Commuting Infrastructure in Fragmented Cities

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November 15, 2024

Fifth Women in International Economics Conference

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Cities, local governments, and transport infrastructure

- Metropolitan areas are politically fragmented $\rightarrow$ 74 jurisdictions on average (OECD)
- However, municipalities are responsible for local transport infrastructure$\rightarrow$ **roads**

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  - Significant commuting across governments:
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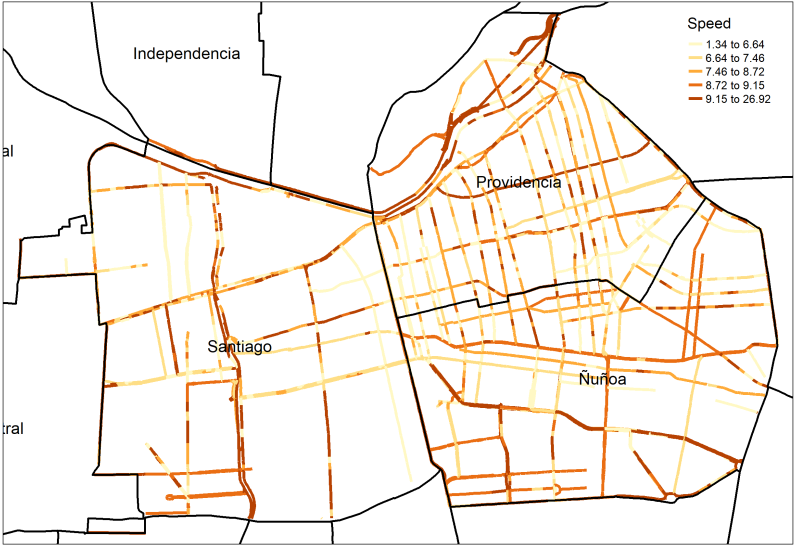
How does decentralization affect commuting infrastructure (roads) within cities?

What are the implications for welfare and the distribution of economic activity?

Santiago: Main avenues across municipalities



This paper

1. **Theory:** City equilibrium $\leftrightarrow$ Commuting infrastructure decided by municipalities
    - Internal structure of the city: Locations with different amenities and productivity
    - Households choose where to live and work within the city
    - Municipalities build infrastructure maximize their residents' and workers' wage bill

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  - $\rightarrow$ "In between" municipalities underinvest the most
- $\uparrow$ cross-jurisdiction commuting costs, $\uparrow$ dispersed employment $\Longrightarrow$ polycentric city

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   - Testing the model predictions $\rightarrow$ Infrastructure at the border
   - Estimate the model
   - Counterfactuals: Centralized Santiago

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Preview of the results from the counterfactual analysis:

- It is not only about building more, but allocating roads more efficiently.

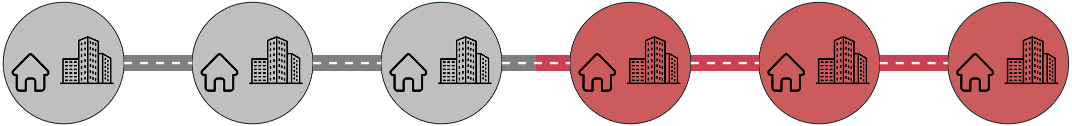
Plan for today

1. **Model:** Simplified model $\rightarrow$ **Linear city**
   - Mechanisms and model predictions
2. **Empirical application:** Santiago, Chile
   - Pattern of infrastructure at the border
   - Estimation of the model's parameters
   - Counterfactual analysis

Theoretical Framework

Overview of the model in words - Linear city

- **Geography:** Locations and edges in a line
  - Locations: Land for production and housing. Heterogeneous productivity and amenities



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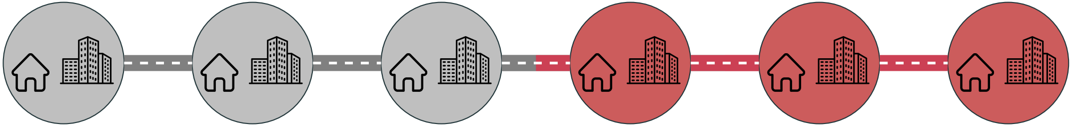
  - Choose where to live and work, commute between home and work
- **Commuting:** Traveling through an edge is costly
  - Function of infrastructure (+ traffic flows in the full model)



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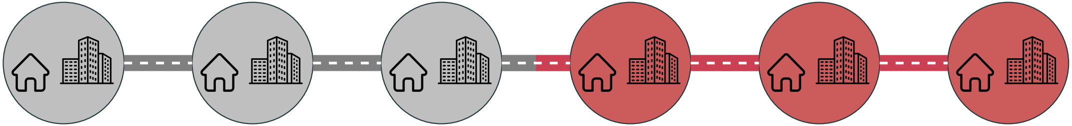
- **Commuting:** Traveling through an edge is costly
  - Function of infrastructure (+ traffic flows in the full model)
- **Local governments:** Subset of locations & edges.
  - Choose the edges' infrastructure level to maximize their residents' and workers' wage bill



City Equilibrium

Households:

- Households face land prices, q_{Ri}, amenities, $\bar{B}_i$, wages, w_j, and commuting costs, τ_{ij}
- $+$ idiosyncratic preference shocks for residency and workplace: $\varepsilon_{ij} \sim$ Fréchet(θ)

Travel Demand: $$L_{ij} = \tau_{ij}^{-\theta} \left(\frac{\bar{B}_i}{q_{Ri}^{1-\alpha}} \right)^{\theta} w_j^{\theta} \frac{L}{U^{\theta}}, \text{ where } U \equiv \left[\sum_{rs} \tau_{ij}^{-\theta} \times \left(\frac{\bar{B}_i}{q_{Ri}^{1-\alpha}} \right)^{\theta} \times w_j^{\theta} \right]^{\frac{1}{\theta}}$$

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Commuting:

$$\tau_{ij} = \prod_{k\ell} \mathbb{1}_{ij}^{k\ell} d_{k\ell}, \qquad \text{where } \mathbb{1}_{ij}^{k\ell} = 1 \text{ if pair } ij \text{ uses edge } k\ell$$

