BUSN 33946 & ECON 35101
International Macroeconomics and Trade

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Autumn 2019, Week 8

The University of Chicago Booth School of Business

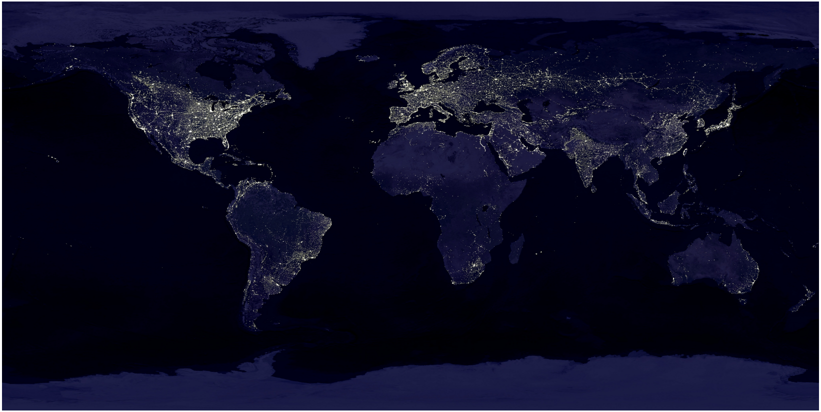
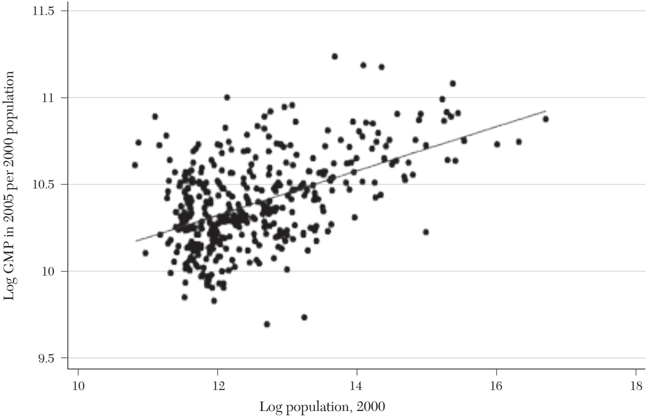


Image from NOAA
(Defense Meteorological Program Operational Linescan System)
Donaldson & Storeygard, "The View from Above:
Applications of Satellite Data in Economics", *JEP*, 2016

Image from NASA

Today: Agglomeration economies

Gross metropolitan product per capita rises with metro population:



Lucas (1988) on local external economies:

> *What can people be paying Manhattan or downtown Chicago rents **for**, if not being near other people?*

Today's agenda

- Spatial equilibrium
- Henderson (1974)
- Behrens, Duranton, Robert-Nicoud (2014) [grab their 2012 slides]
- Ahlfeldt, Redding, Sturm, and Wolf (2015)

Spatial equilibrium

Fundamentally, spatial equilibrium is a no-arbitrage condition.

Glaeser and Gottlieb (*JEL* 2009):

> *The high mobility of labor leads urban economists to assume a spatial equilibrium, where elevated New York incomes do not imply that New Yorkers are better off. Instead, welfare levels are equalized across space and high incomes are offset by negative urban attributes such as high prices or low amenities.*

- The benchmark model of spatial equilibrium is dubbed the "Rosen-Roback" model, due to the theory of equalizing differences (Sherwin Rosen 1974) applied to cities for both workers and firms (Jennifer Roback 1982)
- I'm stealing my exposition of Rosen-Roback model from Owen Zidar's slides

Rosen-Roback framework

Goals

- How does change in amenity s alter local prices (wages and rents)?
- Infer the value of amenities

Markets

- Labor: price w, quantity N
- Land: price r, quantity $L = L^w + L^p$ for workers and production
- Goods: price $p = 1$, quantity X

Agents

- Workers (homogenous, perfectly mobile)
- Firm (perfectly competitive, CRS)

Indifference conditions

- Workers have same indirect utility in all locations
- Firm has zero profit (i.e., unit costs equal 1)

Workers: Preferences and budget constraint

Utility is $u(x, l^c, s)$

- x is consumption of private good
- l^c is consumption of land
- s is amenity

Budget constraint is $x + rl^c - w - I = 0$

- I is non-labor income that is independent of location (e.g., share of national land portfolio)
- w is labor income (note: no hours margin).

Indirect utility is given

$$V(w, r, s) = \max_{x, l^c} u(x, l^c, s) \text{ s.t. } x + rl^c - w - I = 0$$

Let $\lambda = \lambda(w, r, s)$ be the marginal utility of a dollar of income, then

$$V_w = \lambda > 0 \qquad V_r = -\lambda l^c < 0$$
$$\Rightarrow V_r = -V_w l^c$$

Example: Cobb-Douglas preferences

Utility is Cobb Douglas over goods and land with an amenity shifter:

$$u(x, l^c, s) = s^{\theta_W} x^{\gamma} (l^c)^{1-\gamma}$$

- Then $x = \gamma \left(\frac{w+I}{1}\right)$ and $l^c = (1-\gamma)\left(\frac{w+I}{r}\right)$
- Let $\Gamma \equiv \gamma^{\gamma}(1-\gamma)^{(1-\gamma)}$ so that indirect utility is

$$V(w, r, s) = \underbrace{\Gamma}_{\text{constant}} \underbrace{s^{\theta_W}}_{\text{amenities}} \underbrace{1^{-\gamma} r^{-(1-\gamma)}}_{\text{prices}} \underbrace{(w+I)}_{\text{income}}$$

- MU of income is $\lambda(w, r, s)$

$$V_w = \lambda = \Gamma s^{\theta_W} r^{-(1-\gamma)}$$

$$V_r = -\lambda l^c = -\Gamma s^{\theta_W} r^{-(1-\gamma)} \underbrace{(1-\gamma)\left(\frac{w+I}{r}\right)}_{l^c}$$

$$\Rightarrow V_r = -V_w l^c$$

Firms: Unit cost function

CRS production with cost function $C(X, w, r, s)$

- X is output
- Unit cost $c(w, r, s) = \frac{C(X,w,r,s)}{X}$
- L^p is total amount of land used by firms
- N is total employment

From Sheppard's Lemma, we have

$$c_w = N/X > 0$$
$$c_r = L^p/X > 0$$

Example: Cobb-Douglas production

Suppose the production function is

$$X = f(N, L^p) = s^{\theta_F} N^{\alpha} L^{1-\alpha}$$

Let $\mathcal{A} \equiv \alpha^{-\alpha}(1-\alpha)^{-(1-\alpha)}$. Then the cost function is:

$$C(X, w, r, s) = X(s^{\theta_F})^{-1} w^{\alpha} r^{1-\alpha} \mathcal{A} \Rightarrow$$
$$c(w, r, s) = (s^{\theta_F})^{-1} w^{\alpha} r^{1-\alpha} \mathcal{A}$$

Then

$$C_w(X, w, r, s) = \alpha \frac{\left(X(s^{\theta_F})^{-1} w^{\alpha} r^{1-\alpha} \mathcal{A}\right)}{w} = N$$
$$C_r(X, w, r, s) = (1-\alpha) \frac{\left(X(s^{\theta_F})^{-1} w^{\alpha} r^{1-\alpha} \mathcal{A}\right)}{r} = L^p$$

Dividing both sides by X gives:

$$c_w = N/X > 0$$
$$c_r = L^p/X > 0$$

Model recap

Workers parameters: s, θ_W, γ, I

- s is level of amenities
- θ_W governs importance of amenities for utility
- γ governs importance of goods for utility
- $1-\gamma$ governs importance of land for utility
- I is non-labor income

Firm Parameters: s, θ_F, α

- s is level of amenities
- θ_F governs importance of amenities for productivity
- α is output elasticity of labor
- $1-\alpha$ is output elasticity of land

Endogenous outcomes:

- Labor: price w, quantity N
- Land: price r, quantities L^w, L^p for workers and production
- Goods: price $p=1$, quantity X

Equilibrium concept: Two key indifference conditions

In equilibrium, workers and firms are indifferent across cities with different levels of s and endogenously varying wages $w(s)$ and rents $r(s)$:

$$c(w(s), r(s), s) = 1 \tag{1}$$

$$V(w(s), r(s), s) = V^0 \tag{2}$$

where V^0 is the equilibrium level of indirect utility.

