Urban costs around the world

Jordan Rosenthal-Kay

31 July 2026, NBER Summer Institute — Urban Economics

Federal Reserve Bank of San Francisco

How do urban costs inhibit economic development?

Urban costs: constraints on building and transportation technology

- Limit cities' sizes and absorptive capacity
- Three margins: building up, out, and commuting costs

How do urban costs inhibit economic development?

Urban costs: constraints on building and transportation technology

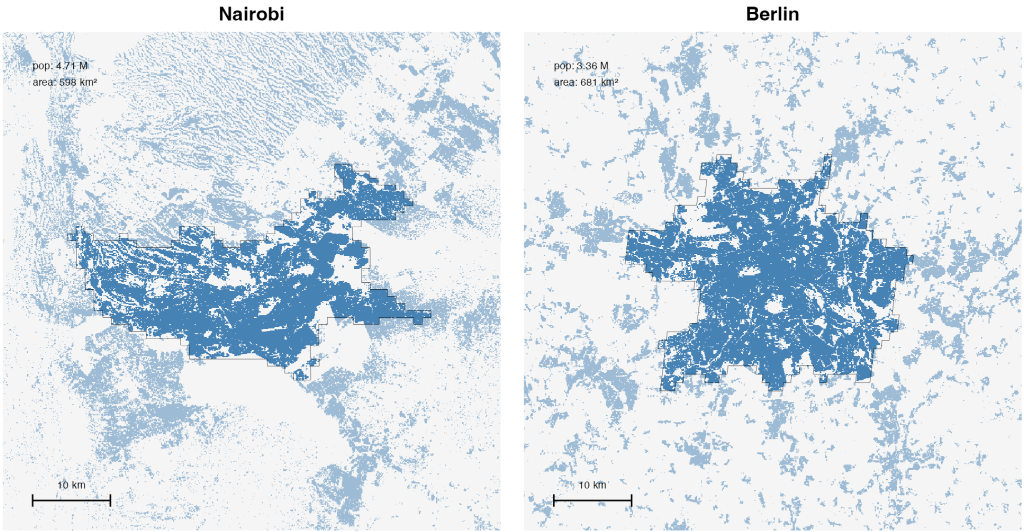
- Limit cities' sizes and absorptive capacity
- Three margins: building up, out, and commuting costs

This paper argues...

urban form → **urban costs**

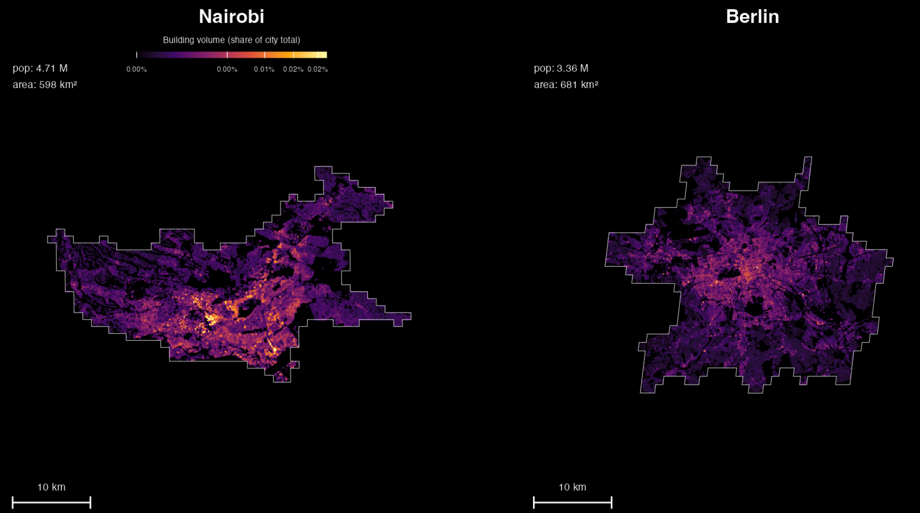
satellite-observed *cost of scaling a city*

A tale of two cities



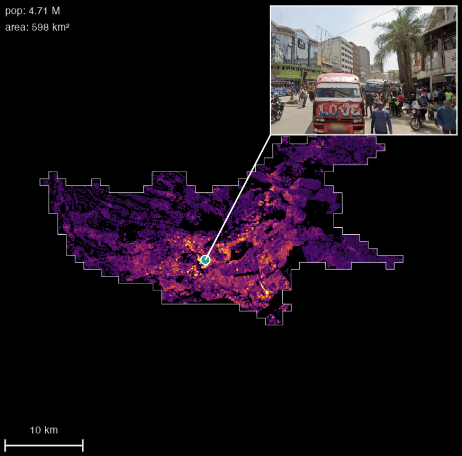
Data: World Settlement Footprint (WSF)

A tale of two cities

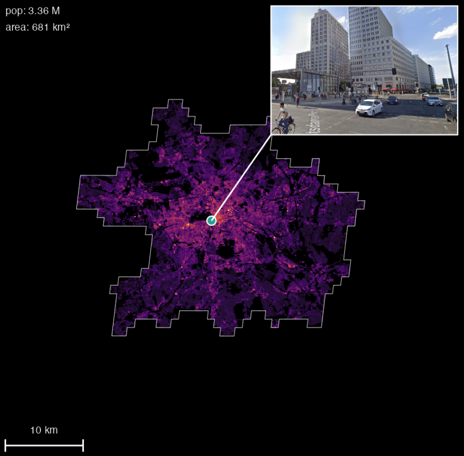


A tale of two cities

Nairobi

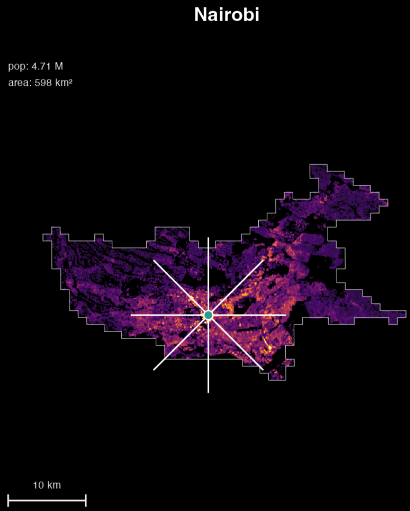


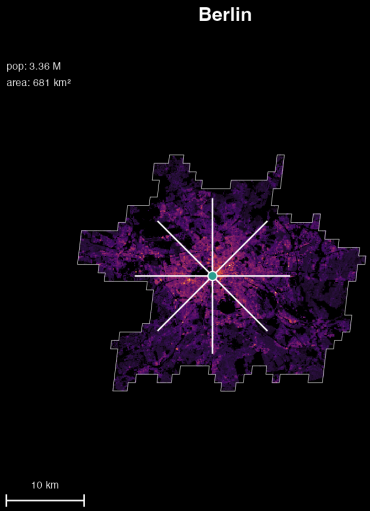
Berlin



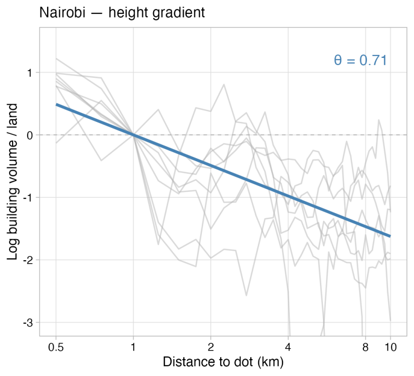
A tale of two cities

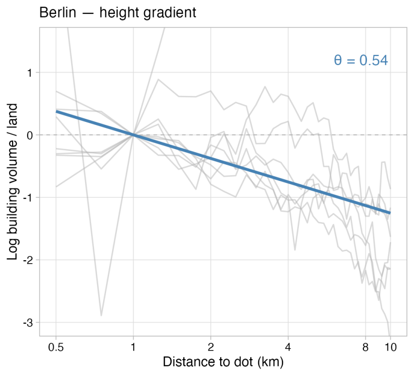
A tale of two cities



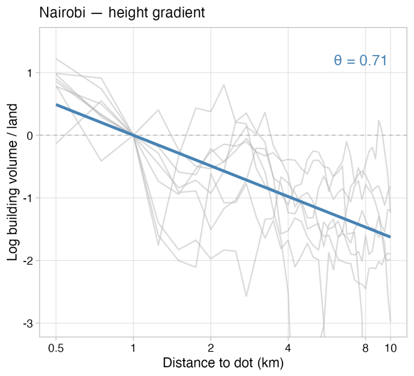


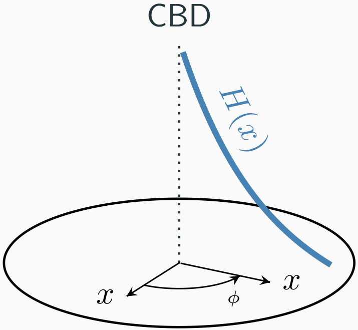
A tale of two cities





A tale of two cities





height gradient,

θ = commuting cost elasticity × floorspace supply elasticity

This paper...