- $d_{k\ell}$: The cost of commuting through (k, ℓ) is a function of the infrastructure, $\mathrm{I}_{k\ell}$

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- $d_{k\ell}$: The cost of commuting through (k, ℓ) is a function of the infrastructure, $\mathbb{I}_{k\ell}$

Firms: Competitively produce a **freely traded** numeraire good using land and labor

Government's objective

- A local government g chooses $\mathrm{I}_{k\ell}$ in their jurisdiction $\{\mathcal{J}^g, \mathcal{E}^g\}$ to maximize their residents' and workers' wage bill, minus building costs:

$$\max_{\mathrm{I}_{k\ell} \in \mathcal{E}^g} \quad \sum_{ij} \left\{ \omega_{\mathrm{R}} \mathbb{1}[i \in \mathcal{J}^g] L_{ij} w_j + \omega_{\mathrm{F}} \mathbb{1}[j \in \mathcal{J}^g] L_{ij} w_j \right\} - \sum_{(k\ell) \in \mathcal{E}^g} \delta^{\mathrm{I}}_{k\ell} \mathrm{I}_{k\ell}$$

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- This objective function nests the following:
  1. Maximize **land value** when

$$\omega_{\mathsf{R}} = (1-\alpha), \quad \omega_{\mathsf{F}} = \frac{(1-\beta)}{\beta}$$

  2. Maximize **tax revenue** when

$$\omega_{\mathsf{R}} = \tau_{\mathsf{H}}(1-\alpha), \quad \omega_{\mathsf{F}} = \tau_{\mathsf{W}}$$

Government's problem

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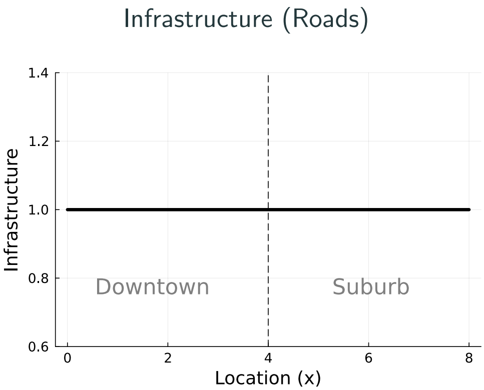
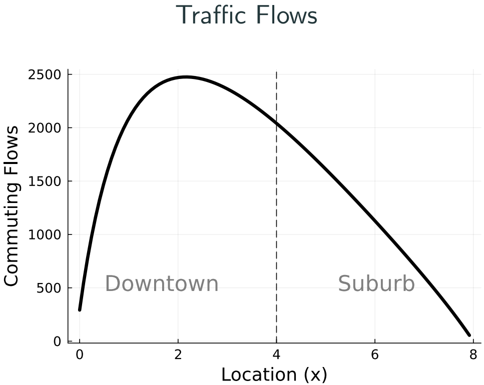
- Subject to:
    1. Equilibrium travel demands: L_{ij} $[\lambda^g_{ij}]$
    2. Equilibrium wage (from labor demand): w_i $[\eta^g_{\mathrm{F}i}]$
    3. Residential land market clearing: q_{Ri} $[\eta^g_{Ri}]$
- Government g takes other governments g' infrastructure investments as given

City Equilibrium

Exogenous Characteristics



Example city: Endogenous quantities



Optimal Infrastructure

Government's problem: Optimal infrastructure

- From the F.O.C. with respect to $\mathrm{I}_{k\ell}$:

$$\underbrace{-\frac{\partial d_{k\ell}}{\partial \mathrm{I}_{k\ell}} \sum_{ij} \lambda_{ij}^{g} \frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Benefit of I}} = \underbrace{\delta_{k\ell}^{\mathrm{I}}}_{\text{Cost of I}}$$

Government's problem: Optimal infrastructure

- From the F.O.C. with respect to $\mathrm{I}_{k\ell}$:

$$\underbrace{-\frac{\partial d_{k\ell}}{\partial \mathrm{I}_{k\ell}}}_{\text{Direct Effect}} \sum_{ij} \lambda_{ij}^{g} \frac{\partial L_{ij}}{\partial d_{k\ell}} = \underbrace{\delta_{k\ell}^{\mathrm{I}}}_{\text{Cost of I}}$$

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- $\sum_{ij} \lambda_{ij}^{g} \frac{\partial L_{ij}}{\partial d_{k\ell}}$ is the total value captured by government g from a reduction in $d_{k\ell}$:

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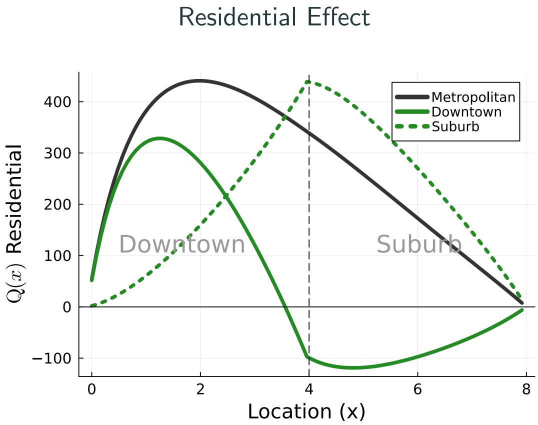
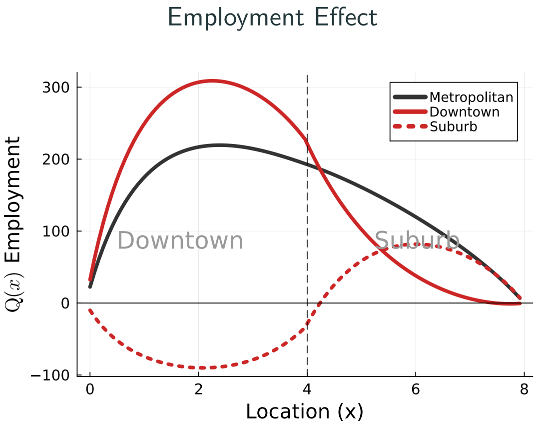
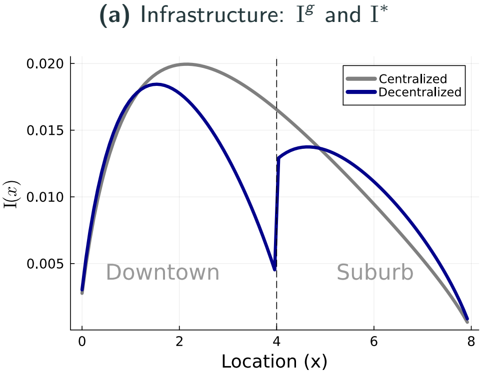
$$\underbrace{\sum_{ij} \left(\mathbb{1}[i \in \mathcal{J}^{g}]\omega_{\mathrm{R}} w_j + \eta_{Ri}^{g} \frac{\partial q_{Ri}}{\partial L_{ij}} \right) \frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Residential Effect: } \equiv Q_{k\ell}^{g}(\mathrm{R})} + \underbrace{\sum_{ij} \left(\mathbb{1}[j \in \mathcal{J}^{g}]\omega_{\mathrm{F}} w_j + \eta_{Fj}^{g} \frac{\partial w_j}{\partial L_{ij}} \right) \frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Employment Effect: } \equiv Q_{k\ell}^{g}(\mathrm{F})}$$

