THE MONOCENTRIC CITY MODEL II

Urban Economics

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I COURSE COMPONENTS

the idea

- Block I
  - Introduction to Urban and Regional Economics and Course Overview
  - Topic I: Regional and urban concentration forces
  - Topic II: The empirics of agglomeration
  - Topic III: Costs and benefits of agglomeration
- Block 2
  - Topic IV: Monocentric city I (household location choice)
  - **Topic V: Monocentric city II (household location choice)**
  - Topic VI: Firm location choice
  - Topic VII: The urban economy in general equilibrium
- Block 3
  - Topic VIII: The vertical dimension of cities
  - Topic IX: Suburbanization and gentrification
  - Topic X: Hedonic analysis

I INTRODUCTION

roadmap

- **Last time: *The monocentric city model I***
  - **1) History of thought**
  - **2) The household bid-rent model**
    - **The utility maximization problem**
    - **Compensating differentials**
    - **Rent gradients**
    - **Substitution effects in consumption**
    - **Convexity of the rent gradient**
  - **3) Density gradients**
    - **Structural density**
    - **Population density**

I INTRODUCTION

roadmap

- **This time: *The monocentric city model II***
  - **1) Equilibrium conditions**
    - **Additional restrictions**
  - **2) Comparative statics: Income**
    - **What happens if people get richer?**
    - **Where do the rich and the poor live in cities?**
  - **3) Comparative statics: Transport cost**
    - **What happens if transport gets cheaper?**
    - **Did cities decentralize over time?**
  - **4) Other predictions**
    - **Distinguishing between open-city and closed-city case**

I RECALL

household bid-rent model

Price and density gradients decrease in distance from the CBD

II EQUILIBIUM CONDITIONS

additional restrictions

Q: How to determine where the city ends?

II MCM BY BRUECKNER (1987)

additional restrictions

Variable/parameter	Description
$D(x)$	Population density at x
$h(x)$	Housing density at x
L	Total city population
$p_q(x)$	Housing rent at x
$q(x)$	Housing consumption at x
$r(x)$	Land rent at x
rA	Agricultural rent
$S(x)$	Structural density at x
t	Transport cost per unit of x
U	City-level utility
X	Distance from the CBD
Y	City-level income per capita

II EQUILIRIUM CONDITIONS

roadmap

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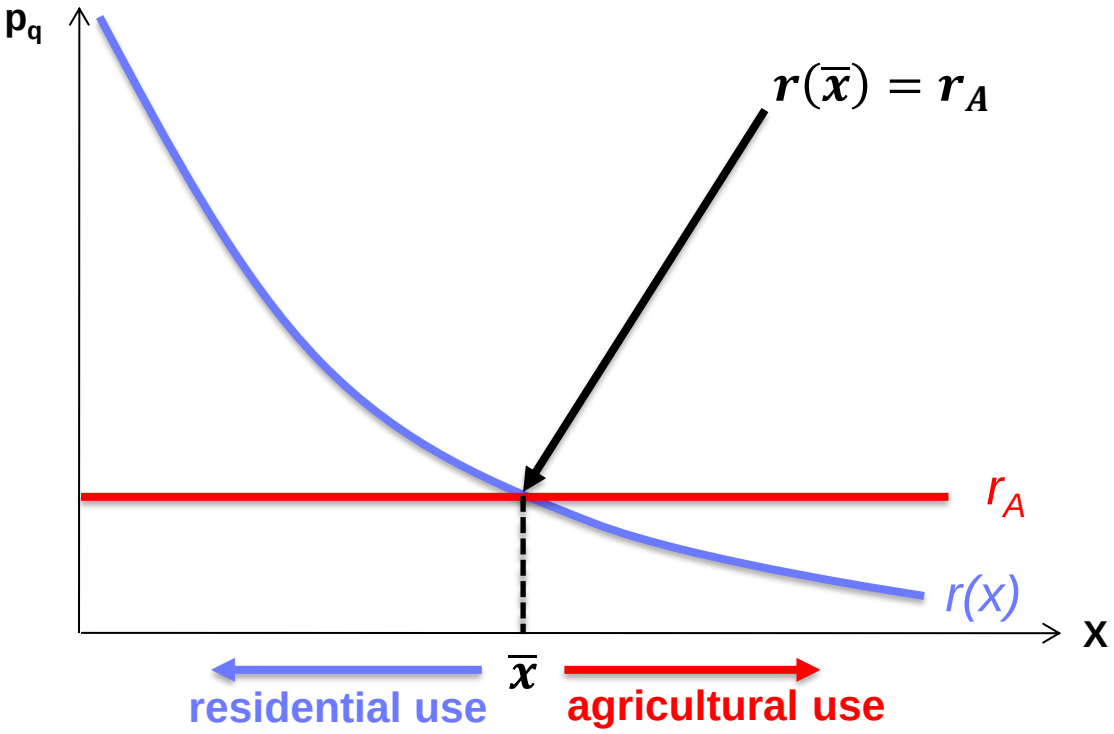
II AGRICULTURAL RENT

additional restrictions

- For land to be „urban“, rent must exceed agricultural rent
  - Land rent paid by residents in Alonso model
  - Land rent paid by developers in Mills-Muth model



II EXOGENOUS VS. ENDOGENOUS VARIABLES

additional restrictions

- **Always <u>exogenous</u>:** ← **Determined outside the model**
  - r_A, y, t
- **Always <u>endogenous</u>:** ← **Solved within the model**
  - $\overline{x}, p_q, r, S, D$
- **„Closed city“ case: No between-city migration**
  - **Population *L* is <u>exogenous</u>**
  - **Utility *U* is <u>endogenous</u>**
- **„Open city“ case: Free between-city migration**
  - **Population *L* is <u>endogenous</u>**
  - **Utility *U* is <u>exogenous</u>**
    - Similar to system of cities and Rosen-Roback framwork
    - See topics I-III

II COMPARATIVE STATIC ANALYSIS

additional restrictions

- **Analyse impact of**
  - **a change in one exogenous variable**
  - **on endogenous variables**
- **Use the structure of the model to establish counterfactuals**
- **Derive predictions**
  - **What happens to rents, densities, etc. $\{\overline{x}, p_q, r, S, D, [L, U]\}$ if incomes, transport costs, or oppourtunity cost of land $\{r_A, y, t\}$ change**

Central to a host of questions that concern policy makers, planners, developers, investor, etc.

Predictions specific to open/closed-city case
Focus on close-city case first

III COMPARATIVE STATICS: INCOME

roadmap

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III INCREASE IN INCOME

comparative statics

Q: What happens to city structure (gradients) if incomes increase?

III DECREASE IN TRANSPORT COST

comparative statics

- **The slope of housing rent gradient (see topic IV):**

$$\frac{\partial p_q}{\partial x} = -\frac{t}{q(y)} < 0 \qquad \left[p_q = \frac{y - tx - c}{q(y)} \right]$$

Budget constraint

$$\frac{\partial q}{\partial y} > 0$$

- **Effect of a marginal increase in income *y* on the slope of bid-rent curve:**

Housing is a normal good ⇒ Consumption increases in income

$$\frac{\partial \left(\frac{\partial p_q}{\partial x} \right)}{\partial y} = \frac{t \frac{\partial q}{\partial y}}{[q(y)]^2} > 0$$

Income *y* increases ⇒ rent gradient flatter!

- **Slope less negative!**

III INCREASE IN INCOME

comparative statics

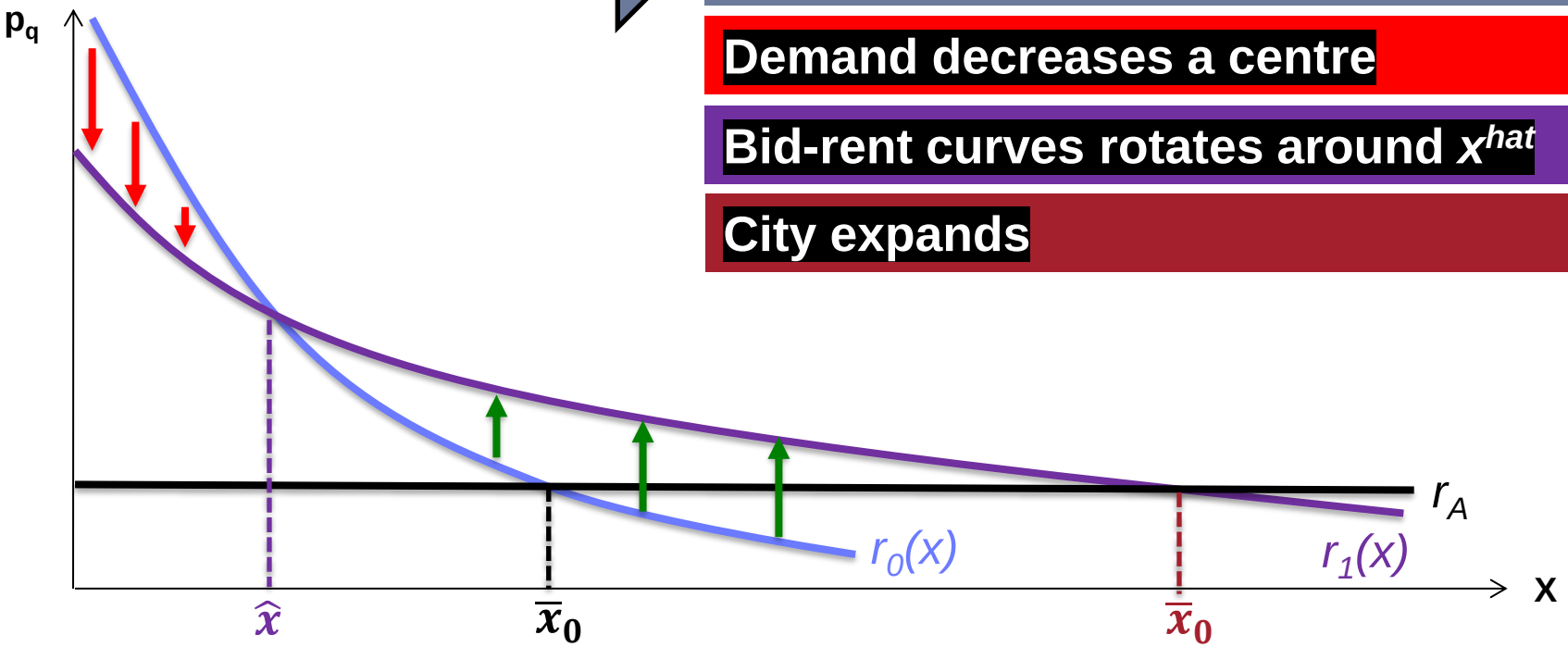
Rent gradient flatter ⇒
Bid-rents increase in periphery

Population → **Population moves to periphery**

Demand decreases a centre

Bid-rent curves rotates around x^{hat}

City expands



III COMPARATIVE STATIC ANALYSIS

additional restrictions

- **Housing rents decrease in centre, increase in periphery**
  - **Structural / housing density and land rent behave similarly**
  - **Housing consumption *q* rises in centre (where *p* falls)**
    - **Population density must decrease in centre**
  - ***q* must increase at city margin (higher income, same rent)**
  - **Ambiguous change of *q* between rotation point and city new city margin**
- **Of course, utility increases since residents consume more**

