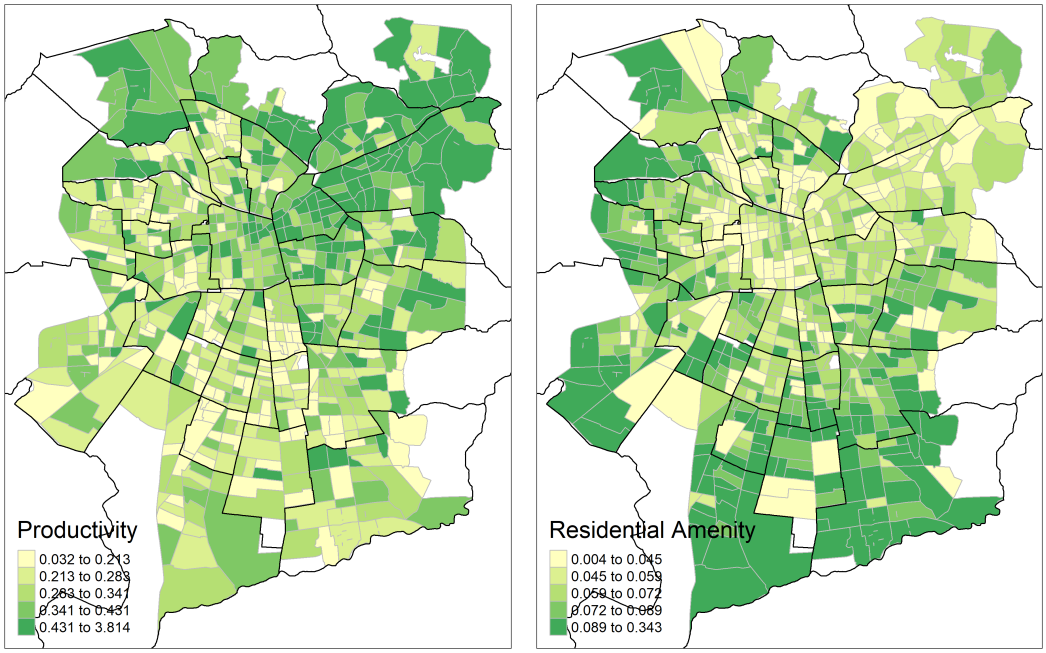
[30] Allen and Arkolakis (2022) choose a value of ρ equal to the value of the commuting elasticity, θ, for additional tractability in their framework.

$$\bar{B}_i = \left(\frac{L_{Ri}}{L}\right)^{\frac{1}{\theta}} q_{Ri}^{1-\alpha} \left(\sum_j (w_j/\tau_{ij})^\theta\right)^{-\frac{1}{\theta}}, \quad \text{where } q_{Ri} = (1-\alpha)\frac{L_{Ri}}{\bar{H}_{Ri}} \sum_j \frac{(w_j/\tau_{ij})^\theta}{\sum_k (w_k/\tau_{ik})^\theta} w_j.$$

Figure 13 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 shown in Figure 8. However, the implied differences in amenities are small.

Amenities are higher in the peripheral locations in the south and southwest. This is because these areas have significant residential population, although they are relatively far from jobs. Hence, the model rationalizes through higher residential amenities. In reality, these areas are quite poor (see Figure 7(b)).

Figure 13: Exogenous amenities and productivity



Note that the variance of productivity in space is much larger than the variance in residential amenities: $\mathbb{V}\text{ar}(\bar{A}_i)/\mathbb{V}\text{ar}(\bar{B}_i) \approx 68$. 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 and network of edges

In the model, travel time in an edge (k, ℓ) is given by

$$\text{Travel Time}_{k\ell} = \bar{t}_{k\ell} \frac{Q_{k\ell}^{\sigma}}{\mathrm{I}_{k\ell}^{\xi}}.$$

I estimate the congestion elasticity, σ, using the real-time traffic flows and speed information described in Section 3.1. This data contains traffic flows and speeds every 15 minutes for 70 key intersections in the city. I estimate $\sigma = 0.14$. For more details on the estimation and the data, see Appendix B.3.1. This value is within the range estimated in 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. However, they estimate an average elasticity of 0.06, which is lower than the one used in this paper.

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 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.3.2 for more detail on the measurement of speed and estimation.

Figure B.10 shows the discontinuity in infrastructure and the corresponding discontinuity in speed. Using this variation, I estimate $\xi = 0.13$ by running a regression between log-speed and log-infrastructure, where I instrument log infrastructure with the municipality border.

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).

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.

Finally, with the constructed network of edges and their corresponding infrastructure levels, $\mathrm{I}_{k\ell}$, I use Google Maps to calculate the travel time for each edge during peak hours on a weekday. I

then set the exogenous shifter, $\bar{t}_{k\ell}$, such that I perfectly match the observed travel times. That is,

$$\bar{t}_{k\ell} = \text{Travel Time}_{k\ell} \frac{I_{k\ell}^{\xi}}{Q_{k\ell}^{\sigma}},$$

where traffic flows, $Q_{k\ell} = \sum_{ij} L_{ij} \pi_{ij}^{k\ell}$. The travel demands, L_{ij}, are observed in the travel survey. The link intensity, $\pi_{ij}^{k\ell}$, I construct using the observed edge-level travel times from Google Maps, κ, and ρ, according to

$$d_{k\ell} = \exp\Big(\kappa \text{Travel Time}_{k\ell}\Big), \quad \tau_{ij}^{-\rho} = (\mathbf{I} - \mathbf{A})^{-1},$$

where, following Allen and Arkolakis (2022), $\mathbf{A} \equiv [d_{k\ell}^{-\rho}]$. Given the matrix of d and τ, I compute the link intensity using equation (14).

Building costs

With all the estimated parameters, location characteristics, and edges characteristics, I use the structure of the model to obtain the infrastructure building costs. I use equation (31) and reorganize it as

$$\underbrace{\delta_{k\ell}^{\text{I}}}_{\text{Building costs}} = \underbrace{\frac{1}{\text{I}_{k\ell}^{g}}}_{\text{Data}} \underbrace{\xi \frac{d_{k\ell} \log d_{k\ell}}{1 + \rho\sigma \log d_{k\ell}} \left(Q_{\text{R}k\ell} + Q_{\text{F}k\ell} + Q_{\text{Q}k\ell}\right)}_{\text{Data + Estimated parameters + Model inversion}}.$$

I use the observed infrastructure in the data as $\text{I}_{k\ell}^{g}$. 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 level of infrastructure through high building costs.[31]

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: aggregate land value net of building costs. In one counterfactual, I allow the metropolitan planner to increase or

[31] One potential issue with this estimation strategy for the building costs is if these additional characteristics change in the centralized equilibrium. For example, suppose there is a high density of roads in areas that benefit the family and friends of the municipalities' mayors. If infrastructure decisions were centralized, then these personal incentives would disappear. However, my counterfactual analysis assumes that building costs would stay unchanged if the city was centralized.

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.[32]

Table 2 shows changes to the aggregate variables of the model in the centralized counterfactuals relative to the baseline decentralized equilibrium. In the centralized equilibrium, the aggregate infrastructure expenditure increases by 77%, implying significant overall underinvestment in the baseline. By construction, aggregate expenditure stays the same in the constrained centralized equilibrium.

Table 2: Aggregate effects (%)

Variable	Centralized	Constrained Centralized
Population	5.3	3.5
Welfare	2.3	1.5
Surplus	4.2	3.9
Expenditure in infrastructure	77	0
Average commuting costs	-0.9	-0.3

In the centralized counterfactual, even after the significant increase in infrastructure, overall commuting costs decreased by 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.

Perhaps interestingly, the counterfactual conditional on the baseline budget achieves a large fraction of the aggregate gains of centralization without increasing aggregate expenditure. Centralization reduces spatial misallocation in infrastructure investments. By shifting investment towards the municipalities that underinvest the most, we can improve connectivity and increase the city's aggregate 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 77% 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.