Specifically, in our example:
Given $s, \theta_W, \theta_F, \gamma, I, \alpha$, equilibrium is defined by local prices and quantities $\{w, r, N, L^w, L^p, X\}$ such that (1) and (2) hold and land markets clear.

N.B. We will mainly be focusing on prices: $w(s)$ and $r(s)$.

Solving for effect of amenity changes on prices

- Differentiate (1) and (2) with respect to s and rearrange, we have:

$$\begin{bmatrix} c_w & c_r \\ V_w & V_r \end{bmatrix} \begin{bmatrix} w'(s) \\ r'(s) \end{bmatrix} = \begin{bmatrix} -c_s \\ -V_s \end{bmatrix}$$

- Solving for $w'(s), r'(s)$, we have

$$w'(s) = \frac{V_r c_s - c_r V_s}{c_r V w - c_w V_r}$$
$$r'(s) = \frac{V_s c_w - c_s V_w}{c_r V w - c_w V_r}$$

- Note we can rewrite

$$c_r V w - c_w V_r = \lambda L^p / X + \lambda l^c N / X = \lambda L / X = V_w L / X$$

Aside: example values for matrix elements

$$
\begin{aligned}
c_w &= \alpha \frac{(s^{\theta_F})^{-1} w^{\alpha} r^{1-\alpha} \mathcal{A}}{w} \\
c_r &= (1-\alpha) \frac{(s^{\theta_F})^{-1} w^{\alpha} r^{1-\alpha} \mathcal{A}}{r} \\
c_s &= \theta_F \frac{(s^{\theta_F})^{-1} w^{\alpha} r^{1-\alpha} \mathcal{A}}{s} \\
V_w &= s^{\theta_W} 1^{-\gamma} r^{-(1-\gamma)} \Gamma \\
V_r &= -s^{\theta_W} 1^{-\gamma} r^{-(1-\gamma)} \Gamma (1-\gamma) \left(\frac{w+I}{r} \right) \\
V_s &= \theta_W \frac{\left(s^{\theta_W} 1^{-\gamma} r^{-(1-\gamma)} \Gamma \left(w+I \right) \right)}{s}
\end{aligned}
$$

Effect of amenity changes on prices

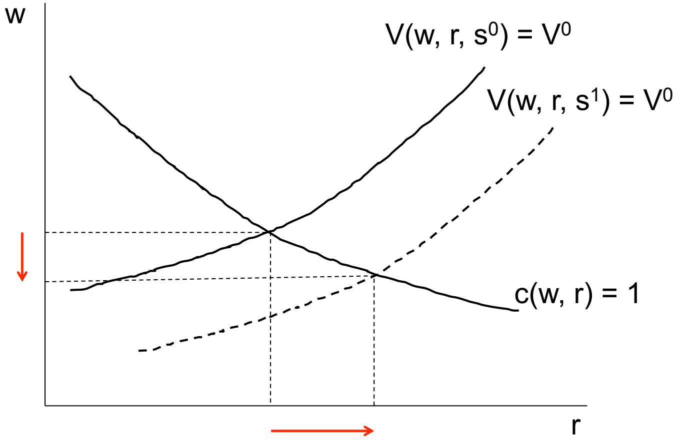
- Price changes

$$w'(s) = \frac{(V_r c_s - c_r V_s)X}{\lambda L}$$
$$r'(s) = \frac{(V_s c_w - c_s V_w)X}{\lambda L}$$

- Special cases of interest:
  1. Amenity only valued by consumers: $\theta_F = 0 \Rightarrow c_s = 0$
  2. Amenity only has productivity effect: $\theta_W = 0 \Rightarrow V_s = 0$
  3. Firms use no land $1 - \gamma = 0$ and amenity is non-productive $\theta_F = 0$: $c(w(s)) = 1$, $c_r = c_s = 0$

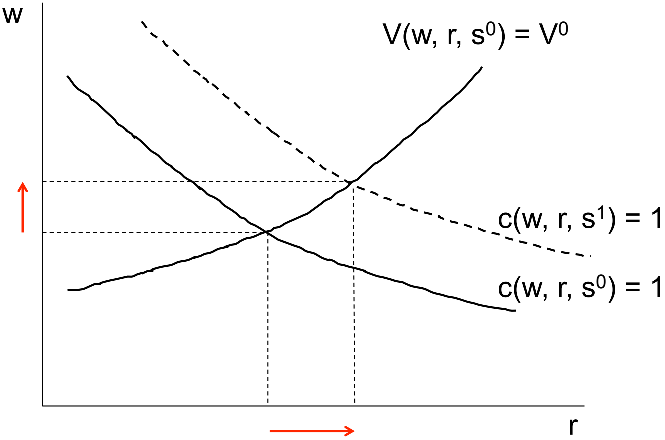
1. Amenity only valued by consumers: $\theta_F = 0 \Rightarrow c_s = 0$

- When $c_s = 0$, higher $s \Rightarrow$ higher r, lower w
- Workers are willing to pay more in land rents and receive less in wages to have access to higher levels of amenities



2. Amenity only valued by firms: $\theta_W = 0 \Rightarrow V_s = 0$

- When $V_s = 0$, higher $s \Rightarrow$ higher r and higher l
- Firms are willing to pay more in land rents and wages to access higher productivity due to amenities



3. Firms don't use land nor value amenity

- Firms don't use land ($\gamma = 1$) nor value amenity ($\theta_F = 0$)
- Only production input is labor and firms are indifferent across locations, so wages must be the same across cities: $c(w(s)) = 1$

- Since $c_r = c_s = 0$,

$$w'(s) = 0$$

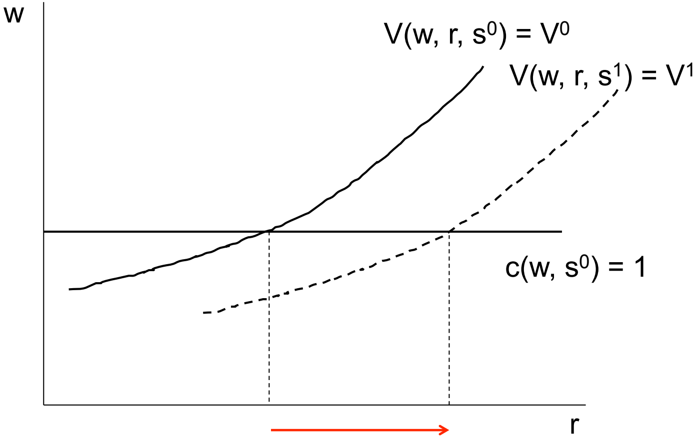
$$r'(s) = \frac{V_s c_w}{-c_w V_r} = \frac{V_s}{l^c V_w}, \text{ since } V_r = -l^c V_w$$

- So the rise in total cost of land for a worker living in a city with higher s is

$$l^c r'(s) = \frac{V_s}{V_w}$$

3. Firms don't use land nor value amenity

- $\frac{V_s}{V_w}$ = marginal WTP for a change in s so the marginal value of a change in the amenity is "fully capitalized" in rents



$\frac{V_s}{V_w} = \theta_W \frac{(w+I)}{s}$ is increasing in income, decreasing in level of amenities

Evidence of agglomeration economies

People are concentrated. Are industries concentrated? Yes.