Measures urban form across 15k 'cities' worldwide

Estimates the urban cost elasticity, κ, for every city

Quantifies how urban costs matter for development

Data: GHSL Urban Centers + WSF-3D built volume + Nightlights + geophysical observables

This paper...

Measures urban form across 15k ‘cities’ worldwide

Estimates the urban cost elasticity, κ, for every city

Quantifies how urban costs matter for development

- Develop new approach to estimating the number and location of CBDs
- Partition 10k polycentric agglomerations into 15k monocentric ‘cities’
- Dev’ping world agglomerations *less* polycentric than rich world, have steeper skylines.

Data: GHSL Urban Centers + WSF-3D built volume + Nightlights + geophysical observables

This paper...

Measures urban form across 15k ‘cities’ worldwide

Estimates the urban cost elasticity, κ, for every city

Quantifies how urban costs matter for development

- Define κ in general urban model; city skylines provide one component
- ‘Causal’ machine learning $\rightarrow$ heterogeneous floorspace and land supply elasticities
- κ is $\approx$2x larger in dev’ping-world cities compared to those in the rich world

Data: GHSL Urban Centers + WSF-3D built volume + Nightlights + geophysical observables

This paper...

Measures urban form across 15k 'cities' worldwide

Estimates the urban cost elasticity, κ, for every city

Quantifies how urban costs matter for development

- QSM with system-of-cities, rural-to-urban migration, intercity trade; global calibration
- Same productivity growth from 1990-today under lower urban costs
  $\rightarrow$ urbanization +4.5pp, +6.4% GDP/cap in dev'ping world

Data: GHSL Urban Centers + WSF-3D built volume + Nightlights + geophysical observables

Detecting city centers

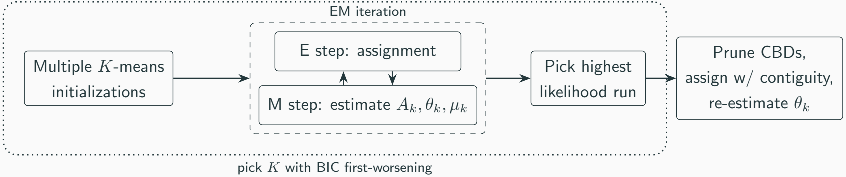
$$\underbrace{H_i}_{\text{Height in pixel } i} = \underbrace{\sum_k H_{ik}}_{\text{latent CBD assignment}} \sim \text{Poisson}\left(f_i \sum_k \bar{A}_k \underbrace{\|\mu_i - \boldsymbol{\mu_k}\|^{-\boldsymbol{\theta_k}}}_{\text{distance to unknown center}} \right)$$

μ_i, μ_k: encode coordinates

θ_k: skyline slope of CBD k.

Detecting city centers

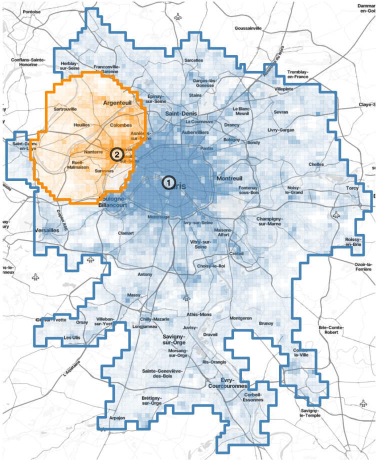
$$\underbrace{H_i}_{\text{Height in pixel } i} = \underbrace{\sum_k H_{ik}}_{\text{latent CBD assignment}} \sim \text{Poisson}\left(f_i \sum_k \bar{A}_k \underbrace{\|\mu_i - \boldsymbol{\mu_k}\|^{-\boldsymbol{\theta_k}}}_{\text{distance to unknown center}} \right)$$



Jointly estimating CBD locations μ_k and skyline slopes θ_k E/M-step detail →

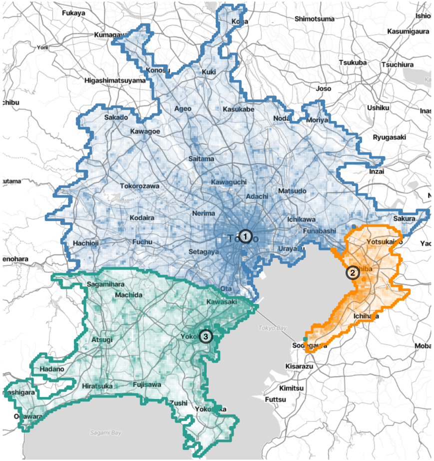
Paris, France

$K^* = 2$

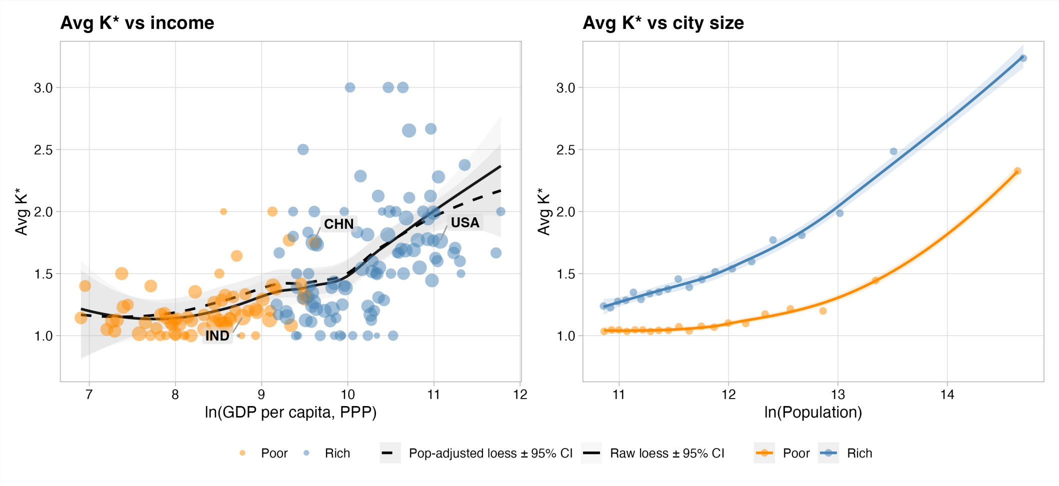


Tokyo, Japan

$K^* = 3$



More polycentricity in the rich world

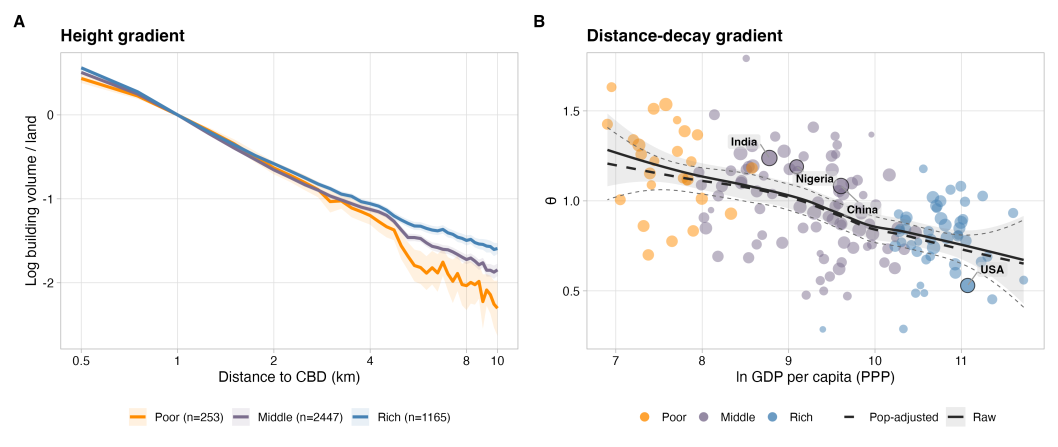


Developing and rich world cities are distinguished by height, not area

City-level averages.

Pop-adjusted residualizes city char'cs on a polynomial in log city pop.

Skyline slopes are steeper in the developing world



Nightlight gradients →

DDL city boundaries →

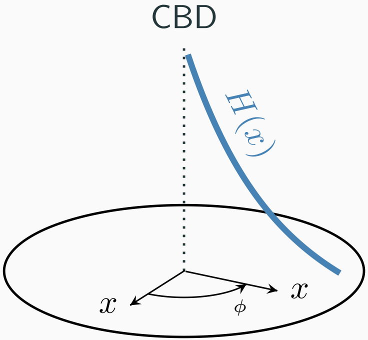
Robustness →

Monocentric city, pop L, wage w exogenous.

