Cities in Bad Shape: Urban Geometry in India

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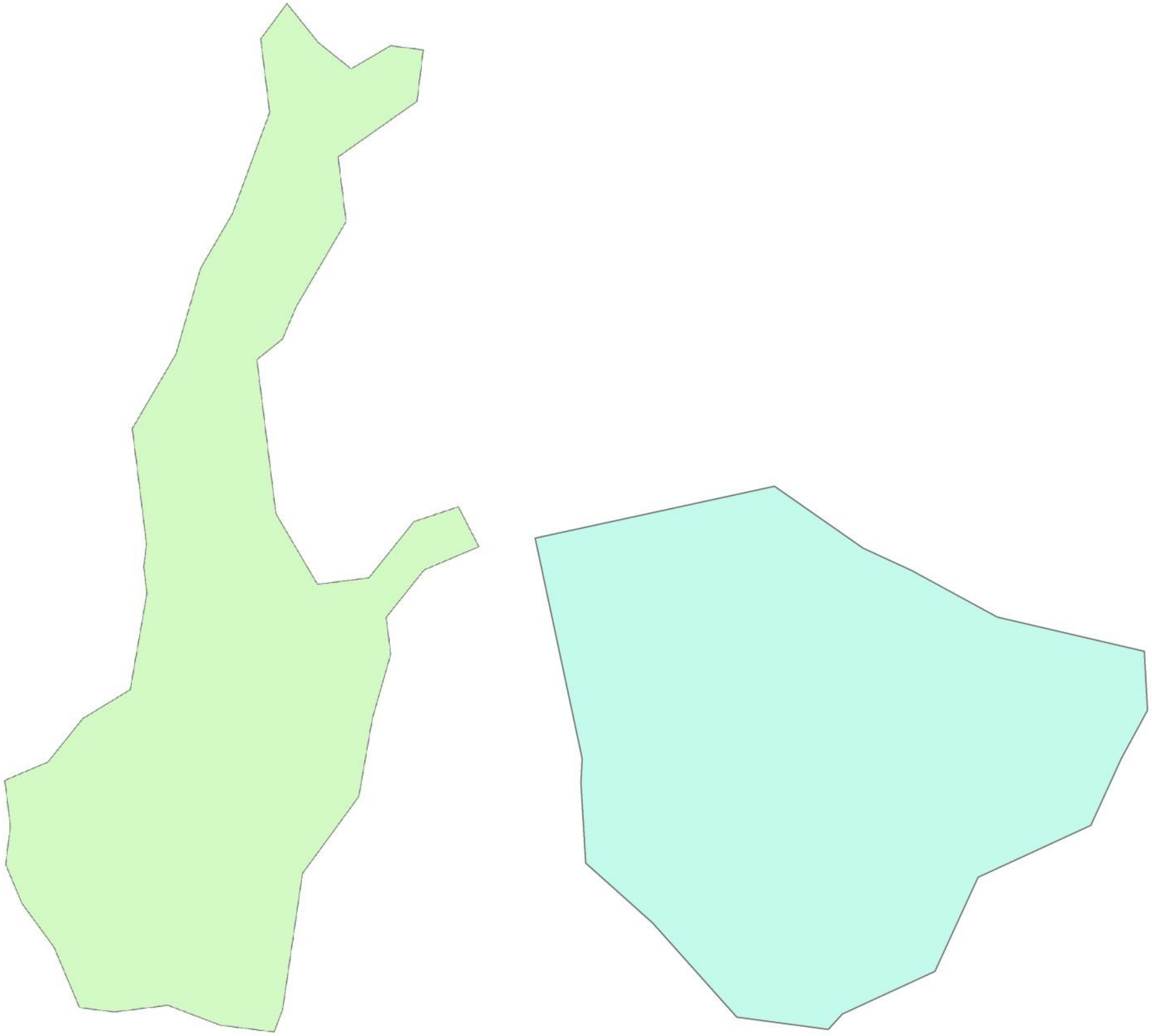
- A wide range of factors determine intra-urban commuting costs: infrastructure, travel demand, land use...
- This study focuses on one which economists tend to overlook: the **spatial layout of cities**
  - More compact geometries = shorter within-city distances

Area: 702 km^2



Why Study City Shape: an Example

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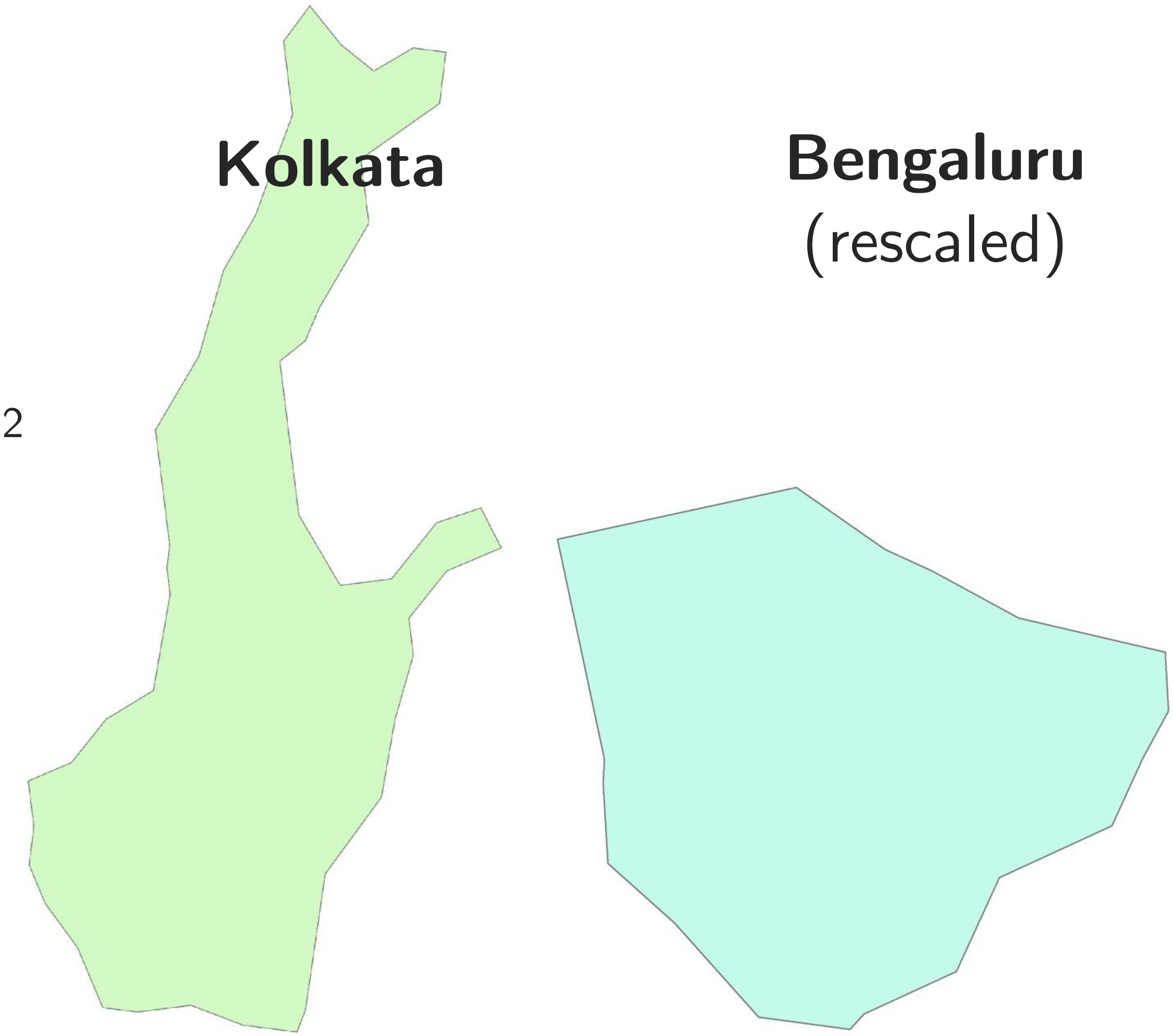