- Ellison and Glaeser (1997) "dartboard approach"
- Duranton and Overman (2005) for continuous space

Identify agglomeration channels empirically

- Estimate directly (faces peer-effects problem)
- Infer from observed spatial equilibrium
- Test for multiple equilibria

References to know

- Greenstone, Hornbeck, and Moretti (2010) use "million-dollar plants" as natural experiment to estimate agglomeration economies
- Combes and Gobillon - "The Empirics of Agglomeration Economies" (*Handbook* 2015)
- Bleakley and Lin - Portage and Path Dependence (QJE 2012)

Bleakley and Lin - Portage and Path Dependence

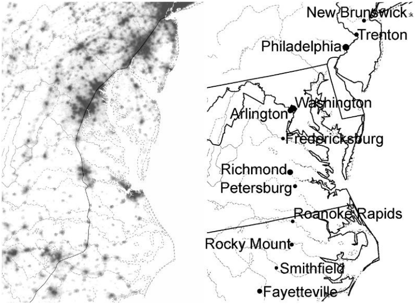


FIGURE IV

Fall-Line Cities from North Carolina to New Jersey

The map in the left panel shows the contemporary distribution of economic activity across the southeastern United States measured by the 2003 nighttime lights layer from NationalAtlas.gov. The nighttime lights are used to present a nearly continuous measure of present-day economic activity at a high spatial frequency. The fall line (solid) is digitized from *Physical Divisions of the United States*, produced by the U.S. Geological Survey. Major rivers (dashed gray) are from NationalAtlas.gov, based on data produced by the U.S. Geological Survey. Contemporary fall-line cities are labeled in the right panel.

Table 1: Proximity to Historical Portage Site and Contemporary Population Density

	(1)	(2)	(3)
	Basic	Other spatial controls	
Specifications:		State fixed effects	Distance from various features
Explanatory variables:			
Panel A: Census Tracts, 2000, N = 21452			
Dummy for proximity	1.113	1.009	1.118
to portage site	(0.340)***	(0.321)***	(0.243)***
Distance to portage	−0.617	−0.653	−0.721
site, natural logs	(0.134)***	(0.128)***	(0.118)***
Panel B: Nighttime Lights, 1996–97, N = 65000			
Dummy for proximity	0.504	0.445	0.490
to portage site	(0.144)***	(0.127)***	(0.161)***
Distance to portage	−0.188	−0.159	−0.151
site, natural logs	(0.065)***	(0.065)**	(0.090)

TABLE II

UPSTREAM WATERSHED AND CONTEMPORARY POPULATION DENSITY

	(1)	(2)	(3)	(4)	(5)
	Basic	Other spatial controls		Water power	
Specifications:		State fixed effects	Distance from various features		
Explanatory variables:					
Panel A: Census Tracts, 2000, N = 21452					
Portage site times	0.467	0.467	0.500	0.496	0.452
upstream watershed	(0.175)**	(0.164)***	(0.114)***	(0.173)***	(0.177)**
Binary indicator	1.096	1.000	1.111	1.099	1.056
for portage site	(0.348)***	(0.326)***	(0.219)***	(0.350)***	(0.364)***
Portage site times				−1.812	
horsepower/100k				(1.235)	
Portage site times					0.110
I(horsepower > 2000)					(0.311)

(Homogeneous) agglomeration: Henderson (1974)

"The Sizes and Types of Cities" addresses basic, fundamental questions about a system of cities in general equilibrium

- Why do cities exist?
- Are cities too large or too small?
- Why do cities of different sizes exist?

(Homogeneous) agglomeration: Henderson (1974)

"The Sizes and Types of Cities" addresses basic, fundamental questions about a system of cities in general equilibrium

- Why do cities exist? "because there are technological economies of scale in production or consumption"
- Are cities too large or too small? a stability argument says that cities tend to be too large
- Why do cities of different sizes exist? "because cities of different types specialize in the production of different traded goods"

Henderson (1974) environment

- Factors: land L, labor N, capital K
- Tradables production (external economies a la Chipman)

$$X_1^{1-\rho_1} = L_1^{\alpha_1} K_1^{\beta_1} N_1^{\gamma_1} \qquad \alpha_1 + \beta_1 + \gamma_1 = 1, \rho_1 \in (0,1)$$

- Housing production

$$X_3 = L_3^{\alpha_3} K_3^{\beta_3} N_3^{\gamma_3} \qquad \alpha_3 + \beta_3 + \gamma_3 = 1,$$

- Land sites produced by labor

$$L = N_0^{1/(1-z)} \qquad z < 0, z'(N) < 0$$

- Clear factor markets with prices p_N, p_K, p_L

$$N_0 + N_1 + N_3 = N, \quad K_1 + K_3 = K, \quad L_1 + L_3 = L$$

- Cobb-Douglas preferences ($U = x_1^a x_2^b x_3^c$) with income y, import of good 2, and prices q deliver indirect utility

$$U \propto y q_1^{-a} q_2^{-b} q_3^{-c}$$

Capitalists and workers

Different (stark) assumptions about capital ownership:

- each laborer owns equal capital stock (Assumption A)
- capital owners live outside of cities (Assumption B)

Utility components for labor income and capital income

$$U_N \propto p_N q_1^{-a} q_2^{-b} q_3^{-c}$$
$$U_K \propto \bar{p}_K \frac{\bar{K}}{\bar{N}} q_1^{-a} q_2^{-b} q_3^{-c}$$

Solving for optimal and equilibrium city sizes

- Optimum: maximize $U_N + U_K$, given the determination of U_N, U_K, and p_K through simultaneous location and investment of labor and capital in cities in the economy
- Equilibrium: atomistic choices of capital owners, firms, and laborers

Utility and factor prices

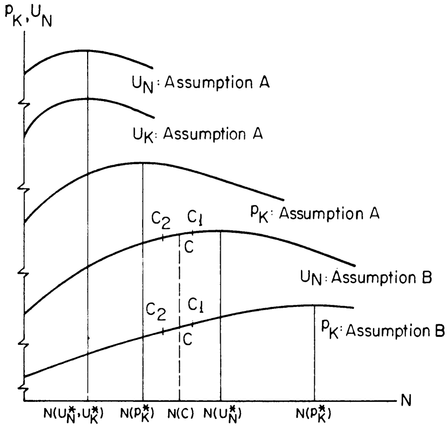


FIGURE 1. UTILITY AND CAPITAL RENTAL PATHS UNDER ASSUMPTIONS A AND B

- $\alpha_1 > \rho_1$ (site intensity vs IRS) is sufficient for both p_K and U_N to exhibit interior maxima
- p_K curve has peak to right of U_N and U_K peak because U_K is p_K deflated by q_3^{-c}
- Assumption B curves peak to right of Assumption A curves because capitalist income doesn't bid up housing prices
- Why isn't "two identical cities at point C" stable?

Optimal city size

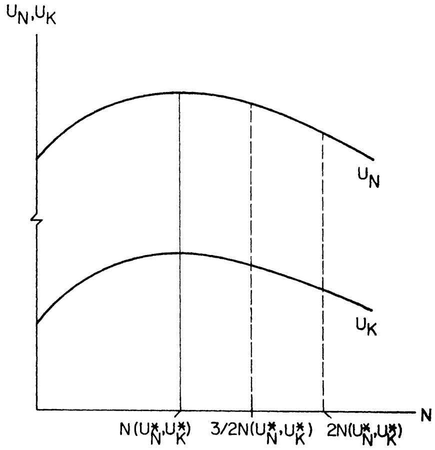


FIGURE 2. OPTIMUM CITY SIZE: ASSUMPTION A

- For Assumption A, maximize the vertical sum of U_N and U_K
- Planner has total population N and faces integer constraint
- Start second city when N is twice $N(U_N^*, U_K^*)$

  (Starting second city earlier is not a stable optimum)
- Figure 3 is more complicated due to Assumption B and the worker vs capitalist disagreement on optimal city size

Equilibrium city size

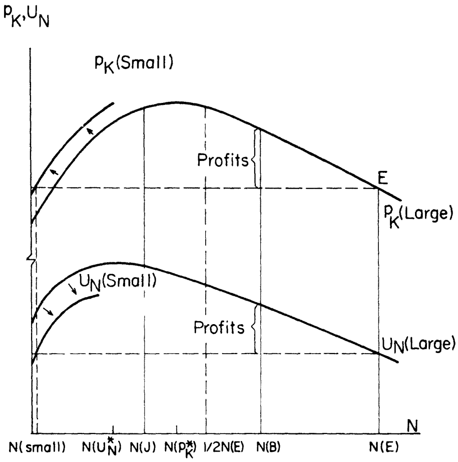


FIGURE 4. EQUILIBRIUM CITY SIZE

- Why is N(small) a bit of a fudge?
- Atomistic equilibrium with particular dynamics is at $N(E)$, way past both peaks
- City corporation attains optimal city sizes under Assumption B
- City corporation achieves $N(J)$ under Assumption A

BDRN (2014): "there is a coordination failure in city formation so that any population size between optimal city size and grossly oversized cities – leaving their residents with zero consumption – can occur in equilibrium."