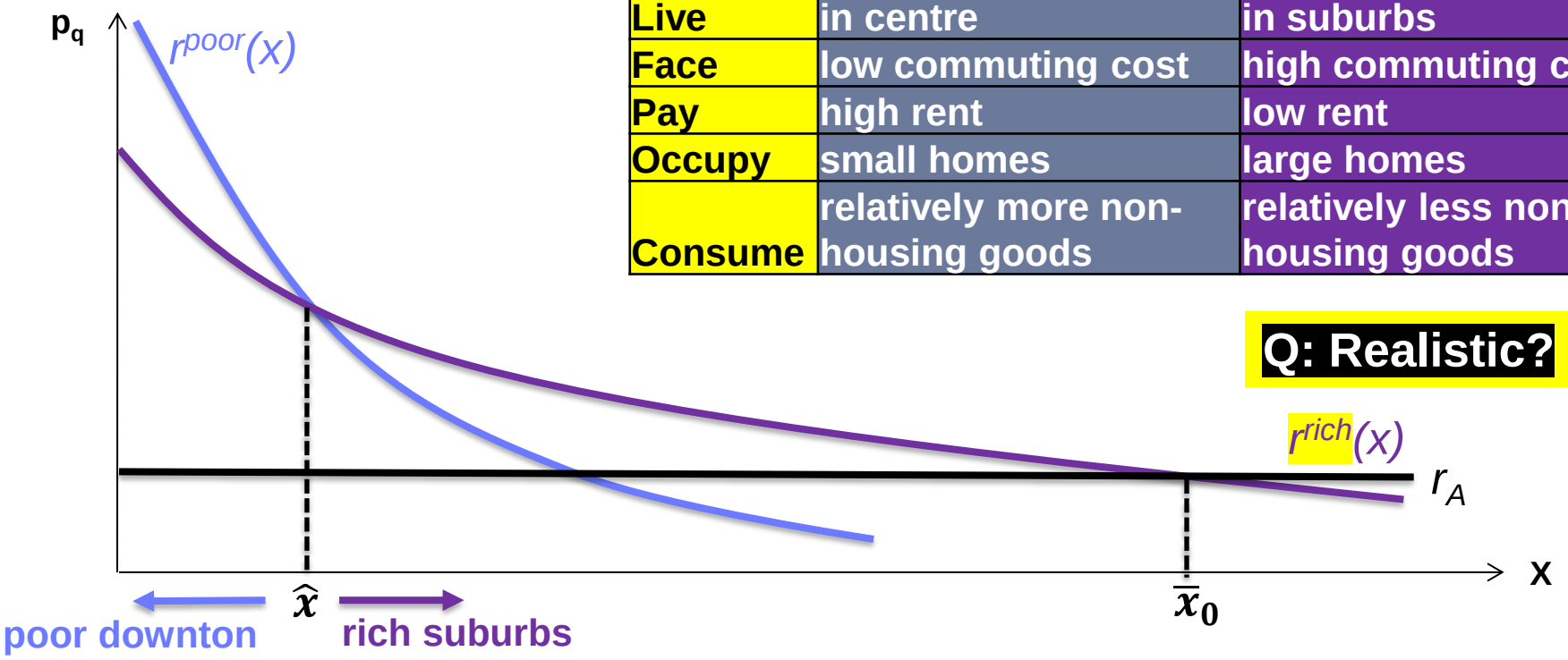
Q: Lessons for within-city income segregation?

III INCOME SEGREGATION

comparative statics

- **Bid-rents by rich and poor with <u>monetary</u> commuting cost**

	Poor	Rich
Enjoy	low utility	high utility
Live	in centre	in suburbs
Face	low commuting cost	high commuting cost
Pay	high rent	low rent
Occupy	small homes	large homes
Consume	relatively more non-housing goods	relatively less non-housing goods



Q: Realistic?

III INCOME SEGREGATION

additional restrictions

- With <u>monetary</u> *t*, rich live in suburbs, poor live in centre
- If we add the <u>value of time</u>, *t* likely depends on income

$$\frac{\partial p_q}{\partial x} = -\frac{t(y)}{q(y)} < 0$$

$$\frac{d\left(\frac{\partial p_q}{\partial x}\right)}{dy} = -\frac{\overbrace{t'(y)}^{>0}q(y) - t(y)\overbrace{q'(y)}^{>0}}{[q(y)]^2}$$

Theoretically ambiguous, elasticities matter!

- Income elasticities of commuting cost and housing consumption appear to be similar (Wheaton, 1977)

$$\frac{\partial t(y)}{\partial y} \approx \frac{\partial q(y)}{\partial y}$$

In line with observed cross-city differences (central Paris rich, downtown Detroit poor)

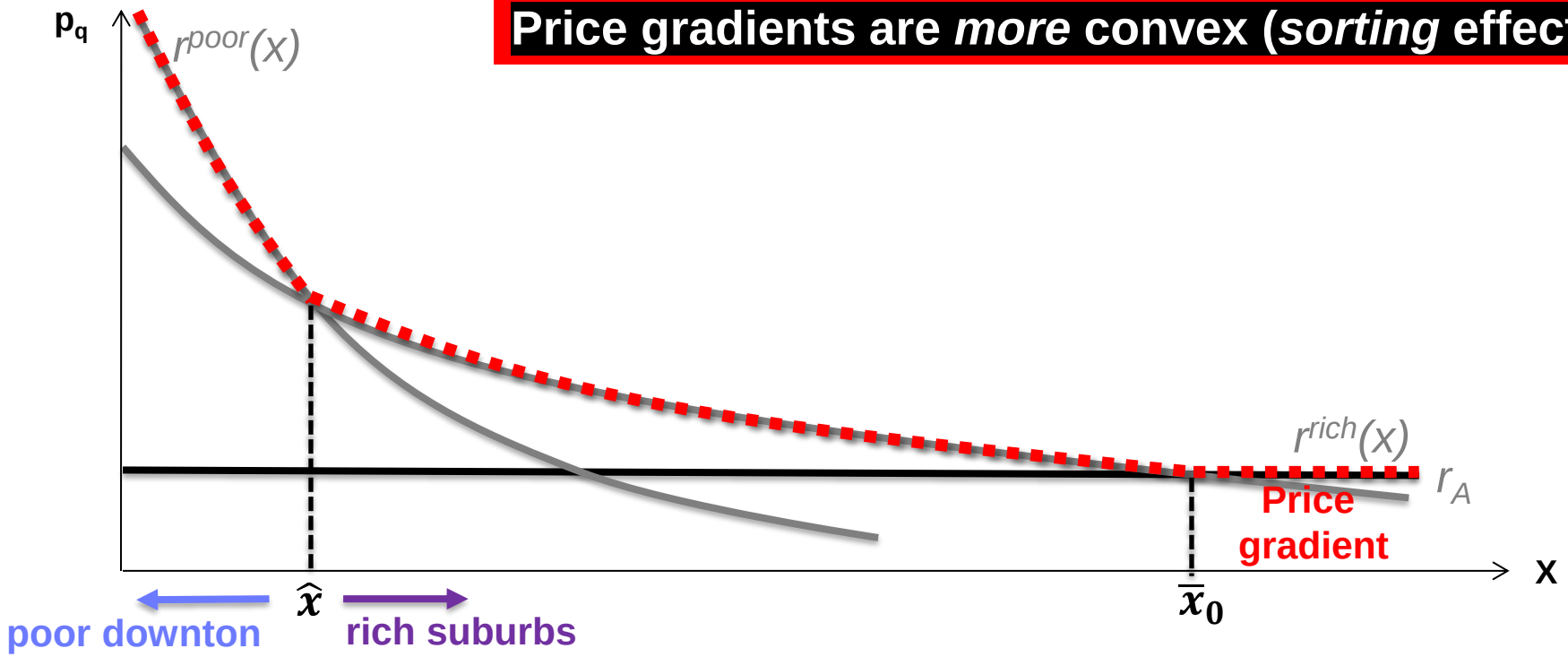
III BID-RENT CURVES VS. PRICE GRADIENTS

comparative statics

- **The observed price gradient (house prices, rents, etc.) is the envelope of individual bid-rent curves**

Each bid-rent curve is convex (*substitution* effect)

Price gradients are *more* convex (*sorting* effect)



IV COMPARATIVE STATICS: TRANSPORT COST

roadmap

- This time: *The monocentric city model II*
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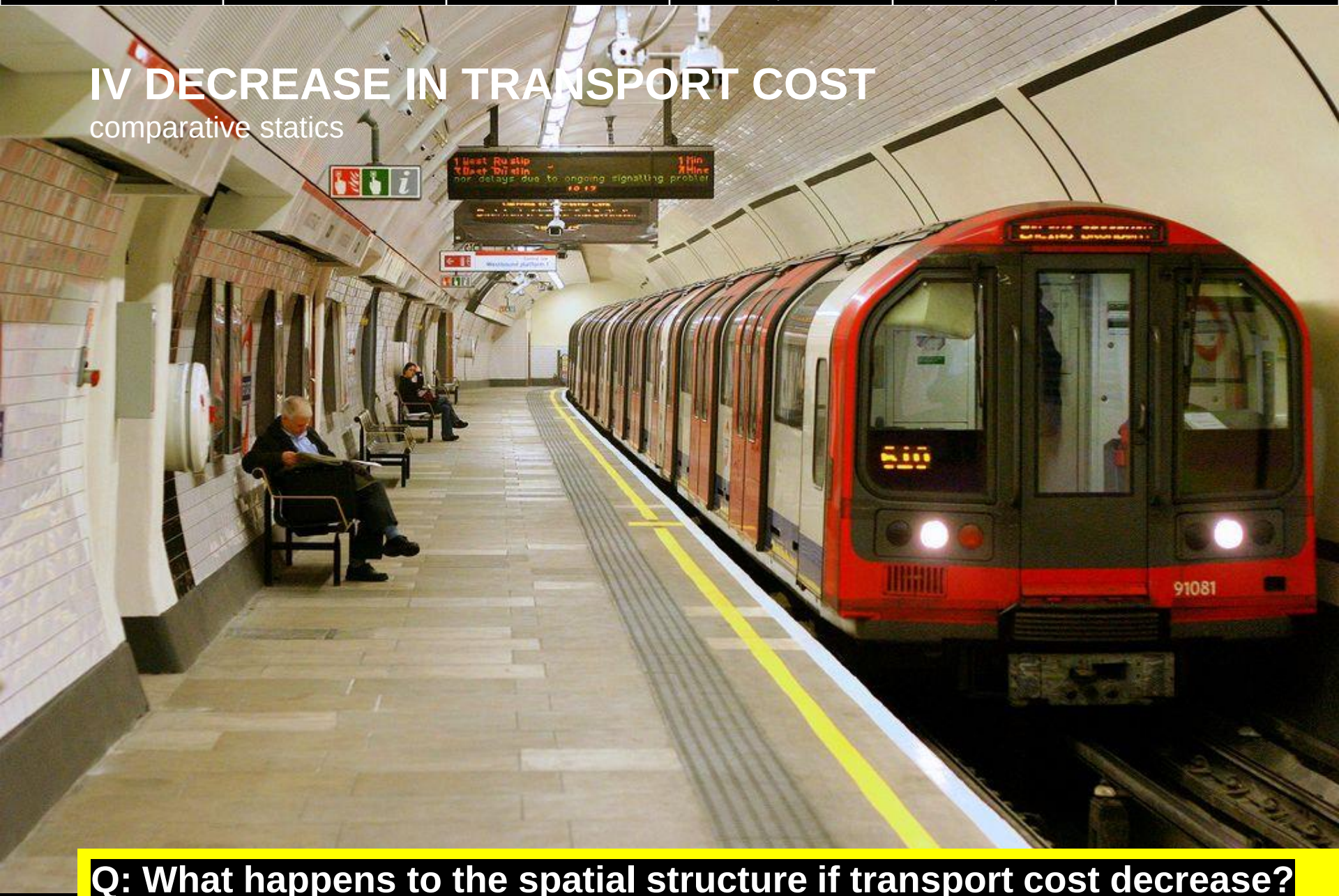
IV DECREASE IN TRANSPORT COST

comparative statics



Q: What happens to the spatial structure if transport cost decrease?