Endogenous: $\underbrace{L(x)}_{\text{pop. dist.}}$, $\underbrace{H(x)}_{\text{height}}$, $\underbrace{q(x)}_{\text{floorspace price}}$, $\underbrace{X}_{\text{radius}}$

Supply

$$\underbrace{H(x) \propto q(x)^{\gamma}}_{\text{build } \textit{up}\text{: land + materials}} \qquad \underbrace{\pi X^2 \propto r(X)^{\rho}}_{\text{build } \textit{out}\text{: fixed cost } F(x)}$$



How does urban form inform urban costs? Defining the urban cost elasticity

Monocentric city, pop L, wage w exogenous.

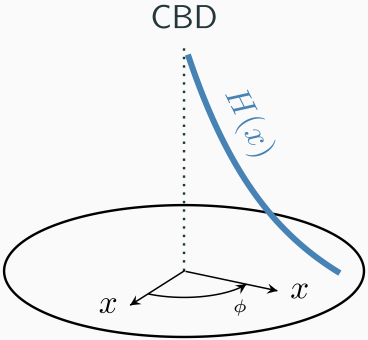
Endogenous: $\underbrace{L(x)}_{\text{pop. dist.}}$, $\underbrace{H(x)}_{\text{height}}$, $\underbrace{q(x)}_{\text{floorspace price}}$, $\underbrace{X}_{\text{radius}}$

Supply

$$\underbrace{H(x) \propto q(x)^{\gamma}}_{\text{build } up\text{: land + materials}} \qquad \underbrace{\pi X^2 \propto r(X)^{\rho}}_{\text{build } out\text{: fixed cost } F(x)}$$

Demand commuting costs $A(x) = \bar{A}\, x^{-\tau}$

$$\max_{c,h,x} U\big(c,\, A(x)\, h(x)\big) \;\text{ s.t. }\; c + q(x)\, h(x) \leq w$$



Defining the urban cost elasticity

Eq'm: $\underbrace{\text{spatial eq'm}}_{\check{q}(x)=\check{q}}$ $\underbrace{\text{labor clearing}}_{2\pi\int_0^X xL(x)dx=L}$ $\underbrace{\text{floorspace clearing}}_{q(x)H(x)=\mathcal{E}\,L(x)}$ $\underbrace{\text{free entry}}_{r(X)=F(X)}$

$\check{q} = q(x)/A(x)$; $\mathcal{E}\big(q(x), w\big)$: expenditure function.

Comparative statics:

$$\underbrace{d\ln\check{q}}_{\text{urban costs}} = \underbrace{\left(\frac{1}{1+\rho}\frac{1}{1+\gamma} + \frac{\rho}{1+\rho}\frac{\tau}{2}\right)}_{\substack{\boldsymbol{\kappa} \\ \text{urban cost elasticity}}} \underbrace{\Big(d\ln L + (1+\epsilon_{\check{h},\check{q}})\,d\ln\check{q} + \epsilon_{\mathcal{E},w}\,d\ln w_i\Big)}_{\text{demand pressures}}$$

Cobb-Douglas: $\epsilon_{\check{h},\check{q}} = -1,\ \epsilon_{\mathcal{E},w} = 1.$

κ a sufficient statistic $\longrightarrow$

Estimating urban cost elasticities

$$\underbrace{\gamma_i}_{\text{floorspace supply elasticity}} \quad \underbrace{\rho_i}_{\text{land supply elasticity}} \quad \underbrace{\tau_i}_{\text{commuting cost elasticity}}$$

Goal: estimate parameters governing the urban technology in every city i

- Partitioned cities + WSF-3D height, and physical expansion over time
- $w_i L_i$: city GDP from VIIRS nightlights scaled to national accounts
- L_i: Gridded Population of the World
- Geophysical observables: slope, soil quality, coastal distance

Estimating urban cost elasticities

$$\underbrace{\gamma_i}_{\text{floorspace supply elasticity}} \quad \underbrace{\rho_i}_{\text{land supply elasticity}} \quad \underbrace{\tau_i}_{\text{commuting cost elasticity}}$$

Model-implied estimating equation:

$$\underbrace{\log \bar{H}_i/\pi X_i^2}_{\text{avg. height}} = \frac{\gamma_i}{1+\gamma_i}\left(\log w_i + \log \frac{L_i}{\pi X_i^2}\right) + \varsigma_i$$

Estimating urban cost elasticities

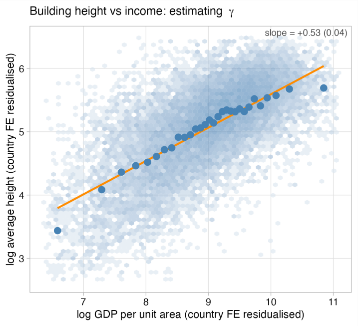
$\underbrace{\gamma_i}_{\text{floorspace supply elasticity}}$ $\underbrace{\rho_i}_{\text{land supply elasticity}}$ $\underbrace{\tau_i}_{\text{commuting cost elasticity}}$

Model-implied estimating equation:

$$\underbrace{\log \bar{H}_i/\pi X_i^2}_{\text{avg. height}} = \frac{\gamma_i}{1+\gamma_i}\left(\log w_i + \log \frac{L_i}{\pi X_i^2}\right) + \varsigma_i$$

w_i endogenous $\rightarrow$ instrument

- Model-based instrument for w_i: invert market-access eq'ns (QSM of intercity trade)



Instrument

Estimating urban cost elasticities

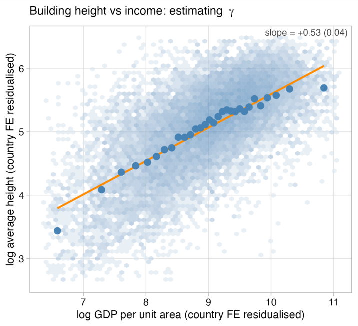
$\underbrace{\gamma_i}_{\text{floorspace supply elasticity}}$ $\underbrace{\rho_i}_{\text{land supply elasticity}}$ $\underbrace{\tau_i}_{\text{commuting cost elasticity}}$

Model-implied estimating equation:

$$\underbrace{\log \bar{H}_i/\pi X_i^2}_{\text{avg. height}} = \underbrace{\frac{\gamma_i}{1+\gamma_i}}_{=f(G_i)} \left(\log w_i + \log \frac{L_i}{\pi X_i^2} \right) + \varsigma_i$$

Nonparametric heterogeneity via *instrumental forest* (GRF):

- G_i: slope, elevation, soil (clay, sand, bulk density, water)



Variable importance | GRF heterogeneity →

Estimating urban cost elasticities

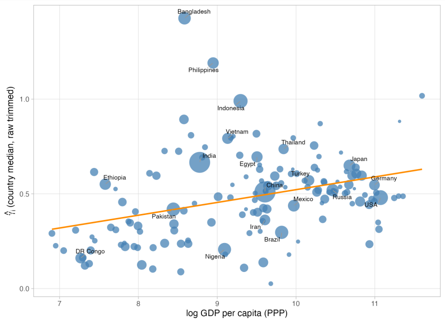
$$\underbrace{\gamma_i}_{\text{floorspace supply elasticity}} \qquad \underbrace{\rho_i}_{\text{land supply elasticity}} \qquad \underbrace{\tau_i}_{\text{commuting cost elasticity}}$$

Model-implied estimating equation:

$$\log \underbrace{\bar{H}_i/\pi X_i^2}_{\text{avg. height}} = \underbrace{\frac{\gamma_i}{1+\gamma_i}}_{=f(G_i)} \left(\log w_i + \log \frac{L_i}{\pi X_i^2} \right) + \varsigma_i$$

Nonparametric heterogeneity via *instrumental forest* (GRF):

- G_i: slope, elevation, soil (clay, sand, bulk density, water)



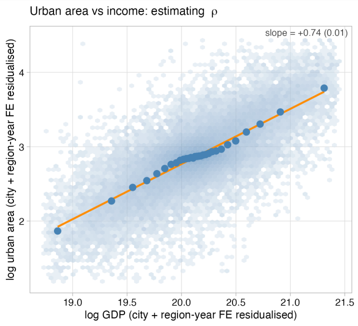
Variable importance | GRF heterogeneity →

Estimating urban cost elasticities

$$\underbrace{\gamma_i}_{\text{floorspace supply elasticity}} \quad \underbrace{\rho_i}_{\text{land supply elasticity}} \quad \underbrace{\tau_i}_{\text{commuting cost elasticity}}$$

Estimating equation:

$$\log \pi X_i^2 = \frac{\rho_i}{1+\rho_i} \log w_i L_i + \xi_i$$



Estimating urban cost elasticities

$\underbrace{\gamma_i}$ floorspace supply elasticity

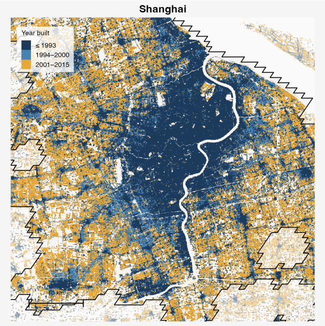
$\underbrace{\rho_i}$ land supply elasticity

$\underbrace{\tau_i}$ commuting cost elasticity

Estimating equation:

$$\Delta \log \text{area}_{it} = \frac{\rho_i}{1+\rho_i} \Delta \log w_{it} L_{it} + \underbrace{\xi_{rt}}_{\text{region-year FE}} + e_{it}$$

Identification from the time series ($t = 1993, 2000, 2015$).