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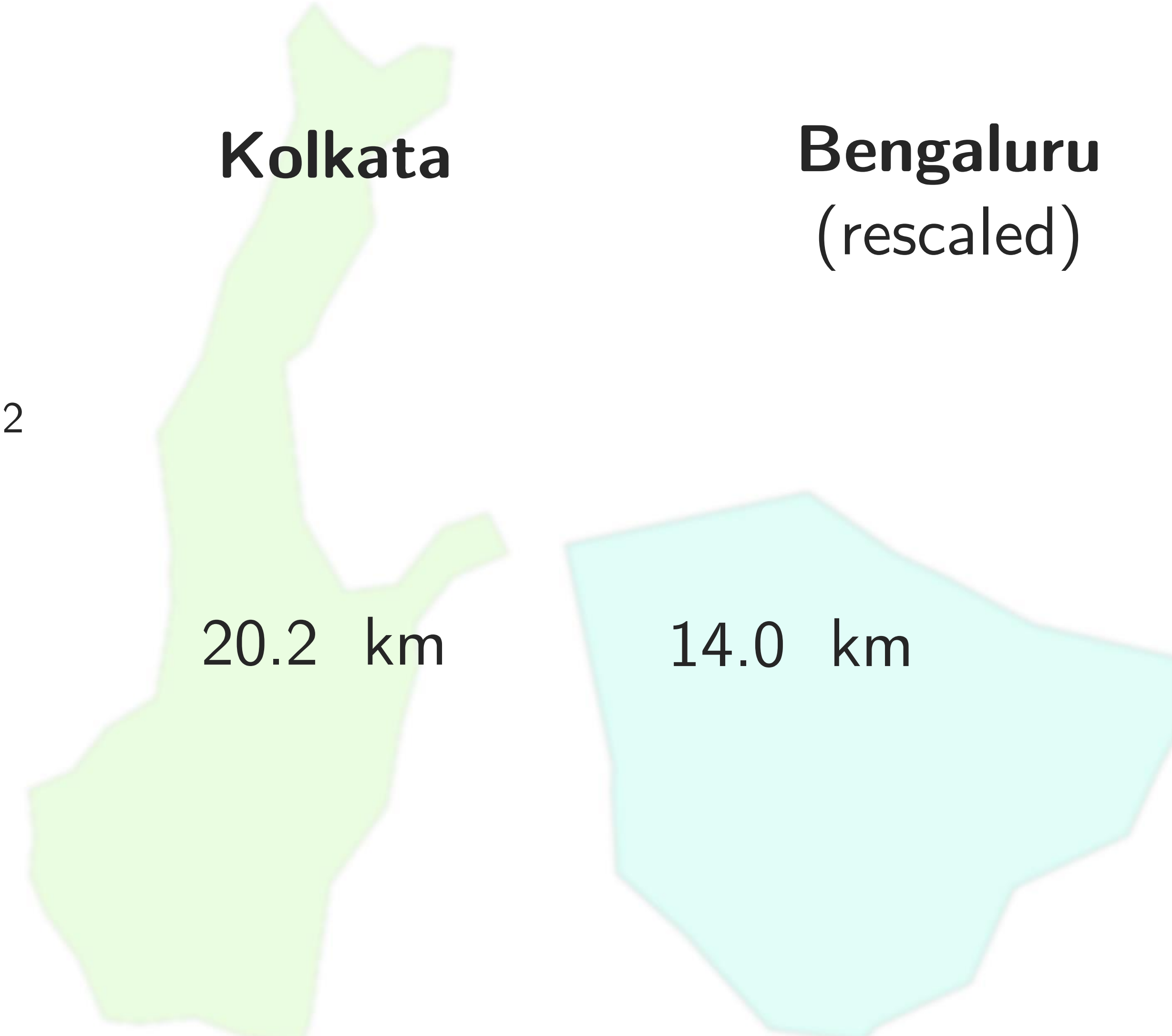

	Kolkata	**Bengaluru** (rescaled)
Area: 702 km^2		
Avg. within-city trip:	20.2 km	14.0 km

This paper:

Empirical investigation of the economic implications of urban geometry in India

- shape as a shifter of *potential* commuting distances
- exogenous variation in shape due to geography
- revealed preference Rosen-Roback framework to assess the welfare loss of deteriorating shape

A unique setting:

- Rapid urbanization: observe city shape as it evolves
- Diffused urbanization: large sample
- Policy relevance:
  - 40% of Indian population will be urban by 2030
  - Highly debated regulatory tools:
    e.g. building height restrictions

(A) Economic implications of city shape:

- How does urban shape affect city choice?
  - Spatial equilibrium across cities (Rosen-Roback)
- Do consumers and firms value "good city shape"?
  - Impact of city shape on population, wages and rents
  - Welfare cost of deteriorating shape
- Mechanisms and heterogeneous effects

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- Mechanisms and heterogeneous effects

(B) Responses to city shape:

- Firms' location within cities : polycentricity
- Interactions of policy and city shape: FARs, roads

- Panel of ~460 urban footprints:
  - Historic maps (1950) + remotely sensed data (DMSP/OLS Night-time Lights, 1992-2010)

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- IV approach: time-varying instrument for urban shape
  - Geographic obstacles + mechanical model for city expansion
  - Instrument actual shape with potential shape that a city can have, given surrounding topography
  - As cities expand, they face different topographic constraints which affect their shape
  - City and year FEs

- Compact city shape as a consumption amenity

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  - As cities grow into more compact shapes
    - Population $\uparrow$
    - Wages $\downarrow$
    - Housing rents $\uparrow$
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- But no impact on firms' productivity

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- Channels:
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- Policy responses to city shape: land use regulations
  - Restrictions on building height (FARs) result in larger and less compact footprints

Outline

- Introduction
- Conceptual Framework
- Data
- Empirical Strategy
- Results
- Conclusion

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Spatial equilibrium across cities :

Rosen (1979)-Roback (1982)

- Consumers and firms must be indifferent across cities
- Wages and rents allocate people and firms to cities with different levels of amenities
- Cities with better consumption amenities should have higher population, lower wages and higher rents

(A) Consumers

$$max_{\,C,H}\ U(C,\ H,\ \theta)\ \ s.t.\ C = W - p_H H$$

- Consumption C, housing H
- Wages W, rental price of housing p_H
- Consumption amenities θ

- $U(C, H, \theta) = \theta C^{1-\alpha} H^{\alpha}$
- α: share of housing in consumption

In equilibrium indirect utility must be equalized across cities:

$$log\,(W) - \alpha log(p_H) + log(\theta) = \overline{V}$$

Full model

(B) Firms :

$$max_{N,K} \quad Y(N, K, \overline{Z}, A) - WN - K$$

- N: number of workers in the city
- K: traded capital ; $\overline{Z}$: non-traded capital
- A: city-specific productivity

(C) Developers:

$$max_{H} \; p_H H - C(H)$$

- $H = Lh =$ land * height

Equilibrium

Equilibrium conditions

(1) consumers' optimal location choice
(2) firms' labor demand
(3) housing market equilibrium

Conceptual framework
Rosen-Roback

Equilibrium conditions

Equilibrium

(1) consumers' optimal location choice

(2) firms' labor demand

(3) housing market equilibrium

Using standard functional form (Cobb Douglas) :

- Population:

$$log(N) = \kappa_1\, log(A) + \kappa_2\, log(\theta) + \kappa_3\, log(L) + \kappa_N$$

- Wages:

$$log(W) = \kappa_4\, log(A) - \kappa_5\, log(\theta) - \kappa_6\, log(L) + \kappa_W$$

- Housing rents:

$$log(p_H) = \kappa_7\, log(A) + \kappa_8\, log(\theta) - \kappa_7\, log(L) + \kappa_H \qquad \kappa_i > 0$$

Equilibrium conditions

"Good shape" S = pure consumption amenity:

$$dlog(\theta) \; / \; dS > 0$$

$$dlog(A) \; / \; dS = 0$$

Compact cities should have:

- $dlog(N) \; / \; dS > 0$ larger population
- $dlog(W) \; / \; dS < 0$ lower wages
- $dlog(p_H) \; / \; dS > 0$ higher rents

Equilibrium conditions

"Good shape" S = consumption & production amenity:

$$dlog(\theta)\ /\ dS > 0$$

$$dlog(A)\ /\ dS > 0$$

Compact cities should have:

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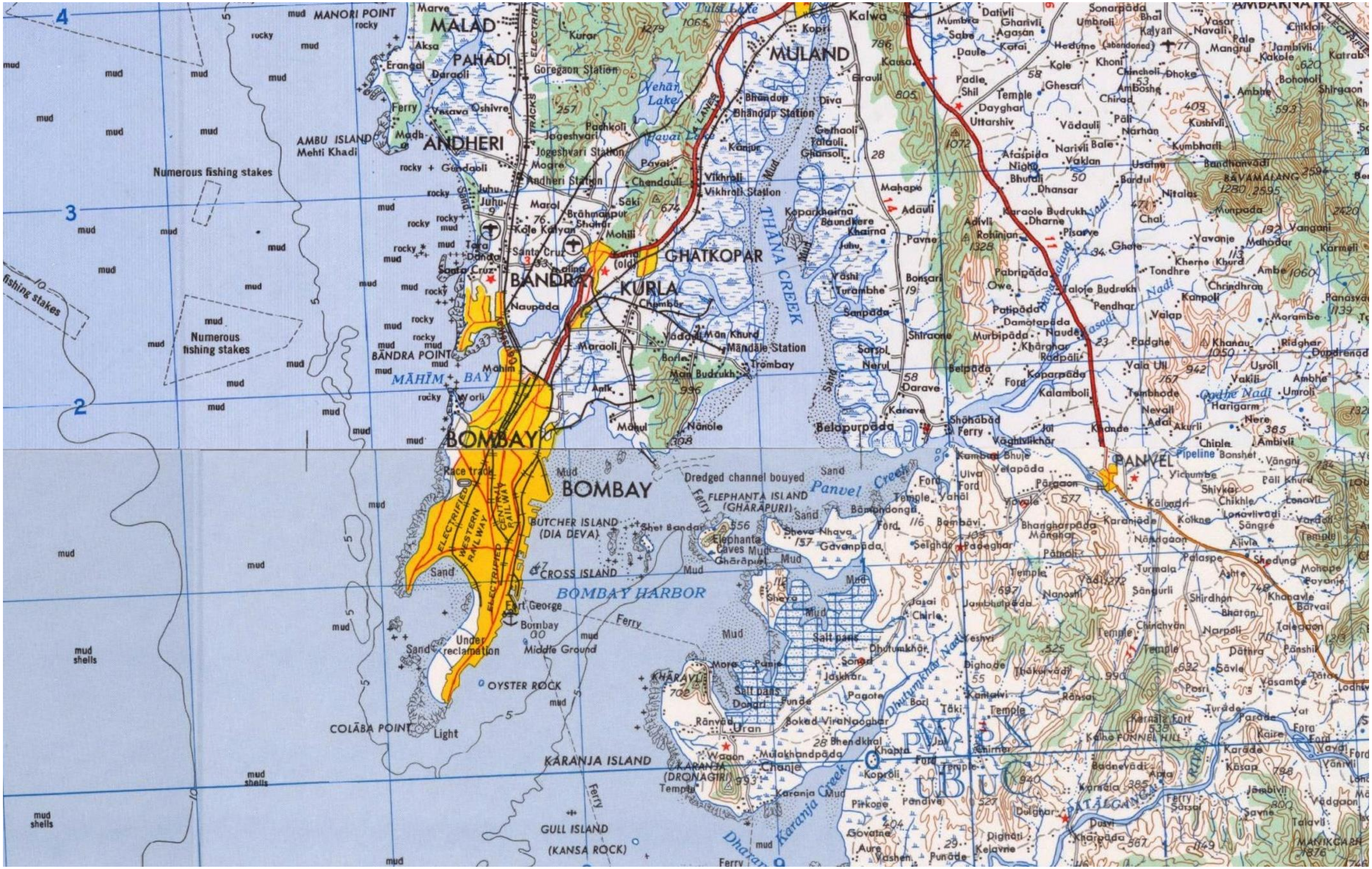
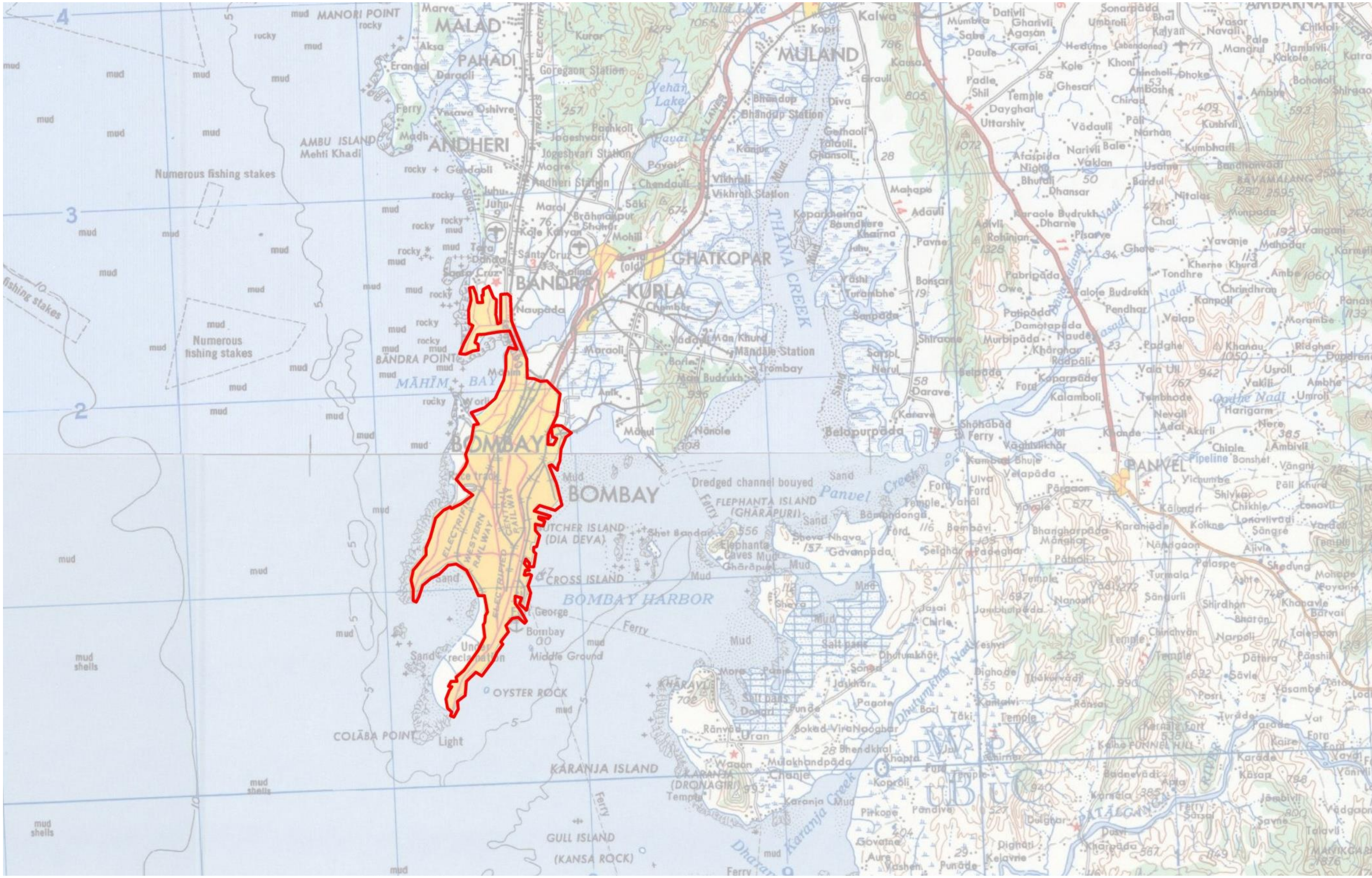
- 1950 : India and Pakistan Topographic Maps, Series U502, 1:250,000, U.S. Army Map Service

Data
Urban footprints




MANORI POINT
MALAD
PAHADI
Goregaon Station
MULAND
Kalwa
Vehar Lake
ANDHERI
AMBU ISLAND
Mehti Khadi
Numerous fishing stakes
Andheri Station
Vikhroli Station
THANA CREEK
GHATKOPAR
BANDRA
KURLA
Numerous fishing stakes
BANDRA POINT
MAHIM BAY
BOMBAY
BOMBAY
Dredged channel bouyed
Panvel Creek
ELEPHANTA ISLAND (GHARAPURI)
PANVEL
BUTCHER ISLAND (DIA DEVA)
CROSS ISLAND
BOMBAY HARBOR
Middle Ground
OYSTER ROCK
COLABA POINT
KARANJA ISLAND
GULL ISLAND (KANSA ROCK)
WESTERN RAILWAY
CENTRAL RAILWAY

- 1950 : India and Pakistan Topographic Maps, Series U502, 1:250,000, U.S. Army Map Service
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  - satellite imagery recording the intensity of Earth-based lights

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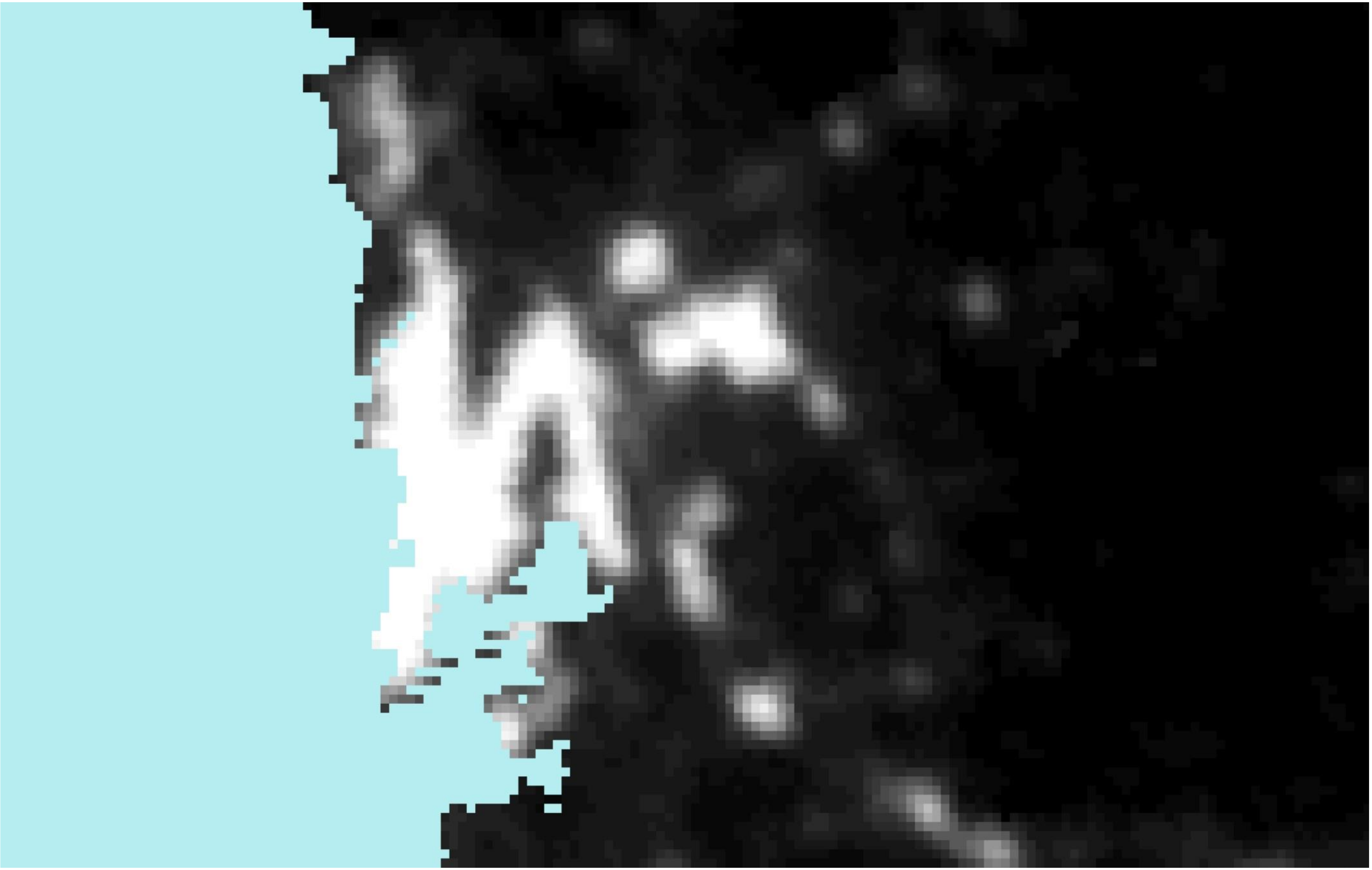