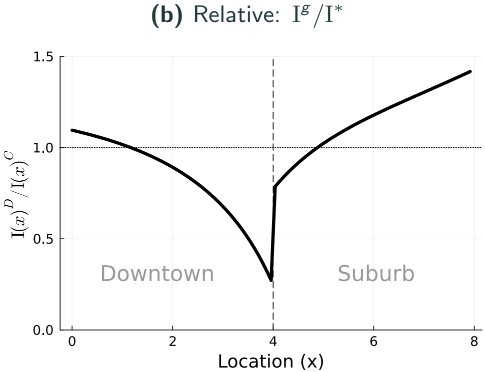
Residential and employment forces





Centralized vs Decentralized Equilibrium



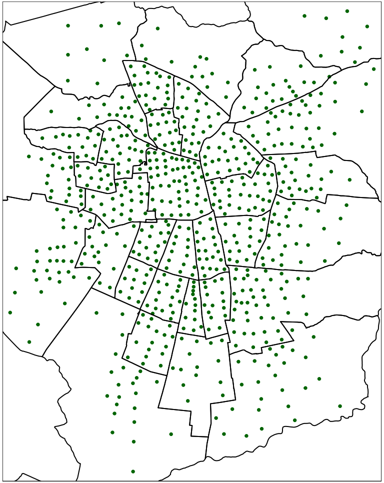


City structure | Political Weights | Other Objectives

Empirical Application: Santiago

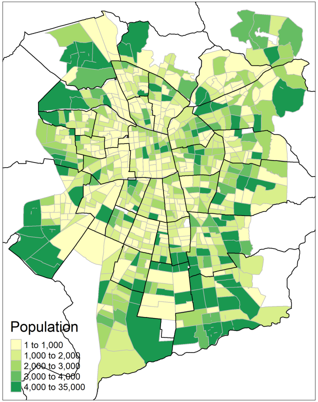
Data

- Origin-Destination Travel Survey (2012)→ L_{ij}
- Land use and tax appraisal data (SII, 2014)→ $\bar{H}_R$ and $\bar{H}_F$
- Traffic flows and speeds (2022) for 70 locations
  - Flows: Automatic traffic measurement stations.
  - Speed: Google Maps API, real-time speed
- Road network:
  - Roads by type (ownership) documented by the government (Census 2017)
  - Open Street Maps: Width and number of lanes, type of road

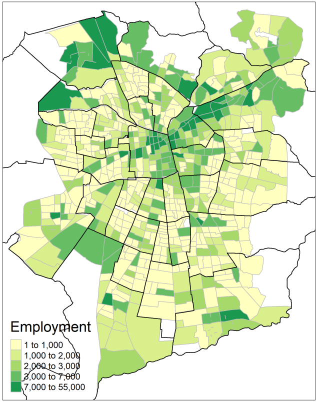


Data: Population, Employment and Density Distribution

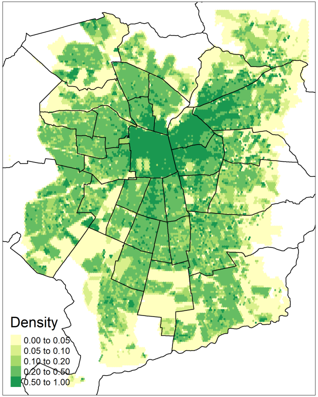
(a) Population



(b) Employment



(c) Urban Density



Infrastructure at the border

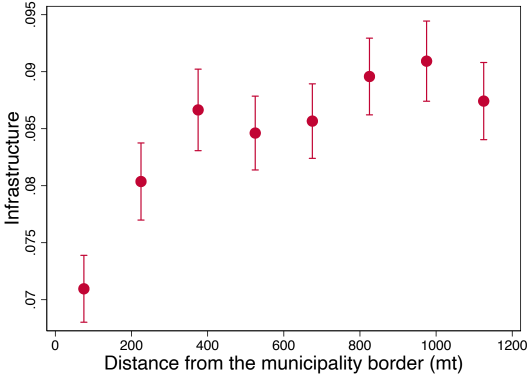
Road density at the border between municipalities

- Select borders that: 1) do not coincide with a highway, 2) smooth geography
- Measure percentage of land covered in roads in a buffer around the border

Figure 3: Example of one border between municipalities

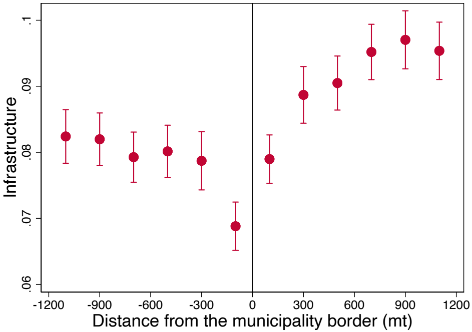
1. Decreasing density of roads closer to the border