Estimating urban cost elasticities

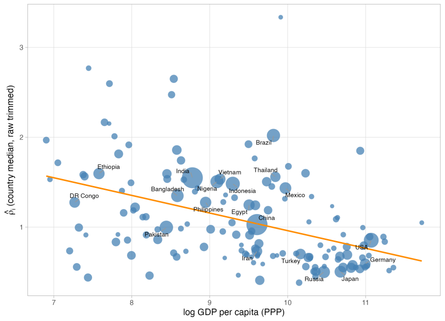
$\underbrace{\gamma_i}_{\text{floorspace supply elasticity}}$ $\underbrace{\rho_i}_{\text{land supply elasticity}}$ $\underbrace{\tau_i}_{\text{commuting cost elasticity}}$

Estimating equation:

$$\Delta \log \text{area}_{it} = \frac{\rho_i}{1+\rho_i} \Delta \log w_{it} L_{it} + \underbrace{\xi_{rt}}_{\text{region-year FE}} + e_{it}$$

Identification from the time series ($t = 1993, 2000, 2015$).

Nonparametric heterogeneity (GRF): $\frac{\rho_i}{1+\rho_i} = f(G_i)$ Variable importance GRF heterogeneity →



Estimating urban cost elasticities

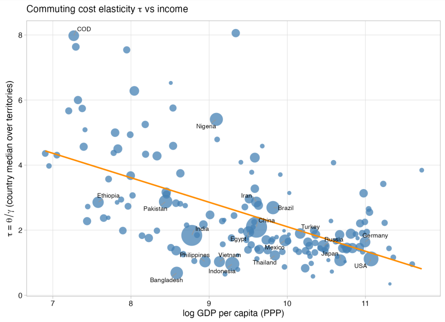
$\underbrace{\gamma_i}_{}$ floorspace supply elasticity

$\underbrace{\rho_i}_{}$ land supply elasticity

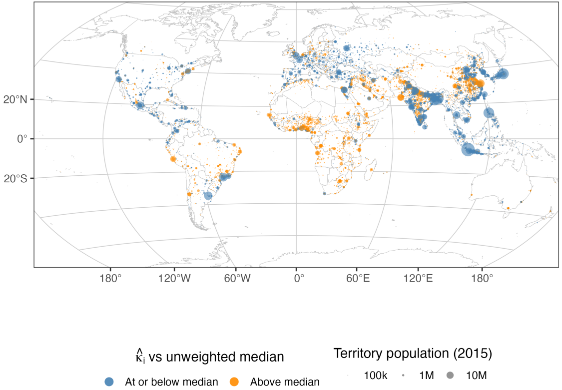
$\underbrace{\tau_i}_{}$ commuting cost elasticity

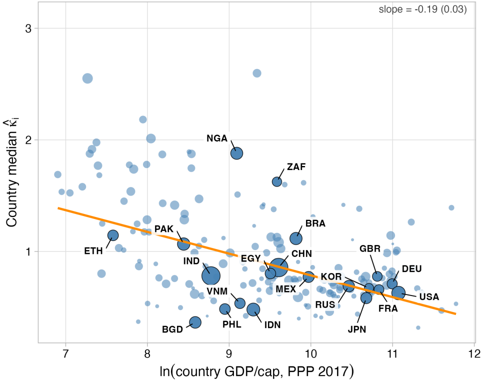
$$\boldsymbol{\tau}_i = \frac{\theta_i}{\gamma_i}$$

θ_i = skyline slopes — already estimated!



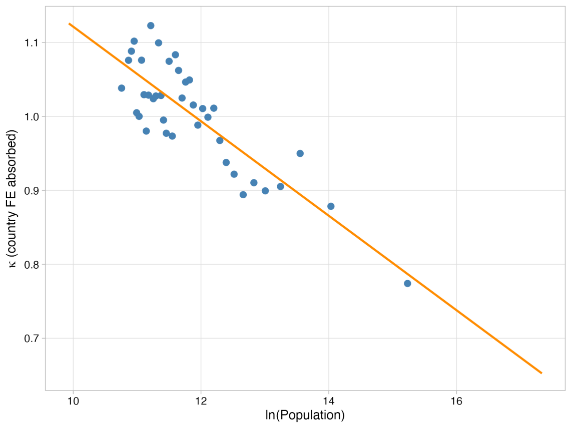
Urban cost elasticities around the world





Does κ measure real spatial frictions?

- Smaller cities have higher κ

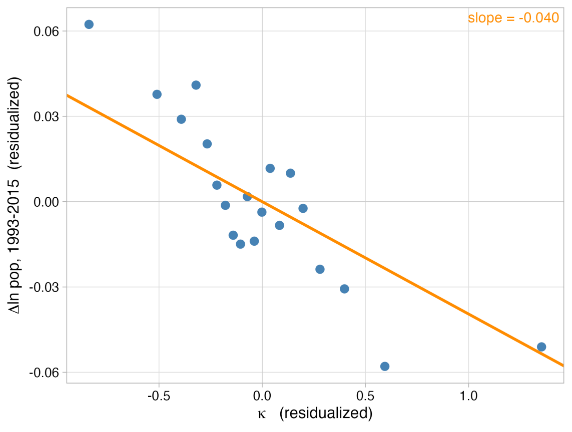


$$\kappa_i = \beta \ln L_i + \underbrace{\alpha_c}_{\text{country FE}} + \varepsilon_i$$

intensive vs. extensive $\rightarrow$ γ/ρ validation $\rightarrow$

Does κ measure real spatial frictions?

- Smaller cities have higher κ
- High-κ cities (conditionally) grew slower, 1993–2015

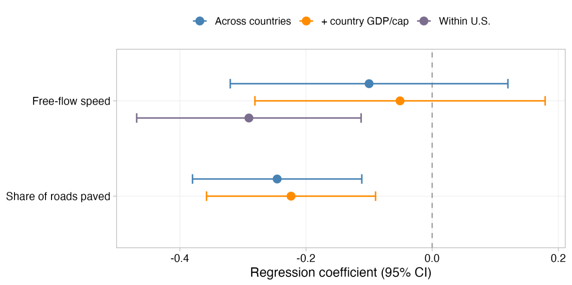


$$\Delta \ln L_i = \beta\, \kappa_i + \delta\, \ln L_{i,1993} + \underbrace{\alpha_c}_{\text{country FE}} + \varepsilon_i$$

intensive vs. extensive → γ/ρ validation →

Does κ measure real spatial frictions?

- Smaller cities have higher κ
- High-κ cities (conditionally) grew slower, 1993–2015
- Slower, less-paved cities have higher τ_i

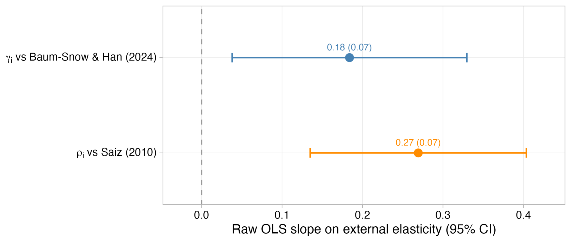


$$\ln \tau_i = \beta \underbrace{X_i}_{\text{transit measures}} + \underbrace{W_c'}_{\text{controls}} \eta + u_i$$

intensive vs. extensive $\rightarrow$ | γ/ρ validation $\rightarrow$

Does κ measure real spatial frictions?

