Quantitative spatial economics

Applied Econometrics for Spatial Economics

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tinbergen institute

1. Introduction

- Yesterday:
  1. Spatial econometrics
  2. Discrete choice
  3. Identification

- Today:
  4. Hedonic pricing
  5. Quantitative spatial economics

1. Introduction

- Yesterday:
  1. Spatial econometrics
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- Today:
  4. Hedonic pricing
  5. Quantitative spatial economics
     - General equilibrium models in spatial economics

1. Introduction

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  → Effect of policy on marginal changes in behaviour

1. Introduction

- Empirical urban economics was often a 'reduced-form' field
  → Effect of policy on marginal changes in behaviour

- Pros and cons
  - Few(er) assumptions (+)
  - Easy interpretation (no black box) (+)
  - Clear identification (+)
  - Partial equilibrium (-)
  - Impossible to evaluate large changes (-)
  - Hard to do scenario analysis (-)

1. Introduction

- Recently, **quantitative spatial equilibrium** models (QSE) have become increasingly popular
  - Given the model structure, one may evaluate large changes in spatial structure
  - Model complex spatial interactions

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- Useful when interested in:
  - Transport infrastructure investments
  - Sorting/gentrification
  - Evaluating large place-based policies
  - (Changes in) agglomeration economies

- Learn about a key contribution of Ahlfeldt *et al.* (2015) [ARSW]
  → QSE of Berlin's Urban Spatial Structure
  → Use the Berlin Wall as a quasi experiment to identify the importance of agglomeration economies
  → *Econometric Society Frisch Medal Award*

- Learn the model structure and estimation of the model
  → Application to the effect of open space on London's urban spatial structure

1. Introduction

- **I have applied similar models in recent papers:**
  - → Koster, H.R.A. (2023). The Welfare Effects of Greenbelt Policy. *Economic Journal*, forthcoming
  - → Dericks, G., Koster, H.R.A. (2021). The Billion Pound Drop: The Blitz and Agglomeration Economies in London. *Journal of Economic Geography*, 21(6): 869-897
  - → Koster, H.R.A, Hayakawa, K., Tabuchi, T., Thisse, J.-F. (2023). High-speed rail and the spatial distribution of economic activity: Evidence from Japan's Shinkansen. RIETI Working Paper.

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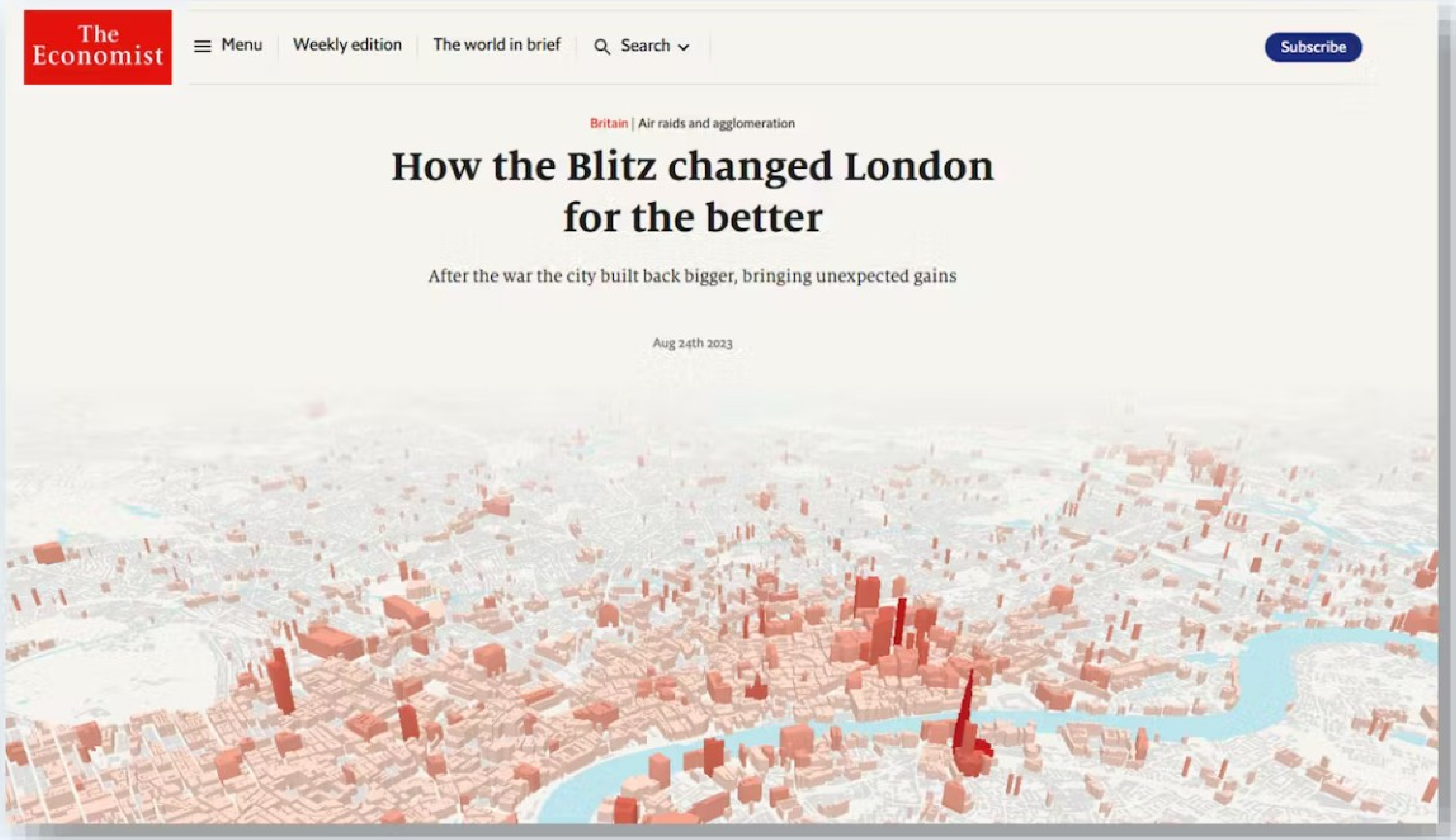