Henderson (1974) on heterogeneous cities

- "Our second type of city specializes in the production of another type of traded good, say, X_2."
- "Different types of cities differ in size because production parameters, in particular α_i and ρ_i, differ between the traded goods of each type of city."
- "Although utility levels will be equalized between cities, wage rates and housing prices will vary with city type and size."

Behrens, Duranton, Robert-Nicoud (2014)

Go to their slidedeck, circa 2012

Ahlfeldt, Redding, Sturm, Wolf (Ecma, 2015)

ARSW is often referred to as "the Berlin Wall paper":

- Develop a quantitative model of the city to identify intra-city agglomeration and dispersion forces
- Estimate model using data for thousands of city blocks in Berlin on land prices, workplace employment, and employment by residential location in 1936, 1986 and 2006
- Use the division of Berlin in the aftermath of the Second World War and its reunification in 1989 as a source of exogenous variation in the surrounding concentration of economic activity

Won the 2018 Frisch Medal for best applied paper in *Econometrica*: "The paper provides an outstanding example of how to credibly and transparently use a quasi-experimental approach to structurally estimate model parameters that can serve as critical inputs for counterfactual policy analyses."

Thanks to Felix for sharing TEX of the following slides.

Dividing Berlin

- A protocol signed during the Second World War organized Germany into American, British, French, and Soviet occupation zones
- Although 200km inside the Soviet zone, Berlin was to be jointly occupied and organized into four occupation red:
  - Boundaries followed pre-war district boundaries, with the same East-West orientation as the occupation zones, and created sectors of roughly equal pre-war population (prior to French sector which was created from part of the British sector)
  - Protocol envisioned a joint city administration ("Kommandatura")
- Following the onset of the Cold War
  - East and West Germany founded as separate states and separate city governments created in East and West Berlin in 1949
  - The adoption of Soviet-style policies of command and control in East Berlin limited economic interactions with West Berlin
  - To stop civilians leaving for West Germany, the East German authorities constructed the Berlin Wall in 1961

ARSW model: Overview

- Reservation level of utility ($\bar{U}$) for living outside the city.
- The city consists of a set of discrete blocks indexed by i
- Single, freely traded (numeraire) final good
- Floor space can be used for residential or commercial use
- Workers choose block of residence, block of employment, and consumption of the final good
- Firms choose a block of production and inputs of labor and floor space

ARSW model: Workers

- Utility for worker ω residing in block i and working in block j:

$$U_{ij\omega} = \frac{B_i z_{ij\omega}}{d_{ij}} \left(\frac{c_{ij}}{\beta}\right)^{\beta} \left(\frac{\ell_{ij}}{1-\beta}\right)^{1-\beta}, \qquad 0 < \beta < 1,$$

  - Consumption of the final good (c_{ij}), numeraire ($p_i = 1$)
  - Residential floor space (ℓ_{ij}), price Q_i
  - Residential amenity B_i
  - Commuting costs d_{ij}
  - Idiosyncratic shock $z_{ij\omega}$
  - Wage w_j
- Indirect utility

$$U_{ij\omega} = \frac{z_{ij\omega} B_i w_j Q_i^{\beta-1}}{d_{ij}},$$

- The idiosyncratic shock to worker productivity is drawn from a Fréchet distribution:

$$F(z_{ij\omega}) = e^{-T_i E_j z_{ij\omega}^{-\epsilon}}, \qquad T_i, E_j > 0,\ \epsilon > 1,$$

ARSW model: Commuting decisions

- Probability worker chooses to live in block i and work in block j is:

$$\pi_{ij} = \frac{T_i E_j \left(d_{ij} Q_i^{1-\beta}\right)^{-\epsilon} \left(B_i w_j\right)^{\epsilon}}{\sum_{r=1}^{S} \sum_{s=1}^{S} T_r E_s \left(d_{rs} Q_r^{1-\beta}\right)^{-\epsilon} \left(B_r w_s\right)^{\epsilon}} \equiv \frac{\Phi_{ij}}{\Phi}.$$

- Residential and workplace choice probabilities

$$\pi_{Ri} = \sum_{j=1}^{S} \pi_{ij} = \frac{\sum_{j=1}^{S} \Phi_{ij}}{\Phi}, \qquad \pi_{Mj} = \sum_{i=1}^{S} \pi_{ij} = \frac{\sum_{i=1}^{S} \Phi_{ij}}{\Phi}.$$

- Conditional on living in block i, the probability that a worker commutes to block j follows a gravity equation:

$$\pi_{ij|i} = \frac{E_j \left(w_j / d_{ij}\right)^{\epsilon}}{\sum_{s=1}^{S} E_s \left(w_s / d_{is}\right)^{\epsilon}},$$

ARSW model: Commuting

- Employment in block j equals the sum across all blocks i of people living in residence times the probability of commuting from i to j:

$$H_{Mj} = \sum_{i=1}^{S} \frac{E_j \left(w_j/d_{ij}\right)^{\epsilon}}{\sum_{s=1}^{S} E_s \left(w_s/d_{is}\right)^{\epsilon}} H_{Ri}, \qquad d_{ij} = e^{\kappa \tau_{ij}}.$$

- This equation be useful to determine equilibrium wages.

ARSW model: Consumers

- Consumers decide before idiosyncratic shocks $z_{ij\omega}$ are realized whether to move to the city or not.
- Population mobility implies that expected utility equals reservation utility level:

$$\mathbb{E}\left[U\right] = \gamma \left[\sum_{r=1}^{S} \sum_{s=1}^{S} T_r E_s \left(d_{rs} Q_r^{1-\beta}\right)^{-\epsilon} \left(B_r w_s\right)^{\epsilon}\right]^{1/\epsilon} = \bar{U},$$

- Residential amenities are influenced by both fundamentals (b_i) and spillovers (Ω_i)

$$B_i = b_i \Omega_i^{\eta}, \qquad \Omega_i \equiv \left[\sum_{s=1}^{S} e^{-\rho\tau_{is}} \left(\frac{H_{Rs}}{K_s}\right)\right].$$

ARSW model: Production

- A single final good (numeraire) is produced under conditions of perfect competition, constant returns to scale and zero trade costs with a larger economy:

$$y_j = A_j \left(H_{Mj}\right)^{\alpha} \left(L_{Mj}\right)^{1-\alpha}, \qquad 0 < \alpha < 1,$$

- H_{Mj} is workplace employment
- L_{Mj} is measure of floor space used commercially
- Productivity (A_j) depends on fundamentals (a_j) and spillovers (Υ_j):

$$A_j = a_j \Upsilon_j^{\lambda}, \qquad \Upsilon_j \equiv \left[\sum_{s=1}^{S} e^{-\delta \tau_{is}} \left(\frac{H_{Ms}}{K_s}\right)\right],$$

- δ is the rate of decay of spillovers
- λ captures the relative importance of spillovers