- Smaller cities have higher κ
- High-κ cities (conditionally) grew slower, 1993–2015
- Slower, less-paved cities have higher τ_i
- $\hat{\gamma}$, $\hat{\rho}$ match external estimates (Baum-Snow–Han, Saiz)

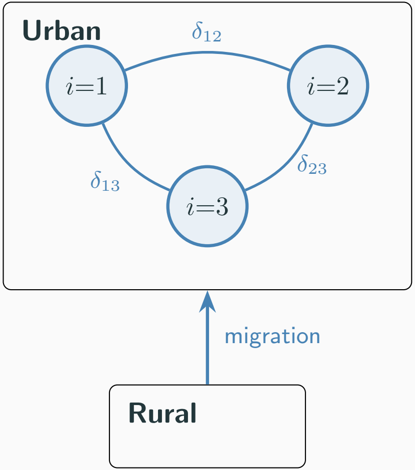


$$\hat{\gamma}_i = \alpha_\gamma + \beta_\gamma\, \gamma_i^{\text{BSH}} + \varepsilon_i$$

$$\hat{\rho}_i = \alpha_\rho + \beta_\rho\, \rho_i^{\text{Saiz}} + u_i$$

intensive vs. extensive $\rightarrow$ γ/ρ validation $\rightarrow$

Urban costs in general equilibrium



Cities

- **Wage determination:** frictional intercity intermediate-input trade block + agglomeration
- **Urban costs:** monocentric city model with estimated κ

Rural $\rightarrow$ Urban migration

- Roy sorting between rural/urban sectors
- "Lewis" ag. sector: workers earn their average product

full model $\rightarrow$

How important are urban costs for economic development?

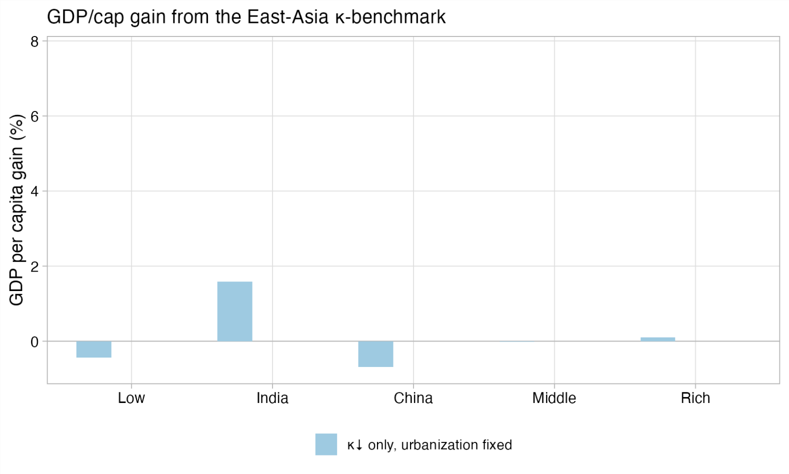
Calibrate GE model for every country in the data.

Counterfactual: how much faster would the developing world have grown 1993–2015 with lower κ?

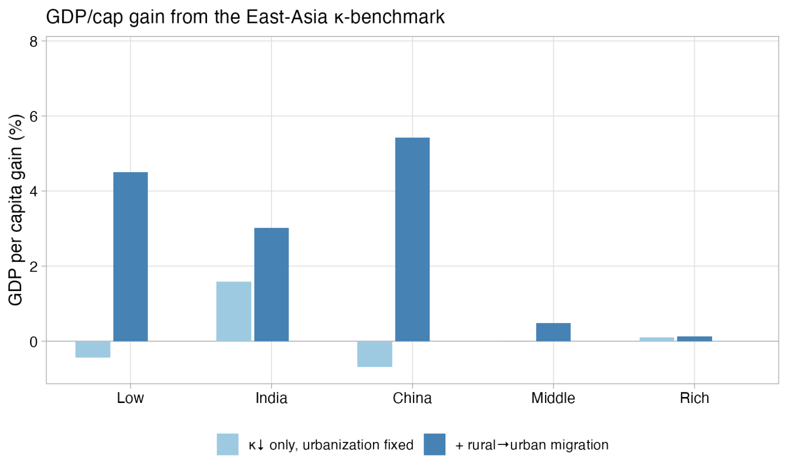
"What if every city could grow like Tokyo?"

Trade-cost calibration $\longrightarrow$ External parameters $\longrightarrow$

1993–2015 growth under lower urban costs



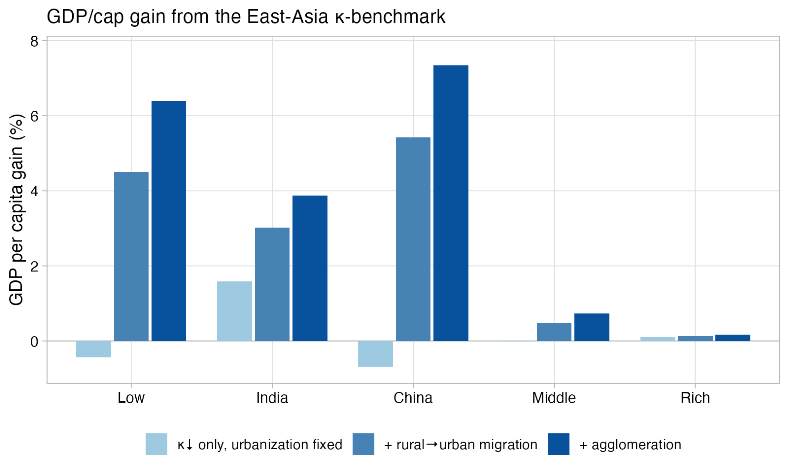
1993–2015 growth under lower urban costs



India: reallocation →

Price of urbanization →

1993–2015 growth under lower urban costs



India: reallocation →

Price of urbanization →

Thanks!

jordan.rosenthalkay@gmail.com | jrosenthalkay.github.io

The full model

Households & migration

Sectoral choice (Roy)

$$\max\{\mathcal{V}_U(s_U), \mathcal{V}_R(s_R)\}, \quad s \sim \text{Fréchet}(\varepsilon)$$

Indirect utilities

$$\mathcal{V}_U(s) = s\Big(\sum_i V_i^{\psi}\Big)^{1/\psi}, \quad \mathcal{V}_R(s) = A_R w_R s$$

$$V_i = \bar{A}_i\, w_i\, \check{q}_i^{-\beta}$$

Urban costs

$$\check{q}_i \propto (w_i L_i)^{\kappa_i}$$

Migration probabilities

$$\frac{L_U}{\bar{L}} = \frac{\mathcal{V}_U^{\varepsilon}}{\mathcal{V}_U^{\varepsilon} + \mathcal{V}_R^{\varepsilon}}, \quad \frac{L_i}{L_U} = \frac{V_i^{\psi}}{\sum_j V_j^{\psi}}$$

Firms & trade

Final good

$$Y = \Big(\sum_i y_i^{\frac{\sigma-1}{\sigma}}\Big)^{\frac{\sigma}{\sigma-1}}$$

City technology

$$y_i = Z_i\, \Big(\underbrace{S_i}_{\text{effective labor}}\Big)^{1-\eta} M_i^{\eta}$$

Agglomeration

$$Z_i = \bar{Z}_i\, L_i^{\zeta}$$

Intermediates

$$M_i = \Big(\sum_j m_{ji}^{\frac{\sigma-1}{\sigma}}\Big)^{\frac{\sigma}{\sigma-1}}$$

Frictional trade (iceberg $\delta_{ji} \geq 1$)

$$p_{ji} \propto \delta_{ji}\, w_j^{1-\eta} P_j^{\eta} / Z_j$$

← Back

κ, a sufficient statistic for how urban costs scale with city size

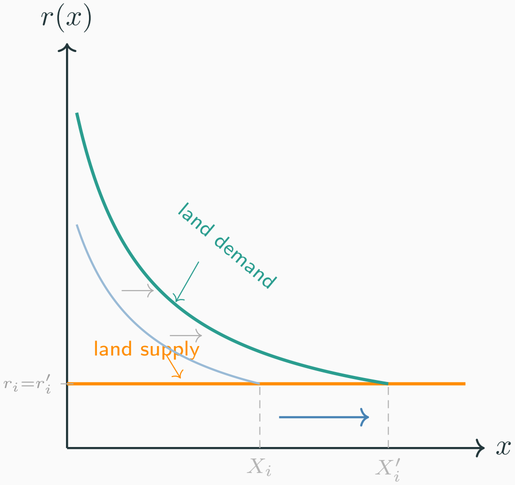
The urban cost elasticity,

$$\boldsymbol{\kappa} \equiv \frac{1}{1+\rho}\frac{1}{1+\gamma} + \frac{\rho}{1+\rho}\frac{\tau}{2}$$