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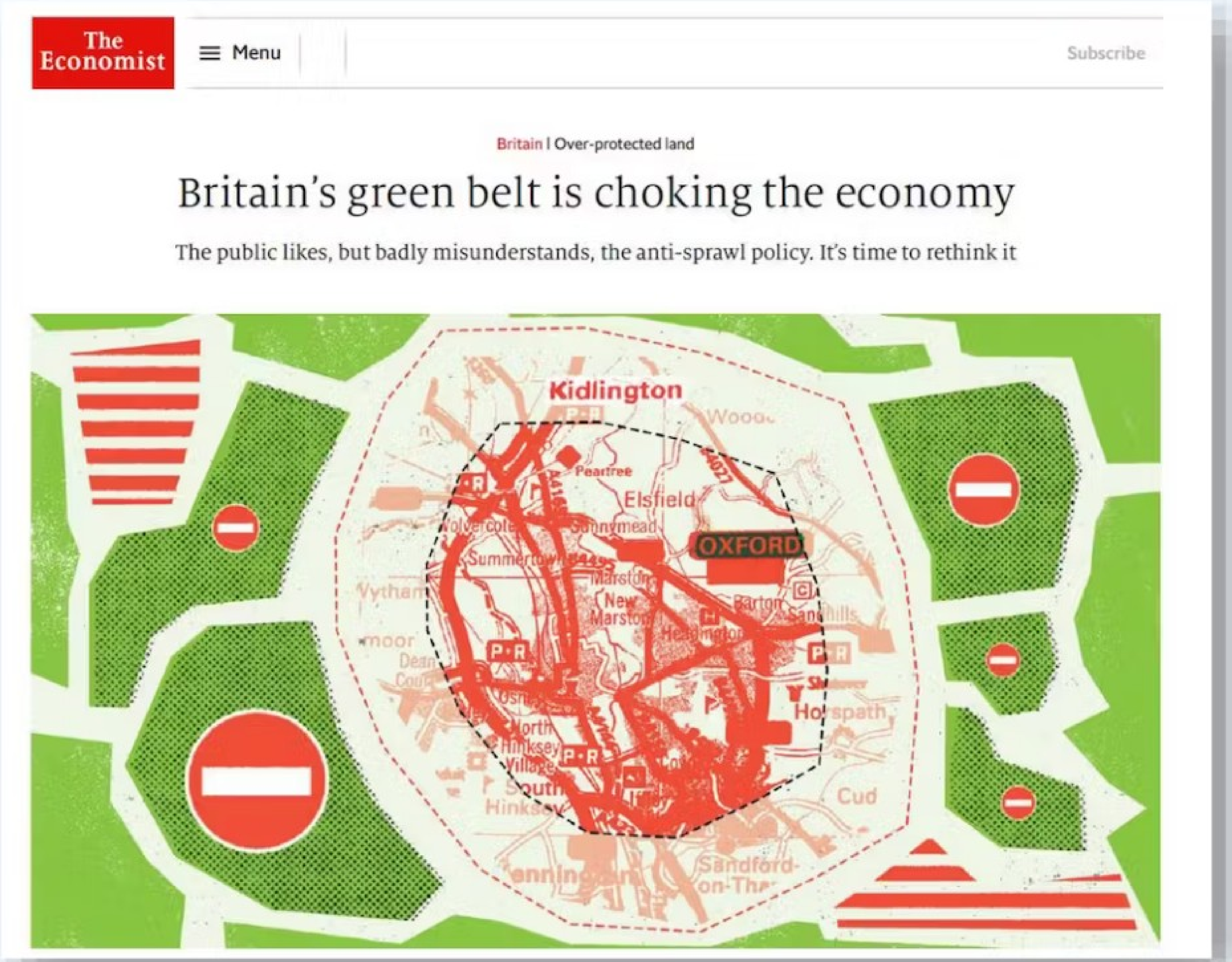

1. Introduction

- The advantages of ARSW
  - → Use **commuting flows** to identify key parameters
  - → Easy ***recursive* estimation** using standard regression techniques
  - → **Proper identification** of model parameters (rather than calibration…)

- Goals of this lecture

  1. You should understand the model structure of ARSW
  2. You should be able to estimate the ARSW model
  3. You should understand the pros and cons of applying the ARSW model

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2. Model set-up

- Main elements:
  - CD-Utility of workers dependent on residential location i and workplace j
  - CD-Production
  - Land market: land available is given
  - Production and workers are linked via commuting
  - Production benefits from agglomeration economies
  - Workers may benefit/lose from residential externalities

Workers

$$U_{ijo} = \frac{B_i z_{ijo}}{d_{ij}} \left(\frac{c_{ijo}}{\beta}\right)^{\beta} \left(\frac{\ell_{ijo}}{1-\beta}\right)^{1-\beta}$$