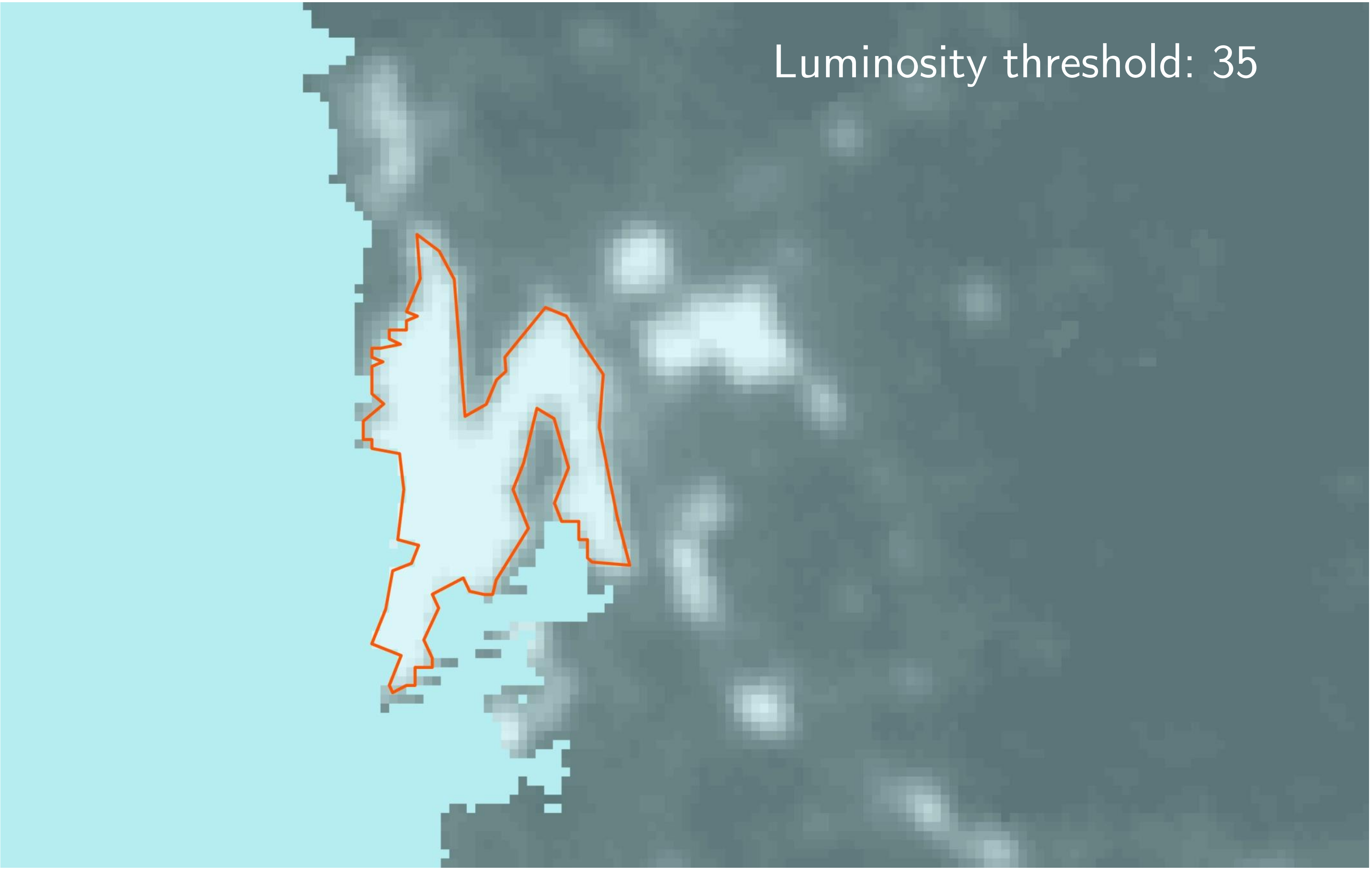
Luminosity threshold: 35

Data
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- 1950 : India and Pakistan Topographic Maps, Series U502, 1:250,000, U.S. Army Map Service
- 1992-2010: DMSP/OLS night-time lights (res. 1 km)
  - satellite imagery recording the intensity of Earth-based lights
- Geography
  - ASTER Digital Elevation Model (res. 30m)
  - Global MODIS raster water mask (res. 500 m)
  - "constrained" = water / slope > 15% (Saiz, 2011)

- Population: Census of India, 1871-2011
- Wages : Annual Survey of Industries
  (1990, 1994, 1995, 1997, 2009, 2010)
- Housing rents:
  NSS Household Consumer Expenditure Survey
  (2005, 2006, 2007)

District urban averages

- Other data
  - Floor Area Ratios (Sridhar, 2010)
  - Directory of Establishments (2005 Economic Census)

Descriptives

- **Disconnection**
  Avg. distance between all pairs of interior points
- **Remoteness**
  Avg. distance between interior points and centroid
- **Range**
  Max. distance between two points on the shape perimeter

Angel and Civco (2009), Bertaud (2004)

- All shape metrics correlated with footprint size:
  can be normalized by footprint radius