Limits:

$$\rho \to \infty \Rightarrow \kappa \to \frac{\tau}{2}$$

With free land, all congestion is in commuting



← Back

κ, a sufficient statistic for how urban costs scale with city size

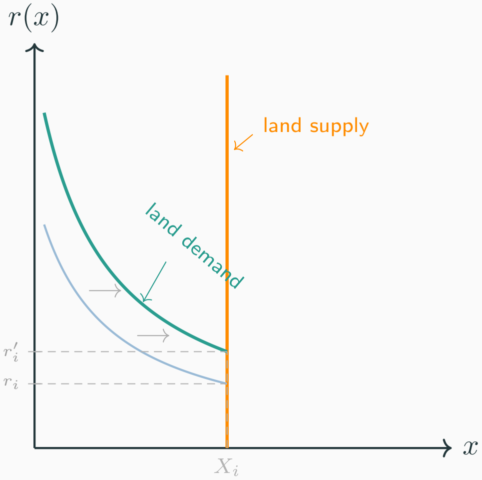
The urban cost elasticity,

$$\boldsymbol{\kappa} \equiv \frac{1}{1+\rho}\frac{1}{1+\gamma} + \frac{\rho}{1+\rho}\frac{\tau}{2}$$

Limits:

$$\rho \to 0 \Rightarrow \kappa \to \frac{1}{1+\gamma}$$

Fixed footprint: all congestion loads onto floorspace prices



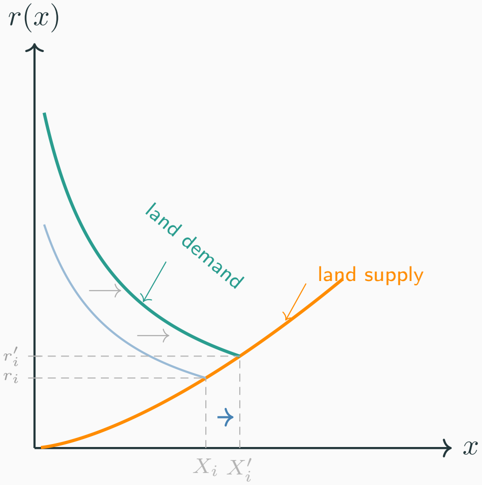
← Back

κ, a sufficient statistic for how urban costs scale with city size

The urban cost elasticity,

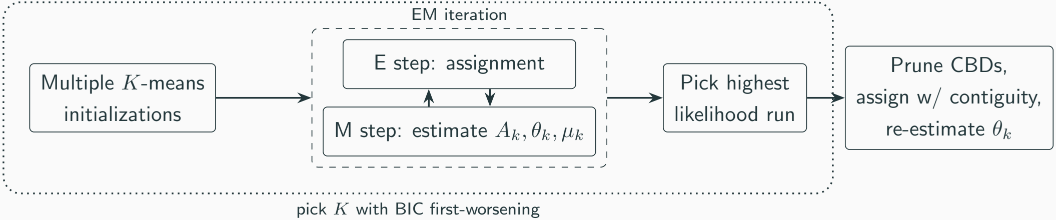
$$\boldsymbol{\kappa} \equiv \frac{1}{1+\rho}\frac{1}{1+\gamma} + \frac{\rho}{1+\rho}\frac{\tau}{2}$$

In general, both margins matter.



← Back

Detecting city centers: EM algorithm



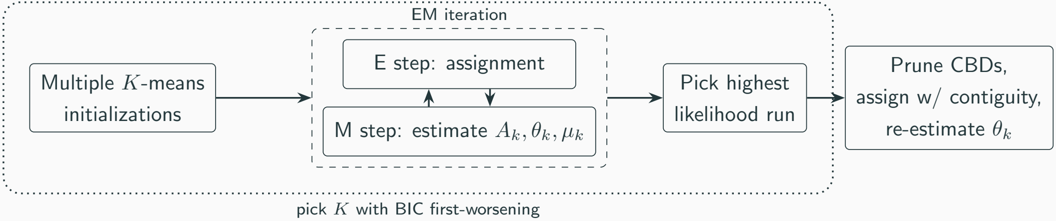
Fix K clusters, aggregate data to 500m resolution (computational necessity)

E-step: attribute fractions of H_i to each k

M-step:

- estimate city fixed effect $\bar{A}_k$, city skyline slope $\theta_k = \tau_k \gamma_k$ (Poisson regression)
- update μ_k via Fisher scoring

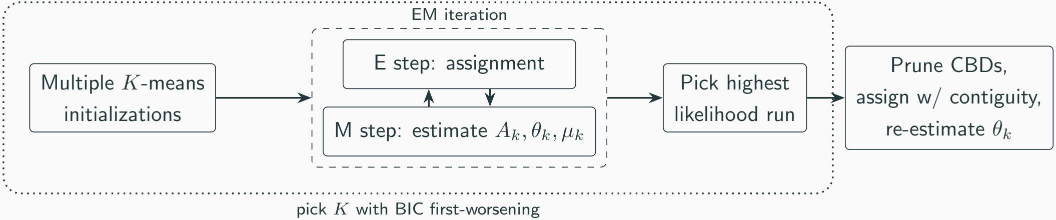
Detecting city centers: EM algorithm



Post-estimation

- Pick K via BIC criterion; stop at first-worsening
- Prune tiny clusters
- Hard assignment via Potts model (spatial smoothing over discrete labels)

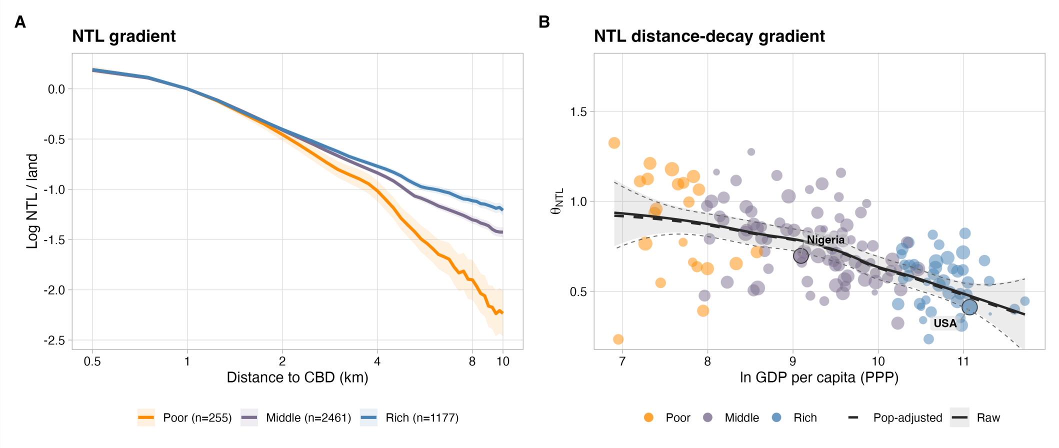
Detecting city centers: EM algorithm



Each i maps to a unique k. Re-estimate θ_k with fixed μ_k.

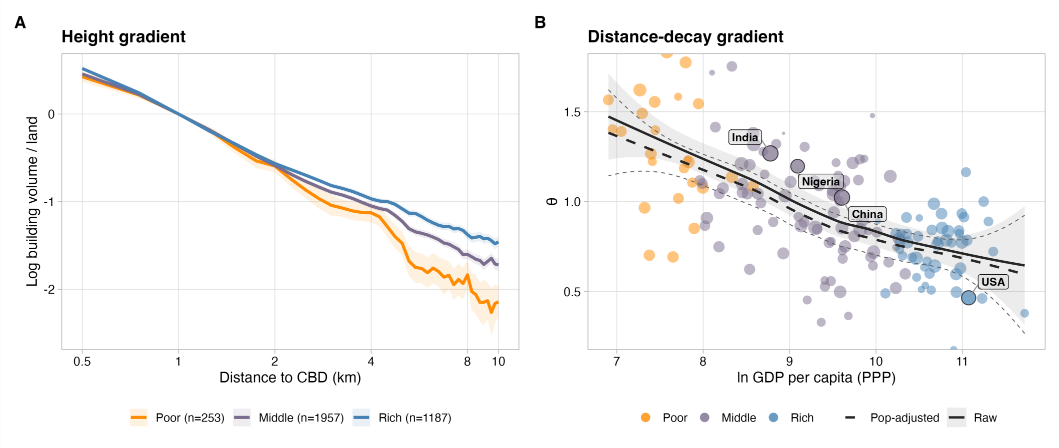
- Re-estimate θ_k at native WSF-3D resolution (90m pixels)
- Strip out 'donut holes' (≈2km in Shanghai) – commercial floorspace; 'plateaus'
- Weight obs $\propto 1/\text{distance}$ – # obs. mechanically rises in distance to CBD