ARSW model: Land prices

- The share of floor space used commerically:

$$\theta_i = 1 \quad \text{if} \qquad q_i > \xi_i Q_i,$$

$$\theta_i \in [0,1] \quad \text{if} \qquad q_i = \xi_i Q_i,$$

$$\theta_i = 0 \quad \text{if} \qquad q_i < \xi_i Q_i.$$

- $\xi_i \geq 1$ represents 1 plus the tax equivalent of land use regulations
- Assume observed land price is maximum of commerical and residential price: $\mathbb{Q}_i = \max\{q_i, Q_i\}$

ARSW model: Production

- Firms choose a block of production, effective employment and commercial land use to maximize profits taking as given goods and factor prices, productivity and the locations of other firms/workers
- Zero profits imply for the price of commercial land q_j:

$$q_j = (1-\alpha)\left(\frac{\alpha}{w_j}\right)^{\frac{\alpha}{1-\alpha}} A_j^{\frac{1}{1-\alpha}}.$$

ARSW model: Land Market Clearing

- Utility max implies demand for residential floor space:

$$(1-\theta_i)L_i = \frac{(1-\beta)\mathbb{E}(w \mid i)}{Q_i} H_{Ri}.$$

- Profit max implies demand for commercial floor space:

$$\theta_i L_i = H_{Mi}\left(\frac{(1-\alpha)A_i}{q_i}\right)^{\frac{1}{\alpha}}.$$

- Floor space L supplied by a competitive construction sector using geographic land K and capital M as inputs

$$L_i = \varphi_i K_i^{1-\mu}, \qquad \varphi_i = M_i^{\mu},$$

- Density of development (φ_i) from land market clearing:

$$\varphi_i = \frac{L_i}{K_i^{1-\mu}} = \frac{(1-\theta_i)L_i + \theta_i L_i}{K_i^{1-\mu}}$$

Equilibrium with exogenous loc. charact.

- **Proposition 1:** Given the model's parameters $[\alpha, \beta, \mu, \epsilon, \kappa]$, the reservation utility $\bar{U}$, and vectors of exogenous location characteristics $[T, E, A, B, \phi, K, \xi, \tau]$, there exists a unique general equilibrium vector $[\pi_M, \pi_R, H, Q, q, w, \theta]$, where H denotes total city population.
- These seven components are determined by the system of seven equations: commercial land market clearing, residential land market clearing, zero profits, no arbitrage between alternative uses of land, residential choice probability π_{Ri}, workplace choice probability π_{Mi}, and indifference with reservation utility.

Overview of remainder of paper

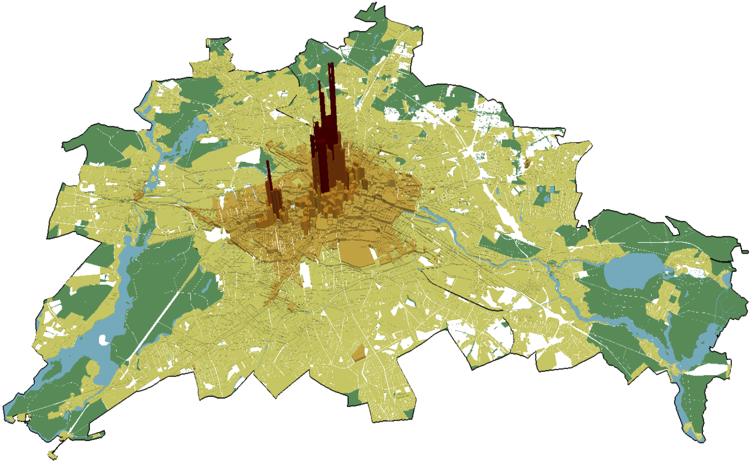
- Relate land prices to distance to pre-war CBD
- Estimate the model without any agglomeration effects. In counterfactuals, this model "is unable to account quantitatively for the observed impact of division and reunification on the pattern of economic activity within West Berlin."
- Next the authors present a reduced-form empirical exercise on land price and population changes
- Then the authors estimate simple version of the model without agglomeration effects. They show that when doing counterfactuals (i.e. establishing / removing a wall, with it's effects on where you can live, work) the counterfactual predictions are different from the data
- Estimate model with local production and residential amenity externalities. These are interesting in their own right and improve model fit (they also create possibility of multiple equilibria, which must be handled carefully)

Data

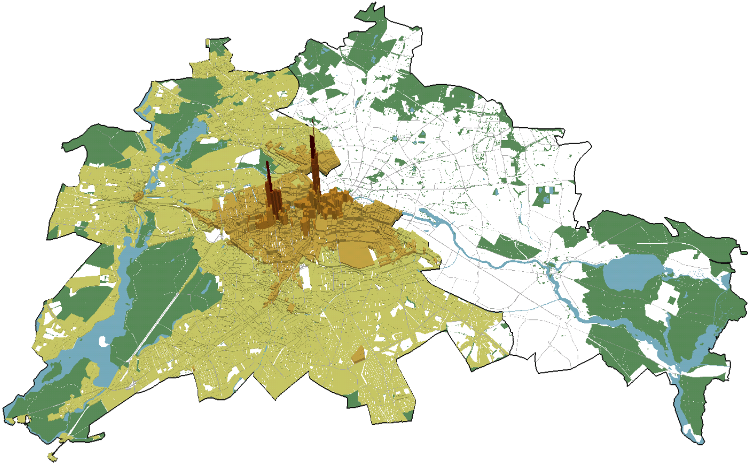
- Data on land prices, workplace employment, residence employment and bilateral travel times
- Data for Greater Berlin in 1936 and 2006
- Data for West Berlin in 1986
- Data at the following levels of spatial aggregation:
  - Pre-war districts (“Bezirke”), 20 in Greater Berlin, 12 in West Berlin
  - Statistical areas (“Gebiete”), around 90 in West Berlin
  - Statistical blocks, around 9,000 in West Berlin
- Land prices: official assessed land value of a representative undeveloped property or the fair market value of a developed property if it were not developed
- Geographical Information Systems (GIS) data on:
  - land area, land use, building density, proximity to U-Bahn (underground) and S-Bahn (suburban) stations, schools, parks, lakes, canals and rivers, Second World War destruction, location of government buildings and urban regeneration programs

Land prices in Berlin in 1936

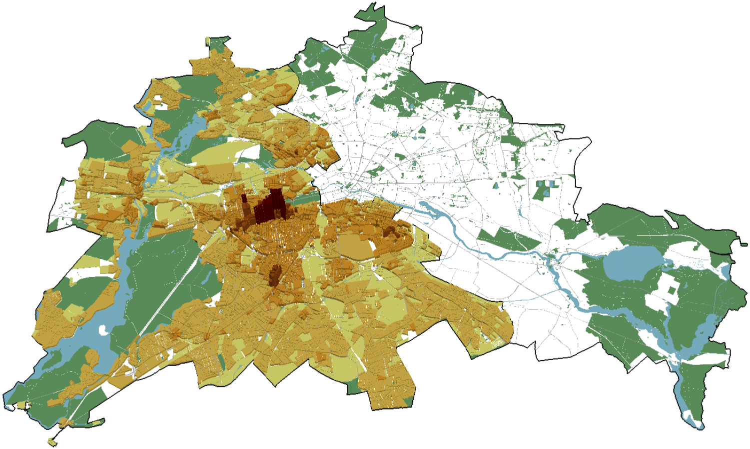
Land prices are normalized to have a mean of 1 in each year.