Example

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Empirical Strategy

$$Outcome_{c,t} = a \cdot shape_{c,t} + cityFE_c + yearFE_t + u_{c,t}$$

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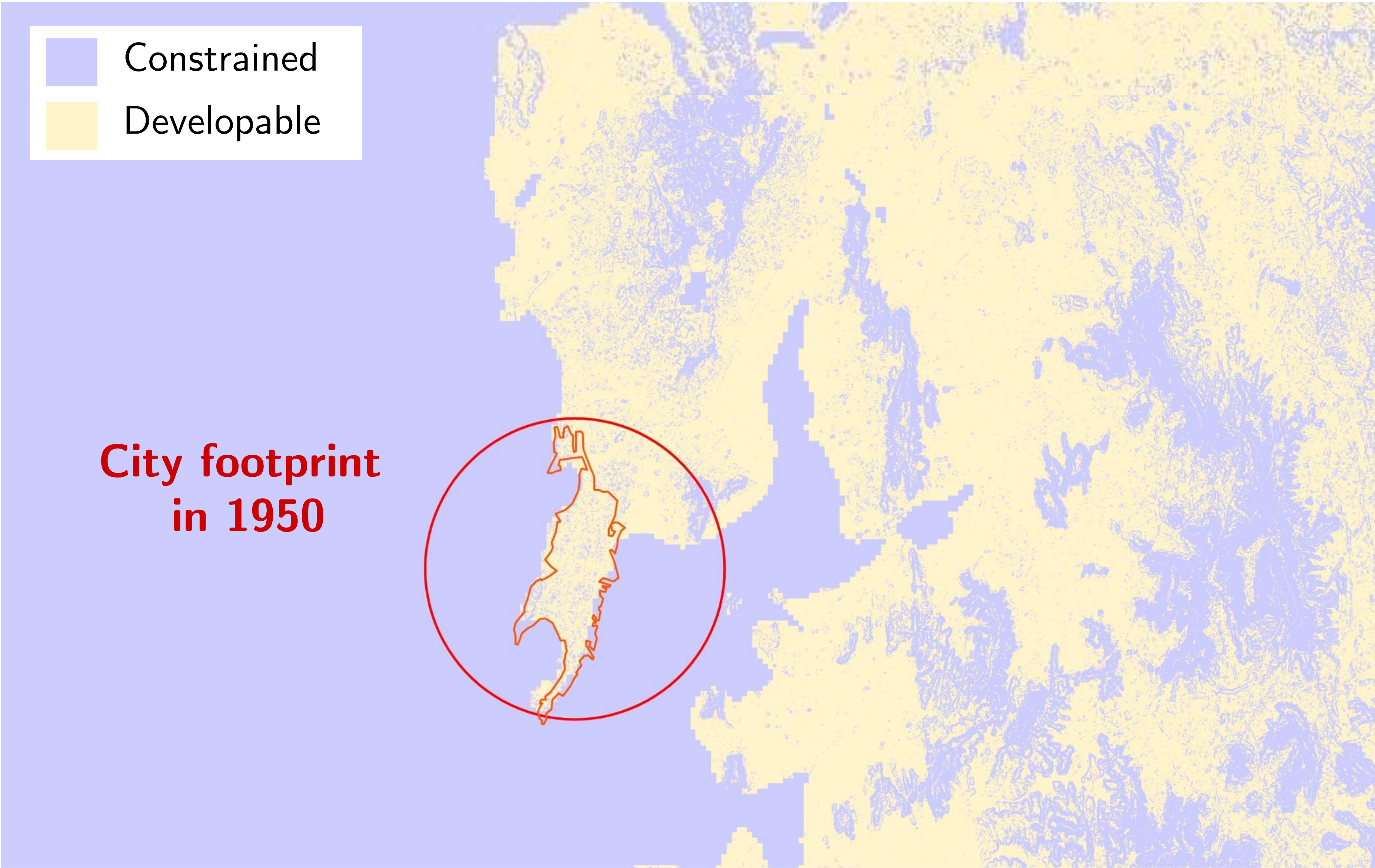
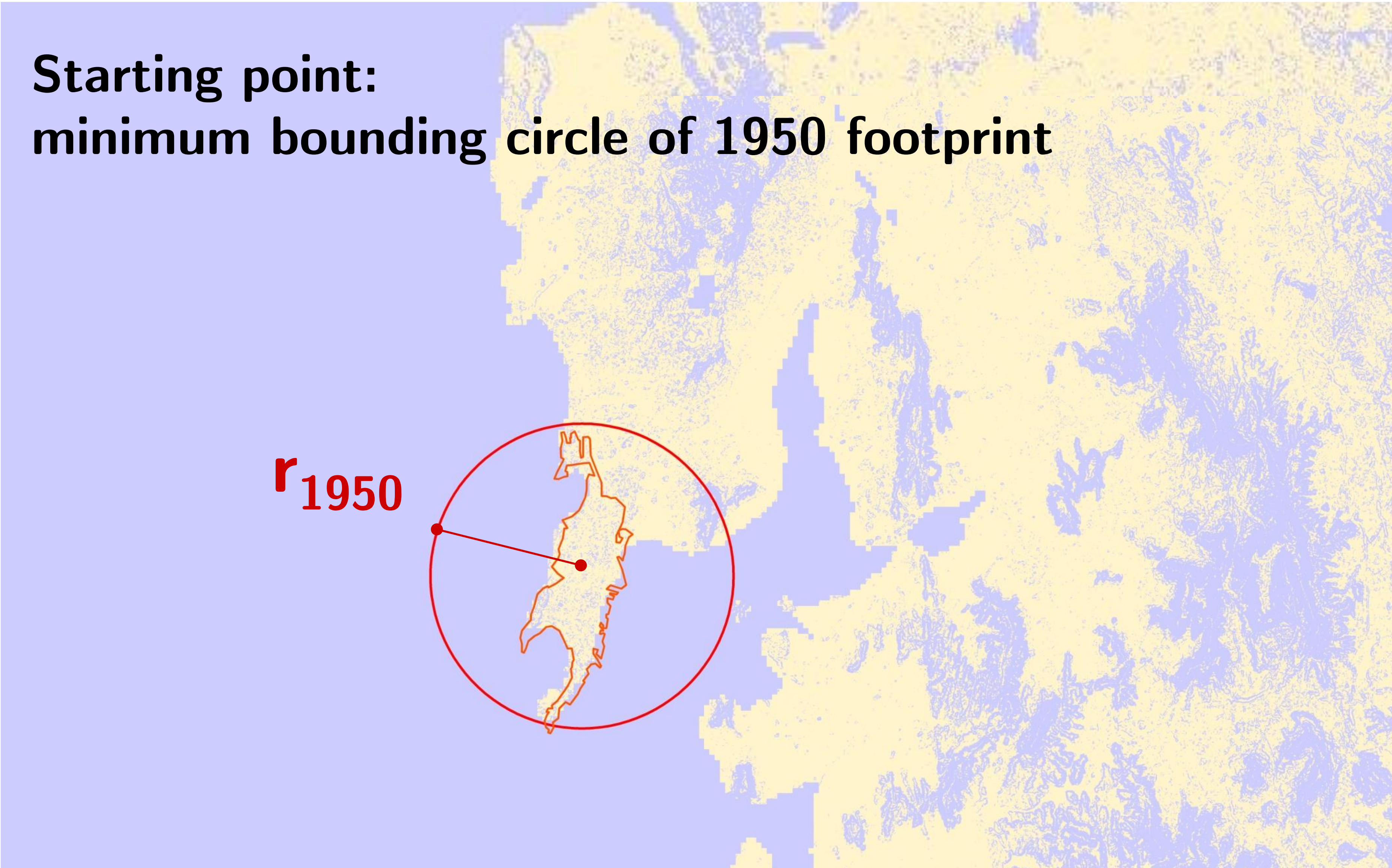
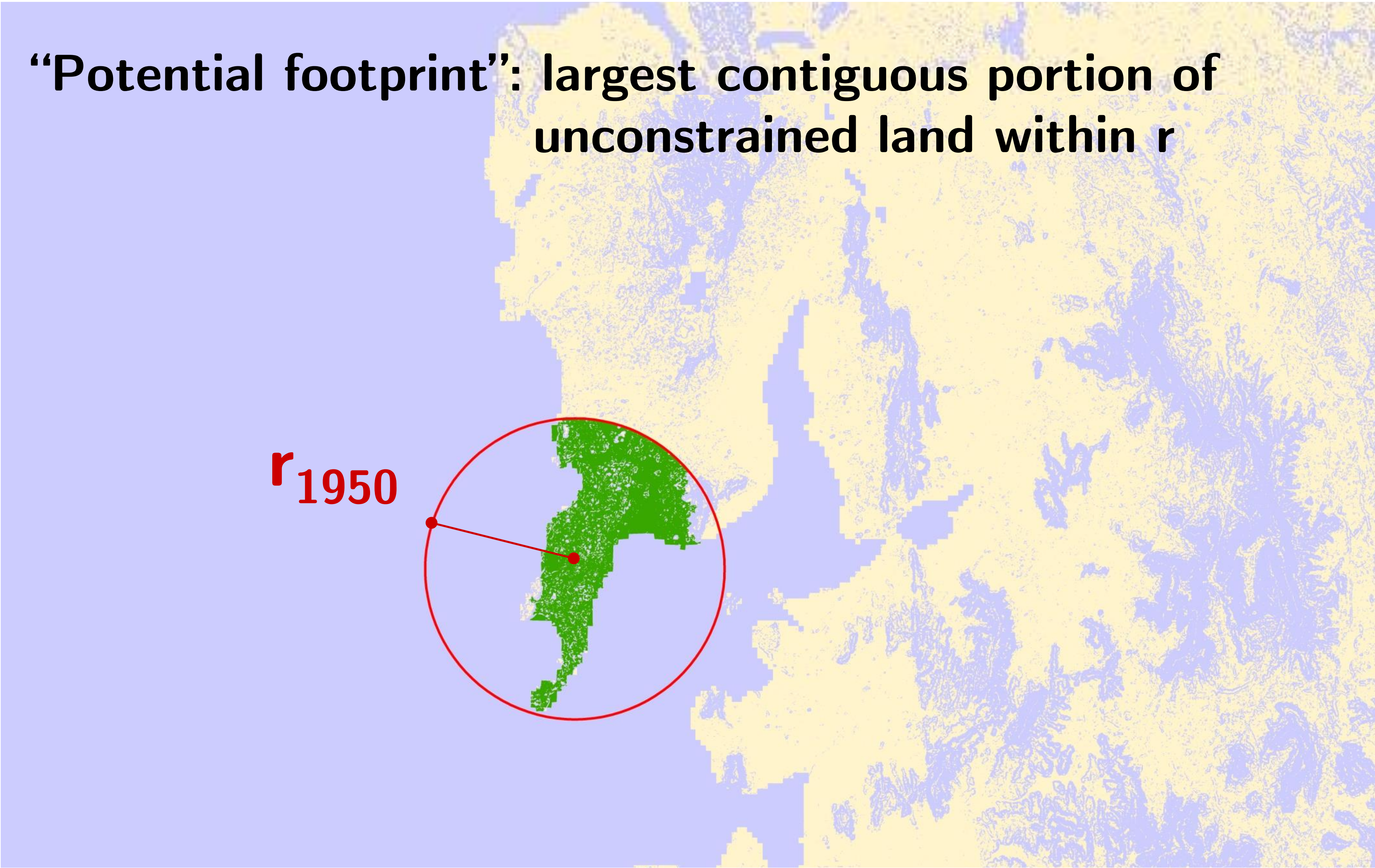
- Consider the largest contiguous portion of unconstrained land within a given radius around each city: "*potential footprint*"
- Instrument the shape properties of the *actual* city footprint with the shape properties of the *potential* footprint
- Add time variation by considering time-varying radii: as cities expand they hit new constraints