Nightlight gradients are steeper in the developing world



← Back

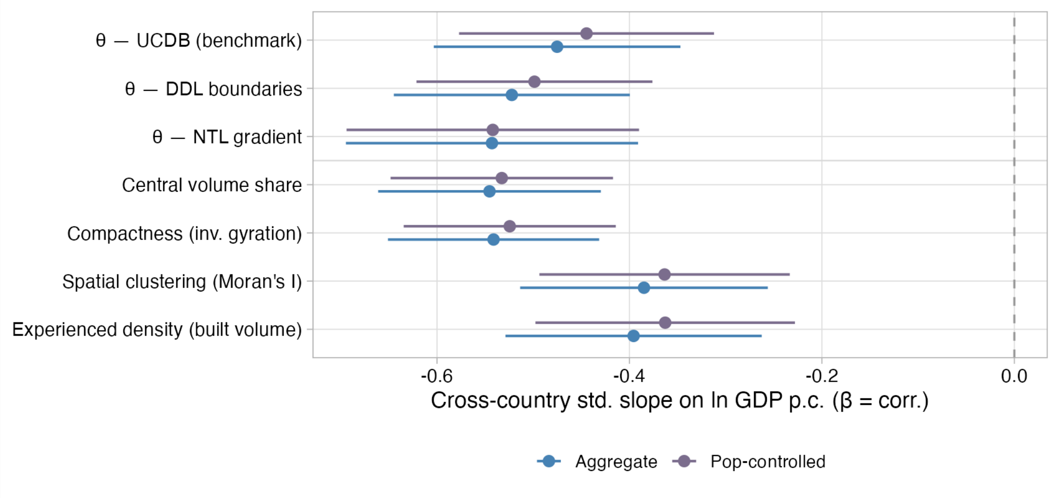
Skyline fact is robust to DDL city boundaries



9,813 cities under Development Data Lab (DDL) urban boundaries, not GHSL/UCDB.

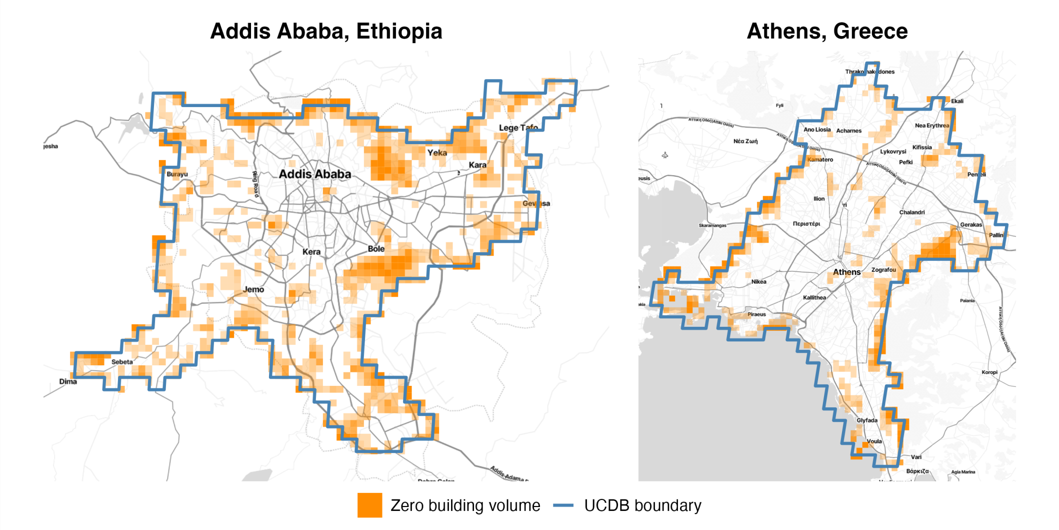
← Back

The skyline fact is robust to alternative concentration measures



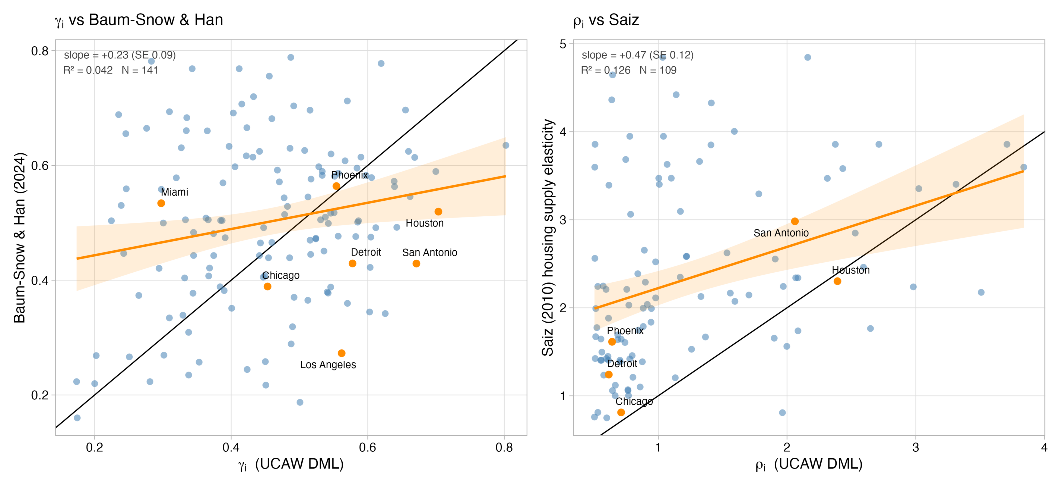
← Back

Structural zeros



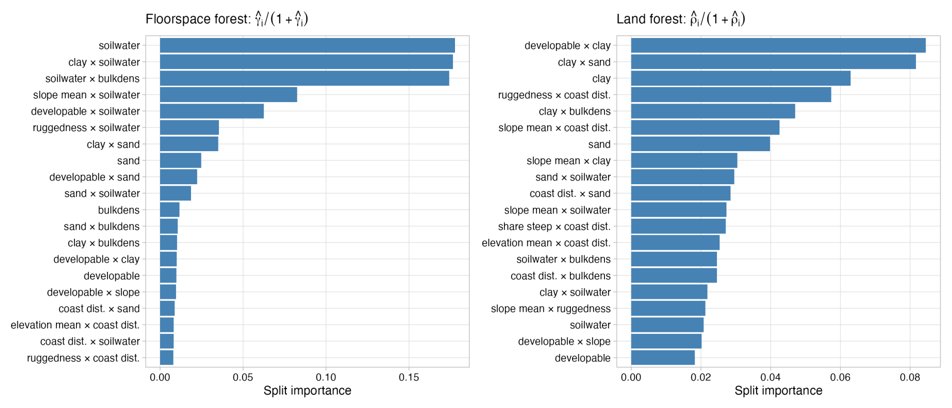
← Back

Validation: γ and ρ against external estimates



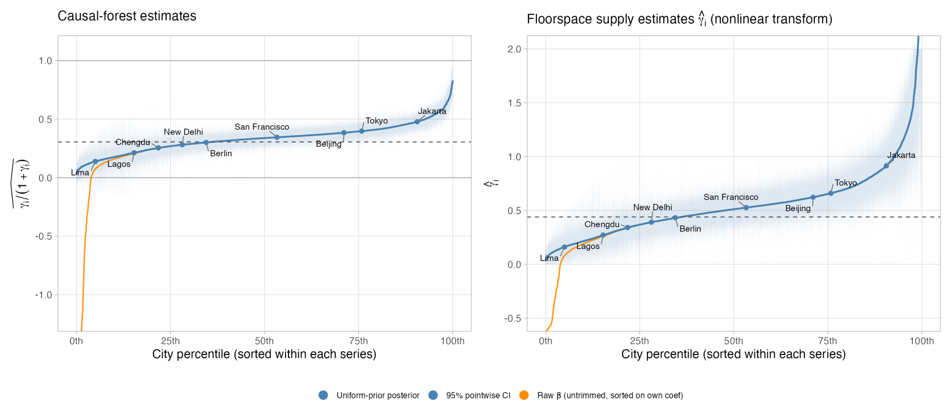
Left: $\hat{\gamma}$ vs. Baum-Snow & Han (2024). Right: $\hat{\rho}$ vs. Saiz (2010).