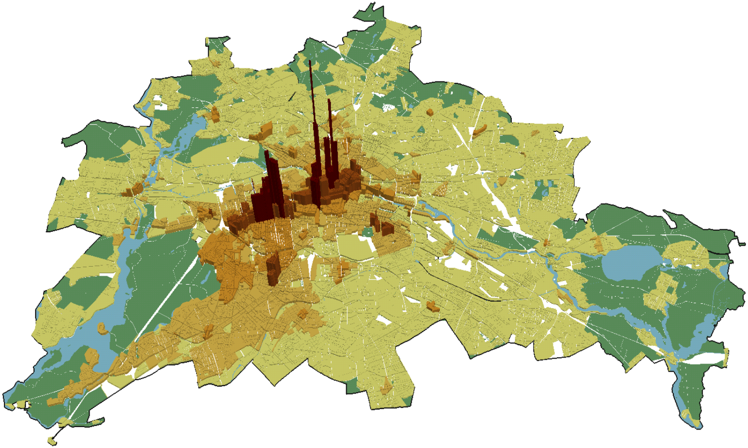
Land prices in West Berlin in 1936



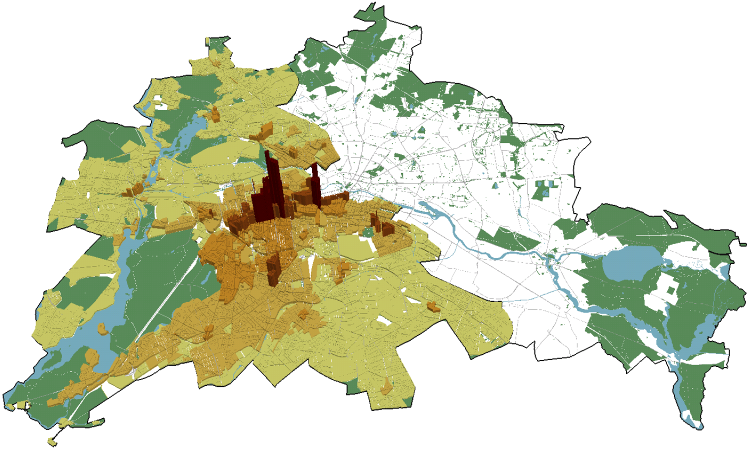
Land prices in West Berlin in 1986



Land prices in Berlin in 2006



Land prices in West Berlin in 2006



Diff-in-diffs specification

- Estimate difference in difference specification for division and reunification separately (for areas in West Berlin):

$$\Delta \ln Q_i = \psi + \sum_{k=1}^{K} \mathbf{1}_{ik} \beta_k + \ln X_i \zeta + \chi_i,$$

- $\mathbf{1}_{ik}$ is a $(0, 1)$ dummy which equals one if block i lies within distance grid cell k from the pre-war CBD and zero otherwise
- Observable block characteristics (X_i): Land area, land use, distance to nearest U-Bahn station, S-Bahn station, school, lake, river or canal, and park, war destruction, government buildings and urban regeneration programs

Division and Pre-War CBD

Diff-in-diffs West Berlin 1936-86

	(1) Δ ln Q	(2) Δ ln Q	(3) Δ ln Q	(4) Δ ln Q	(5) Δ ln Q	(6) Δ ln EmpR	(7) Δ ln EmpR	(8) Δ ln EmpW	(9) Δ ln EmpW
CBD 1	-0.800***	-0.567***	-0.524***	-0.503***	-0.565***	-1.332***	-0.975***	-0.691*	-0.639*
	(0.071)	(0.071)	(0.071)	(0.071)	(0.077)	(0.383)	(0.311)	(0.408)	(0.338)
CBD 2	-0.655***	-0.422***	-0.392***	-0.360***	-0.400***	-0.715**	-0.361	-1.253***	-1.367***
	(0.042)	(0.047)	(0.046)	(0.043)	(0.050)	(0.299)	(0.280)	(0.293)	(0.243)
CBD 3	-0.543***	-0.306***	-0.294***	-0.258***	-0.247***	-0.911***	-0.460**	-0.341	-0.471**
	(0.034)	(0.039)	(0.037)	(0.032)	(0.034)	(0.239)	(0.206)	(0.241)	(0.190)
CBD 4	-0.436***	-0.207***	-0.193***	-0.166***	-0.176***	-0.356**	-0.259	-0.512***	-0.521***
	(0.022)	(0.033)	(0.033)	(0.030)	(0.026)	(0.145)	(0.159)	(0.199)	(0.169)
CBD 5	-0.353***	-0.139***	-0.123***	-0.098***	-0.100***	-0.301***	-0.143	-0.436***	-0.340***
	(0.016)	(0.024)	(0.024)	(0.023)	(0.020)	(0.110)	(0.113)	(0.151)	(0.124)
CBD 6	-0.291***	-0.125***	-0.094***	-0.077***	-0.090***	-0.360***	-0.135	-0.280**	-0.142
	(0.018)	(0.019)	(0.017)	(0.016)	(0.016)	(0.100)	(0.089)	(0.130)	(0.116)
Inner Boundary 1-6			Yes	Yes	Yes		Yes		Yes
Outer Boundary 1-6			Yes	Yes	Yes		Yes		Yes
Kudamm 1-6				Yes	Yes		Yes		Yes
Block Characteristics					Yes		Yes		Yes
District Fixed Effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6260	6260	6260	6260	6260	5978	5978	2844	2844
R-squared	0.26	0.51	0.63	0.65	0.71	0.19	0.43	0.12	0.33

Note: Q denotes the price of floor space. EmpR denotes employment by residence. EmpW denotes employment by workplace. CBD1-CBD6 are six 500m distance grid cells for distance from the pre-war CBD. Inner Boundary 1-6 are six 500m grid cells for distance to the Inner Boundary between East and West Berlin. Outer Boundary 1-6 are six 500m grid cells for distance to the outer boundary between West Berlin and East Germany. Kudamm 1-6 are six 500m grid cells for distance to Breitscheid Platz on the Kurfürstendamm. The coefficients on the other distance grid cells are reported in Table A2 of the web appendix. Block characteristics include the logarithm of distance to schools, parks and water, the land area of the block, the share of the block's built-up area destroyed during the Second World War, indicators for residential, commercial and industrial land use, and indicators for whether a block includes a government building and urban regeneration policies post-reunification. Heteroscedasticity and Autocorrelation Consistent (HAC) standard errors in parentheses (Conley 1999). * significant at 10%; ** significant at 5%; *** significant at 1%.