Figure 4: Average road density as function of distance



2. Discontinuity in road density at the border between municipalities

Figure 5: Average road density

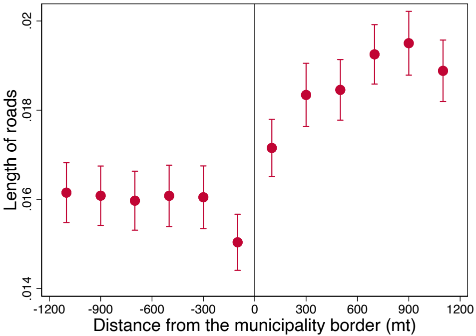


Placebo Borders Balance

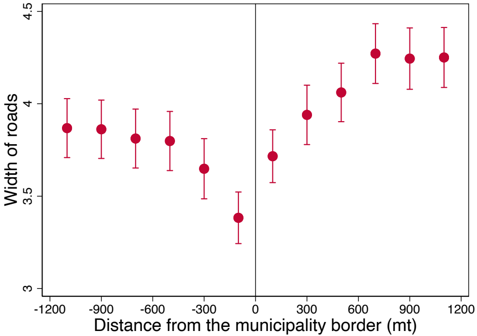
- **Ordering** procedure around the border:
  → Average infrastructure: Highest overall level on the right side of the border
- Similar pattern in other cities in Latin America: Other cities

3. Discontinuity in road density at the border: “Extensive” vs “Intensive”

(a) Average length



(b) Average width



Model Estimation

Estimation: Key Parameters

1. **Land share parameters**: $(1-\alpha)$ and $(1-\beta)$
   - Household survey (CASEN): Land share of utility, $1-\alpha = 0.25$
   - From Tsivanidis (2019): Land share of production, $1-\beta = 0.2$

Estimation: Key Parameters

1. **Land share parameters**: $(1-\alpha)$ and $(1-\beta)$
   - Household survey (CASEN): Land share of utility, $1-\alpha = 0.25$
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2. **Parameters of the transportation technology**:
   - Congestion elasticity, $\sigma = 0.14$: real time flow and speed data in Santiago Estimation
   - Infrastructure elasticity, $\xi = 0.13$: Discontinuity in infrastructure at the border
   - Exogenous edge-level speed, $\bar{t}_{k\ell}$: invert given σ, ξ, and travel times from Google maps

Estimation: Government Weights

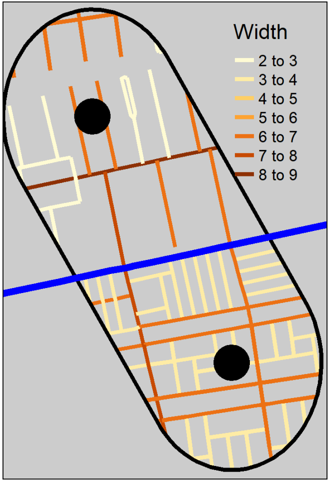
Take a link (k, ℓ) across municipalities: $g(k)! = g(\ell)$

- **Assumption:** Building costs are the same across the municipality border
- This implies the following moment condition:

$$\underbrace{\frac{I_{k\ell}^{g(k)}}{I_{k\ell}^{g(\ell)}}}_{\text{Data}} = \underbrace{\frac{t_{k\ell}^{k} \sum_{ij} \lambda_{ij}^{g(k)} \frac{\partial L_{ij}}{\partial d_{k\ell}}}{t_{k\ell}^{\ell} \sum_{ij} \lambda_{ij}^{g(\ell)} \frac{\partial L_{ij}}{\partial d_{k\ell}}}}_{\text{Data + Model function of } \omega_R \text{ and } \omega_F}$$

- By minimum distance estimation:

$$\omega_R = 0.33, \quad \omega_F = 0.26$$



Estimation: Other Parameters

3. **Location characteristics**:
   - Use the gravity equation and observed L_{ij} to invert $\{\bar{A}_i, \bar{B}_i\}$
4. **Building costs:** Building costs at the border
   - Invert from the model such that the observed infrastructure $= \mathrm{I}^g_{k\ell}$ from the model:

$$\underbrace{-\frac{\partial d_{k\ell}}{\partial \mathrm{I}_{k\ell}}\left(1-\frac{\partial Q_{k\ell}}{\partial d_{k\ell}}\frac{\partial d_{k\ell}}{\partial Q_{k\ell}}\right)^{-1}\sum_{ij}\lambda^g_{ij}\frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Data+Model}} = \underbrace{\delta^{\mathrm{I}}_{k\ell}}_{\text{Building Cost}}$$

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5. **Shape parameters of idiosyncratic preferences**: μ, θ, and ρ
   - **City choice:** From Head and Mayer (2013) $\mu = 2$
   - **Within city residence-work choice:** From Pérez Pérez et al. (2022): $\theta = 8$
   - **Commuting Route choice:** I am setting $\rho = 90$ (condition for spectral radius <1)

Counterfactual: Centralized City

Centralized counterfactual: Aggregate results $\bar{A}$ and $\bar{B}$

Two counterfactuals:

1. Centralized city: one metropolitan planner choosing the transport infrastructure
2. Centralized city | budget: metropolitan planner, **conditional to baseline budget**

Table 1: Aggregate effects (%)

Variable	Centralized	Centralized|Budget
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

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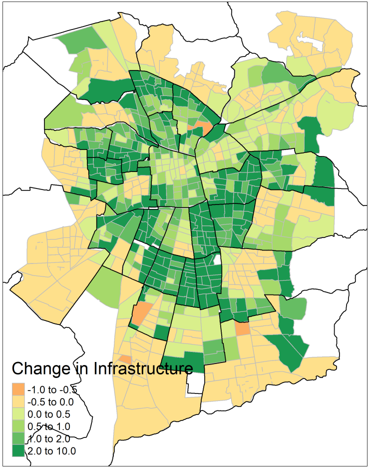
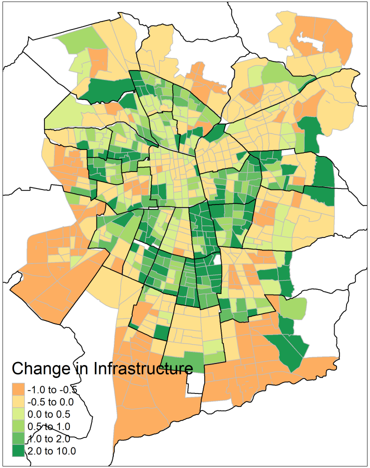
Variable	Centralized	Centralized|Budget	Relative
Population	5.3	3.5	66%
Welfare	2.3	1.5	65%
Surplus	4.2	3.9	93%
Expenditure in Infrastructure	77	0	-
Average commuting costs	-0.9	-0.3	30%