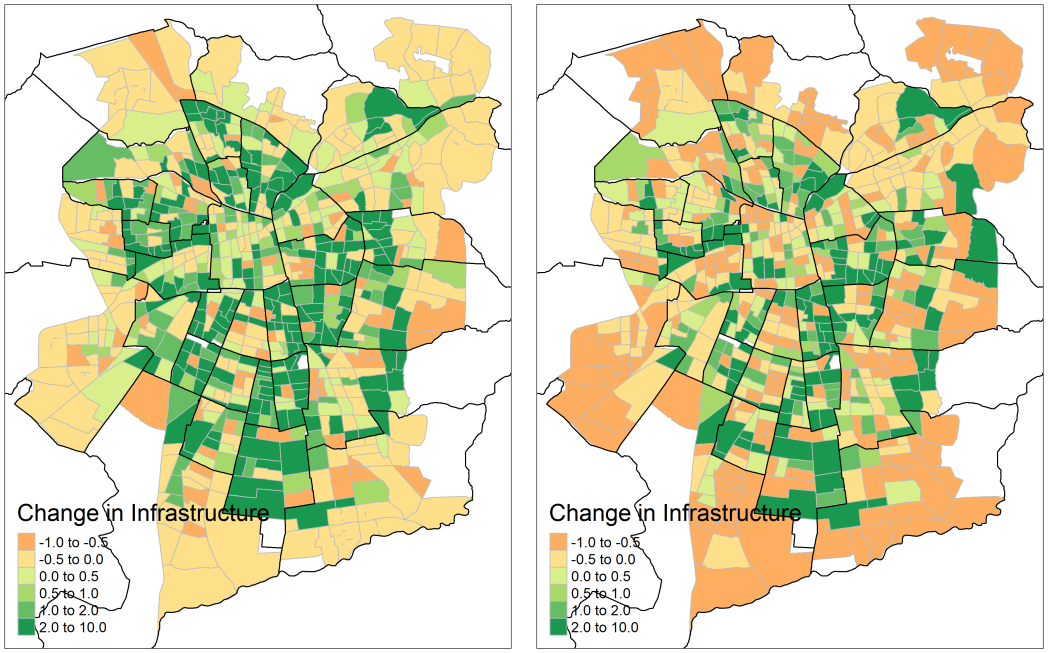
[32] I compute the counterfactuals using the procedure described in Appendix A.8.

5.1 Effects in space

Figure 14 shows the distribution in space of changes to commuting infrastructure relative to the baseline in both counterfactuals. 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 9). 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.[33]

Figure 14: Changes to the city's infrastructure

(a) Centralized (b) Conditional on baseline budget



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 15(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 5(b). Importantly, the

[33] Figure B.11 in the Appendix shows the distribution of changes in infrastructure for both of these counterfactuals. In the full counterfactual, there is an increase in infrastructure in most areas of the city (70%). Instead, in the constrained, there is a reduction in infrastructure in more than half the edges in the city (56%).

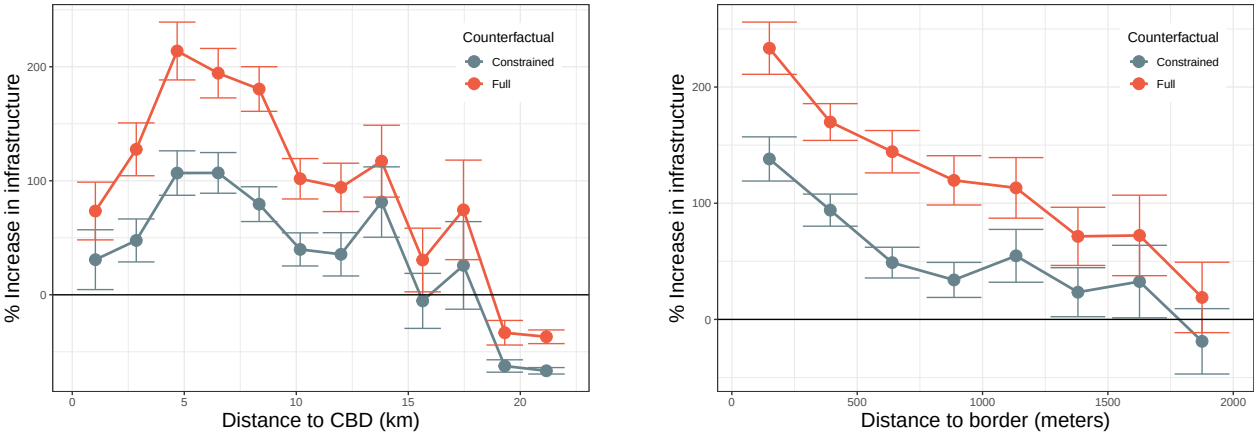
metropolitan planner substantially increases infrastructure at the ring around the city's center, effectively improving the connection between residential and employment areas of the city. Note that the investment pattern is similar between the centralized and the constrained centralized counterfactual. The constraint on the overall budget introduces a level effect, limiting the extent to which the metropolitan planner can expand infrastructure without reducing it elsewhere.

Figure 15(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. These are the areas with the most underinvestment in the baseline, as an important fraction of the benefits from infrastructure in these locations is accrued to neighboring municipalities.

Figure 15: Changes to the city's infrastructure as a function of distance

(a) Distance to CBD

(b) Distance to border



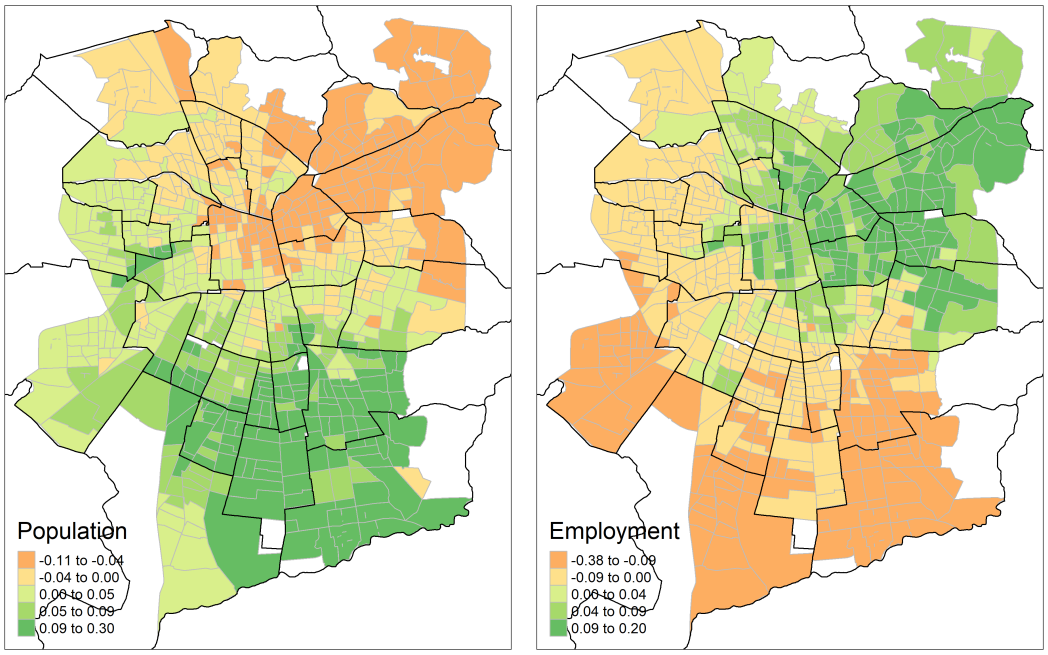
Note: Distance to the city's center is calculated as distance to *Plaza de Armas*, the main square in the downtown municipality.

Now, focusing on the effects of this reallocation of infrastructure on the city's equilibrium, Figure 16 shows how the distribution of population changes in space for the constrained counterfactual. 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.[34]

[34]The pattern of changes in the population of residents and workers looks very similar in the full counterfactual. However, the movements are larger in size.

Figure 16: Constrained 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 $\Delta L_{\mathrm{R}i} = \frac{L^C_{\mathrm{R}i} - L^g_{\mathrm{R}i}}{L^g_{\mathrm{R}i}}$.