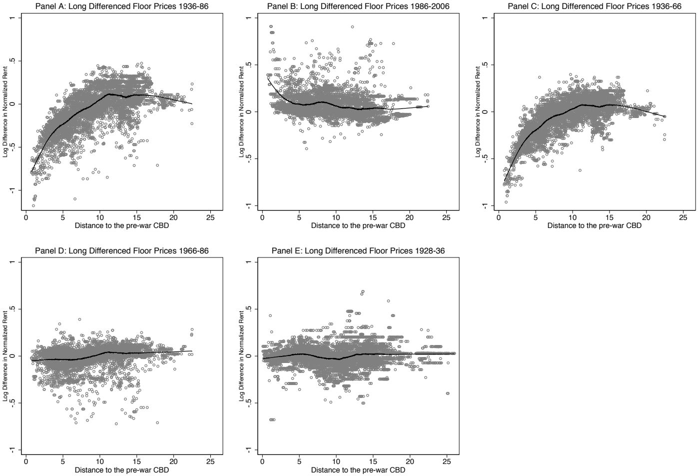
Diff-in-diffs West Berlin 1986-2006

	(1) Δ ln Q	(2) Δ ln Q	(3) Δ ln Q	(4) Δ ln Q	(5) Δ ln Q	(6) Δ ln EmpR	(7) Δ ln EmpR	(8) Δ ln EmpW	(9) Δ ln EmpW
CBD 1	0.398***	0.408***	0.368***	0.369***	0.281***	1.079***	1.025***	1.574***	1.249**
	(0.105)	(0.090)	(0.083)	(0.081)	(0.088)	(0.307)	(0.297)	(0.479)	(0.517)
CBD 2	0.290***	0.289***	0.257***	0.258***	0.191**	0.589*	0.538*	0.684**	0.457
	(0.111)	(0.096)	(0.090)	(0.088)	(0.087)	(0.315)	(0.299)	(0.326)	(0.334)
CBD 3	0.122***	0.120***	0.110***	0.115***	0.063**	0.340*	0.305*	0.326	0.158
	(0.037)	(0.033)	(0.032)	(0.032)	(0.028)	(0.180)	(0.158)	(0.216)	(0.239)
CBD 4	0.033***	0.031	0.030	0.034	0.017	0.110	0.034	0.336**	0.261
	(0.013)	(0.023)	(0.022)	(0.021)	(0.020)	(0.068)	(0.066)	(0.161)	(0.185)
CBD 5	0.025***	0.018	0.020	0.020	0.015	-0.012	-0.056	0.114	0.066
	(0.010)	(0.015)	(0.014)	(0.014)	(0.013)	(0.056)	(0.057)	(0.118)	(0.131)
CBD 6	0.019**	-0.000	-0.000	-0.003	0.005	0.060	0.053	0.049	0.110
	(0.009)	(0.009)	(0.012)	(0.012)	(0.011)	(0.039)	(0.041)	(0.095)	(0.098)
Inner Boundary 1-6			Yes	Yes	Yes		Yes		Yes
Outer Boundary 1-6			Yes	Yes	Yes		Yes		Yes
Kudamm 1-6				Yes	Yes		Yes		Yes
Block Characteristics					Yes		Yes		Yes
District Fixed Effects		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7050	7050	7050	7050	7050	6718	6718	5602	5602
R-squared	0.08	0.32	0.34	0.35	0.43	0.04	0.07	0.03	0.06

Note: Q denotes the price of floor space. EmpR denotes employment by residence. EmpW denotes employment by workplace. CBD1-CBD6 are six 500m distance grid cells for distance from the pre-war CBD. Inner Boundary 1-6 are six 500m grid cells for distance to the Inner Boundary between East and West Berlin. Outer Boundary 1-6 are six 500m grid cells for distance to the outer boundary between West Berlin and East Germany. Kudamm 1-6 are six 500m grid cells for distance to Breitscheid Platz on the Kurfürstendamm. The coefficients on the other distance grid cells are reported in Table A4 of the web appendix. Block characteristics include the logarithm of distance to schools, parks and water, the land area of the block, the share of the block's built-up area destroyed during the Second World War, indicators for residential, commercial and industrial land use, and indicators for whether a block includes a government building and urban regeneration policies post-reunification. Heteroscedasticity and Autocorrelation Consistent (HAC) standard errors in parentheses (Conley 1999).* significant at 10%; ** significant at 5%; *** significant at 1%.

Land prices over time

Placebo test: Land price change from 1928 to 1936. Of the change from 1936 - 1986, most of the effect is already in place by 1966.



Note: Log floor prices are normalized to have a mean of zero in each year before taking the long difference. Solid lines are fitted values from locally-weighted linear least squares regressions.

Gravity regression for commuting

Gravity equation for commuting from residence i to workplace j:

$$\ln \pi_{ij} = -\nu \tau_{ij} + \vartheta_i + \varsigma_j + e_{ij},$$

where τ_{ij} is transit minutes, $\nu = \epsilon\kappa$, and ϑ_i and ς_j are fixed effects

	(1) ln Bilateral Commuting Probability 2008	(2) ln Bilateral Commuting Probability 2008	(3) ln Bilateral Commuting Probability 2008	(4) ln Bilateral Commuting Probability 2008
Travel Time (−κε)	-0.0697***	-0.0702***	-0.0771***	-0.0706***
	(0.0056)	(0.0034)	(0.0025)	(0.0026)
Estimation	OLS	OLS	Poisson PML	Gamma PML
More than 10 Commuters		Yes	Yes	Yes
Fixed Effects	Yes	Yes	Yes	Yes
Observations	144	122	122	122
R-squared	0.8261	0.9059	-	-

Note: Gravity equation estimates based on representative micro survey data on commuting for Greater Berlin for 2008. Observations are bilateral pairs of 12 workplace and residence districts (post 2001 Bezirke boundaries). Travel time is measured in minutes. Fixed effects are workplace district fixed effects and residence district fixed effects. The specifications labelled more than 10 commuters restrict attention to bilateral pairs with 10 or more commuters. Poisson PML is Poisson Pseudo Maximum Likelihood estimator. Gamma PML is Gamma Pseudo Maximum Likelihood Estimator. Standard errors in parentheses are heteroscedasticity robust. * significant at 10%; ** significant at 5%; *** significant at 1%.

Backing out amenities and productivities

- Using estimated ν, and data on residence and workplace employment, one can solve for transformed wages $\omega_j = w_j^\epsilon$ from commuting equation (summed over origins)
- Recover overall productivity A_j from zero-profit equation:

$$\ln\left(\frac{A_{it}}{\bar{A}_t}\right) = (1-\alpha)\ln\left(\frac{\mathbb{Q}_{it}}{\bar{\mathbb{Q}}_t}\right) + \frac{\alpha}{\epsilon}\ln\left(\frac{\omega_{it}}{\bar{\omega}_t}\right)$$

  where $\bar{A}_t = \exp\Big(1/S\sum_{s=1}^{S}\ln A_{st}\Big)$ (geometric mean)
- High floor prices and wages require high final good productivity for zero profits to be satisfied

Backing out amenities and productivities

- Recover amenities B_i from residential choice probabilities:

$$\ln\left(\frac{B_{it}}{\bar{B}_t}\right) = \frac{1}{\epsilon}\ln\left(\frac{H_{Rit}}{\bar{H}_{Rt}}\right) + (1-\beta)\ln\left(\frac{\mathbb{Q}_{it}}{\bar{\mathbb{Q}}_t}\right) + \frac{1}{\epsilon}\ln\left(\frac{W_{it}}{\bar{W}_t}\right)$$

  where $W_{it} = \sum_{s=1}^{S} \omega_{st}/e^{\nu\tau_{ist}}$ and variables with an upper bar denote that variable's geometric mean.
- High floor prices and high residence employment must be explained either by high wage commuting access or high amenities.
- (So far not making assumptions about the relative importance of production and residential externalities versus fundamentals)

Backing out amenities and productivities

- Fix other parameters (α, ...) to values from the literature.
- Estimate ϵ from dispersion of log adjusted wages backed out in the model and log wages in the data for a selected year.
- Next table shows in columns 1-4 how the amenities and productivities changed over time.
- Also, simulate the impact of the division on West Berlin, holding productivity, amenities constant at their 1936 values. Column 5 shows that the models prediction are off from the diff and diff results (-.4 versus -.8 log points) Similarly for column 6 (re-unification; 0 versus -.4 log points).

Changes in Amenities and Productivity

TABLE IV

PRODUCTIVITY, AMENITIES, AND COUNTERFACTUAL FLOOR PRICES[a]

	(1) $\Delta \ln A$ 1936–1986	(2) $\Delta \ln B$ 1936–1986	(3) $\Delta \ln A$ 1986–2006	(4) $\Delta \ln B$ 1986–2006	(5) $\Delta \ln QC$ 1936–1986	(6) $\Delta \ln QC$ 1986–2006
CBD 1	−0.207***	−0.347***	0.261***	0.203***	−0.408***	−0.010
	(0.049)	(0.070)	(0.073)	(0.054)	(0.038)	(0.020)
CBD 2	−0.260***	−0.242***	0.144**	0.109*	−0.348***	0.079**
	(0.032)	(0.053)	(0.056)	(0.058)	(0.017)	(0.036)
CBD 3	−0.138***	−0.262***	0.077***	0.059**	−0.353***	0.036
	(0.021)	(0.037)	(0.024)	(0.026)	(0.022)	(0.031)
CBD 4	−0.131***	−0.154***	0.057***	0.010	−0.378***	0.093***
	(0.016)	(0.023)	(0.015)	(0.008)	(0.021)	(0.026)
CBD 5	−0.095***	−0.126***	0.028**	−0.014*	−0.380***	0.115***
	(0.014)	(0.013)	(0.013)	(0.007)	(0.022)	(0.033)
CBD 6	−0.061***	−0.117***	0.023**	0.001	−0.354***	0.066***
	(0.015)	(0.015)	(0.010)	(0.005)	(0.018)	(0.023)
Counterfactuals					Yes	Yes
Agglomeration Effects					No	No
Observations	2,844	5,978	5,602	6,718	6,260	7,050
R^2	0.09	0.06	0.02	0.03	0.07	0.03