IV DECREASE IN TRANSPORT COST

comparative statics

- **The slope of housing rent gradient (see topic IV):**

$$\frac{\partial p_q}{\partial x} = -\frac{t}{q} \qquad \left[p_q = \frac{y - tx - c}{q} \right]$$

Budget constraint

- **Effect of a marginal increase in transport cost *t* on the slope of bid-rent curve:**

Larger transport *t* cost ⇒ steeper bid-rent curve

$$\frac{d\left(\frac{\partial p_q}{\partial x}\right)}{dt} = -\frac{1}{q} < 0$$

Transport cost *t* decrease ⇒ rent gradient flatter!

- **Slope more negative!**

IV DECREASE IN TRANSPORT COST

comparative statics

Population

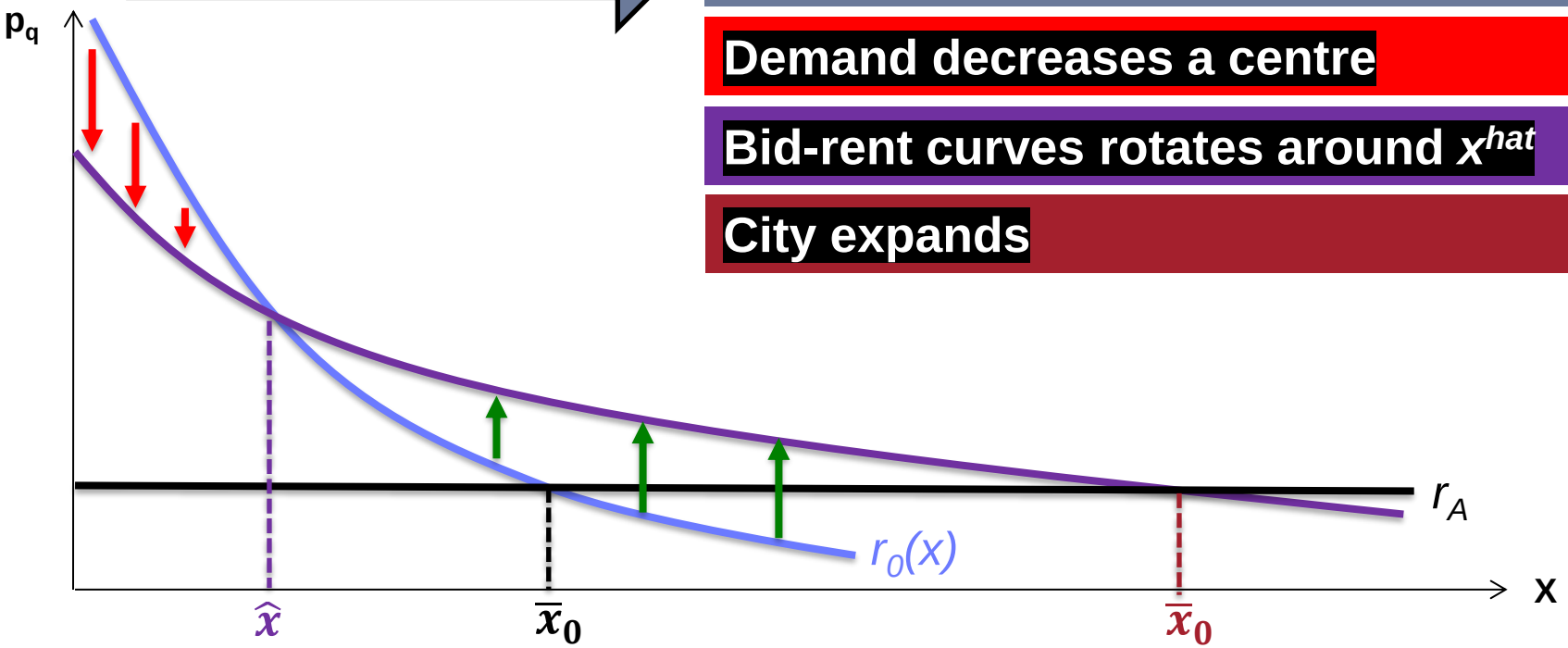
Rent gradient flatter⇒
Bid-rents increase in periphery

Population moves to periphery

Demand decreases a centre

Bid-rent curves rotates around x^{hat}

City expands



IV COMPARATIVE STATIC ANALYSIS

additional restrictions

- **Housing rents decrease in centre, increase in periphery**
  - **Structural / housing density and land rent behave similarly**
  - **Housing consumption *q***
    - **rise in centre (where *p* falls)**
    - **fall in periphery (where *p* increases)**
  - **Population density**
    - **Falls in centre, rises in periphery**
- **Utility increases since cost of commuting decreases**
  - **Similar to a positive income shock**

IV DECENTRALIZATION

comparative statics

- **Steady *income growth* in real terms over more than a century**
  - **Real GDP p.c. growth since 1900 in US, Western Europe (and world) about *2% per year* (Maddison Project Data)**

Could possibly lead to decentralization

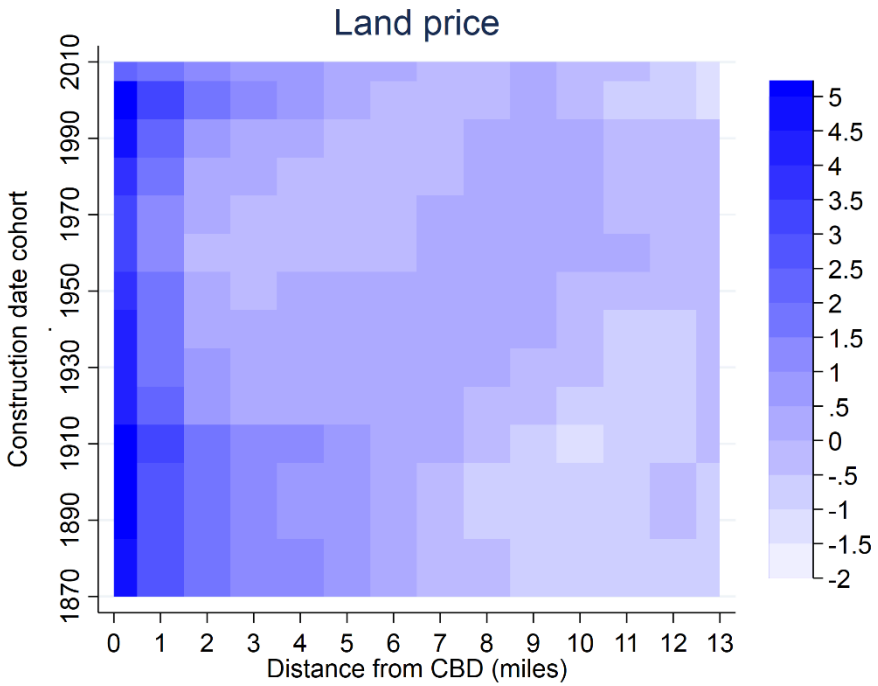
- **Major transport improvements since late 19th century**
  - **Subway and commuter rail**
  - **Mass produced cars and highways**
  - **Passenger travel p.c. growth since 1880 in the US about *2.7% per year* (Asubel et al. 1998)**

Should most likely cause decentralization

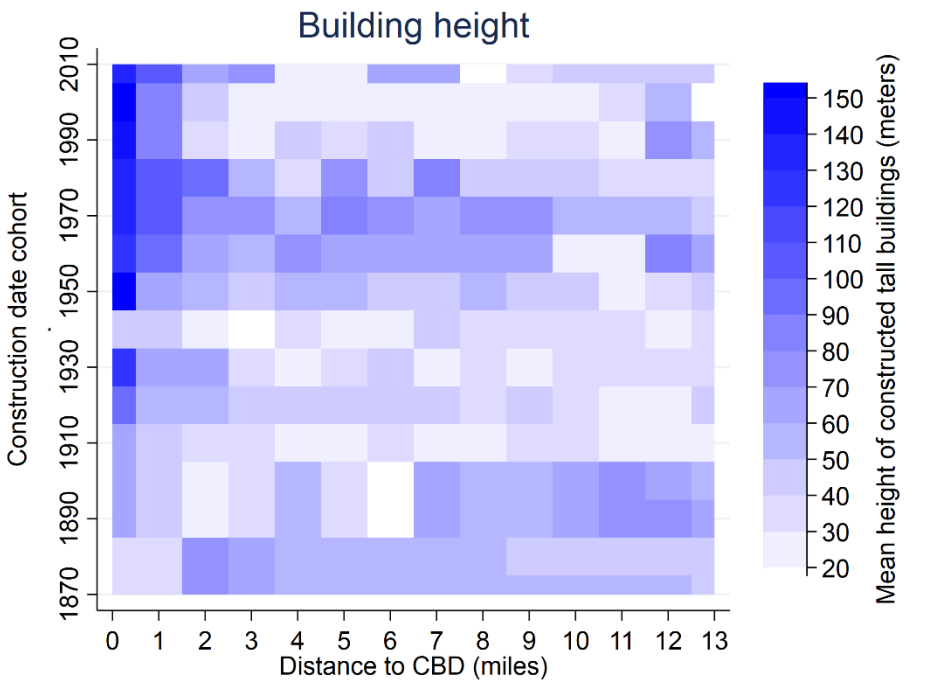
Q: Is there evidence?