We can study the economic forces that explain the pattern of increase (and decrease) in infrastructure shown in Figure 14 by comparing the residential and employment forces defined in Section 2.2.1 under both equilibria. We can interpret these forces as weighted traffic flows, that is, the sum over the commuters that use a given link, weighted by the marginal value of that commuter from the perspective of the government. The residential force, which we can also call residential *flows*, are the traffic flows weighted by the marginal residential value from the government's perspective. Similarly, the employment force can be interpreted as the traffic flows weighted by the marginal commercial value from the government's perspective. These government-specific weights are a function of the government-specific Lagrange multipliers.[35]

Figure 17(a) shows the ratio between the residential flows in the decentralized equilibrium relative to the residential flows in the centralized equilibrium. Figure 17(b) shows the ratio between the employment flows in the decentralized equilibrium relative to the employment flows in the centralized equilibrium. We can think of these relative flows 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.[36]

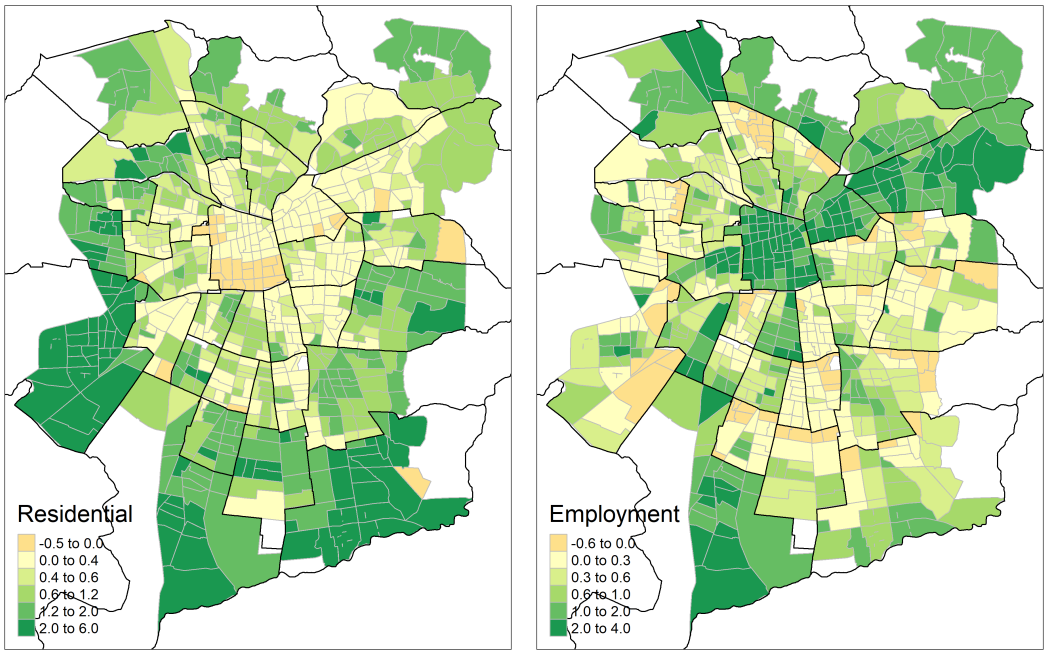
[35] See Appendix A.4 for the derivation.

[36] When calculating the relative flows, we consider the flows from the perspective of municipality g for edges in g's control relative to the metropolitan flows.

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 flows: additional infrastructure would translate into a loss in residents and land value for this municipality.

Figure 17: Relative flows

(a) Residential flows (b) Employment flows



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 flows in Figure 17(a). Areas around the city's center have low relative residential flows, 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. In some locations at the center, the municipality loses overall residential value from investing in infrastructure. 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 relative employment flows in Figure 17(b), the central and eastern municipalities (areas with high exogenous productivity) have relative employment flows larger 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 flows.[37] These governments have relatively low productivity and residential amenities 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 exogenous characteristics (high productivity or high amenity). 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,

Winners and Losers of Decentralization

We now compute the differences in aggregate surplus by municipality, that is, 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, and the aggregate gains in land value are the largest.

Figure 18(a) shows the difference in surplus, and Figure 18(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 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.

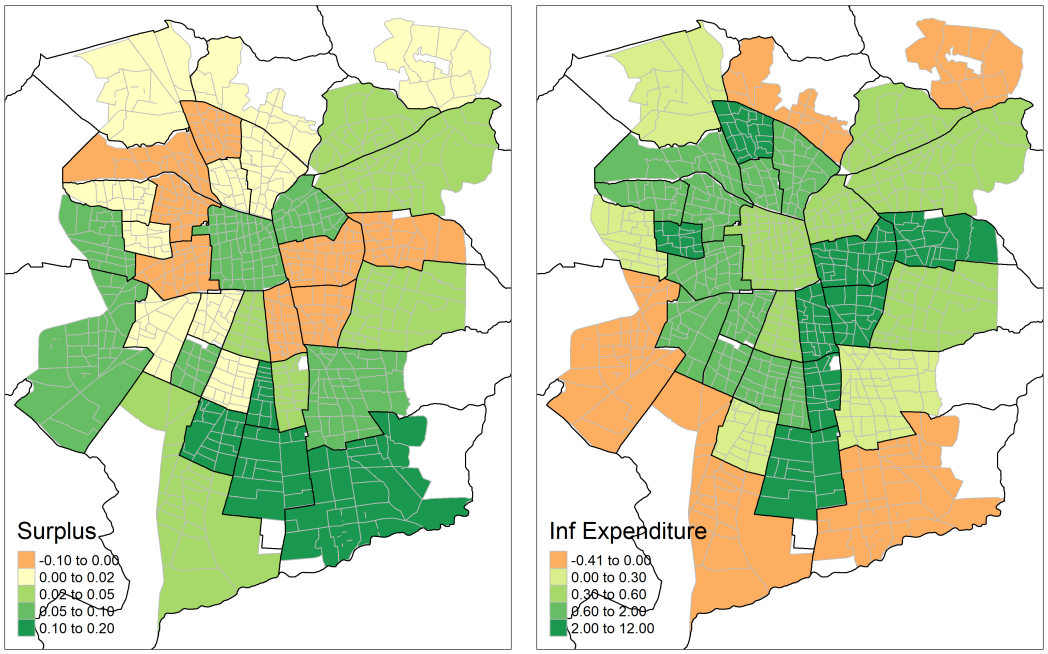
The municipalities in orange are the ones that benefit from decentralization and are losing surplus

[37] We can see a government's overall level of underinvestment in Figure 18(b). This figure shows the overall increase in expenditure by the government in the full centralized counterfactual, where the total metropolitan budget doubles. 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.

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 18: Full counterfactual - Change in surplus and socioeconomic status

(a) Δ surplus by government (b) Δ expenditure by gov.



The central municipality, called Santiago, is better off in the centralized equilibrium, even though improving its infrastructure causes a loss in residential land value compared to the baseline. This result is because an increase in productive land value compensates for the loss.

6 Conclusions

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.

I then turn to an empirical application: Santiago, Chile. I first test one of the key predictions

of the model. I document that road density decreases with proximity to the boundary between municipalities and, moreover, it changes discontinuously at the border, as the identity of the municipality that makes the investment decisions changes. I then estimate the model's parameters and fundamentals by matching the pattern of commuting, population, employment, and infrastructure in Santiago. With the estimated model, I quantify both the aggregate and allocative effects of decentralization in Santiago by considering two counterfactual centralized economies.

From the counterfactual analysis, I show that centralizing investment decisions would substantially increase investment: total expenditure on infrastructure would double. Importantly, the gains from centralizing are not only about building more but also about allocating the infrastructure more efficiently. By shifting infrastructure towards the locations that underinvest the most, without increasing aggregate infrastructure expenditure, centralization achieves 63% of the aggregate gains in welfare and population from the full centralized counterfactual.

I expect that the findings and framework presented in this paper will be valuable for future research. For instance, municipalities that most benefit from centralization are also the most economically disadvantaged. Figure 7(b) illustrates the distribution of socio-economic status in the city, while Figure 18(a) shows the surplus changes across municipalities. Lower-income households are mainly concentrated in the southern and western outskirts of the city. These areas are far from the job-rich zones and, moreover, they commute through the areas that underinvest the most. Therefore, lower-income households stand to benefit more from increased investments in their nearby municipalities than higher-income households.

It would be interesting to extend my framework to account for income or skills differences across households. First, the socioeconomic distribution in space would likely change in response to a more efficient allocation of infrastructure, so we would need a model that accounts for different income groups to study the consequences of decentralization on inequality. Second, and perhaps more interesting, having different types of households would also affect the incentives of municipalities to build infrastructure. Municipalities might want to attract higher-income households because they have a bigger impact on land value. Additionally, if higher-income households face higher commuting costs because they have a higher value of time, they might be more responsive to infrastructure investment.

Finally, it would be valuable to study how local governments choose to invest in different types of commuting infrastructure, such as public transit versus roads. Particularly if we account for different types of households, who might have heterogeneous preferences for public and private modes of transport. If wealthier households prefer private options, such as cars, and municipalities aim to attract them, decentralization could impact investment choices across different types of infrastructure.

References

Agrawal, David R., Hoyt, William H., and Wilson, John D. (2022). "Local Policy Choice: Theory and Empirics". *Journal of Economic Literature* 60.4, pp. 1378–1455.

Ahlfeldt, Gabriel M. et al. (2015). "The Economics of Density: Evidence From the Berlin Wall". *Econometrica* 83.6, pp. 2127–2189.