Centralized counterfactual: Distribution of $\Delta I_{k\ell}$ in space

(a) $\%\Delta I_{k\ell}$

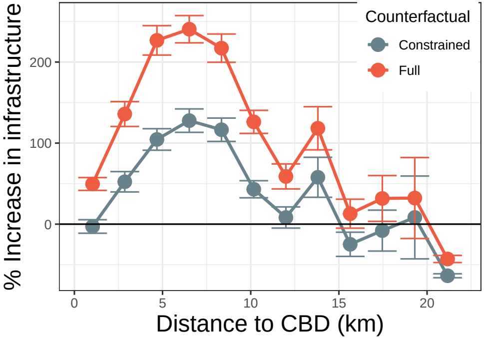


(b) $\%\Delta I_{k\ell}$ with budget

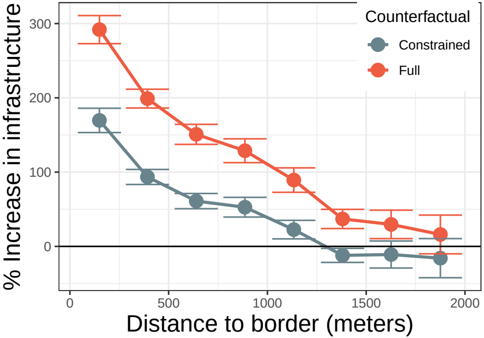


Centralized counterfactual: Distribution of $\Delta I_{k\ell}$ in space

(a) Distance to CBD

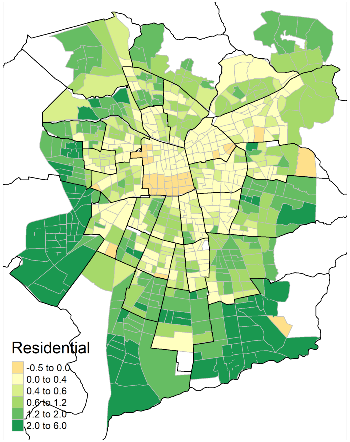


(b) Distance to border

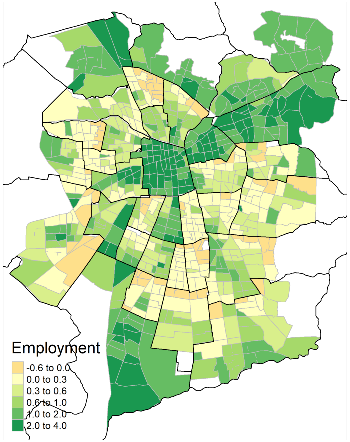


Explaining under-investment: Residential and employment forces

(a) Residential Flows: $\frac{Q(R)^g}{Q(R)^*}$

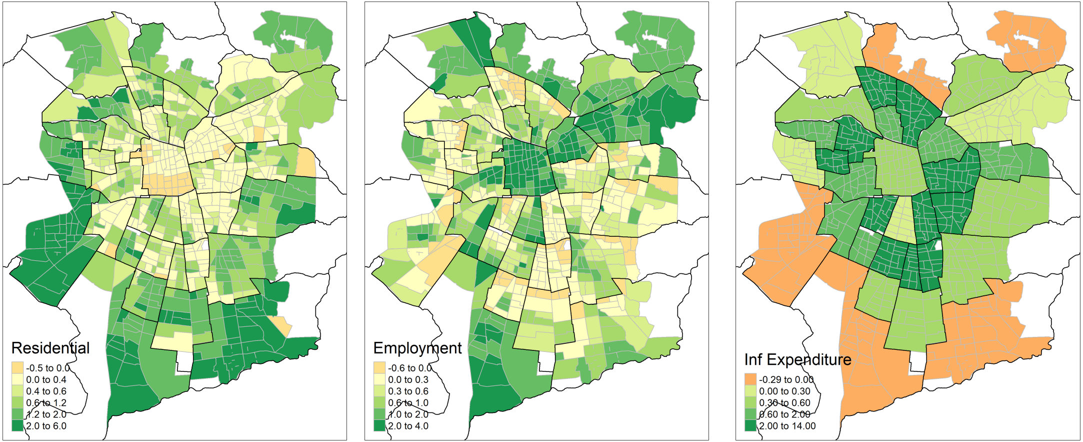


(b) Employment Flows: $\frac{Q(F)^g}{Q(F)^*}$



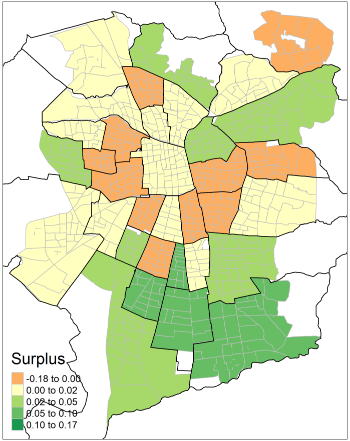
Explaining under-investment: Residential and employment forces

(a) Residential Flows: $\frac{Q(R)^g}{Q(R)^*}$ **(b)** Employment Flows: $\frac{Q(F)^g}{Q(F)^*}$ **(c)** %Δ Total Expenditure



Discussion: Trade-offs of decentralization

Figure 10: Δ in surplus



- **Centralized city:**

  $\Longrightarrow$ Bigger + more "specialized" + longer commutes

- **Decentralized city:**

  $\Longrightarrow$ Smaller + Polycentric + "15-minute" city

- Trade-offs of these two urban patters:

  $\Longrightarrow$ Winners and losers of decentralization

Conclusion

Conclusion

- Local governments around the world play an important role in local commuting infrastructure investment
- Metropolitan areas are highly fragmented
- **This paper:**
  New quantitative spatial model studying local governments' incentives to invest in commuting infrastructure $\implies$ **misallocation of infrastructure**