IV EVIDENCE FROM CHICAGO

comparative statics



Land price

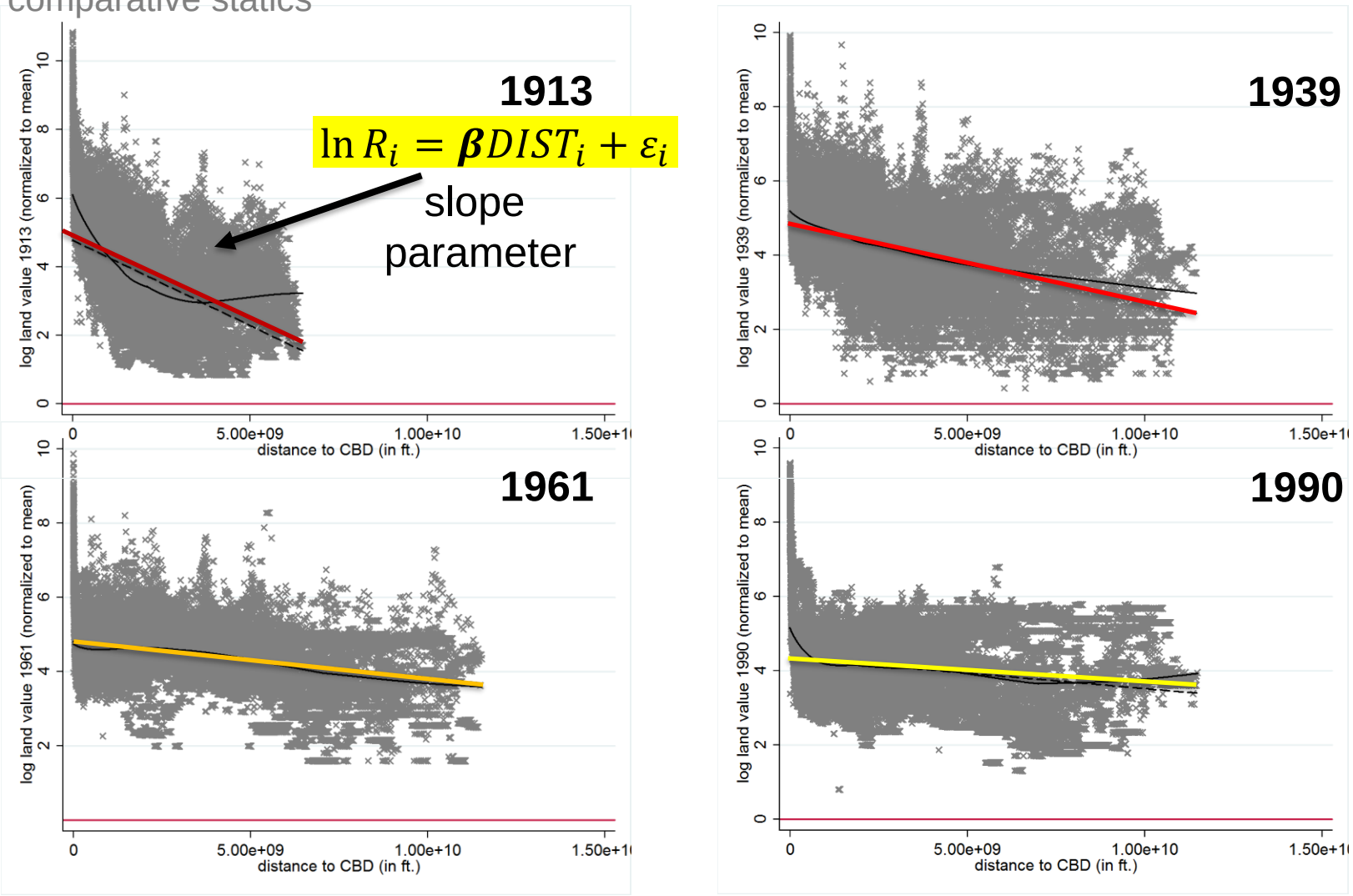


Building height

Ahlfeldt & McMillen 2018

IV LAND PRICE GRADIENTS IN CHICAGO

comparative statics



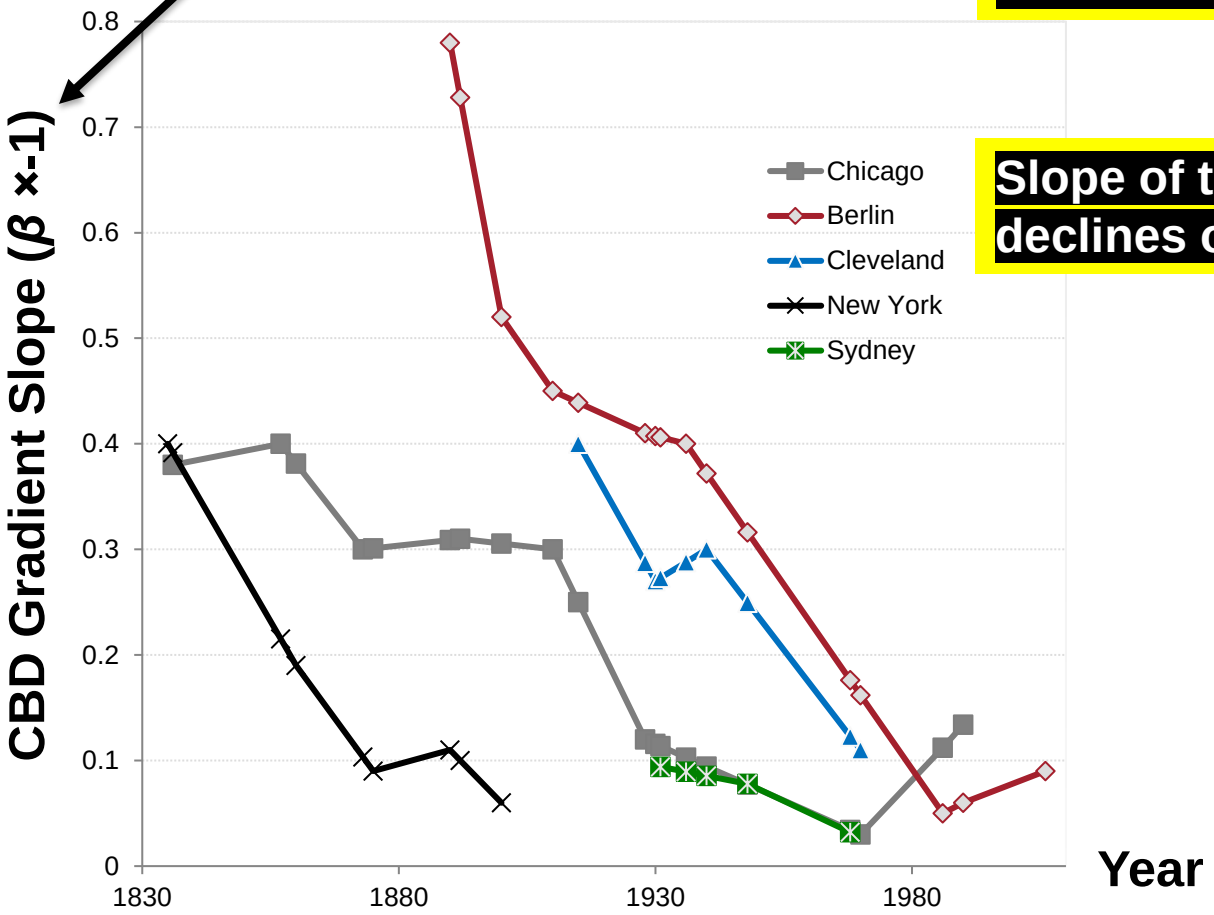
Distance gradients become flatter!

IV LAND PRICE GRADIENTS OVER TIME

comparative statics

$$\ln R_i = \boldsymbol{\beta} DIST_i + \varepsilon_i$$

Based on Ahlfeldt & Wendland, 2011

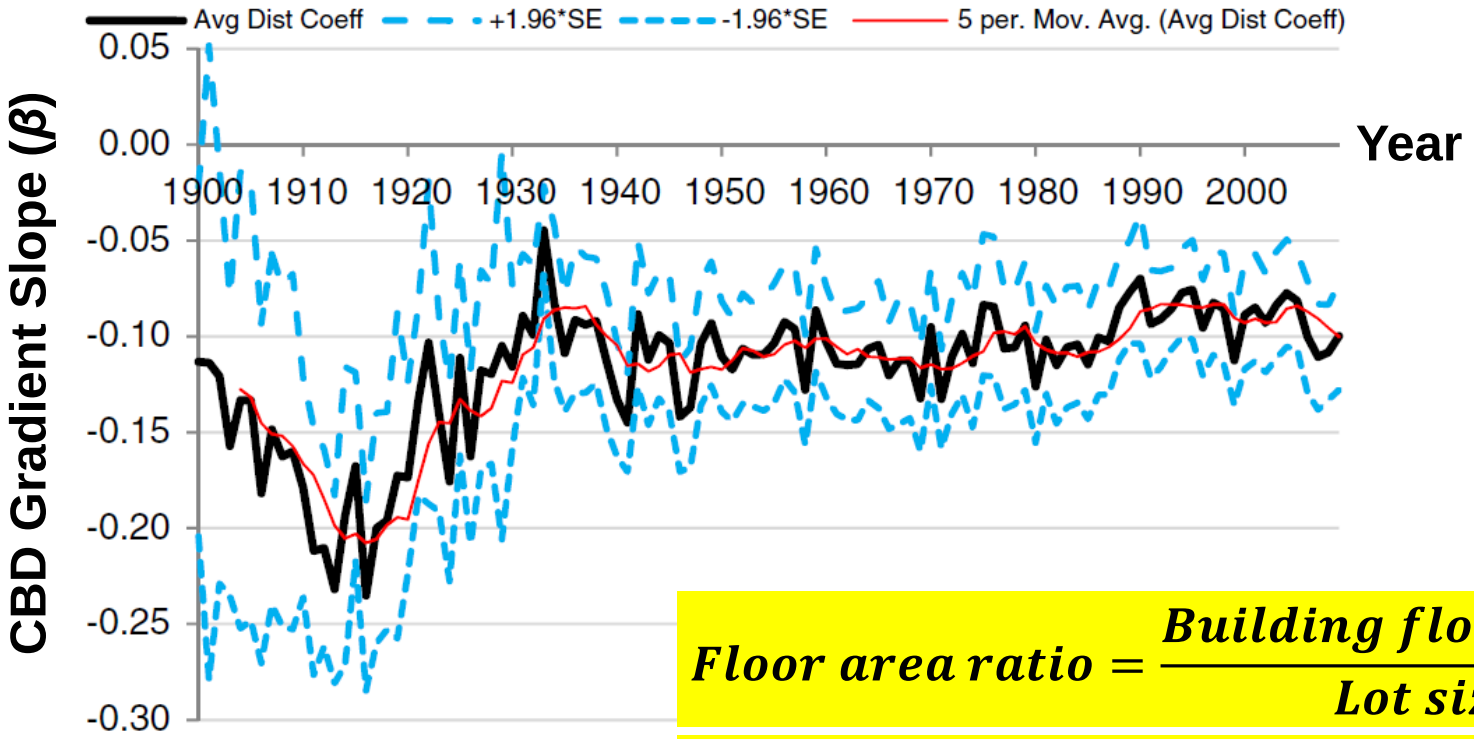


Slope of the price gradient also declines over time in other cities

IV FAR GRADIENT IN NEW YORK OVER TIME

comparative statics

$$\ln FAR_i = \boldsymbol{\beta} DIST_i + \varepsilon_i$$



$$\textbf{Floor area ratio} = \frac{\textbf{Building floor space } (m^2)}{\textbf{Lot size} (m^2)}$$