Akbar, Prottoy A. and Duranton, Gilles (2017). "Measuring the Cost of Congestion in Highly Congested City: Bogotá".

Allen, Treb and Arkolakis, Costas (2022). "The Welfare Effects of Transportation Infrastructure Improvements". *The Review of Economic Studies*. rdac001.

Baum-Snow, Nathaniel (2007). "Did Highways Cause Suburbanization?" *The Quarterly Journal of Economics* 122.2, pp. 775–805.

Bravo Rodríguez, Javiera (2014). "Fondo común municipal y su desincentivo a la recaudación en Chile". *Temas de la Agenda Pública* 9.68.

Brinkman, Jeffrey and Lin, Jeffrey (2022). "Freeway Revolts! The Quality of Life Effects of Highways". *The Review of Economics and Statistics*, pp. 1–45.

Brueckner, Jan K. and Selod, Harris (2006). "The political economy of urban transport-system choice". *Journal of Public Economics* 90.6, pp. 983–1005.

CitiesToBe (2023). *Claudio Orrego: "Metropolitan challenges cannot be solved at the national nor local level"*. URL: https://www.citiestobe.com/claudio-orrego-metropolitan-challenges-santiago-chile/.

Donaldson, Dave and Hornbeck, Richard (2016). " Railroads and American Economic Growth: A "Market Access" Approach". *The Quarterly Journal of Economics* 131.2, pp. 799–858.

Fajgelbaum, Pablo and Schaal, Edouard (2020). "Optimal Transport Networks in Spatial Equilibrium". *Econometrica* 88.4, pp. 1411–1452.

Fajgelbaum, Pablo D et al. (2023). *Political Preferences and the Spatial Distribution of Infrastructure: Evidence from California's High-Speed Rail*. Working Paper 31438. National Bureau of Economic Research.

Felbermayr, Gabriel J. and Tarasov, Alexander (2022). "Trade and the spatial distribution of transport infrastructure". *Journal of Urban Economics* 130, p. 103473.

Glaeser, Edward L. and Ponzetto, Giacomo A.M. (2018). "The political economy of transportation investment". *Economics of Transportation* 13. The political economy of transport decisions, pp. 4–26.

Hornbeck, Richard and Rotemberg, Martin (2019). *Railroads, Reallocation, and the Rise of American Manufacturing*. Working Paper 26594. National Bureau of Economic Research.

Jannin, Nicolas and Sotura, Aurelie (2020). *This Town Ain't Big Enough? Quantifying Public Good Spillovers*. Working papers 796. Banque de France.

Kanemoto, Yoshitsugu (1977). "Cost-benefit analysis and the second best land use for transportation". *Journal of Urban Economics* 4.4, pp. 483–503.

Loumeau, Gabriel (2023). "Regional Borders, Commuting and Transport Network Integration". *The Review of Economics and Statistics*, pp. 1–45.

Monte, Ferdinando, Redding, Stephen J., and Rossi-Hansberg, Esteban (2018). "Commuting, Migration, and Local Employment Elasticities". *American Economic Review* 108.12, pp. 3855–90.

Oates, Wallace (2005). "Toward A Second-Generation Theory of Fiscal Federalism". *International Tax and Public Finance* 12.4, pp. 349–373.

OECD (2019). *Making Decentralisation Work*, p. 204.

Pérez Pérez, Jorge, Vial Lecaros, Felipe, and Zárate, Román (2022). *Urban Transit Infrastructure: Spatial Mismatch and Labor Market Power*. Working papers. Working Paper.

Redding, Stephen J. and Rossi-Hansberg, Esteban (2017). "Quantitative Spatial Economics". *Annual Review of Economics* 9.1, pp. 21–58.

Rossi-Hansberg, Esteban (2004). "Optimal urban land use and zoning". *Review of Economic Dynamics* 7.1, pp. 69–106.

Silva, J. M. C. Santos and Tenreyro, Silvana (2006). "The Log of Gravity". *The Review of Economics and Statistics* 88.4, pp. 641–658.

Solow, Robert M. (1973). "Congestion Cost and the Use of Land for Streets". *The Bell Journal of Economics and Management Science* 4.2, pp. 602–618.

Starrett, David A. (1981). "Land Value Capitalization in Local Public Finance". *Journal of Political Economy* 89.2, pp. 306–327.

Stiglitz, Joseph E. (1977). "The Theory of Local Public Goods". *The Economics of Public Services: Proceedings of a Conference held by the International Economic Association at Turin, Italy*. Ed. by Martin S. Feldstein and Robert P. Inman. London: Palgrave Macmillan UK, pp. 274–333.

Tiebout, Charles M. (1956). "A Pure Theory of Local Expenditures". *Journal of Political Economy* 64.5, pp. 416–424.

Train, Kenneth E. (2009). *Discrete Choice Methods with Simulation*. 2nd ed. Cambridge University Press.

Tsivanidis, Nick (2019). *Evaluating the Impact of Urban Transit Infrastructure: Evidence from Bogotá's TransMilenio*. Tech. rep. University of California, Berkeley.

Wallis, John Joseph and Oates, Wallace E. (1988). "Decentralization in the Public Sector: An Empirical Study of State and Local Government". Rosen, Harvey S. *Fiscal Federalism: Quantitative Studies*. University of Chicago Press, pp. 5–32.

Wheaton, William C. (1998). "Land Use and Density in Cities with Congestion". *Journal of Urban Economics* 43.2, pp. 258–272.

Zárate, Román David (2020). *Spatial Misallocation, Informality, and Transit Improvements: Evidence from Mexico City*. Tech. rep. University of California, Berkeley.

Zegras, Christopher P. and Gakenheimer, Ralph A. (2000). "Urban Growth Management for Mobility: The Case of the Santiago, Chile Metropolitan Region".

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,

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

We can combine these two equations to express the equilibrium wage as a function of the equilibrium commercial land value. As I mentioned in the main text, expressing the wage as a function of the commercial land value instead of a function of land and labor demand allows me to group all the destination effects in one Lagrange multiplier, the multiplier of the commercial land value.

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

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:

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

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.

$$[q_{\mathrm{R}i}]: \eta^g_{\mathrm{R}i} = \mathbb{1}[i \in \mathcal{J}^g]\bar{H}_{\mathrm{R}i} - \frac{(1-\alpha)}{q_{\mathrm{R}i}}\left(\theta\sum_j \lambda^g_{ij}L_{ij} - \frac{L_{\mathrm{R}i}}{L}(\theta - \varepsilon_L)\sum_{od}\lambda^g_{od}L_{od}\right) \tag{A.2}$$

$$[q_{\mathrm{F}j}]: \eta^g_{\mathrm{F}j} = \mathbb{1}[j \in \mathcal{J}^g]\bar{H}_{\mathrm{F}j} - \frac{1-\beta}{\beta}\frac{1}{q_{Fj}}\left(\theta\sum_i \lambda^g_{ij}L_{ij} + \sum_i \eta^g_{\mathrm{R}i}\frac{1-\alpha}{\bar{H}_{\mathrm{R}i}}L_{ij}w_j - \frac{L_{\mathrm{F}j}}{L}(\theta-\varepsilon_L)\sum_{od}\lambda^g_{od}L_{od}\right) \tag{A.3}$$

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

where:

$$\begin{aligned}
\lambda^g_{ij} &= \eta^g_{\mathrm{R}i}\frac{1-\alpha}{\bar{H}_{\mathrm{R}i}}w_j + \beta\eta_{\mathrm{F}j}\frac{q_{\mathrm{F}j}}{L_{\mathrm{F}j}} + \sum_{k\ell}\phi^g_{k\ell}\Big(\frac{\tau_{ij}}{\tau_{ik}t_{k\ell}\tau_{\ell j}}\Big)^{\rho} \\
\gamma^g_{ij} &= -\frac{L_{ij}}{\tau_{ij}}\left(\theta\lambda^g_{ij} - \frac{(\theta-\varepsilon_L)}{L}\sum_{od}\lambda^g_{od}L_{od}\right) + \frac{\rho}{\tau_{ij}}\sum_{k\ell}\phi^g_{k\ell}L_{ij}\pi^{k\ell}_{ij} - \\
&\quad \frac{\rho}{\tau_{ij}}\sum_{\ell}\phi^g_{j\ell}\sum_m L_{im}\pi^{j\ell}_{im} - \frac{\rho}{\tau_{ij}}\sum_k\phi^g_{ki}\sum_m L_{mj}\pi^{ki}_{mj} \\
\varepsilon_L &\equiv \mu\Big(1 - \frac{L}{\bar{L}_c}\Big) \quad = \frac{\partial L}{\partial U}\times\frac{U}{L}
\end{aligned}$$

where the optimal infrastructure is given by:

$$(\mathrm{I}^*_{k\ell})^g = \frac{\xi}{\sigma}\frac{1}{\delta^{\mathrm{I}}_{k\ell}}\Big(\frac{1}{\sigma \log d_{k\ell}} + \rho\Big)^{-1} \sum_{ij} -\gamma^g_{ij}\tau_{ij}\pi^{k\ell}_{ij}$$

A.4 Weighted flows

In this section, I will show we can go from the residential, employment, and congestion effects to weighted flows. These effects map to the flow of commuters using the edge, weighted by government-specific weights.