- U_{ijo} **utility for worker o living in i and working in j**
- B_i **amenities**
- c_{ijo} **composite good consumption**
- ℓ_{ijo} **residential floor space consumption**
- z_{ijo} **idiosyncratic component where:**

$$F\left(z_{ijo}\right) = \mathrm{e}^{-T_i E_j z_{ijo}^{-\varepsilon}}$$

where T_i and E_j denote average utilities

- d_{ij} **commuting discount factor: $\mathrm{e}^{\kappa\tau_{ij}}$**

Workers

- **Budget constraint**

$$w_j = Q_i \ell_{ijo} + c_{ijo}$$

where Q_i are floor space prices

- **The indirect utility is given by:**

$$u_{ijo} = B_i \left(w_j \mathrm{e}^{-\kappa \tau_{ij}} \right) Q_i^{\beta - 1} z_{ijo}$$

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Workers

- Fréchet shock on commuting
  - Eaton and Kortum (2002) in trade
  - Captures (realistic) idiosyncratic preferences for living in i and working in j

- Hence:

$$\pi_{ij} = \frac{T_i E_j \bar{u}_{ij}^{\varepsilon}}{\sum_{r=1}^{S} \sum_{s=1}^{S} T_r E_s \bar{u}_{rs}^{\varepsilon}} = \frac{T_i E_j \left(B_i \left(w_j e^{-\kappa \tau_{ij}}\right) Q_i^{\beta-1}\right)^{\varepsilon}}{\sum_{r=1}^{S} \sum_{s=1}^{S} T_r E_s \left(B_r \left(w_s e^{-\kappa \tau_{rs}}\right) Q_r^{\beta-1}\right)^{\varepsilon}}$$

- Conditional on living in i, the commuting probability to j is given by (Why?):

$$\pi_{ij|i} = \frac{E_j \left(w_j \mathrm{e}^{-\kappa \tau_{ij}}\right)^{\varepsilon}}{\sum_{s=1}^{S} E_s \left(w_s \mathrm{e}^{-\kappa \tau_{is}}\right)^{\varepsilon}}$$

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Workers

- **Commuting market clearing condition:**

$$H_{Mj} = \sum_{i=1}^{S} \pi_{ij|i} H_{Ri}$$

$$H_{Mj} = \sum_{i=1}^{S} \frac{E_j \left(w_j \mathrm{e}^{-\kappa \tau_{ij}}\right)^{\varepsilon}}{\sum_{s=1}^{S} E_s \left(w_s \mathrm{e}^{-\kappa \tau_{is}}\right)^{\varepsilon}} H_{Ri}$$