Conclusion

- Local governments around the world play an important role in local commuting infrastructure investment
- Metropolitan areas are highly fragmented
- **This paper:**
  New quantitative spatial model studying local governments' incentives to invest in commuting infrastructure $\Longrightarrow$ **misallocation of infrastructure**

Future research:

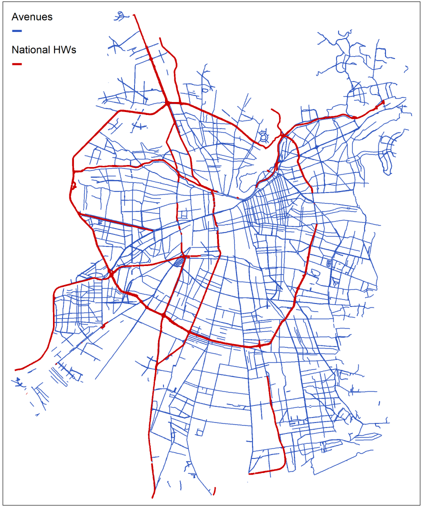
- Incorporate households' socio-economic heterogeneity Results by SES
- Environmental externalities: pollution and disamenities from traffic/infrastructure

Thank you!

Santiago and its municipal infrastructure back

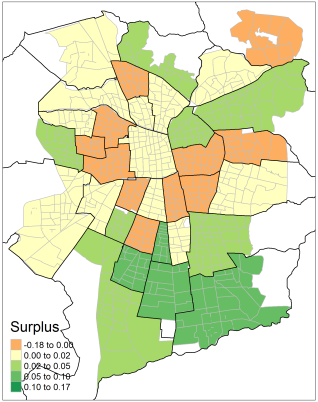
- Metropolitan infrastructure is provided by municipalities and the national governments:
  - 83% of "large" roads are municipal
  - 96% of all roads are municipal
- Using Google Maps and the Origin-Destination travel survey (2012):
  - The average commuting trip **spends 80% of the travel time** on municipal infrastructure
- I focus on the road network:
  - 62% of commutes use surface transport (car, taxi, bus, bike). 31% travel by car

Spillovers

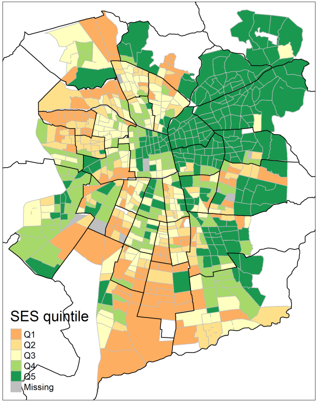


Winners and losers by socio-economic status

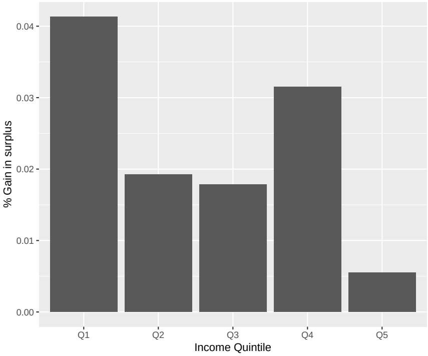
(a) Δ in surplus by municipality



(b) SES



(c) Surplus gain by income quantile



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Government's Problem: Constraints

- Travel demand:

$$L_{ij} = \tau_{ij}^{\theta} \left(\frac{\bar{B}_i}{r_{Ri}^{1-\alpha}} \right)^{\theta} w_j^{\theta} \frac{L}{\bar{W}^{\theta}}, \quad \forall i, j \in \mathcal{J}$$

- Wage (from labor demand)

$$w_i = \bar{A}_i \left(\frac{\beta}{1-\beta} \frac{\bar{H}_{Fi}}{L_{Fi}} \right)^{1-\beta}, \quad \forall i \in \mathcal{J}$$

- Residential land market clearing:

$$r_{Ri} = (1-\alpha) \frac{L_{Ri}}{\bar{H}_{Ri}} \mathbb{E}[w_k | i], \quad \forall i \in \mathcal{J}$$

- Business land market clearing:

$$r_{Fi} = \left(\frac{w_i^{\beta}}{\bar{A}_i} \right)^{\frac{1}{\beta-1}}, \quad \forall i \in \mathcal{J}$$

- Commuting costs:

$$\tau_{ij} = \prod_{(k,\ell) \in \mathcal{R}_{ij}} d_{k\ell}, \quad d_{k\ell} = \exp\left(\bar{t}_{k\ell} \frac{Q_{k\ell}^{\sigma}}{I_{k\ell}^{\xi}} \right)$$

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Stochastic Routing: Matrix Magic

- Idiosyncratic preferences for routes + no restrictions on possible routes:

$$\mathbf{A} \equiv [d_{ij}^{-\rho}], \quad \tau_{ij} \equiv \left(\sum_{r \in \mathcal{R}_{ij}} \tau_{ij,r}^{-\rho} \right)^{-\frac{1}{\rho}} \implies \tau_{ij}^{-\rho} = \sum_{K=0}^{\infty} A_{ij}^{K}$$

- Under some conditions of **A**:

$$\sum_{K=0}^{\infty} \mathbf{A}^{K} = (\mathbf{I} - \mathbf{A})^{-1} \equiv \mathbf{B} \implies \tau_{ij} = b_{ij}^{-\frac{1}{\rho}}$$

back

Role of congestion

- Now the optimal infrastructure is given by:

$$\underbrace{-\frac{\partial d_{k\ell}}{\partial \mathrm{I}_{k\ell}}\left(1-\frac{\partial Q_{k\ell}}{\partial d_{k\ell}}\frac{\partial d_{k\ell}}{\partial Q_{k\ell}}\right)^{-1}\sum_{ij}\lambda_{ij}^{g}\frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Benefits}} = \underbrace{\delta_{k\ell}^{\mathrm{I}}}_{\text{Building cost}}$$