Residential Effect

After some algebra and using the definitions of the Lagrange multipliers, we can simplify the residential force as

$$\begin{aligned} Q^g_{\mathrm{R}k\ell} &= \sum_{ij} -\eta^g_{\mathrm{R}i}\frac{\partial q_{\mathrm{R}i}}{\partial L_{ij}}\frac{\partial L_{ij}}{\partial d_{k\ell}} \\ &= \sum_{ij} \eta^g_{\mathrm{R}i} \underbrace{\frac{(1-\alpha)}{\bar{H}_{\mathrm{R}i}} w_j}_{\frac{\partial q_{\mathrm{R}i}}{\partial L_{ij}}} \underbrace{\frac{L_{ij}}{d_{k\ell}}\left(\theta\pi^{k\ell}_{ij} - \frac{Q_{k\ell}}{L}(\theta - \varepsilon_L)\right)}_{\frac{\partial L_{ij}}{\partial d_{k\ell}}}. \end{aligned}$$

A reduction in d_{ij} will affect L_{ij} throughout the city, not only the origin-destination pairs that most intensely use the link $k\ell$, but also it affects L_{ij} through the effect in U and L. These population movements also affect residential (origin) land value across all locations. These changes in land value are multiplied by η^g_{R}, which transforms residential land changes to land value captured by the government g.

Now, by using equation (15) and reorganizing the above expression to express as a weighted traffic flow

$$Q^g_{\mathrm{R}k\ell} = \sum_{ij} \frac{\pi^{k\ell}_{ij}}{d_{k\ell}} L_{ij} \underbrace{\left(\theta\eta^g_{\mathrm{R}i}\frac{1-\alpha}{\bar{H}_{\mathrm{R}i}} w_j - \frac{\theta - \varepsilon_L}{L}\sum_h \eta^g_{\mathrm{R}h} q_{\mathrm{R}h}\right)}_{\equiv \omega^g_{\mathrm{R}ij}}. \tag{A.5}$$

Recall that traffic flows are given by $Q_{k\ell} = \sum_{ij} L_{ij}\pi^{k\ell}_{ij}$. So we can interpret these residential flows as the commuters using edge $k\ell$, weighted by $\omega^g_{\mathrm{R}ij}$, which represents the value derived by the government g from changes to residential land value caused by a reduction in commuting costs for link $k\ell$, $d_{k\ell}$.

Employment Effect

After some algebra and using the definitions of the Lagrange multipliers, we can simplify the

employment force to

$$
\begin{aligned}
Q^g_{\mathrm{F}k\ell} &= \sum_{ij} -\eta^g_{\mathrm{F}j} \frac{\partial q_{\mathrm{F}j}}{\partial L_{ij}} \frac{\partial L_{ij}}{\partial d_{k\ell}} \\
&= \sum_{ij} \eta^g_{\mathrm{F}j} \underbrace{\beta \frac{q_{\mathrm{F}j}}{L_{\mathrm{F}j}}}_{\frac{\partial q_{\mathrm{F}j}}{\partial L_{ij}}} \underbrace{\frac{L_{ij}}{d_{k\ell}} \left(\theta \pi^{k\ell}_{ij} - \frac{Q_{k\ell}}{L}(\theta - \varepsilon_L) \right)}_{\frac{\partial L_{ij}}{\partial d_{k\ell}}}
\end{aligned}
$$

A reduction in d_{ij} will affect L_{ij} throughout the city, not only the origin-destination pairs that most intensely use the link $k\ell$, but also it affects L_{ij} through the effect in U and L. These population movements also affect commercial (destination) land value across all locations. These changes in land value are multiplied by η^g_{F}, which transforms residential land changes to land value captured by the government g.

Now, by using equation (15) and reorganizing the above expression to express as a weighted traffic flow

$$
Q^g_{\mathrm{F}k\ell} = \sum_{ij} \frac{\pi^{k\ell}_{ij}}{d_{k\ell}} L_{ij} \underbrace{\left(\theta \beta \eta^g_{\mathrm{F}j} \frac{q_{\mathrm{F}j}}{L_{\mathrm{F}j}} - \frac{\theta - \varepsilon_L}{L} \sum_h \beta \eta^g_{\mathrm{F}h} q_{\mathrm{F}h} \right)}_{\equiv \omega^g_{\mathrm{F}ij}}. \tag{A.6}
$$

We can interpret these employment flows as the commuters using edge $k\ell$, weighted by $\omega^g_{\mathrm{F}ij}$, which represents the value derived by the government g from changes to commercial land value caused by a reduction in commuting costs for link $k\ell$, $d_{k\ell}$.

Congestion Effect

Following a similar approach to the congestion effect, we can express the congestion force as a weighted traffic flow:

$$
Q^g_{\mathrm{C}k\ell} = \sum_{ij} \frac{\pi^{k\ell}_{ij}}{d_{k\ell}} L_{ij} \underbrace{\left(\theta \sum_{k\ell} \phi^g_{k\ell} \pi^{k\ell}_{ij} - \frac{\theta - \varepsilon_L}{L} \sum_{mn} \phi^g_{mn} Q_{mn} \right)}_{\equiv \omega^g_{\mathrm{C}ij}} \tag{A.7}
$$

We can interpret these congestion flows as the commuters using edge $k\ell$, weighted by $\omega^g_{\mathrm{Q}ij}$, which represents the value (or cost) derived by the government g from changes to traffic flows caused by a reduction in commuting costs for link $k\ell$, $d_{k\ell}$.

A.5 Discussion: Role of productivity and amenities in space

The heterogeneity in the relative productivity and residential amenities across locations is an important determinant of how decentralization plays out.[38] First, differences in productivity or amenities determine how concentrated employment or residents are in some municipalities and how many households commute across jurisdiction boundaries. Cross-jurisdiction commuting relates to the size of infrastructure spillovers; more benefits accrue to other municipalities when many commuters live or work in other municipalities. Second, differences in productivity or amenities shape the ability of local governments to engage in "business stealing": the more productive or high-amenity a municipality is relative to its neighbors, the greater its ability to increase its land value through infrastructure investments.

Let us consider the edge-level commuting elasticity of travel demand. 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, $d_{k\ell}$:

$$-\frac{\partial L_{ij}}{\partial d_{k\ell}} \times \frac{d_{k\ell}}{L_{ij}} = \theta \pi_{ij}^{k\ell} - \frac{Q_{k\ell}}{L}\Big(\theta - \varepsilon_L\Big). \tag{A.8}$$

where ε_L is the elasticity of the aggregate metropolitan populations with respect to the ex-ante expected utility level, U. 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 expected utility of the city, U, and the aggregate population of 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, grows.

Since $\theta > \varepsilon_L$, that is, the population supply to a location pair within the city is higher than the aggregate population supply to the metropolitan area. In that case, this indirect effect is negative. Hence, for location pairs that do not use the edge $k\ell$ (and therefore, the direct effect is zero), the indirect effect reflects how the population declines. This decline translates into population growth in the locations pairs that do use the edge $k\ell$.

Equation (A.8) implies that the edge-level commuting elasticity of travel demand depends on two edge-level variables: the "centrality" of the edge, captured by $\mathbb{1}_{ij}^{k\ell}$, and the equilibrium traffic flows, $Q_{k\ell}$. First, suppose an edge is used by many location pairs thanks to its position in the network. In that case, municipalities can better influence the population distribution within the city by investing in it. Second, the more traffic flows on an edge, the more a government can "steal" population away from location pairs that do not benefit from this edge. Moreover, equilibrium

[38] What matters is the difference in productivity across locations, more than the level. How much more productive are the best locations relative to the low-productivity ones? The same goes for amenities.

traffic flows are endogenous and increase in the dispersion of productivities and amenities.