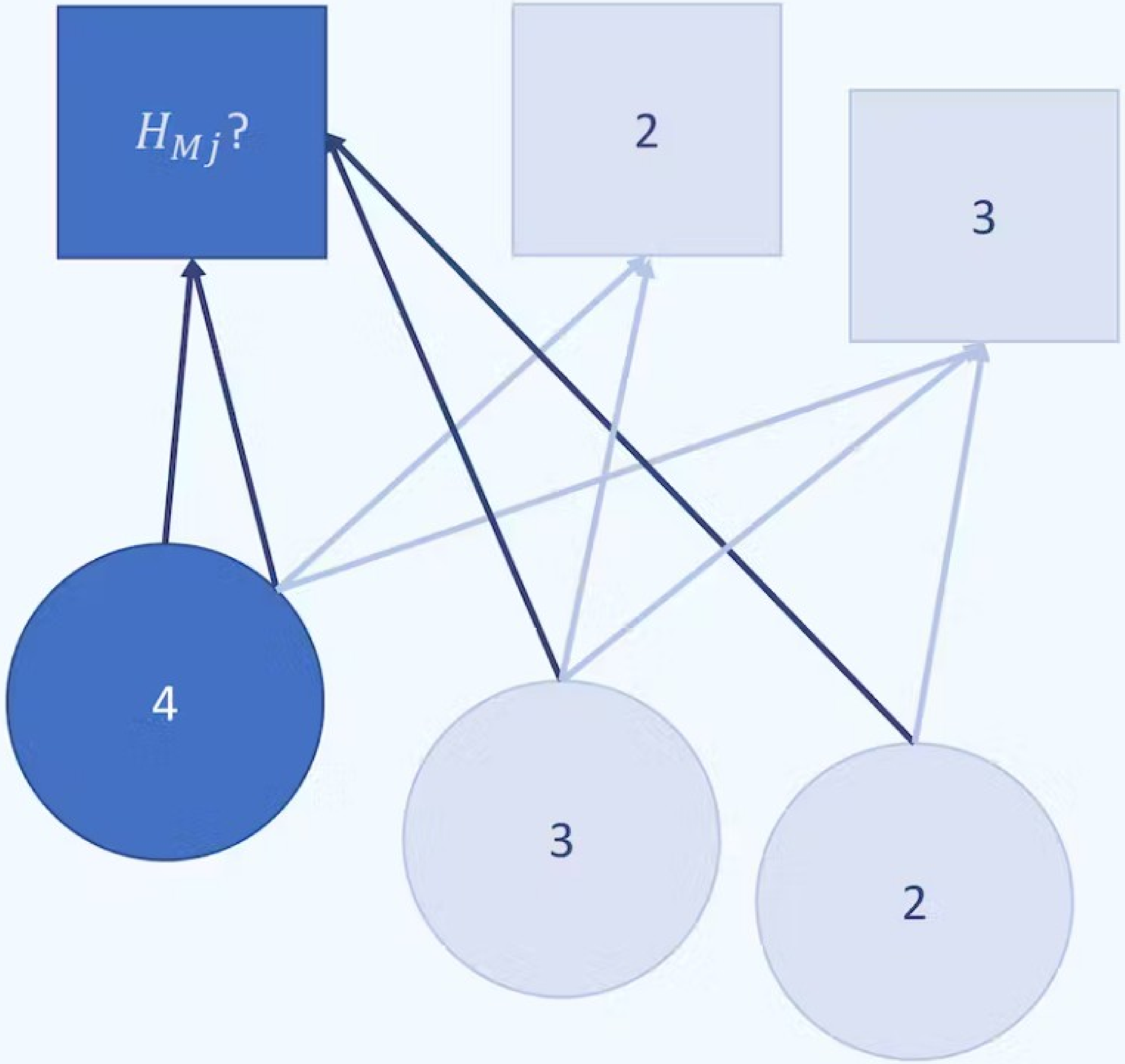
H_{Mj} workers at j

H_{Ri} residents at i

Workers

- **Commuting market clearing condition:**

$$H_{Mj} = \sum_{i=1}^{S} \pi_{ij|i} H_{Ri}$$



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Workers

- **Spatial equilibrium** so that workers have the same *expected* utility everywhere:

$$\mathbb{E}[\bar{u}] = \Gamma\left(\frac{\varepsilon - 1}{\varepsilon}\right)\left[\sum_{r=1}^{S}\sum_{s=1}^{S} T_r E_s \left(B_r (w_s e^{-\kappa\tau_{rs}}) Q_r^{\beta-1}\right)^{\varepsilon}\right]^{\frac{1}{\varepsilon}}$$

where $[\cdot]$ is the denominator of π_{ij} and $\Gamma(\cdot)$ is the gamma function

- **Production**

$$y_j = A_j H_{Mj}^{\alpha} L_{Mj}^{1-\alpha}$$

y_j	**output**
A_j	**final goods productivity**
H_{Mj}	**labour input**
L_{Mj}	**commercial floor space used**

Then:

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

- **Land market clearing**
  - $\mathbb{Q}_i = \max(q_i, Q_i)$
  - $\theta_i = 1$ **if** $q_i > Q_i$
  - $\theta_i \in [0,1]$ **if** $q_i = Q_i$
  - $\theta_i = 0$ **if** $q_i < Q_i$

- **Land market clearing for households**

$$\mathbb{E}[\ell_i]H_{Ri} = \frac{(1-\beta)\mathbb{E}[w_s|i]}{Q_i}H_{Ri} = (1-\theta_i)L_i$$

- **Land market clearing for firms**

$$\left(\frac{(1-\alpha)A_j}{q_j}\right)^{\frac{1}{\alpha}} H_{Mj} = \theta_j L_j$$

- **Total demand equals total supply:**

$$(1-\theta_i)L_{Ri} + \theta_i L_{Mi} = L_i = K_i^{\mu} M_i^{1-\mu}$$

where K_i is the land available at i and $M_i^{1-\mu}$ is the density of development

2. Model set-up

- **General equilibrium with fixed B_i and A_i**

- **Equilibrium is determined by**
  - **Population mobility (*i.e.* expected utility)**
  - **Residential choice probability**
  - **Workplace choice probability**
  - **Commercial land market clearing**
  - **Residential land market clearing**
  - **Profit maximization**
  - **Zero profit**
  - **No-arbitrage between alternative land uses**

- **ARSW prove existence and uniqueness of equilibrium**

2. Model set-up

- **Allow for endogenous agglomeration forces**
  - ***Not in the assignment***

- **Production externalities:**

$$A_i = a_i \left(\sum_{s=1}^{S} \mathrm{e}^{-\delta \tau_{is}} \frac{H_{Ms}}{K_s} \right)^{\lambda}$$

- **Residential externalities:**

$$B_i = b_i \left(\sum_{s=1}^{S} \mathrm{e}^{-\rho \tau_{is}} \frac{H_{Rs}}{K_s} \right)^{\eta}$$

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2. Model set-up

- **Recovering A_i and B_i from the model**
  - **There are closed forms of A_i and B_i, *up to multiplication constants***
  - **'Structural residuals'**

- **Recovering A_i and B_i from the model**

- **Productivity (using zero profit condition)**

$$A_i = (1-\alpha)^{1-\alpha}\alpha^{-\alpha}\mathbb{Q}_j^{1-\alpha}w_j^{\alpha}$$

- **Amenities (using the expected utility):**

$$\frac{\tilde{B}_i}{\bar{\tilde{B}}} = \left(\frac{H_{Ri}}{\bar{H}_R}\right)^{\frac{1}{\varepsilon}}\left(\frac{\mathbb{Q}_i}{\bar{\mathbb{Q}}}\right)^{1-\beta}\left(\frac{W_i}{\bar{W}}\right)^{-\frac{1}{\varepsilon}}$$

where bars denote geometric means and W_i is the expected wage:

$$W_i = \sum_{s=1}^{S} E_s\left(w_j \mathrm{e}^{-\kappa\tau_{ij}}\right)^{\varepsilon}$$

3. Recursive estimation

- **We aim to estimate**

$\kappa\varepsilon > 0$ **commuting time elasticity**
$\varepsilon > 1$ **utility dispersion parameter**

λ **productivity elasticity**
$\delta > 0$ **productivity decay**

η **residential elasticity**
$\rho > 0$ **residential decay**

3. Recursive estimation

- Estimate the parameters using its recursive structure
  1. Estimate commuting gravity equation
  2. Back out wages
  3. Obtain utility dispersion parameter ε
  4. Obtain amenities and productivity
  5. Regress productivity on worker density
  6. Regress amenities on residential density

- **Important:**
  - **Everything is identified up to multiplication constants**
  - **We cannot say much about *absolute* utility levels**

- **Good identification strategies are key to obtain correct model parameters!**
  - ***Like in reduced-form estimation***
  - **Model can be seen as a collection of reduced-form estimations**
  - **… much better than in structural models in the past**

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1. Estimate gravity equation:

We can write π_{ij} as:

$$\log \pi_{ij} H = -\varkappa \tau_{ij} + \upsilon_i + \upsilon_j$$

which identifies $\varkappa = \varepsilon\kappa$

- **This is a standard gravity equation, as $\pi_{ij} H$ represents the commuting flow between i and j**
  - υ_i **and** υ_j **absorb** T_i, B_i, Q_i, E_j.