Variable importance: instrumental forest



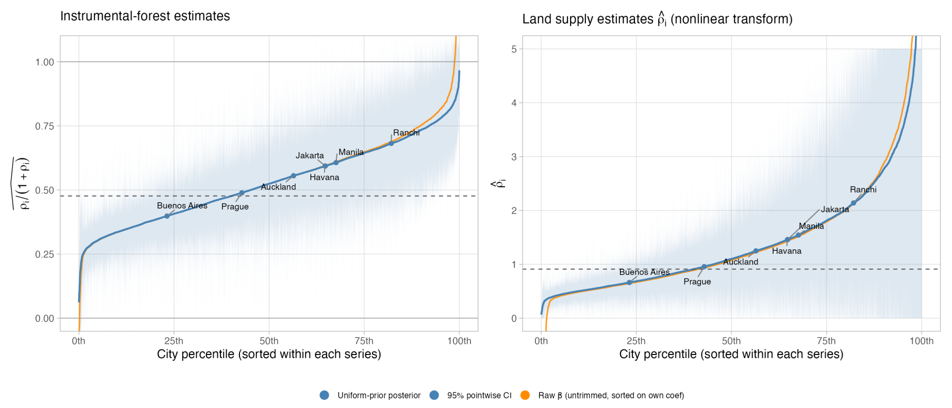
← Back

GRF heterogeneity: $\hat{\gamma}_i$ sorted by estimate



← Back

GRF heterogeneity: $\hat{\rho}_i$ sorted by estimate

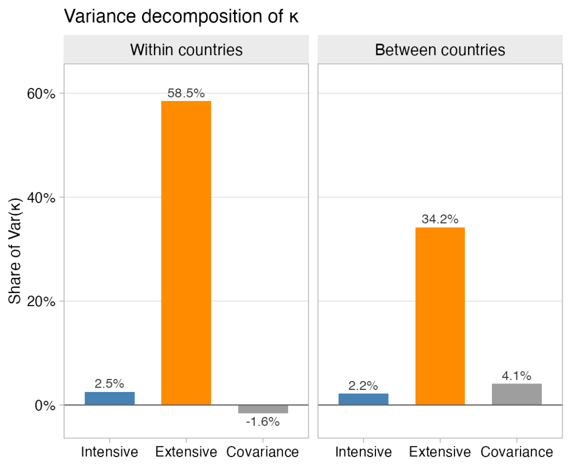


← Back

κ: intensive vs. extensive margin

$$\kappa_i = \underbrace{\frac{1}{1+\rho_i}\frac{1}{1+\gamma_i}}_{\text{intensive}} + \underbrace{\frac{\rho_i}{1+\rho_i}\frac{\tau_i}{2}}_{\text{extensive}}$$

- Variance of κ is dominated by the extensive margin (τ_i)
- 1/3rd of κ variation is extensive margin cross-country



← Back

Calibrating trade costs

Intercity trade network via 'road' network (OSRM)

δ_{ij} from gravity mapping (estimated in the US CFS)

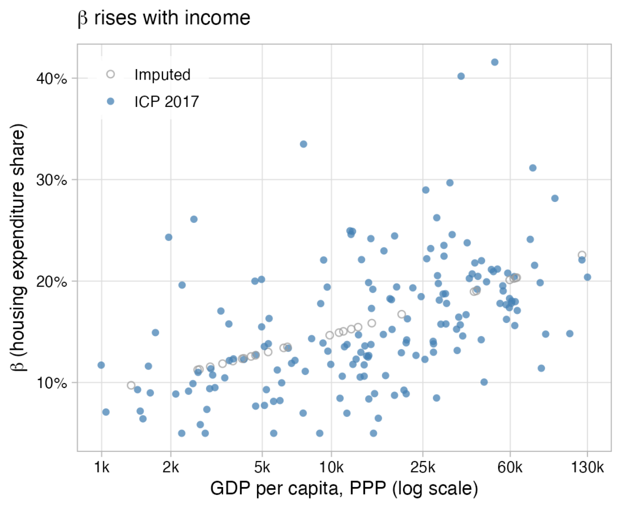
Back

Externally calibrated parameters

Parameter	Value	Description	Source
$\sigma - 1$	4	Trade elasticity	Standard
η	0.5	Intermediate input share	Jones (2011)
ζ	0.04	Agglomeration elasticity	Ahlfeldt & Pietrostefani (2019)
ψ	3.3	Intercity migration elasticity	Monte et al. (2018)
ε	2	Rural-urban migration elasticity	Mid-range: 1.2 (Sahai & Bailey 2022) to 3.3 (Bryan & Morten 2019)
β	–	Housing expenditure share	**Calibrated country-by-country from ICP 2017 surveys**

← Back

Externally calibrated parameters



← Back

Inverting the productivity instrument $\bar{Z}_i^y$

Trade block

$$y_i = \tilde{Z}_i\, L_i^{1-\eta} M_i^{\eta}, \quad \tilde{Z}_i = \bar{Z}_i^y\, L_i^{\zeta} S^{1-\eta}$$

$$p_i = \tilde{Z}_i^{-1} \Big(\frac{w_i}{1-\eta}\Big)^{1-\eta} \Big(\frac{P_i}{\eta}\Big)^{\eta}$$

$$P_i = \Big(\textstyle\sum_k (\delta_{ki} p_k)^{1-\sigma}\Big)^{\frac{1}{1-\sigma}}$$

$$w_j L_j = p_j^{1-\sigma} \big[(1-\eta) W + \eta\, \mathrm{MA}_j^F\big]$$

$M_i = \big(\sum_k m_{ki}^{\frac{\sigma-1}{\sigma}}\big)^{\frac{\sigma}{\sigma-1}}$ (intermediates), $W = \sum_i w_i L_i$

$\mathrm{MA}_j^F = \sum_i \delta_{ji}^{1-\sigma} P_i^{\sigma-1} w_i L_i$, $S = L_u^{1-1/\varepsilon}$ (selection)

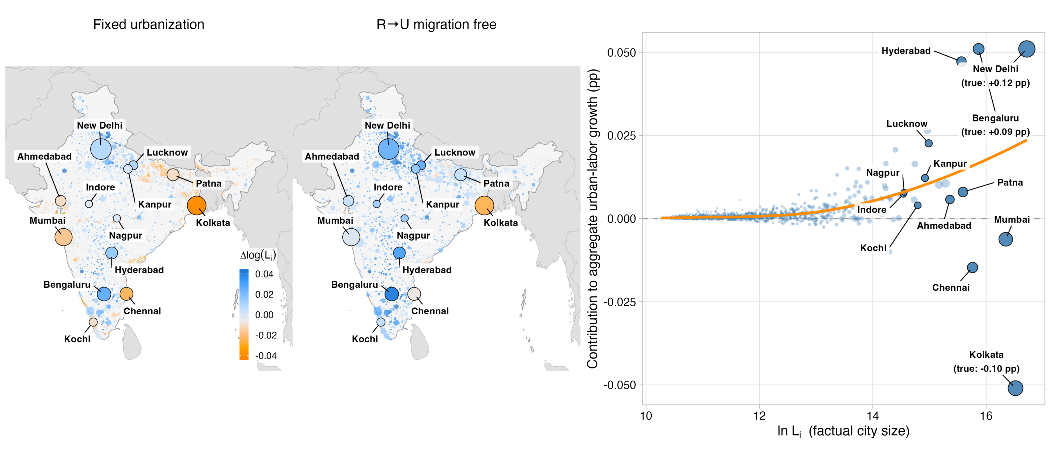
← Back

Inversion

- Data: urban $\{w_i, L_i\}$; $\{\delta_{ij}\}$ (OSRM drive times; gravity from US CFS)
- Solve {price index, clearing, numéraire $\sum_j p_j^{1-\sigma} = 1$} for $\{p_i, P_i\}$
- $\tilde{Z}_i$ from FOB price
- $\bar{Z}_i^y = \tilde{Z}_i / (L_i^{\zeta} S^{1-\eta})$ (strip agglomeration, selection)

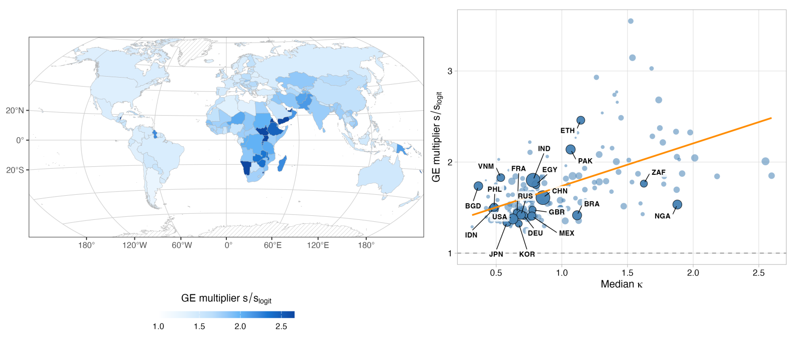
No γ, no κ: shifts w_i, excluded from floorspace TFP Z_i^H.

India: Reallocation within the urban system



← Back

The price of urbanization



Price of urbanization: s/s_{logit}, where s = uniform productivity subsidy to raise urban population by 1% in GE, and $s_{\text{logit}} = 0.01 / [\varepsilon_{ru}(1 - \text{urb})]$ is the pure-logit (no-congestion) benchmark.

← Back