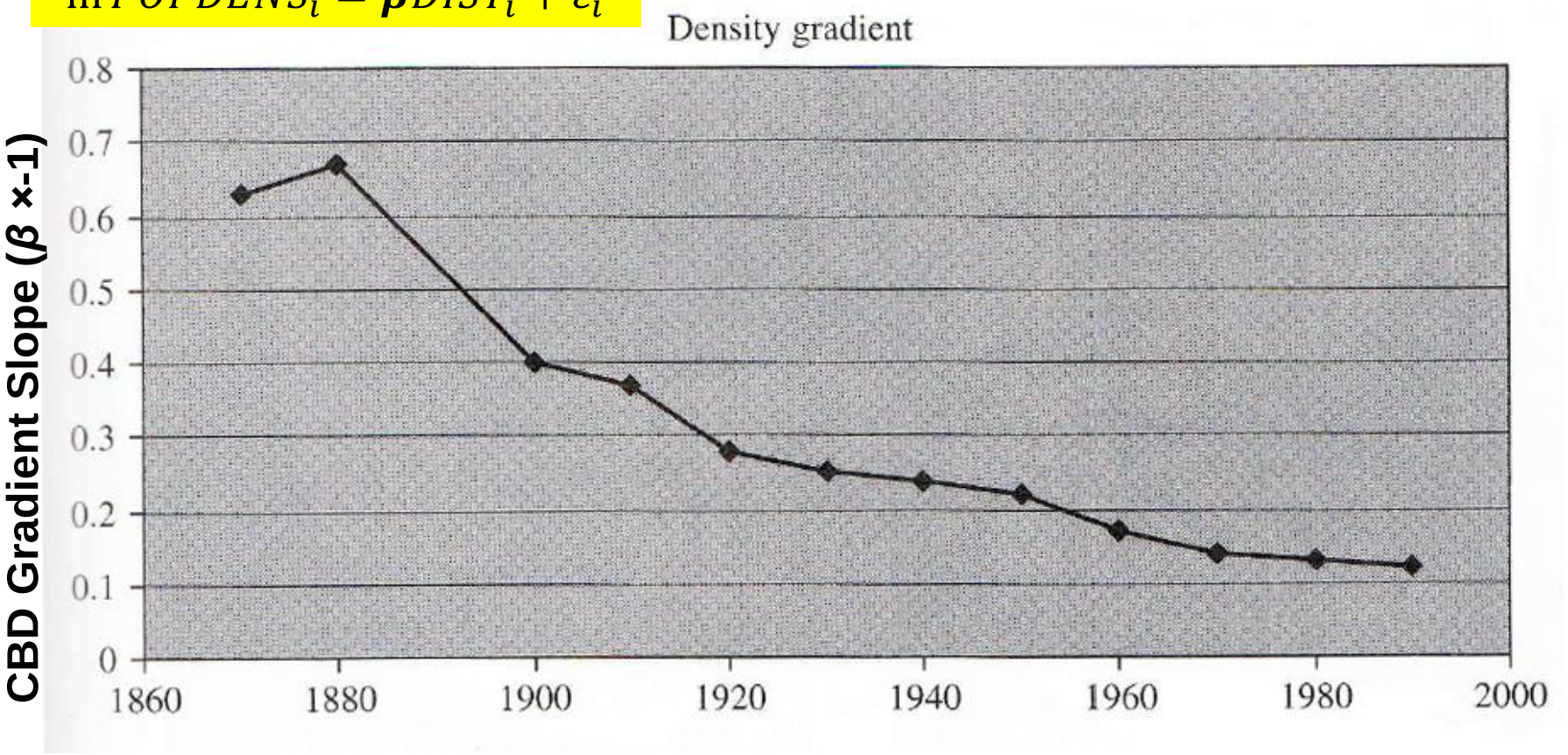
Structural density gradient also flattens

Barr & Cohen (2014)

IV POPULATION DENSITY GRADIENTS IN CHIAGO

comparative statics

$$\ln POPDENS_i = \boldsymbol{\beta} DIST_i + \varepsilon_i$$



McMillen & McDonald, ch. 8

Population density gradient also flattens

IV CAUSES OF DECENTRALIZATION

comparative statics

- **Strong evidence for *urban „decentralization“***
  - **In line with *transport improvements* since mid-19th century (rail & road)**
- **But *other explanations* theoretically possible**
  - **Increase in income (in MCM with monetary travel cost)**
  - **Increase in preference for suburban amenities**
  - **Increase in downtown disamenities (pollution, noise)**
  - **Aeging of dowtown housing (Brueckner & Rosethal 2009)**

Q: Is there „causal“ evidence for transport effects on decentralization?

IV HIGHWAYS AND POPULATION DECENTRALIZATION

comparative statics

TABLE I

AGGREGATE TRENDS IN SUBURBANIZATION, 1950–1990

	1950	1960	1970	1980	1990	Percent change 1950–1990
Panel A: Large MSAs						
MSA population	92.9	115.8	134.0	144.8	159.8	72
Total CC population	44.7	48.5	51.3	49.2	51.0	14
Constant geography CC population	44.7	44.2	42.6	37.9	37.1	−17
N for constant geog. CC population	139	132	139	139	139	
Panel B: Large Inland MSAs						
MSA population	39.2	48.9	57.0	65.0	73.5	88
Total CC population	16.8	19.7	22.1	22.1	23.2	38
Constant geography CC population	16.8	16.5	15.4	13.3	12.5	−26
N for constant geog. CC population	100	94	100	100	100	
Total U. S. population	150.7	178.5	202.1	225.2	247.1	64

Baum-Snow (2006)

Total US MSA population increased

Constant-geography central population decreased

IV BAUM-SNOW (2006)

comparative statics

- **Estimation equation:**

$$\Delta \log N_i^c = \delta_0 + \delta_1 \Delta \text{ray}_i + \delta_2 r_{ci} + \delta_3 \Delta \tilde{w}_i + \delta_4 \Delta \log N_i^{\text{MSA}} + \delta_5 \Delta \tilde{G}_i + \varepsilon_i$$

1950-1990 central city population

Change in number of highway passing through central city

Controls

$\text{cov}(\text{IV}, \varepsilon) = 0$

Use number of planned highways in 1947 plan as *instrument* to addresses *endogeneity*

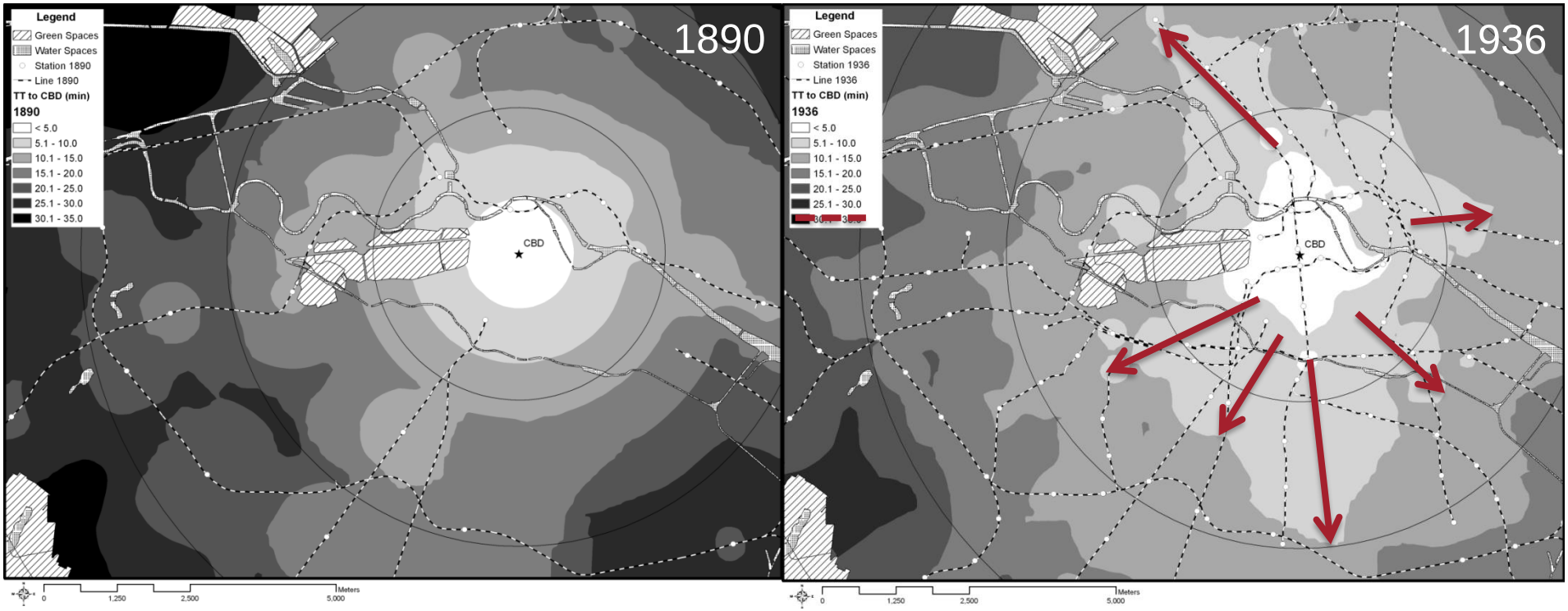
Causal effect of an additional highway passing through on central city population: -18%!

Highways decentralize population

IV RAIL EXPANSION IN PRE-WWII BERLIN

comparative statics

- **Estimated travel time (min) to the CBD accounting for rapid transit (U-/S-Bahn)**