3. Recursive estimation

2. **Given data on H_{Mj}, H_{Rj} and $\hat{\varkappa}$, we can obtain transformed wages $\omega_j = \left(E_j w_j\right)^{\varepsilon}$ for each location:**

$$H_{Mj} = \sum_{i=1}^{S} \frac{\omega_j \mathrm{e}^{-\hat{\varkappa}\tau_{ij}}}{\sum_{s=1}^{S} \omega_s \mathrm{e}^{-\hat{\varkappa}\tau_{is}}} H_{Ri}$$

- **There exists a unique vector of ω_j that makes sure that the commuting market clearing condition holds**

- **Use Newton-Raphson procedure**
  - $\omega_{j,0} = 1$
  - $\omega_{j,r+1} = \omega_{j,r} \frac{H_{Mj}}{\hat{H}_{Mj,r}}$
  - **We programmed this for you in STATA**

3. Recursive estimation

3. **Given aggregate data on wages $\mathbb{w}_i$, $\widehat{\omega}_j$ and $\hat{\varkappa}$, we can back out ε**

$$\operatorname{var}\left(\log \omega_j\right) = \operatorname{var}\left(\log\left(E_j w_j\right)^{\varepsilon}\right) = \varepsilon \operatorname{var}\left(\log\left(w_j\right)^{\varepsilon}\right)$$

Hence,

$$\mathbb{E}\left[\operatorname{var}(\log(\mathbb{w}_i)) - \frac{1}{\varepsilon}\operatorname{var}\left(\log \omega_j\right)\right] = 0$$

➔ **Use OLS (without a constant) to obtain ε**

3. Recursive estimation

4. **Given data on H_{Mi}, H_{Ri}, $\hat{\varkappa}$, $\hat{\varepsilon}$, $\widehat{\omega}_j$ and data on floor space prices $\mathbb{Q}_j$ we recover A_i and B_i (up to a constant)**

- **Productivities in logs (eq. 27):**

$$\log \tilde{A}_i = \log \tilde{a}_i + (1-\alpha)\log \mathbb{Q}_i + \frac{\alpha}{\hat{\varepsilon}} \log \omega_i$$

- **Amenities in logs (eq. 28):**

$$\log \tilde{B}_i = \log \tilde{b}_i + \frac{1}{\hat{\varepsilon}} \log H_{Ri} + (1-\beta)\log \mathbb{Q}_i - \frac{1}{\hat{\varepsilon}} \log W_i$$

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5. Production externalities

- **We have data on H_{Ms} and have data on K_s:**

$$\log \hat{A}_i = \log \tilde{a}_i + \lambda \log \left(\sum_{s=1}^{S} \mathrm{e}^{-\delta \tau_{is}} \frac{H_{Ms}}{K_s} \right) + \xi_i$$

5. Production externalities

- **We have data on H_{Ms} and have data on K_s:**

$$\log \hat{A}_i = \log \tilde{a}_i + \lambda \log\left(\sum_{s=1}^{S} \mathrm{e}^{-\delta \tau_{is}} \frac{H_{Ms}}{K_s}\right) + \xi_i$$

- **Use changes in density due to Berlin Wall**

$$\Delta \log \hat{A}_{it} = \Delta \log \tilde{a}_{it} + \lambda\, \Delta \log\left(\sum_{s=1}^{S} \mathrm{e}^{-\delta \tau_{is,t}} \frac{H_{Ms,t}}{K_{s,t}}\right) + \Delta \xi_{it}$$

6. Residential externalities

- **Similarly, we have data on H_{Rs} and estimated K_s:**

$$\log \hat{B}_i = \log \tilde{b}_i + \eta \log \left(\sum_{s=1}^{S} e^{-\rho \tau_{is}} \frac{H_{Rs}}{K_s} \right) + \xi_i$$

- **Use again variation in density due to Berlin Wall…**

3. Recursive estimation

- **Ahlfeldt *et al.* use a GMM approach to estimate all the parameters in one go**
- **In principle this should deliver (more or less) the same estimates**
- **Only possible with linear (no PPML) gravity model without too many observations**