Constrained
Developable
City footprint in 1950

Starting point:
minimum bounding circle of 1950 footprint

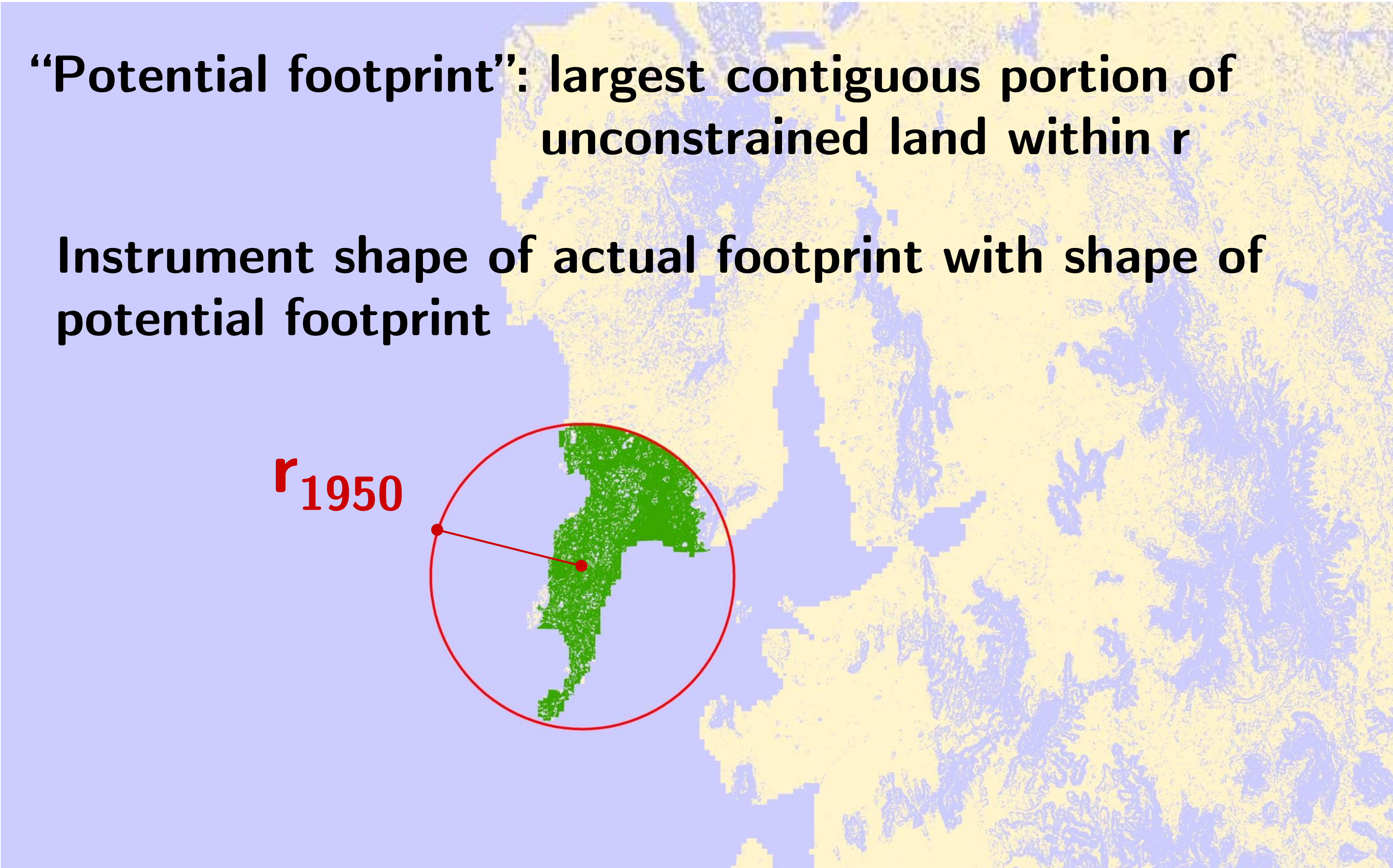


"Potential footprint": largest contiguous portion of unconstrained land within r

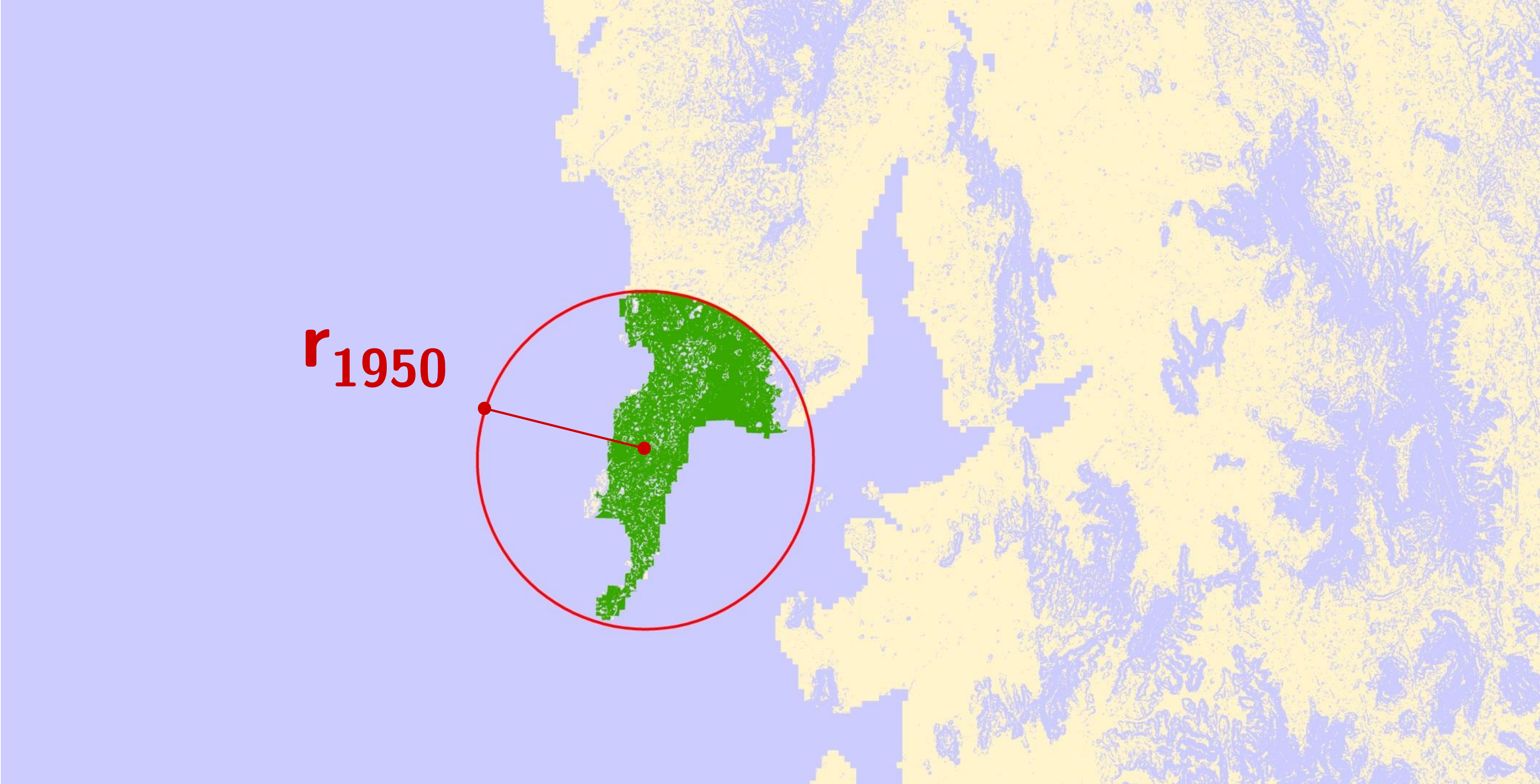


"Potential footprint": largest contiguous portion of unconstrained land within r

Instrument shape of actual footprint with shape of potential footprint



Time variation : every year consider a larger concentric disc around 1950 footprint



Empirical Strategy
Instrumenting city shape

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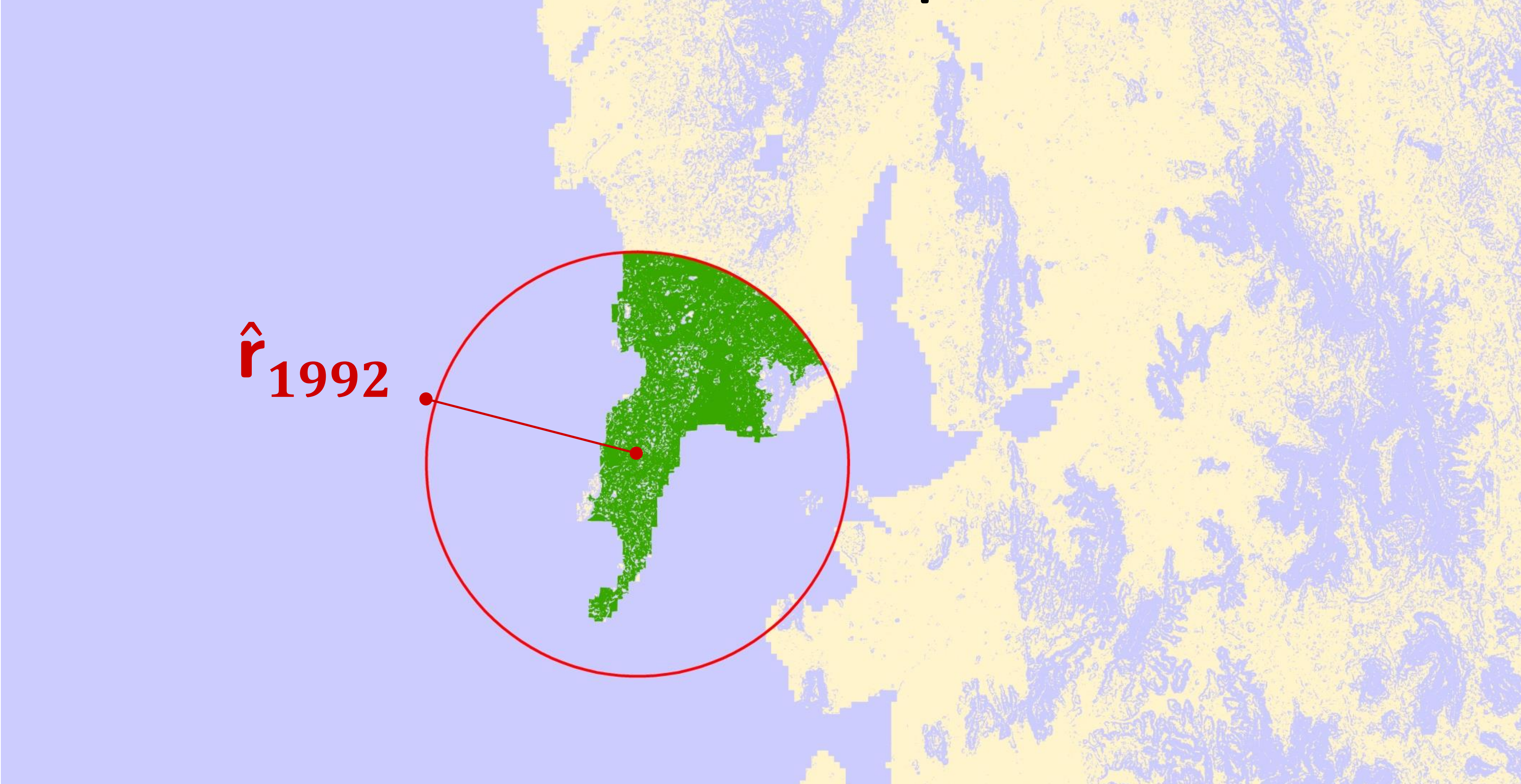