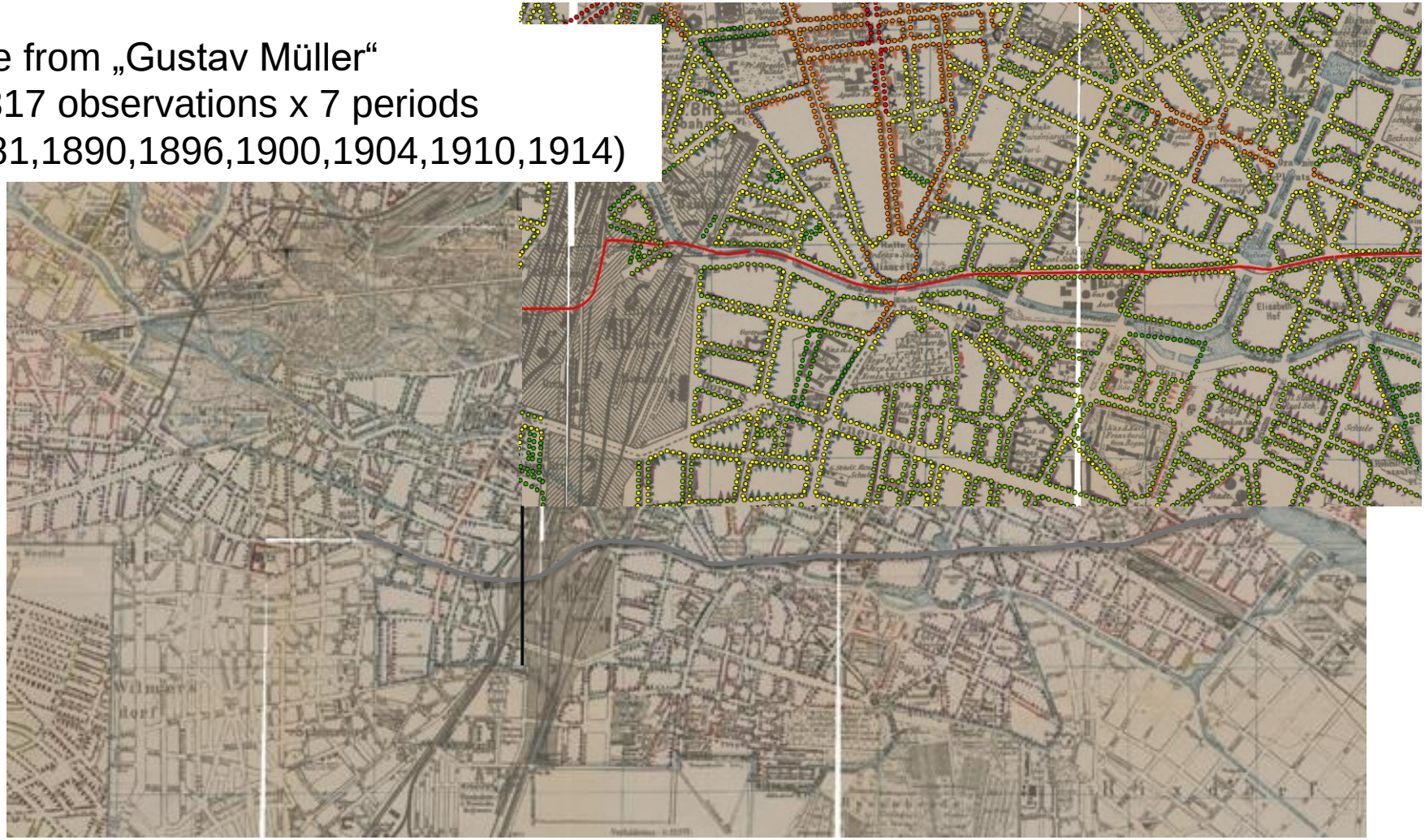


Ahlfeldt & Wendland (2011)

IV HISTORIC LAND PRICES IN BERLIN

comparative statics

Date from „Gustav Müller“
11,817 observations x 7 periods
(1881,1890,1896,1900,1904,1910,1914)



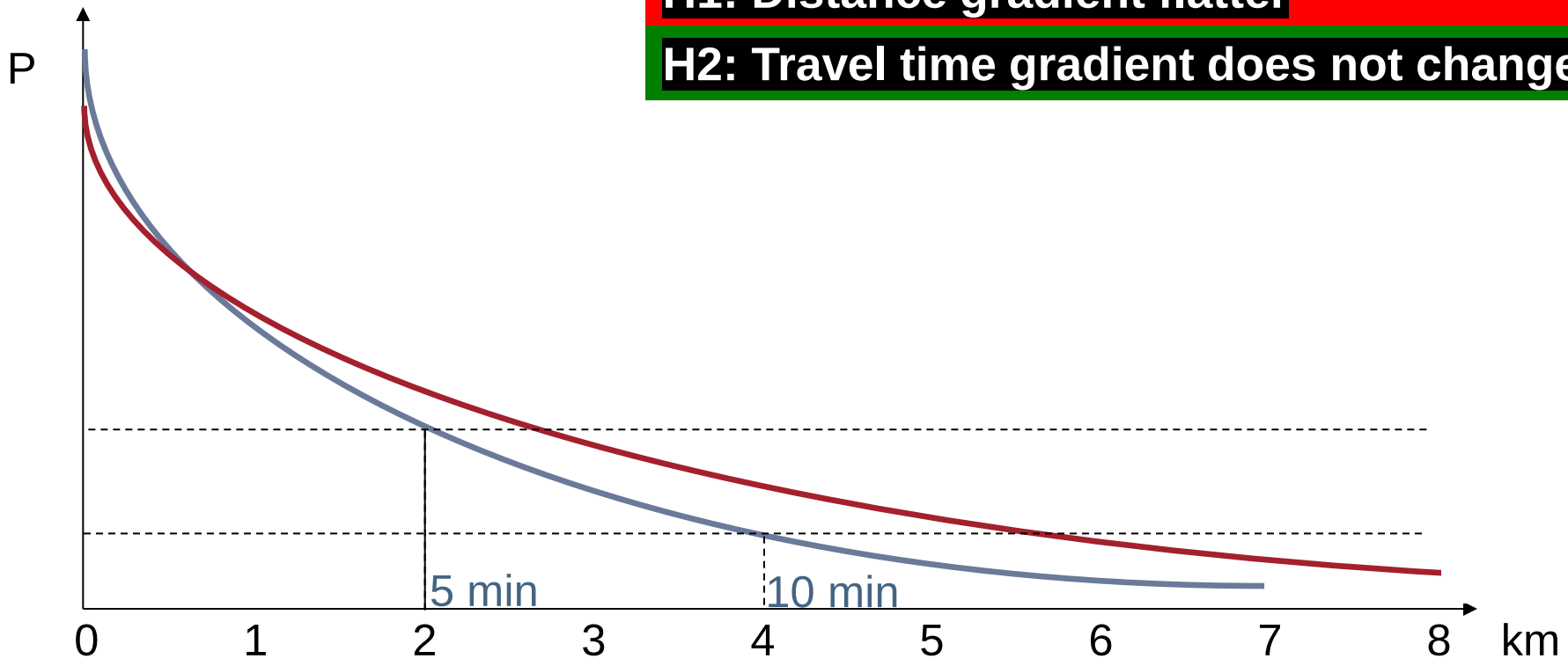
IV DECENTRALIZATION

comparative statics

City expands if transport cost decrease

H1: Distance gradient flatter

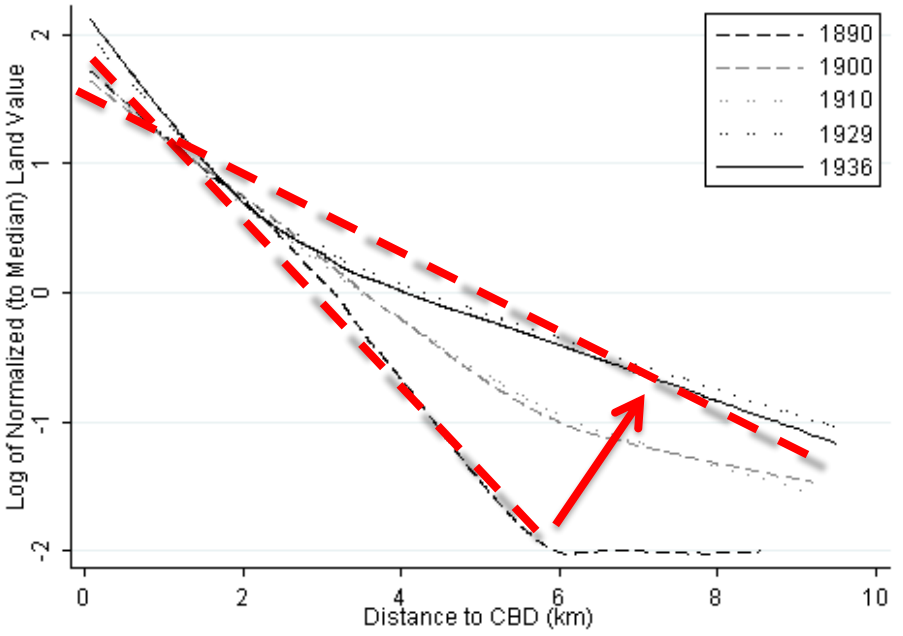
H2: Travel time gradient does not change