A.6 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	0.15
ξ	Infrastructure elasticity	0.10
θ	Commuting elasticity	7
μ	Migration elasticity	5

A.7 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 (18) 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

$$\pi = \frac{\sum_i \{q_{\mathrm{R}i}\bar{H}_{\mathrm{R}i} + q_{\mathrm{F}i}\bar{H}_{\mathrm{F}i}\} - \sum_{k\ell}\delta^{\mathrm{I}}_{k\ell}\mathrm{I}_{k\ell}}{\sum_{ij} L_{ij} w_j}. \tag{A.9}$$

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:

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

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

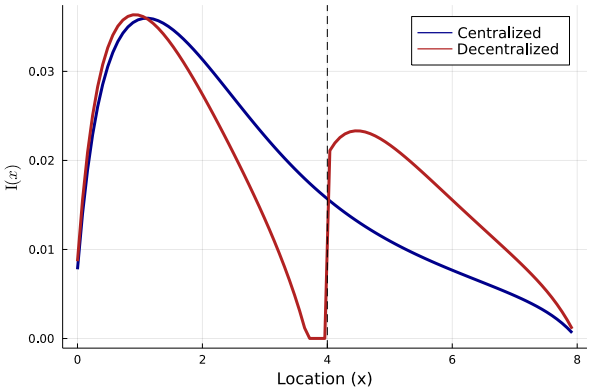
$$U = \left(\sum_{ij} \tau_{ij}^{-\theta} \left(\frac{\bar{B}_i}{q_{\mathrm{R}i}^{1-\alpha}} \right)^{\theta} y_j^{\theta} \right)^{\frac{1}{\theta}}.$$

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.9) when solving their optimal investment problem.

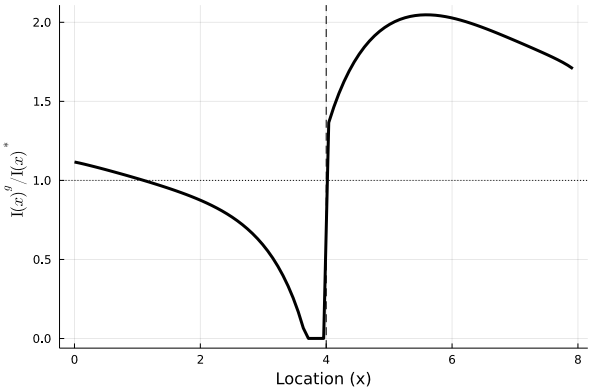
Figure A.1 shows the optimal investment with these land value transfers. I am using the same parameter values as in the linear city example in the main text. Note that the distortions from decentralization are amplified given the land transfers. First, these subsidies increase the implicit weight placed 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.8 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:

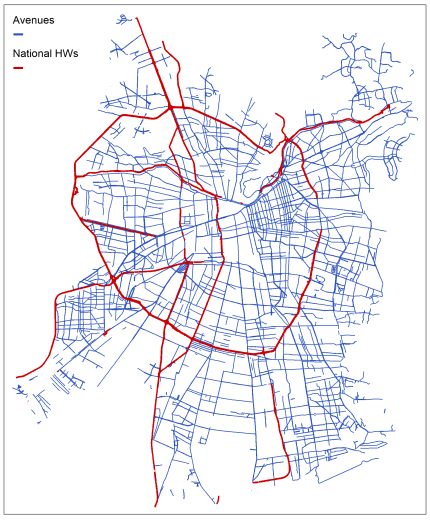
1. Given a city equilibrium $\mathbf{x} = \{L_{ij}, q_{\mathrm{R}i}, q_{\mathrm{F}j}, Q_{k\ell}, d_{k\ell}\}$, I compute the Lagrange multipliers $\lambda = \{\eta_{\mathrm{R}i}, \eta_{\mathrm{F}j}, \phi_{k\ell}\}$: This implies inverting a linear system of equations of size $2N + E$, where N is the number of locations and E is the number of edges. The system of equations is given by equations (A.2), (A.3), and (A.4).[39]
2. Given $\mathbf{x}$ and λ, I compute the optimal infrastructure $\mathrm{I}^g_{k\ell}$ using equation (31).
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), (13), (14), (15), (16), (17), and (19).

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 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 Data and Estimation Appendix

B.1 Figures

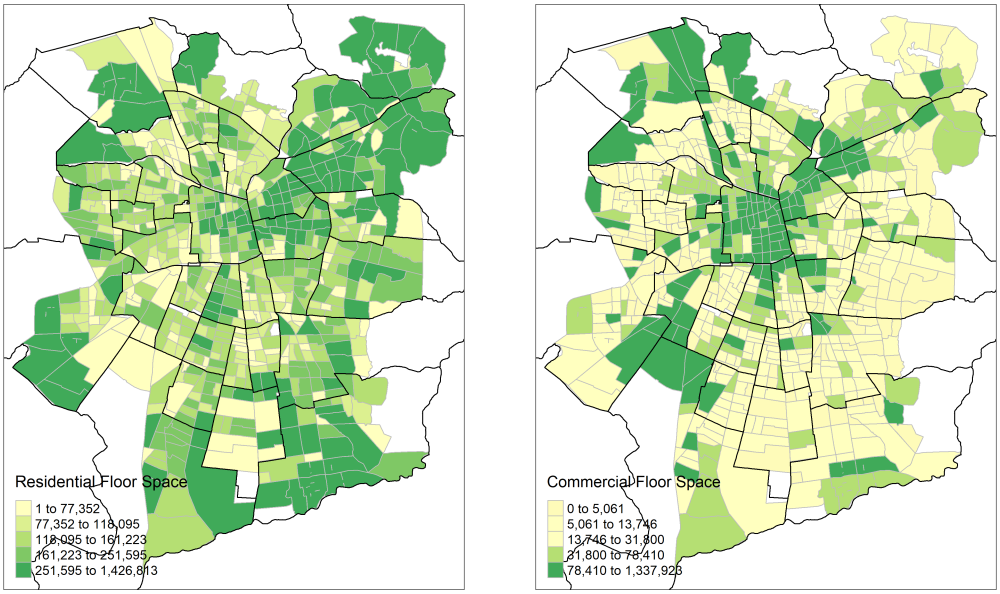
Figure B.1: Santiago's road network



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

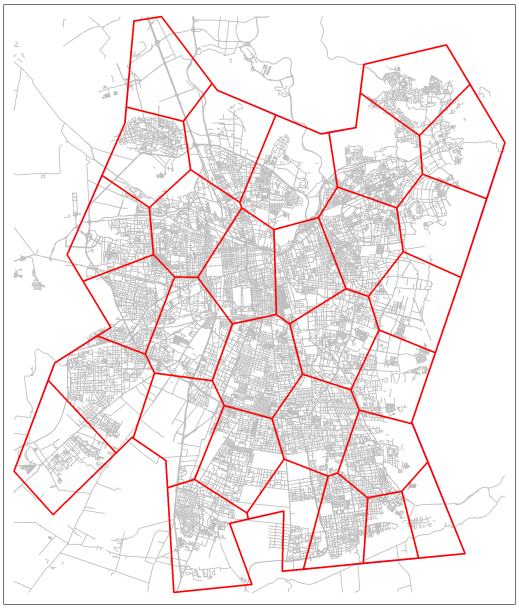
Figure B.2: Available floor space by purpose in Santiago

(a) Residential (b) Productive



Note: Constructed using the public database of real estate appraisals by the tax authority (2018).

Figure B.3: Example: Placebo Municipalities

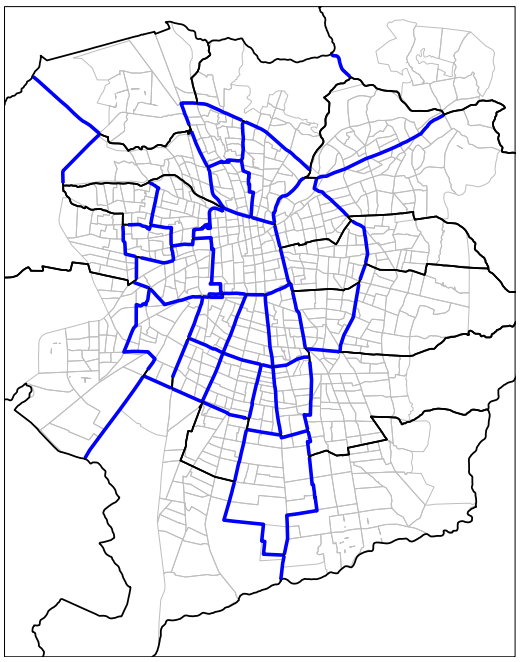


B.2 Empirical patterns

B.2.1 Discontinuity in infrastructure

This section explains how I construct the investment pattern at the boundary documented in Figure 11. 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 63 borderlines that follow a pattern closer to a straight line.[40] The resulting set of borders is shown in the following figure:

Figure B.4: Selected Borders

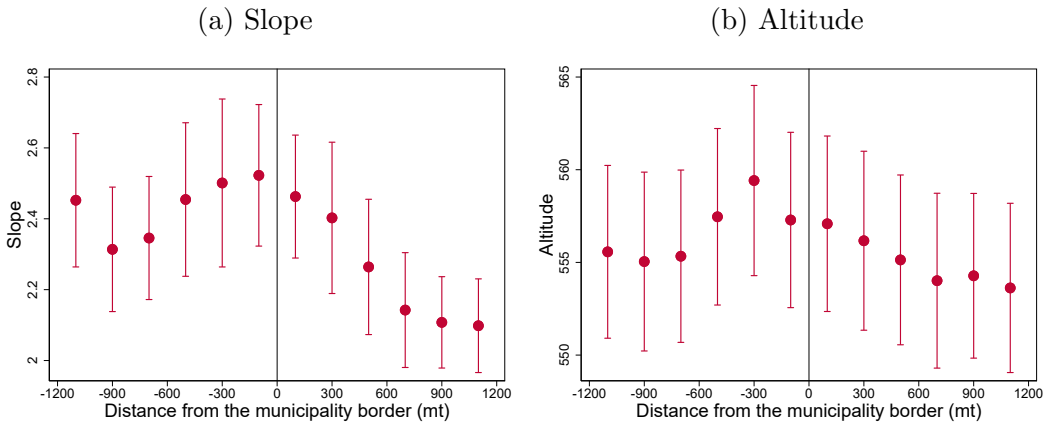


Note: In black, I plot the municipality boundaries. In blue, I plot the selected borders. As you can see, they follow a pattern closer to a straight line than the borders I excluded.

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.

[40] To select these borders, I calculate the number of points that define the boundary. A straight line is defined by two points; a more complicated border will be defined by more points. I selected 60 points as the threshold: if the boundary line is defined by less than 60 points, it is included in the sample.

Figure B.5: Balance at the border



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 11, 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. Standard errors are clustered at the border level.

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 1.5pp and 2.1pp 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 15 to 20% change in the infrastructure level.

Table B.1: Discontinuity in infrastructure at the border

	<1200 mt		<600 mt	
	(1) Linear	(2) Quadratic	(3) Linear	(4) Quadratic
$\mathbb{1}$(Distance>0)	0.0175***	0.0145*	0.0165**	0.0211**
	(0.00548)	(0.00778)	(0.00671)	(0.0103)
N	7938	7938	3932	3932
Border FE	Yes	Yes	Yes	Yes

Standard errors in parentheses

Robust standard errors, adjusted for clustering by border.

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

B.2.2 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.

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

- *Traffic flows:* Number of commuters traveling through grid k located in municipality g.

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

These traffic flows are a simpler parallel of the residential and employment flows defined in the model, where instead of weighing each commuter by the full government-specific marginal land 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. Moreover, do municipalities care both about their residents and workers? However, there are important empirical challenges when taking this prediction to the data. The main one is that traffic flows are also 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 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.

With this in mind, I run the following regression:

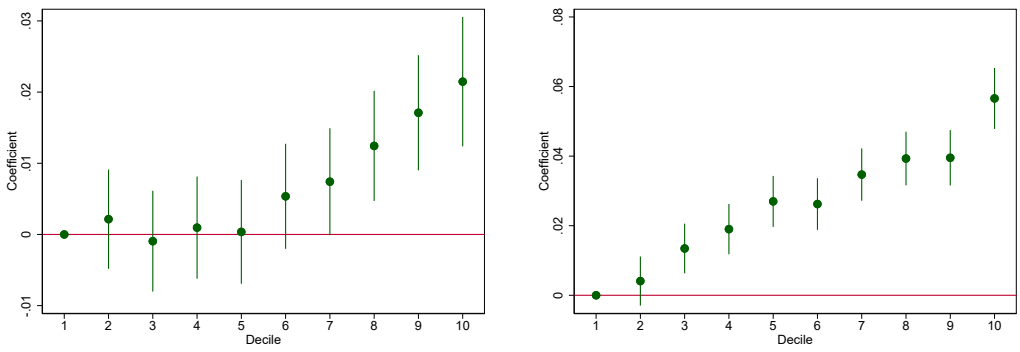
$$\mathrm{I}_k = \alpha + f(Q_k) + \sum_{d=1}^{10} \beta_d \mathrm{Decile}_d^{\mathrm{R}} + \sum_{d=1}^{10} \gamma_d \mathrm{Decile}_d^{\mathrm{F}} + \mathbb{X}_k^{\mathrm{Geo}} + \delta_{g(k)} + \varepsilon_k,$$

where $f(Q_k)$ is a flexible function of overall traffic flows in the grid k. $\text{Decile}_d^{\text{R}}$ and $\text{Decile}_d^{\text{F}}$ are indicator variables for the deciles of residential flows, $Q_{\text{R}k}^g$, and employment flows, $Q_{\text{F}k}^g$, respectively. Further, I control for geographical variables such as density (built floor space over the area), altitude and slope of the terrain, and a municipality fixed effect, $\delta_{g(k)}$.

Figure B.6 plots the coefficients and their 95% confidence intervals for the decile indicators, on the left for residential flows and the right for employment flows. The omitted category is the first decile (the lowest), so the coefficient is zero.

Figure B.6: Infrastructure and local flows

(a) Residential Flows (b) Employment Flows

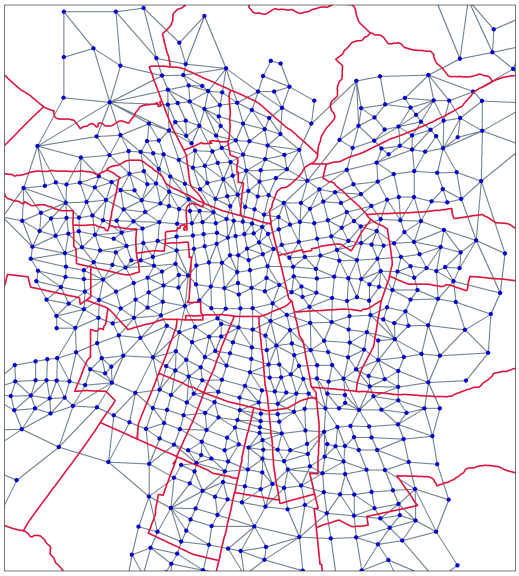


Note: In this case, I am controlling for a quadratic function of overall traffic flows. $f(Q_k) = \alpha Q_k + \beta Q_k^2$.

Figure B.6 shows a positive relationship between the density of roads and the number of residents and workers using a given grid cell (area of the city). We can read the above as: areas in the city with similar levels of overall traffic flows and geographical characteristics have a higher density of roads when there is a larger number of the municipality's own residents or own workers traveling through those areas. This is a correlation in the data and not a causal relationship. Having said that, it is still suggestive that municipalities prioritize their residents and workers more than external commuters with road investment decisions.

B.3 Estimation of the model's parameters

Figure B.7: Network of locations and edges



B.3.1 Estimating the congestion elasticity, σ

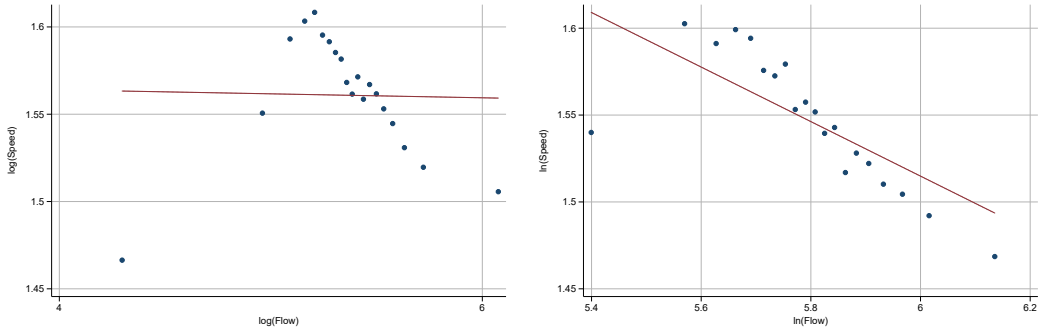
Using the Ministry's automatic readers data on traffic flows, and combining this data with my Google Maps data on real-time speed for the same intersection where the readers are located, I can study the relationship between travel times and traffic flows.