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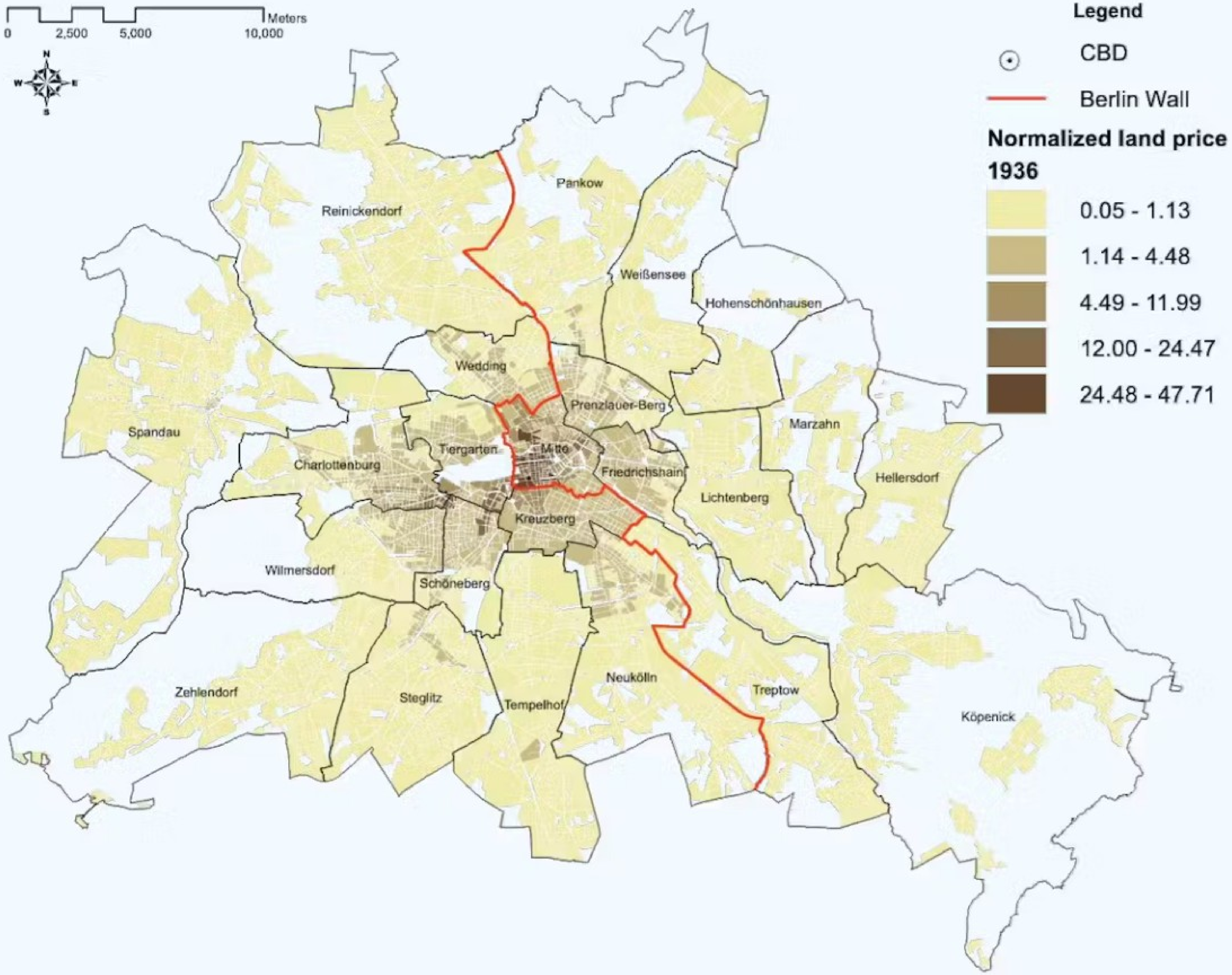
4. Empirical evidence