- $\sum_{ij}\lambda_{ij}^{g}\frac{\partial L_{ij}}{\partial d_{k\ell}}$ is the total land value captured by government g from a reduction in $d_{k\ell}$:

$$\sum_{ij}\lambda_{ij}^{g}\frac{\partial L_{ij}}{\partial d_{k\ell}} = \underbrace{\sum_{ij}\eta_{Ri}^{g}\frac{\partial q_{Ri}}{\partial L_{ij}}\frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Residential E.: } \equiv Q_{k\ell}^{g}(\mathrm{R})} + \underbrace{\sum_{ij}\eta_{Fj}^{g}\frac{\partial q_{Fj}}{\partial L_{ij}}\frac{\partial L_{ij}}{\partial d_{k\ell}}}_{\text{Employment E.: } \equiv Q_{k\ell}^{g}(\mathrm{F})} + \underbrace{\sum_{ij}\sum_{k\ell}\phi_{k\ell}^{g}\left(\frac{\partial Q_{k\ell}}{\partial L_{ij}}\frac{\partial L_{ij}}{\partial d_{k\ell}}+\frac{\partial Q_{k\ell}}{\partial \pi_{ij}^{k\ell}}\frac{\partial \pi_{ij}^{k\ell}}{\partial d_{k\ell}}\right)}_{\text{Congestion Effect: } \equiv Q_{k\ell}^{g}(\mathrm{Q})}$$

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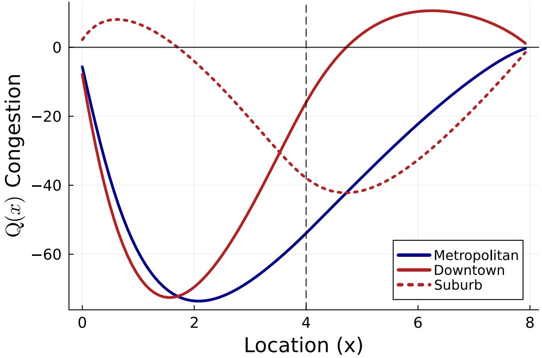
Congestion effect

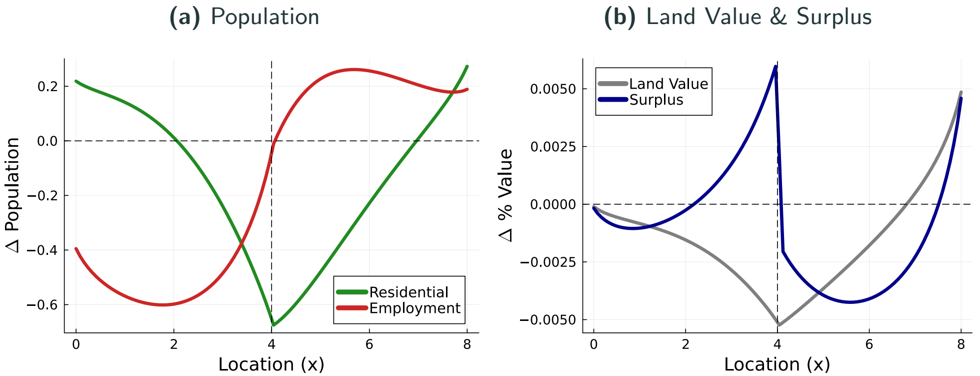
back



Effect to City Structure

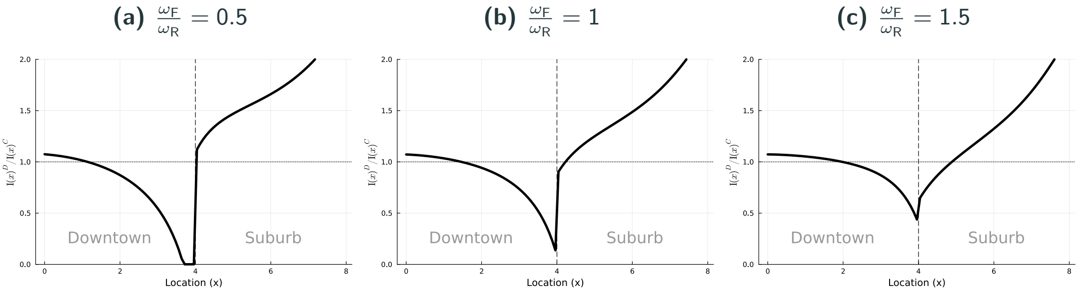
back

- Difference between decentralized and centralized equilibrium: $\Delta X = X_{\text{Decentralized}} - X_{\text{Centralized}}$



Different weights for workers relative to residents

back

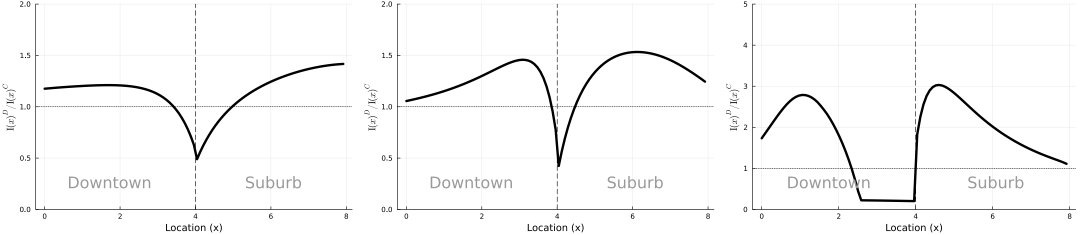


Other objective functions for the governments back

(a) Total Utility:
$\sum_{ij} \{\omega_{\mathrm{R}} \mathbb{1}_i L_{ij} U + \omega_{\mathrm{F}} \mathbb{1}_j L_{ij} U\}$

(b) Weighted by "real" wages:
$\left\{\omega_{\mathrm{R}} \mathbb{1}_i L_{ij} \frac{w_j}{\tau_{ij} q_{\mathrm{R}i}^{1-\alpha}} + \omega_{\mathrm{F}} \mathbb{1}_j L_{ij} \frac{w_j}{\tau_{ij} q_{\mathrm{R}i}^{1-\alpha}}\right\}$