Figure B.8 (a) shows the binscatter of the relationship between log speed and log flows. We can see that for low levels of traffic, there is a positive relationship between speed and flows. On the other hand, as traffic increases and the road gets congested, the relationship becomes negative; driving speed slows down.

The increasing portion of the relationship is due to the following: When the road is uncongested, more speed by construction translates into more flow (more cars traveling in front of the reader). Intuitively, we can think about flows as a function of speed for this portion. Hence, I filter the data to capture the congested portion of the relationship.

Figure B.8: Speed as a function of traffic flows

(a) Full sample (b) Congested portion



Note: These binscatters include the following Fixed Effects: Hour of the day, day of the week, and intersection. For panel (b), I defined congested as having more than 160 cars in a 15-minute window.

I ran the following regression:

$$\ln \text{Speed}_{it} = \beta \ln \text{Flow}_{it} + \delta_i + \delta_h + \delta_d + \epsilon_{it}$$

where δ_i is an intersection fixed effect; the place where the automatic reader is located. Then, δ_h is an hour of the day fixed effect, and δ_d is a day of the week fixed effect. Note that $\beta = -\sigma$.

Table B.2: Regression Results

	ln(Speed)
ln(Traffic Flow)	-0.144***
	(0.0103)
Observations	35068
Adjusted R^2	0.617

FE: Hour, day of the week, intersection.

B.3.2 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.2.1.

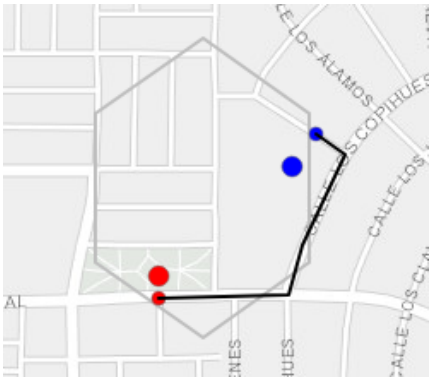
The identifying assumptions behind this strategy are that unobserved omitted variables that might affect infrastructure and speed are continuous at the border. Second, the exclusion restriction for

the instrument of crossing the border has to hold; that is, crossing the border only affects the speed of travel through the available infrastructure.

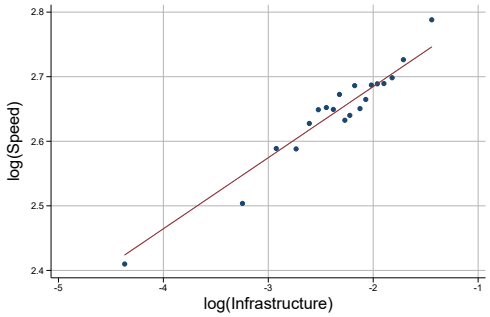
I compute speed using the same grid of hexagonal polygons used to calculate infrastructure in space. For each grid cell, I take a random sample of origin and destination points within the polygon and then use Open Street Map to calculate the travel time and distance between these two points in the road 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.9(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



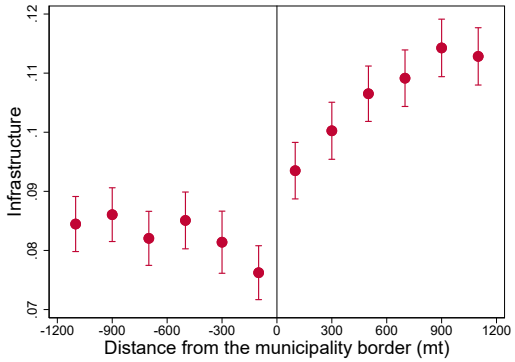
Note: In (b), I control for log(Flows), urban density, slope, and altitude.

Figure B.9(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.

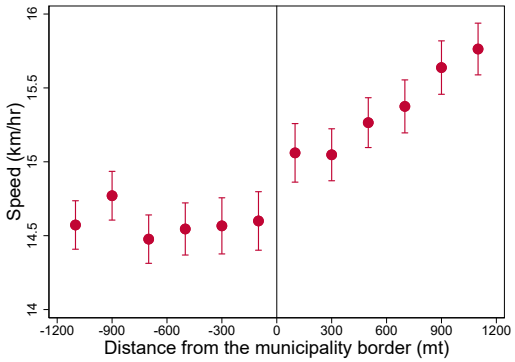
Now, with a set of speed measurements for every grid cell in the 1.2 km buffer around the municipality borders, we can use the discontinuity in infrastructure at the border and relate that jump to the difference in speed around the border.

Figure B.10: Discontinuity at the border

(a) Infrastructure



(b) Speed



I estimate ξ through the following 2SLS strategy

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

where $\log(\widehat{\text{Infrastructure}}_i)$ 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.[41]

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)	0.135***	0.129*	0.133*	0.0712
	(0.00195)	(0.0725)	(0.0741)	(0.0751)
N	70983	70983	58362	46026
Border FE	Yes	Yes	Yes	Yes

Standard errors in parentheses

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

[41] 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.

B.4 Counterfactual Analysis

Figure B.11 compares the distribution of changes in infrastructure for both counterfactuals. In the centralized case (in red), the metropolitan planner increases infrastructure for almost all locations. There is a reduction in infrastructure for roughly 30% of the links in the network, mostly located at the periphery of the city. In contrast, the constrained counterfactual reduces the infrastructure in more than half of the edges in the city (56%). This reduction goes towards increasing the infrastructure in the inner ring and improving the connectivity between the periphery and the city's core.

Figure B.11: Distribution of increase in infrastructure

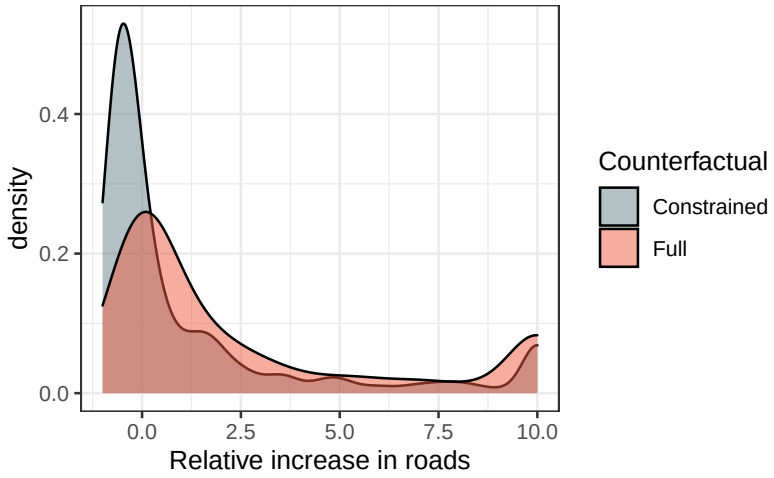
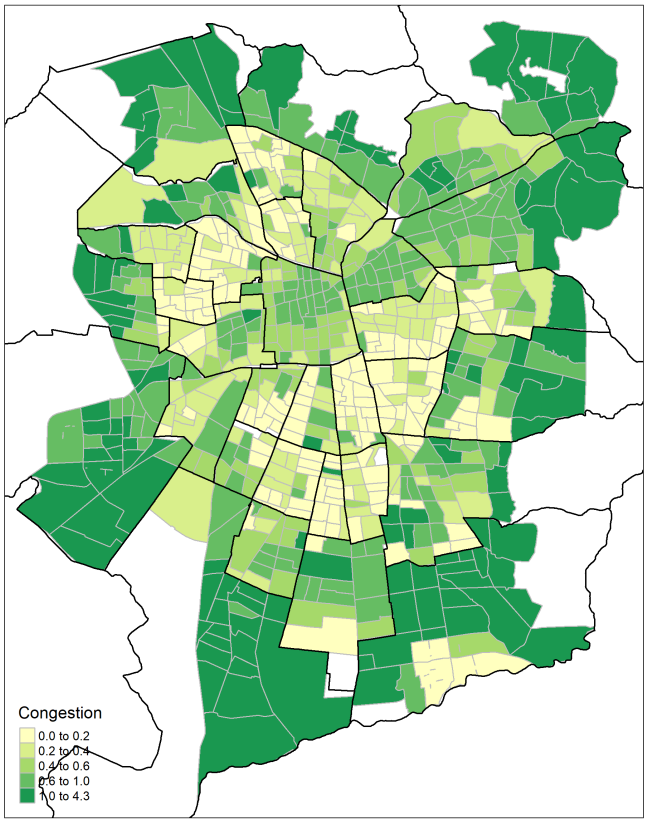


Figure B.12: Relative flows: Congestion



Note: Relative flows are defined as $\frac{Q_C^D}{Q_C^C}$. 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.