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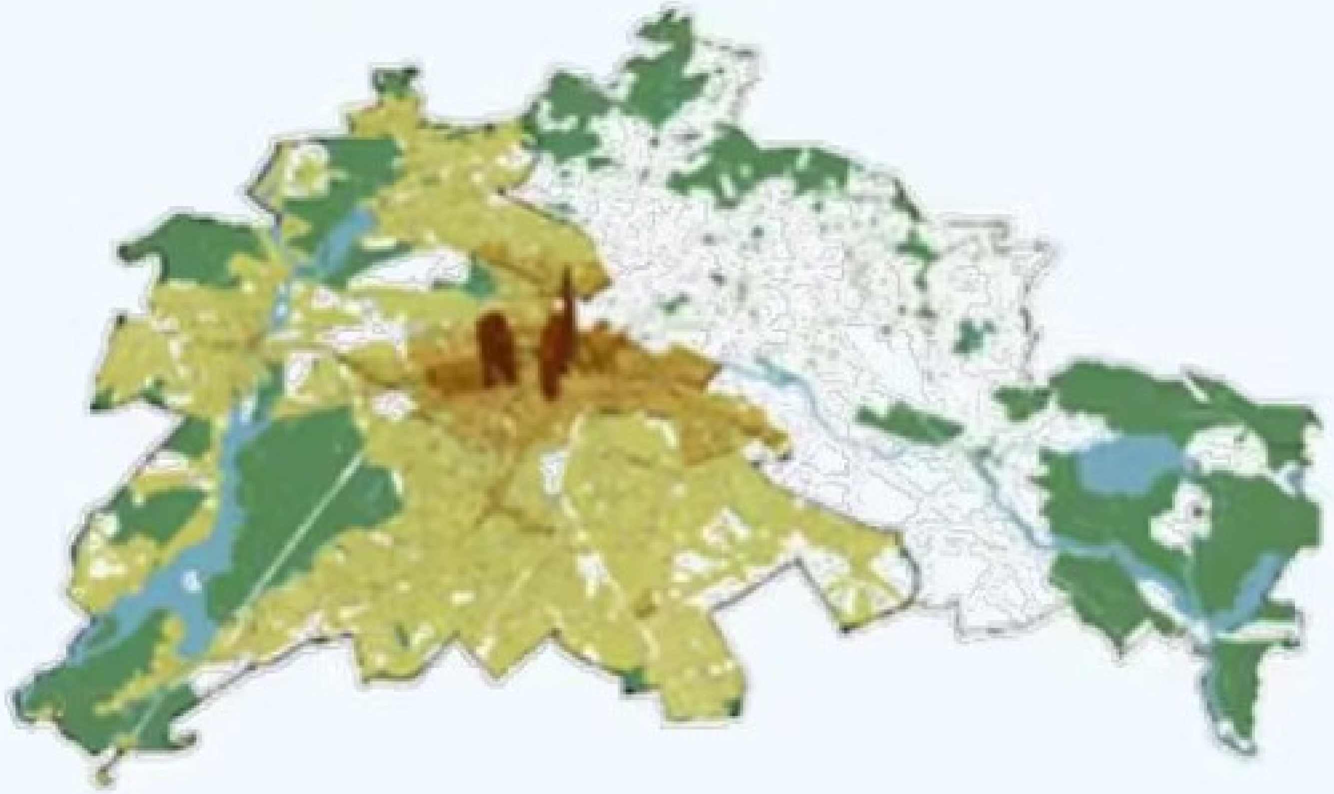
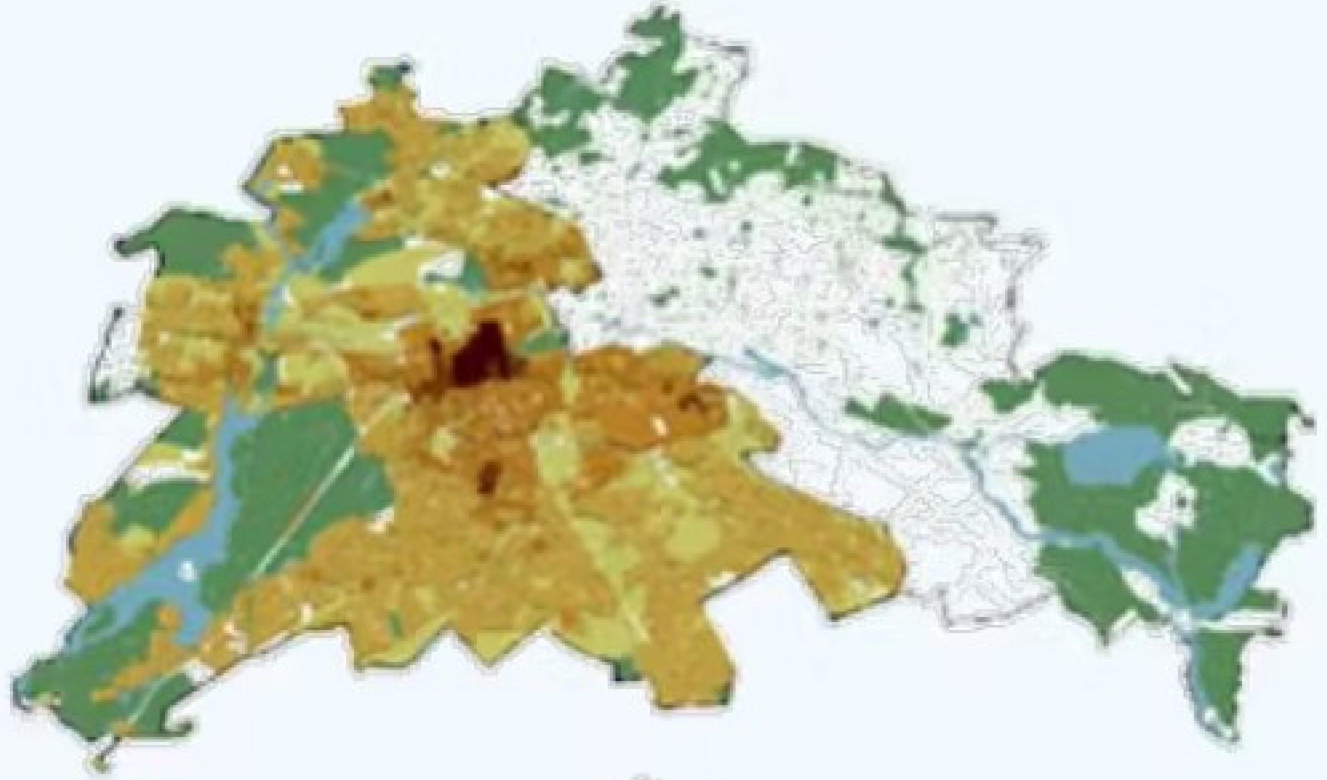
4. Empirical evidence

- They use block data from 1936, 1986 and 2006
  - 15,937 blocks, 9,000 in West-Berlin
  - Land values, commuting times, block characteristics