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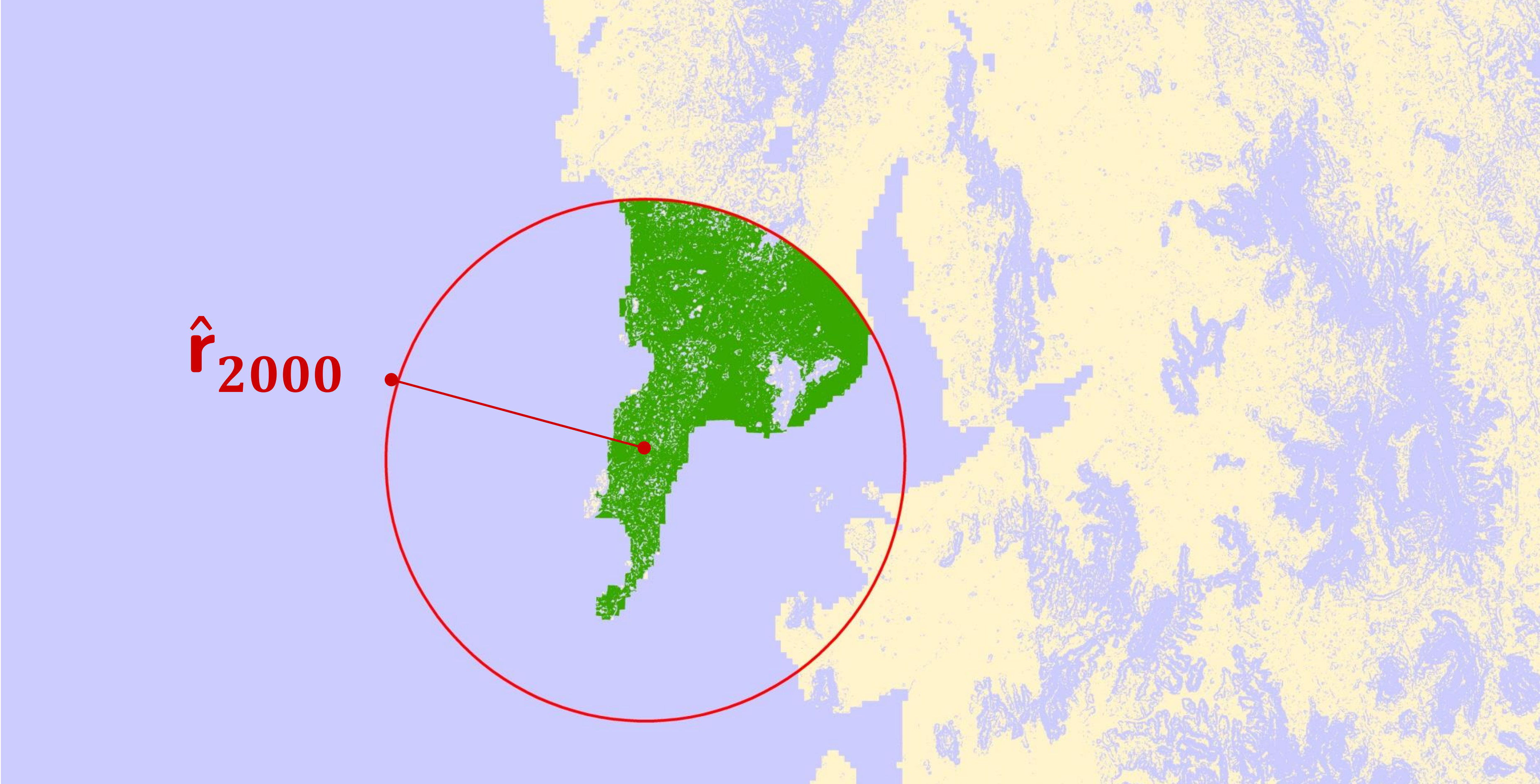

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- Common rate model

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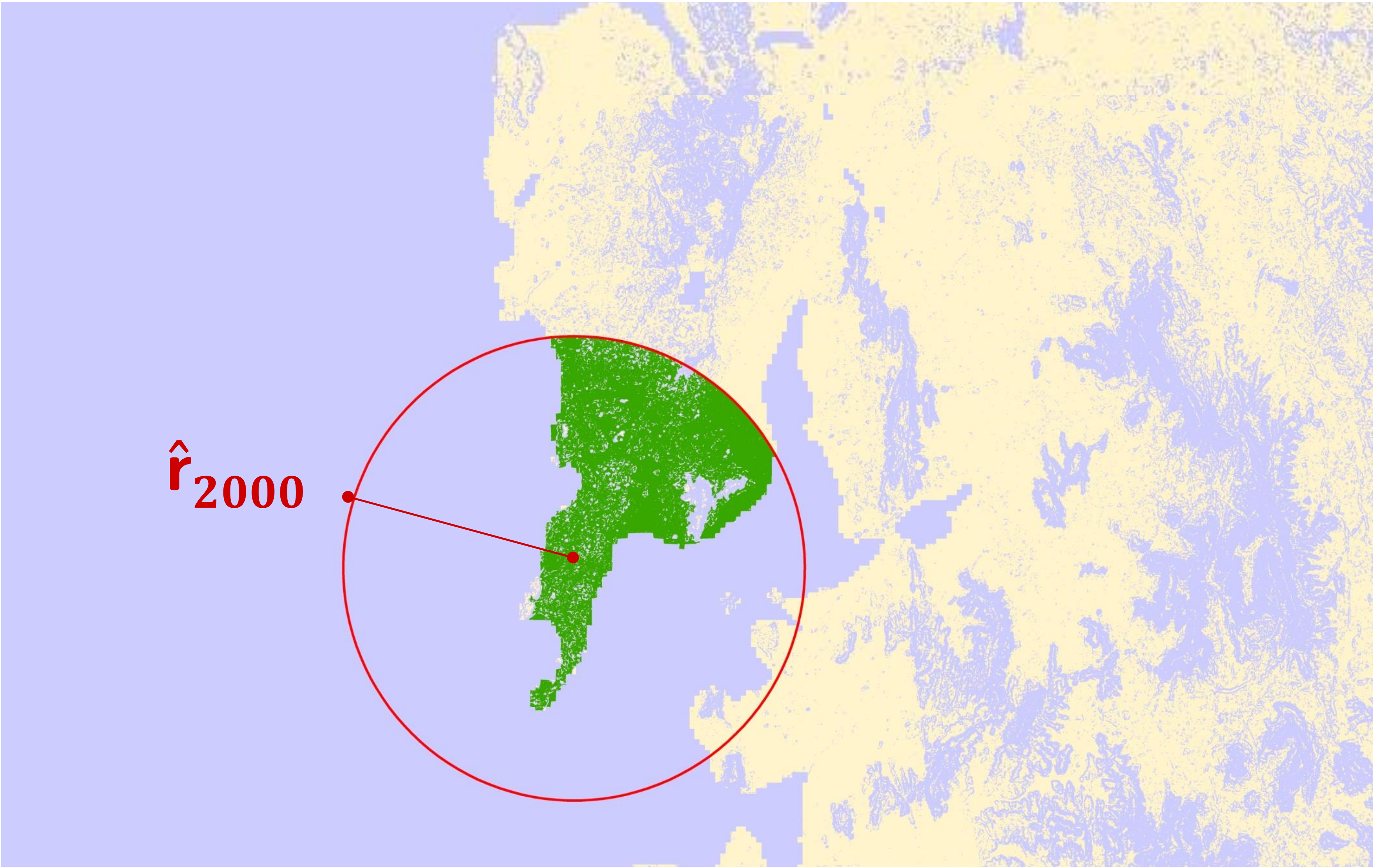
- City-specific model

  rate of expansion of the radii varies across cities based on historic population growth rates

  $\widehat{pop}_{c,t}$: log-linear projection of city 1871-1951 population Details

Empirical Strategy
Instrumenting city shape



Estimating equations: double-instrument specification

$$\log(Y_{c,t}) = a \cdot S_{c,t} + b \cdot \log(area_{c,t}) + \mu_c + \rho_t + \eta_{c,t}$$

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- 2 endogenous regressors: city shape $S_{c,t}$, $log(area_{c,t})$
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- 1st stage (1):

$$S_{c,t} = \sigma \cdot \widetilde{S_{c,t}} + \delta \cdot \log(\widehat{pop_{c,t}}) + \omega_c + \varphi_t + \theta_{c,t}$$

- 1st stage (2):

$$\log(area_{c,t}) = \alpha \cdot \widetilde{S_{c,t}} + \beta \cdot \log(\widehat{pop_{c,t}}) + \lambda_c + \gamma_t + \varepsilon_{c,t}$$

Empirical Strategy

Estimating equations: single-instrument specification

Outcome $Y_{c,t}$= population:

$$\frac{pop_{c,t}}{area_{c,t}} = a \cdot nS_{c,t} + \mu_c + \rho_t + \eta_{c,t}$$

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- 1 instrument: normalized shape of potential footprint $\widetilde{nS_{c,t}}$

- 1st stage: $nS_{c,t} = \beta \cdot \widetilde{nS_{c,t}} + \lambda_c + \gamma_t + \varepsilon_{c,t}$

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First Stage

	(1)	(2)	(3)
	Norm. shape of actual footprint	Shape of actual footprint, km	Log area of actual footprint, km^2
		Shape Metric: Disconnection	
Norm. shape of potential footprint	0.0663***		
	(0.0241)		
Shape of potential footprint, km		1.392***	0.152***
		(0.229)	(0.0457)
Log projected historic population		-1.180***	0.307***
		(0.271)	(0.117)
Observations	6,276	6,276	6,276
Model for r	common rate	city-specific	city-specific
City FE	YES	YES	YES
Year FE	YES	YES	YES

Notes: each observation is a city-year. Disconnection is the average length of within-city trips. Standard errors clustered at the city level.*** p<0.01,** p<0.05,* p<0.1.

Other shape metrics

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Other shape metrics

Impact of City Shape on Population

	(1)	(2)	(3)
	IV	IV	OLS
	Population density	Log population	Log population
	Shape Metric: Disconnection		
Norm. shape of actual footprint	-254.6***		
	(80.01)		
Shape of actual footprint, km		-0.0991**	0.0249***
		(0.0386)	(0.00817)
Log area of actual footprint, km^2		0.782***	0.167***
		(0.176)	(0.0318)
Observations	1,440	1,440	1,440
Model for r	common rate	city-specific	
City FE	YES	YES	YES
Year FE	YES	YES	YES

Notes: each observation is a city-year. Disconnection is the average length of within-city trips. Population density is measured in thousand inhabitants per km^2. Standard errors clustered at the city level.*** p<0.01,** p<0.05,* p<0.1.