IV DECENTRALIZATION

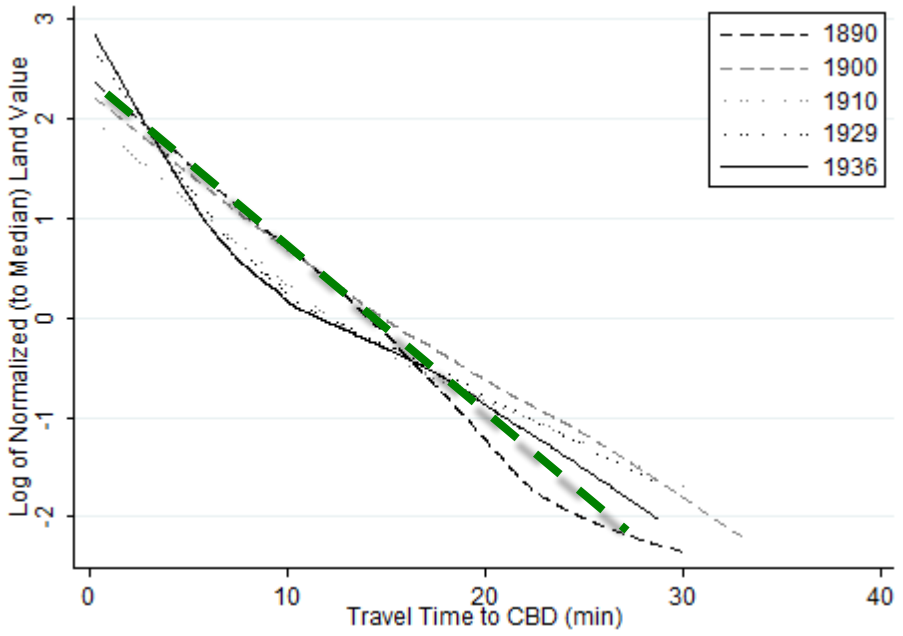
comparative statics

H1: Distance Gradients



β for distance *does* changes

H2: Travel Time Gradients



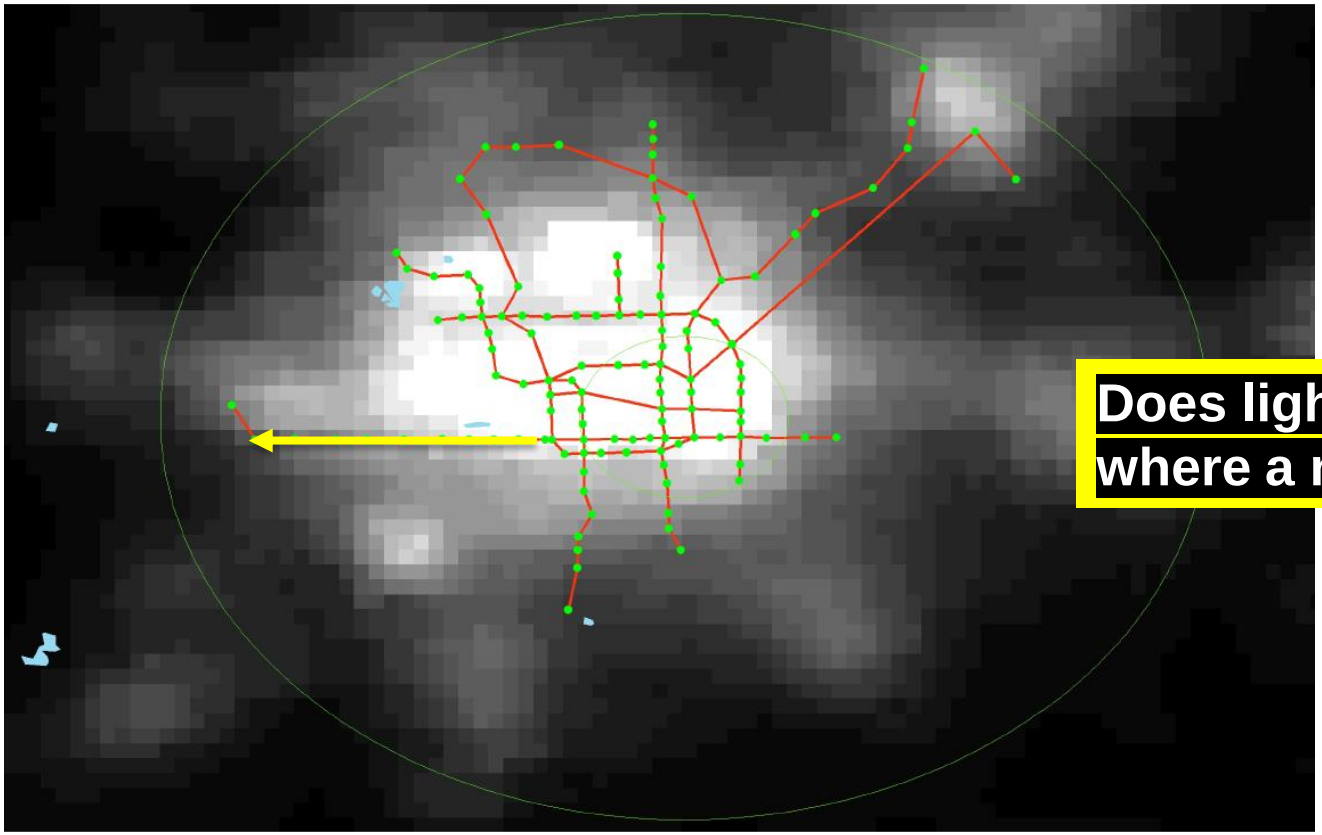
β for travel time *does not* change

Almost three quarters of "decentralization" (change in distance gradient β over time) can be explained by changes in travel time!

IV SUBWAYS AND "LIGHT" DECENTRALIZATION

comparative statics

- **Gonzalez-Navarro and Turner (2016) look at decentralization of „lights at night" in response to subway expansions in 138 cities**



Does light intensity go up where a new line is built?

IV GONZALEZ-NAVARRO AND TURNER (2016)

comparative statics

- **1st step**
  - **Estimate „light“ gradient at five-year intervals *t* for city *c***

$$\ln LIGHTINTENSITY_{ict} = \boldsymbol{\beta_{ct}} \ln DIST_{it} + \varepsilon_{ict}$$

- **2nd-step**
  - **Estimate elasticity of gradient with respect to network size *s***

$$\Delta \ln \widehat{\boldsymbol{\beta}}_{ct} = \gamma \Delta \ln s_{ct} + X_{ct} b + \epsilon_{ct}$$

    - ***X is a vector of controls***
    - **Find that** $\frac{\partial \boldsymbol{\beta}}{\partial \boldsymbol{s}} = 0.06$

Elastictiy of light gradient with respect to network size is 6%
Subways decentralize light emissions

IV URBAN DECENTRALIZATION

comparative statics

- **Cities around the world have been decentralizing in terms of prices (housing rent, land price) and quantities (densities)**
- ***Causal evidence* that part of this trend is due to better transport**
  - ***If* we build radial connections, urban structure *will* decentralize**
  - **Direct implications**
    - **People will move to periphery and travel longer distances**
    - **Demand for housing will increase in periphery**
    - **Prices/values will increase in periphery**

Causal evidence important for predictions. Relevant for planners, developers, investors, etc.

IV COMPARATIVE STATICS: TRANSPORT COST

roadmap

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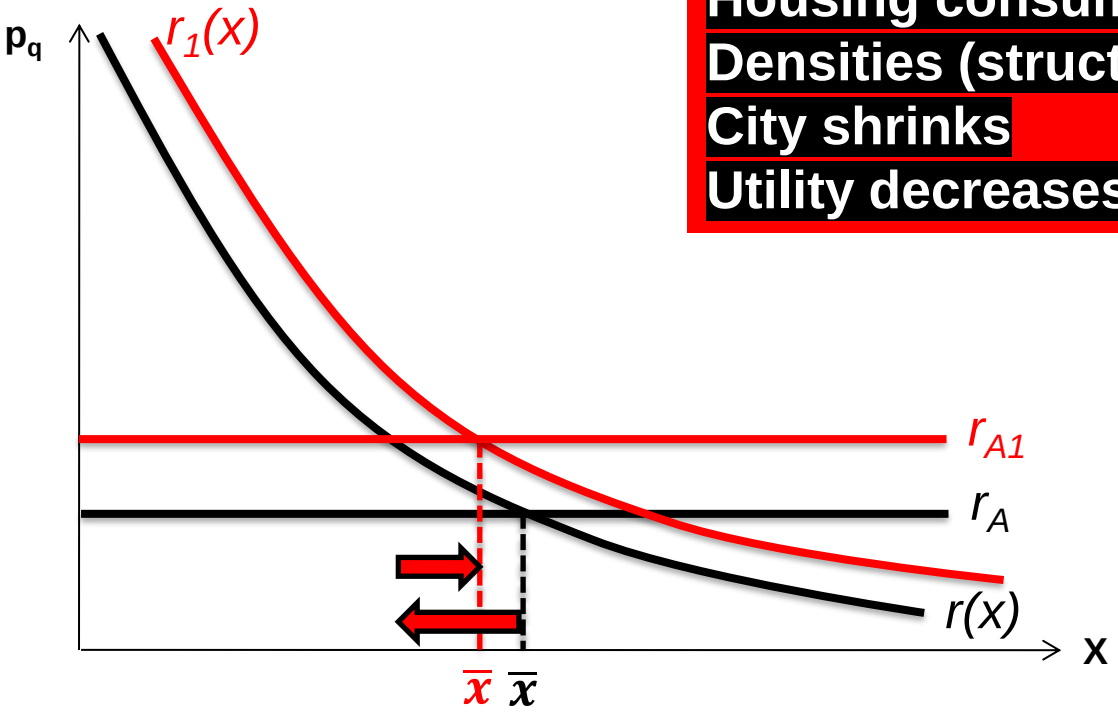
    - **Distinguishing between open-city and closed-city case**

V INCREASE IN AGRICULTURAL RENT

other predictions

- **Increase in r_A creates scarcity at all locations in the city**

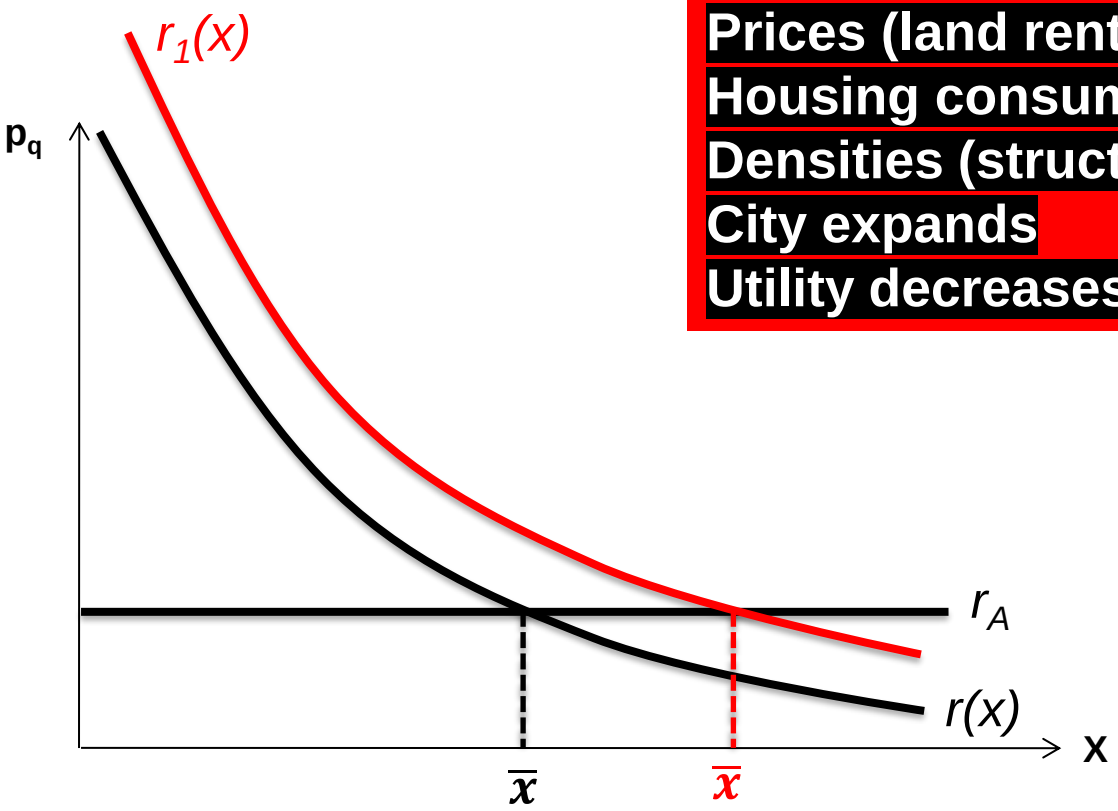
Prices (land rent, housing rent) increase
Housing consumption decreases
Densities (structural, population) increase
City shrinks
Utility decreases (ignoring density benefits)



V INCREASE IN POPULATION

other predictions

- **Increase in *L* increases demand at all locations in the city**



Prices (land rent, housing rent) increase
Housing consumption decreases
Densities (structural, population) increase
City expands
Utility decreases (ignoring density benefits)

IV OPEN-CITY CASE

other predictions

- „Open city“ case: Free between-city migration
  - Population *L* is endogenous
  - Utility *U* is exogenous
- Predictions in open-city case are similar, but require an additional step
  - 1) Hold *L* constant and evaluate the change using closed-city model
    - Same as before in closed-city case
  - 2) Adjust population to cancel the utility change
    - Larger *L* => higher prices and lower housing consumption

Q: What does an increase in income mean for the centre?