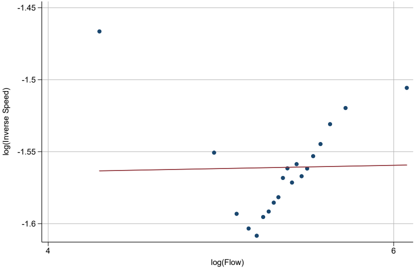
(c) Average real wages:
$\left\{\omega_{\mathrm{R}} \mathbb{1}_i \frac{L_{ij}}{L_{\mathrm{R}i}} \frac{w_j}{\tau_{ij} q_{\mathrm{R}i}^{1-\alpha}} + \omega_{\mathrm{F}} \mathbb{1}_j \frac{L_{ij}}{L_{\mathrm{F}j}} \frac{w_j}{\tau_{ij} q_{\mathrm{R}i}^{1-\alpha}}\right\}$



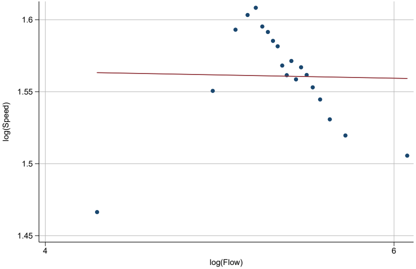
70 locations in Santiago→ Relationship between flows and speed

Bin-scatter controlling for Fixed Effects: day of the week, hour of the day, and intersection.

(a) log(Travel time) and log(traffic flows)



(b) log(Speed) and log(traffic flows)



Congested roads: Relationship between flows and speed

Bin-scatter controlling for Fixed Effects: day of the week, hour of the day, and intersection.

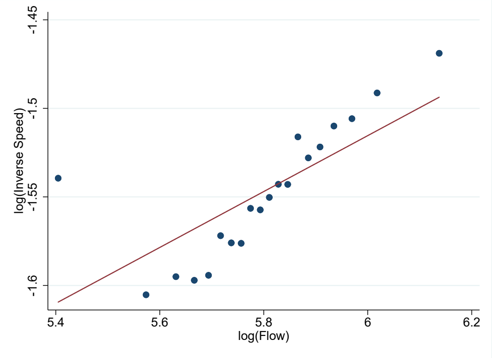


Table 2: OLS

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

FE: Hour, day of the week, intersection.

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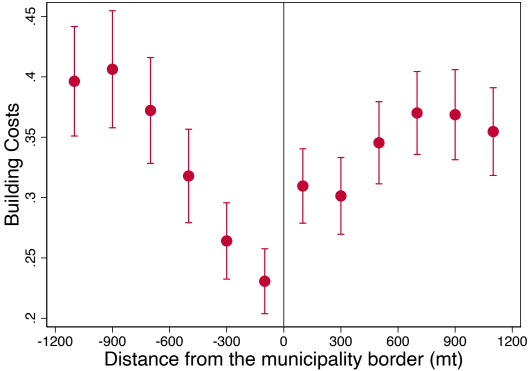
Recovered building costs at the border

Figure 16: Average building cost



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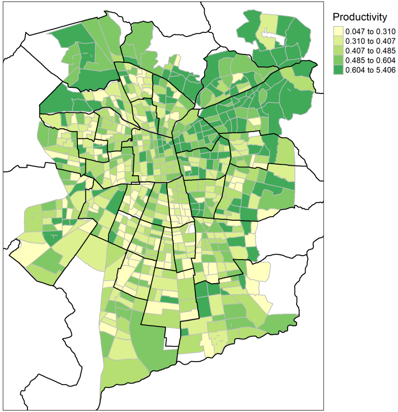
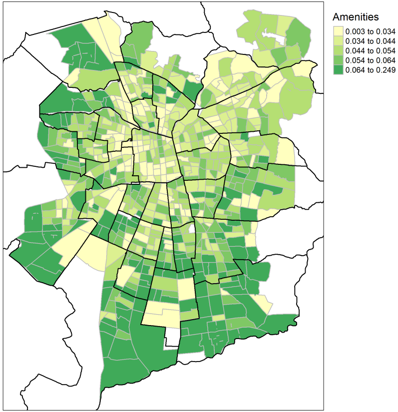
Amenities and Productivities

(a) Productivities



(b) Amenities



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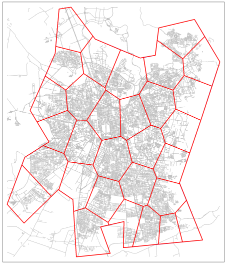
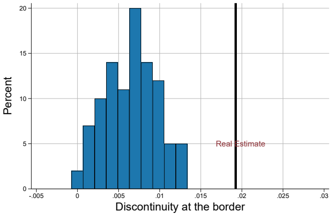
Placebo Test: Fake municipality borders

Figure 18: Placebo Analysis

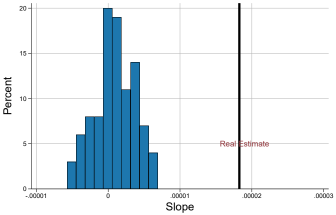
Placebo municipalities



(a) Discontinuities histogram



(b) Slope histogram



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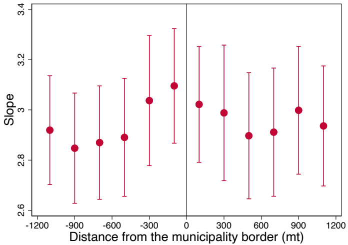
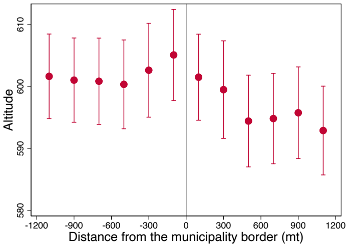
Other variables at the border between municipalities

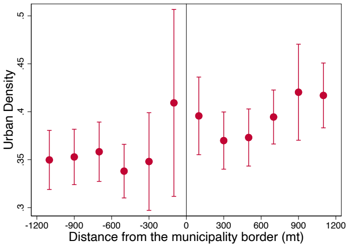
(a) Slope



(b) Altitude



(c) Built density (endogenous)



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Other cities in Latin America have similar patterns back

(a) Bogotá, Colombia　(b) Lima, Peru　(c) Mexico City