Structural Estimation

- Next, use exogenous variation from Berlin's division and reunification to structurally estimate model parameters including the agglomeration forces.
- From the previous equations and definitions:

$$\Delta \ln\left(\frac{a_{it}}{\bar{a}_t}\right) = (1-\alpha)\Delta \ln\left(\frac{\mathbb{Q}_{it}}{\bar{\mathbb{Q}}_t}\right) + \frac{\alpha}{\epsilon}\Delta \ln\left(\frac{\omega_{it}}{\bar{\omega}_t}\right) - \lambda \Delta \ln\left(\frac{\Upsilon_{it}}{\bar{\Upsilon}_t}\right)$$

$$\begin{aligned}\Delta \ln\left(\frac{b_{it}}{\bar{b}_t}\right) &= \frac{1}{\epsilon}\Delta \ln\left(\frac{H_{Rit}}{\bar{H}_{Rt}}\right) + (1-\beta)\Delta \ln\left(\frac{\mathbb{Q}_{it}}{\bar{\mathbb{Q}}_t}\right) \\ &\quad + \frac{1}{\epsilon}\Delta \ln\left(\frac{W_{it}}{\bar{W}_t}\right) - \eta \Delta \ln\left(\frac{\Omega_{it}}{\bar{\Omega}_t}\right)\end{aligned}$$

- Production externalities Υ_{it} depend on travel-time weighted sum of observed workplace employment densities
- Residential externalities Ω_{it} depend on travel-time weighted sum of observed residence employment densities
- Adjusted fundamentals relative to geometric mean are structural residuals

Parameters

Assumed Parameter		Source	Value
Residential land	$1-\beta$	Davis & Ortalo-Magne (2011)	0.25
Commercial land	$1-\alpha$	Valentinyi-Herrendorf (2008)	0.20
Fréchet Scale	T	(normalization)	1
Expected Utility	$\bar{u}$	(normalization)	1000

Estimated Parameter	
Production externalities elasticity	λ
Production externalities decay	δ
Residential externalities elasticity	η
Residential externalities decay	ρ
Commuting semi-elasticity	$\nu = \epsilon\kappa$
Commuting heterogeneity	ϵ

Moment Conditions

- Changes in adjusted fundamentals uncorrelated with exogenous change in surrounding economic activity from division/reunification

$$\mathbb{E}\left[\mathbb{I}_k \times \Delta \ln\left(a_{it}/\bar{a}_t\right)\right] = 0, \qquad k \in \{1, \ldots, K_{\mathbb{I}}\},$$

$$\mathbb{E}\left[\mathbb{I}_k \times \Delta \ln\left(b_{it}/\bar{b}_t\right)\right] = 0, \qquad k \in \{1, \ldots, K_{\mathbb{I}}\}.$$

  where $\mathbb{I}_k$ are indicators for distance grid cells from pre-war CBD

- Other moments are fraction of workers that commute less than 30 minutes and wage dispersion

$$\mathbb{E}\left[\vartheta H_{Mj} - \sum_{i \in \aleph_j}^{S} \frac{\omega_j / e^{\nu \tau_{ij}}}{\sum_{s=1}^{S} \omega_s / e^{\nu \tau_{is}}} H_{Ri}\right] = 0,$$

$$\mathbb{E}\left[(1/\epsilon)^2 \ln\left(\omega_j\right)^2 - \sigma^2_{\ln w_i}\right] = 0,$$

Estimated Parameters

TABLE V

GENERALIZED METHOD OF MOMENTS (GMM) ESTIMATION RESULTS[a]

	(1) Division Efficient GMM	(2) Reunification Efficient GMM	(3) Division and Reunification Efficient GMM
Commuting Travel Time Elasticity ($\kappa\varepsilon$)	0.0951***	0.1011***	0.0987***
	(0.0016)	(0.0016)	(0.0016)
Commuting Heterogeneity (ε)	6.6190***	6.7620***	6.6941***
	(0.0939)	(0.1005)	(0.0934)
Productivity Elasticity (λ)	0.0793***	0.0496***	0.0710***
	(0.0064)	(0.0079)	(0.0054)
Productivity Decay (δ)	0.3585***	0.9246***	0.3617***
	(0.1030)	(0.3525)	(0.0782)
Residential Elasticity (η)	0.1548***	0.0757**	0.1553***
	(0.0092)	(0.0313)	(0.0083)
Residential Decay (ρ)	0.9094***	0.5531	0.7595***
	(0.2968)	(0.3979)	(0.1741)

Localized Externalities

TABLE VI

EXTERNALITIES AND COMMUTING COSTS[a]

	(1) Production Externalities $(1 \times e^{-\delta\tau})$	(2) Residential Externalities $(1 \times e^{-\rho\tau})$	(3) Utility After Commuting $(1 \times e^{-\kappa\tau})$
0 minutes	1.000	1.000	1.000
1 minute	0.696	0.468	0.985
2 minutes	0.485	0.219	0.971
3 minutes	0.338	0.102	0.957
5 minutes	0.164	0.022	0.929
7 minutes	0.079	0.005	0.902
10 minutes	0.027	0.001	0.863
15 minutes	0.004	0.000	0.802
20 minutes	0.001	0.000	0.745
30 minutes	0.000	0.000	0.642

Counterfactuals

TABLE VII
COUNTERFACTUALS[a]

	(1) $\Delta \ln QC$ 1936–1986	(2) $\Delta \ln QC$ 1936–1986	(3) $\Delta \ln QC$ 1936–1986	(4) $\Delta \ln QC$ 1936–1986	(5) $\Delta \ln QC$ 1986–2006	(6) $\Delta \ln QC$ 1986–2006	(7) $\Delta \ln QC$ 1986–2006
CBD 1	−0.836***	−0.613***	−0.467***	−0.821***	0.363***	1.160***	0.392***
	(0.052)	(0.032)	(0.060)	(0.051)	(0.041)	(0.052)	(0.043)
CBD 2	−0.560***	−0.397***	−0.364***	−0.624***	0.239***	0.779***	0.244***
	(0.034)	(0.025)	(0.019)	(0.029)	(0.028)	(0.044)	(0.027)
CBD 3	−0.455***	−0.312***	−0.336***	−0.530***	0.163***	0.594***	0.179***
	(0.036)	(0.030)	(0.030)	(0.036)	(0.031)	(0.045)	(0.031)
CBD 4	−0.423***	−0.284***	−0.340***	−0.517***	0.140***	0.445***	0.143***
	(0.026)	(0.019)	(0.022)	(0.031)	(0.021)	(0.042)	(0.021)
CBD 5	−0.418***	−0.265***	−0.351***	−0.512***	0.177***	0.403***	0.180***
	(0.032)	(0.022)	(0.027)	(0.039)	(0.032)	(0.038)	(0.032)
CBD 6	−0.349***	−0.222***	−0.304***	−0.430***	0.100***	0.334***	0.103***
	(0.025)	(0.016)	(0.022)	(0.029)	(0.024)	(0.034)	(0.023)
Counterfactuals	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Agglomeration Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,260	6,260	6,260	6,260	7,050	6,260	7,050
R^2	0.11	0.13	0.07	0.13	0.12	0.24	0.13

Next week

Next week, we do economic geography with trade costs. This amounts to Krugman (1980) with labor mobility.

We will work through Krugman (1991) equation by equation in class. Read it, work through the math, and bring a copy to class.