IV OPEN-CITY CASE: INCREASE IN INCOME

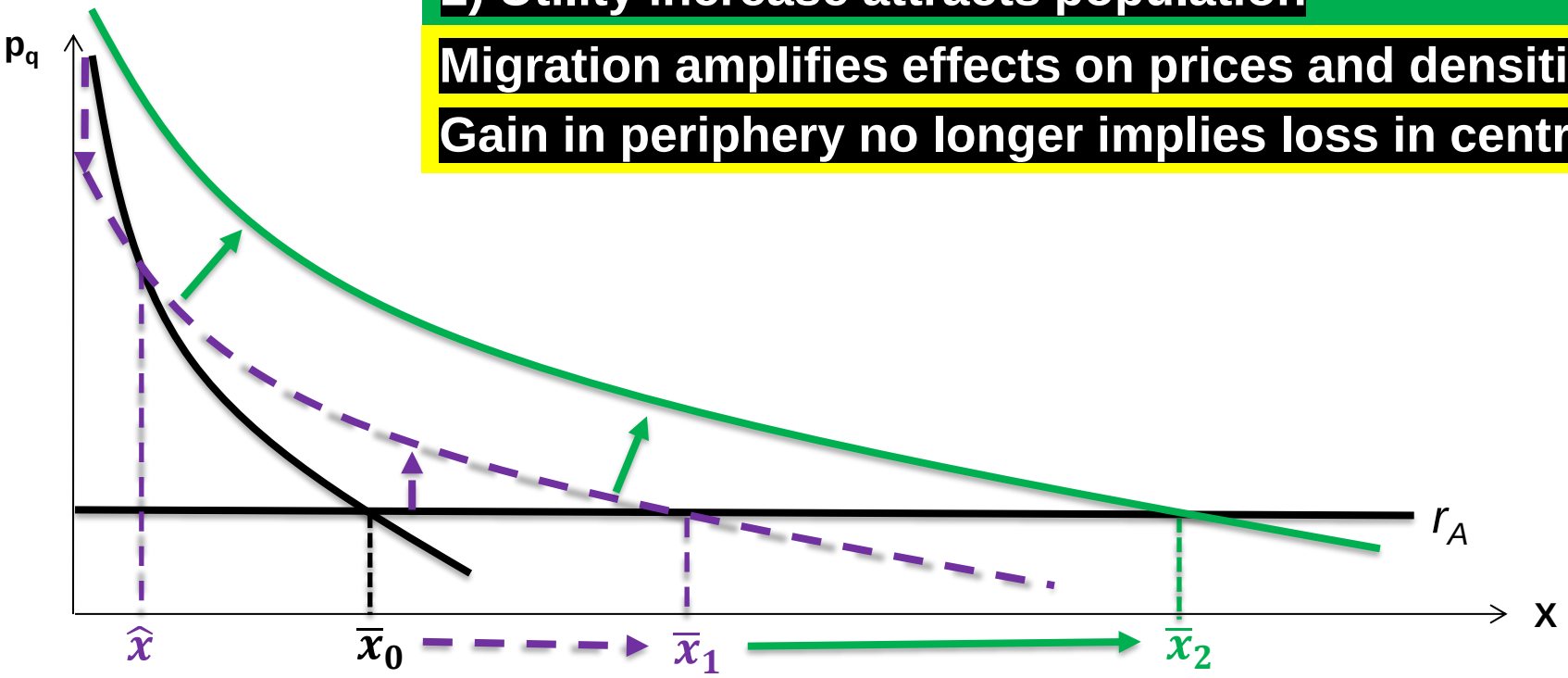
other predictions

1) Bid-rent curves rotates around x^{hat}

2) Utility increase attracts population

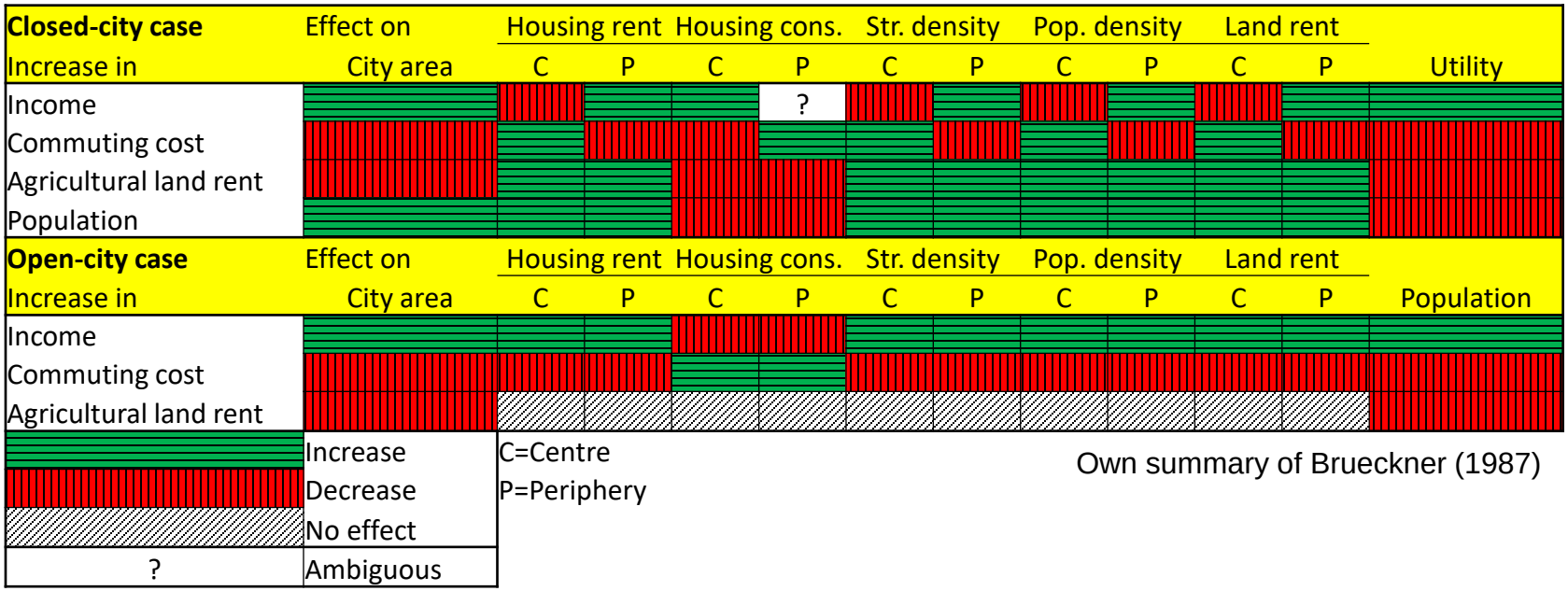
Migration amplifies effects on prices and densities

Gain in periphery no longer implies loss in centre



IV SUMMARY OF PREDICTIONS

comparative statics



Own summary of Brueckner (1987)

Homework: Can you derive these predictions?

IV WHEN TO APPLY OPEN- OR CLOSD-CITY MODEL

other predictions

- **Recall**
  - **„Closed city“ Case: No between-city migration**
  - **„Open city“ case: Free between-city migration**
- **When doing predictions, ask the quesiton:**
  - **Do we expect cross-city migration?**
    - **If all cities change in the same way => no migration**
    - **If just one city changes => migration incentive**

Use closed-city model to predict changes occuring in all cities in country
Use open-city model to predict changes occuring in one city in a country

SUMMARY

Conclusion

- **Monocentric city model provides useful predictions**
  - Higher income leads to decentralization (monetary commuting cost)
  - Better transport leads to decentralization
    - Flatter gradients
    - Larger city areas
  - Higher agricultural rent shrinks cities
- **Some predictions substantiated by causal evidence**
  - City decentralizes with better transport
- **Predictions are useful for planners, developers, investors**
  - Insights into expected effects on demand, prices, densities
- **Next: Firm location**
  - Determinants of firm locations within cities

THANKS

READING

- Core readings:
  - Ahlfeldt, Gabriel M., Wendland, Nicolai (2011), Fifty years of urban accessibility: The impact of the urban railway network on the land gradient in Berlin 1890–1936. Regional Science and Urban Economics. Vol.41(2), pp.77-88
  - Brueckner J., 1987, “The Structure of Urban Equilibria”, Handbook of Regional and Urban Economics, Vol II, 821-846.
  - DiPasquale-Wheaton, chapter 3: The urban land market: Rents and prices
  - McDonald & McMillen, chapter 6 & 7
- Complementary readings and references:
  - Ahlfeldt, McMillen (2018): Tall buildings and land values. Height and construction cost elasticities in Chicago 1870-2010. Review of Economics and Statistics, forthcoming
  - Asubel, J., Marchetti, C., Meyer, P. (1998): Toward green mobility: the evolution of transport. European review 6(2), 137-156.
  - Barr, J., & Cohen, J. P. (2014). The Floor Area Ratio Gradient: New York City, 1890-2009. Regional Science and Urban Economics, 48(0), 110-119
  - Baum-Snow, N. (2006): Did highways cause suburbanization? The Quarterly Journal of Economics 122 (2), 775-805.
  - Gonzalez-Navarro, Marco, Turner, Matthew A. (2016): Subways and Urban Growth: Evidence from Earth. Working paper.
  - Wheaton, W. (1977): American Economic Review, 67(4), pp. 620-631

APPENDIX: URBAN POPULATION

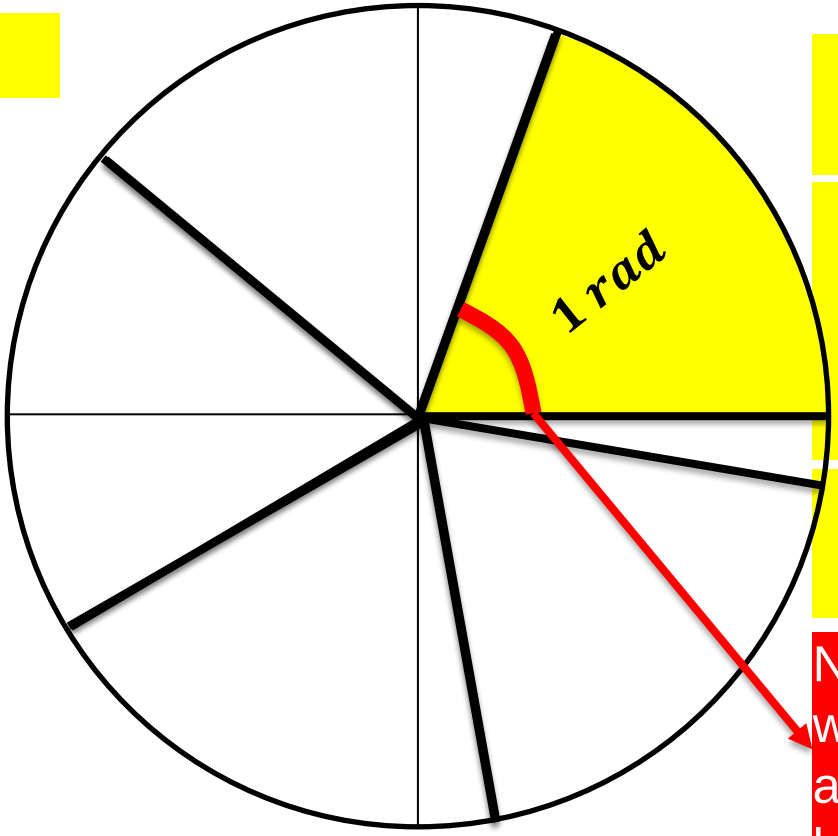
additional restrictions

- **Urban population must fit into the urban area marked by $\bar{x}$**

1 radian ≈ 57.3°

$0 < \boldsymbol{\theta} < 2\pi$ is the number of radians available for housing (rest for e.g. infrastructure)

With $\boldsymbol{\theta} = 2\pi$ all area for a given radius x will be used for housing



$$\int_0^{\bar{x}} \boldsymbol{\theta x D(x,t,y,u)dx} = \boldsymbol{L}$$

At every *x*, population is the product of area and population density

Integrate over all x to get population

Note: With $\theta = 1$, a ring with a width of $dx = 1km$ at $x = 5km$ from the CDB has an area of $A = 1 \times 1km \times 5km = 5km^2$