Other shape metrics

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Other shape metrics

Robustness:

- Different shape metrics Table
- Different luminosity thresholds – resulting in more or less restrictive definitions of urban areas Table
- Excluding cities with "extreme" topographies (coastal and mountainous) Table
- Initial shape x year FEs Table

Impact of City Shape on Wages

	(1) IV	(2) IV	(3) OLS
	Dependent variable: log wage		
Shape of actual footprint, km	0.0996***	0.0626	0.0586***
	(0.0336)	(0.0536)	(0.0150)
Log area of actual footprint, km^2		-0.167	-0.00936
		(0.465)	(0.0516)
Obs.	1,075	1,075	1,075
Model for r	common rate	city-specific	
City FE	YES	YES	YES
Year FE	YES	YES	YES

Notes: each observation is a city-year. Dependent variable: log urban average of individual yearly wages in the city's district, in thousand 2014 Rupees. Sample includes only districts with one city. Shape is captured by the disconnection index, which measures the average length of trips within the city footprint, in km. Wages are from the Annual Survey of Industries, waves 1990, 1994, 1995, 1997, 1998, 2009, 2010. Standard errors are clustered at the city level. *** p<0.01,** p<0.05,* p<0.1.

City Shape as an Amenity: wages

Impact of City Shape on Wages

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	(0.0336)	(0.0536)	(0.0150)
Log area of actual footprint, km^2		-0.167	-0.00936
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Obs.	1,075	1,075	1,075
Model for r	common rate	city-specific	
City FE	YES	YES	YES
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Impact of City Shape on Rents

	(1) IV	(2) IV	(3) OLS
	Dependent variable: log yearly rent per square meter		
Shape of actual footprint, km	-0.636	-0.518*	-0.00857
	(1.661)	(0.285)	(0.0736)
Log area of actual footprint, km^2		-0.919	-0.0632
		(0.870)	(0.108)
Obs.	476	476	476
Model for r	common rate	city-specific	
City FE	YES	YES	YES
Year FE	YES	YES	YES

Notes: each observation is a city-year. Dependent variable : log urban average of housing rent per m^2 in the city's district. Sample includes only districts with one city. Shape is captured by the disconnection index, which measures the average length of trips within the city footprint, in km. Housing rents are from the NSS Household Consumer Expenditure Survey, rounds 62 (2005-2006), 63 (2006-2007) and 64 (2007-2008). Standard errors are clustered at the city level. *** p<0.01,** p<0.05,* p<0.1.

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Obs.	476	476	476
Model for r	common rate	city-specific	
City FE	YES	YES	YES
Year FE	YES	YES	YES

Notes: each observation is a city-year. Dependent variable : log urban average of housing rent per m^2 in the city's district. Sample includes only districts with one city. Shape is captured by the disconnection index, which measures the average length of trips within the city footprint, in km. Housing rents are from the NSS Household Consumer Expenditure Survey, rounds 62 (2005-2006), 63 (2006-2007) and 64 (2007-2008). Standard errors are clustered at the city level. *** p<0.01,** p<0.05,* p<0.1.

Robustness:

- Rent control: exclude bottom 50% of rent distribution Rents
- Alternative city-district matching approaches Wages Rents
- Initial shape x year FEs Wages Rents

Model

From consumers' optimization:

$$log(W) - \alpha log(p_H) + log(\theta) = \overline{V}$$

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Reduced-form estimates: $\frac{\partial \widehat{log(p_H)}}{\partial S} = -\ 0.525\,,\ \frac{\partial \widehat{log(W)}}{\partial S} = 0.038$

From NSS Household Consumer Expenditure:
share of housing in consumption $\alpha = 0.16$

$$\Rightarrow\ \frac{\partial \widehat{log(\theta)}}{\partial S} = -\ 0.14$$

One standard deviation increase in disconnection
for the average-sized city (~ 720 m potential round-trip)

$= \mathbf{5\%}$ decrease in income

One standard deviation increase in disconnection
for the average-sized city ($\sim$ 720 m potential round-trip)

$=$ **5%** decrease in income

Compare it to actual cost of a 720 m round trip:

- at walking speed (4.5 km per hour): 2.3 % of working day $= \sim$ 45% of welfare cost
- 225 extra commute km per year

From firms' profit maximization:

$$(1-\gamma)log\,(W) = -\,(1-\beta-\gamma)\,log\,(N)\; +\; log(A) + \kappa_W$$

$$\frac{\partial log(A)}{\partial S} = (1-\gamma)\,\frac{\partial log(W)}{\partial S} + (1-\beta-\gamma)\,\frac{\partial log(N)}{\partial S}$$

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Reduced-form estimates: $\frac{\partial \widehat{\log(W)}}{\partial S} = 0.038$, $\frac{\partial \widehat{\log(N)}}{\partial S} = -0.098$

Labor share $\beta = 0.4$; traded capital share $\gamma = 0.3$

$\Rightarrow \frac{\partial \widehat{\log(A)}}{\partial S} = -0.003$ = - **0.1%** productivity for a one standard deviation deterioration in shape

Firms' location within cities

Are non-compact cities more polycentric?

Firms' location within cities

Are non-compact cities more polycentric?

- Data: 2005 Economic Census, Urban Directories
  - Address and employment class of urban productive establishments
- Compute number of employment sub-centers in each city
  - Non-parametric approach (McMillen, 2001):

    Sub-centers have larger employment density than nearby locations, and have a significant impact on the overall employment density function in a city

Remoteness

Impact of City Shape on the Number of Employment Subcenters, 2005

	(1)	(2)	(3)
	IV	IV	OLS
	Shape Metric: Disconnection		
	Subcenters/km^2	Log subcenters	Log subcenters
Norm. shape of actual footprint	-0.371		
	(0.507)		
Shape of actual footprint, km		-0.0639*	-0.0579***
		(0.0379)	(0.0154)
Log area of actual footprint, km^2		0.611***	0.571***
		(0.125)	(0.0568)
Observations	188	188	188
Model for □	common rate	city-specific	

Notes: each observation is a city in year 2005. Number of employment subcenters computed following Mc Millen (2001). Data on firms' addresses and employment are from the Economic Census (2005). Disconnection is the average length of trips within the city footprint, in km. *** p<0.01,** p<0.05,* p<0.1

Results
Firms' location within cities: degree of polycentricity

Remoteness

Impact of City Shape on the Number of Employment Subcenters, 2005

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- Infrastructure mitigates impact of shape

Interactions of City Shape with Infrastructure: Urban Roads

Dependent variable: population density

	(1) IV	(2) IV	(3) IV
		Disconnection	
Norm. shape	-327.6***	-306.2***	-204.8***
	(103.8)	(98.46)	(54.16)
Norm. shape x urban road density, 1981	1.955**	1.848**	1.485***
	(0.827)	(0.779)	(0.451)
Observations	1,205	1,205	1,205
Model for r	common rate	common rate	city-specific
City FE	YES	YES	YES
Year FE	YES	YES	YES
Year FE x Banks in 1981	NO	YES	YES

Notes: each observation is a city-year. Dependent variable: population density in thousand inhabitants per km^2. Urban road density is from the 1981 Census. Disconnection is the average length of within-city trips. Range is the maximum length of within-city trips. Standard errors are clustered at the city level. *** p<0.01,** p<0.05,* p<0.1.

Details

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Details

Floor Area Ratios =
total floor area of building / area of plot on which it sits

- FARs in top Indian cities are exceptionally low compared to international standards (avg. = 2.3)
- Argument against FARs: they induce sprawl by preventing cities from growing vertically
- Data: FARs as of mid-2000s in 60 cities, from Sridhar (2010)

FARs determinants

First-stage Impact of FARs on City Shape

	(1) OLS Norm. shape actual footprint	(2) OLS Shape actual footprint	(3) OLS Log area
Norm. shape potential footprint	0.435***		
	(0.123)		
Norm. shape potential footprint x FAR	-0.0908**		
	(0.0452)		
Log projected hist. pop.		2.998	1.984**
		(2.758)	(0.795)
Log projected hist. pop. x FAR		-1.958*	-0.686**
		(1.023)	(0.319)
Shape potential footprint		0.156	-0.186
		(1.182)	(0.233)
Shape potential footprint x FAR		0.665	0.135
		(0.487)	(0.106)
Observations	1,183	1,183	1,183
FAR	average	average	average
Model for r	common rate	city-specific	city-specific
City FE	YES	YES	YES
Year FE	YES	YES	YES

Notes: each observation is a city-year. FARs are drawn from Sridhar (2010) and correspond to the maximum allowed Floor Area Ratios in each city as of the mid-2000s. Higher FARs allow for taller buildings. Shape is captured by the disconnection index, which measures the average length of trips within the city footprint, in km. Standard errors are clustered at the city level. *** p<0.01,** p<0.05,* p<0.1.

Results

Responses to city shape: Floor Area Ratios

FARs determinants

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Outline

- Introduction
- Conceptual Framework
- Data
- Empirical Strategy
- Results
- Conclusions

Conclusions

Poor urban connectivity driven by less compact shape

- Entails welfare losses
- Affects the spatial equilibrium across cities and urbanization patterns

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Poor urban connectivity driven by less compact shape

- Entails welfare losses
- Affects the spatial equilibrium across cities and urbanization patterns

Policy relevance:

- A range of possible policy responses
  - Investments in infrastructure and public transit
  - Land use regulations:
    encourage land consolidation, promote vertical growth

Conclusion

Thank you!