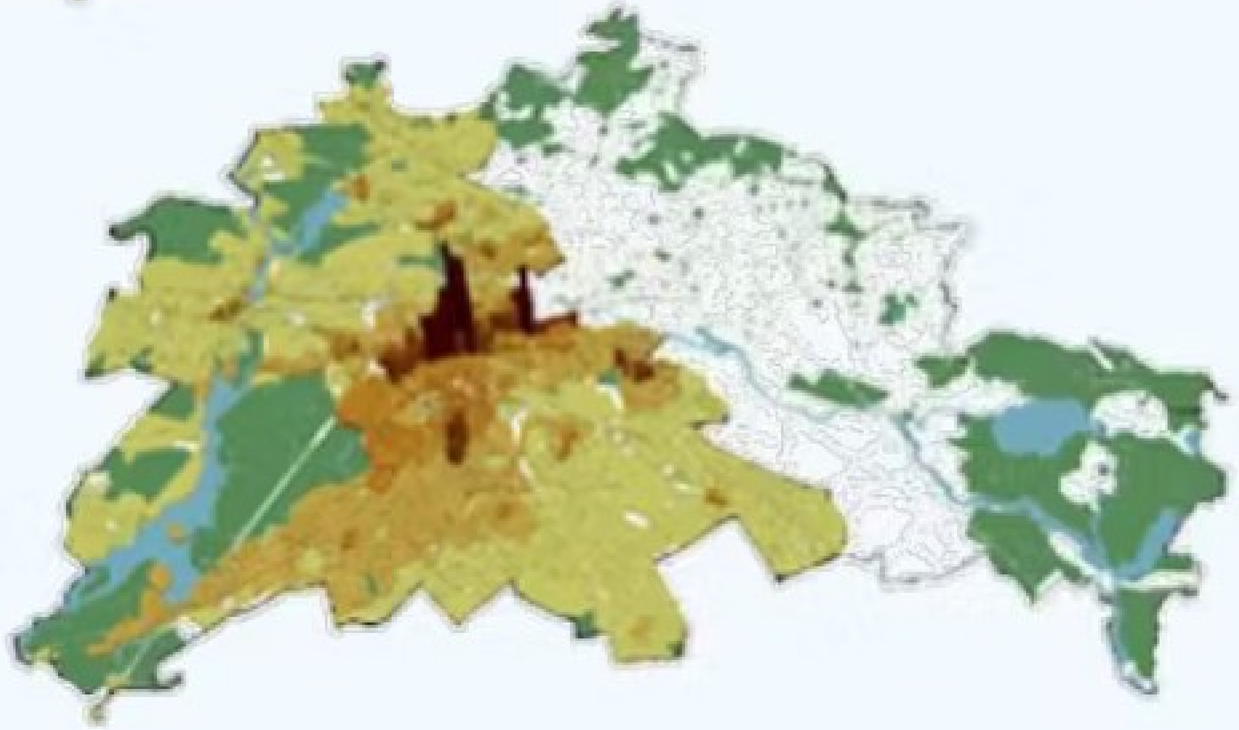
- **Graphical illustration of changes**



1936



1986



2006

4. Empirical evidence

- Let's first consider the reduced-form evidence
  - This is an important starting point of any analysis!

- **Three regressions for division and reunification**
  - $\Delta \log Q_i = \alpha + \sum_{k=1}^{K} \beta_k I_{ik} + \gamma \log M_i + \epsilon_i$
  - $\Delta \log EmpR_i = \breve{\alpha} + \sum_{k=1}^{K} \breve{\beta}_k I_{ik} + \breve{\gamma} \log M_i + \breve{\epsilon}_i$
  - $\Delta \log EmpW_i = \tilde{\alpha} + \sum_{k=1}^{K} \tilde{\beta}_k I_{ik} + \tilde{\gamma} \log M_i + \tilde{\epsilon}_i$

I_{ik}	**Within a distance 500m bands of the pre-war CBD**
M_i	**time-invariant block characteristics**
Q_i	**land values**
$EmpR_i$	**~ Household density**
$EmpW_i$	**Workplace density**

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Results from division

Table – RENTS, EMPLOYMENT AND THE BERLIN WALL

	Division		Reunification	
	Rents *(log)*	Empl. *(log)*	Rents *(log)*	Empl. *(log)*
	(1)	(2)	(3)	(4)
CBD 0-500m	-0.567***	-0.691*	0.408***	1.574***
	(0.071)	(0.408)	(0.090)	(0.479)
CBD 500-1000m	-0.422***	-1.253***	0.289***	0.684**
	(0.047)	(0.293)	(0.096)	(0.326)
CBD 1000-1500m	-0.306***	-0.341	0.120***	0.326
	(0.039)	(0.241)	(0.033)	(0.216)
CBD 1500-2000m	-0.207***	-0.512***	-0.031	0.336**
	(0.033)	(0.199)	(0.023)	(0.161)
CBD 2000-2500m	-0.139***	-0.436***	0.018	0.114
	(0.024)	(0.151)	(0.015)	(0.118)
CBD 2500-3000m	-0.125***	-0.280***	-0.000	0.049
	(0.019)	(0.130)	(0.012)	(0.095)
District fixed effects	Yes	Yes	Yes	Yes
Number of observations	6,260	2,844	7,050	5,602
Kleibergen-Paap F-statistic	0.51	0.12	0.32	0.03

Notes: Data on pre-division is from 1936, during the division it is from 1986 and from reunification it is from 2006. Standard errors adjusted for spatial correlation are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

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Gravity model

TABLE III

COMMUTING GRAVITY EQUATION[a]

	(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 ($-\kappa\varepsilon$)	−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^2	0.8261	0.9059	–	–

Structural 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)

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Implied decay of commuting and 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

[a] Proportional reduction in production and residential externalities with travel time and proportional reduction in utility from commuting with travel time. Travel time is measured in minutes. Results are based on the pooled efficient GMM parameter estimates: $\delta = 0.3617$, $\rho = 0.7595$, $\kappa = 0.0148$.

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5. Counterfactuals

- **Given chosen parameters $\{\alpha, \beta, \mu\}$ and estimated parameters $\{\hat{\kappa}, \hat{\varepsilon}, \hat{\lambda}, \hat{\delta}, \hat{\eta}, \hat{\rho}\}$ we can investigate what happens if you change fundamentals**

- **The procedure is described in Supplement, pp. 56-57**

- **The idea is that you have a change in say travel times τ_{ij}**
  - **Due to reunification or division**
  - **Update values iteratively**

$$\{\pi_{ij}, \pi_{ij|i}, H_{Ri}, H_{Mi}, Y_i, \tilde{w}_i, \mathbb{E}[\tilde{w}_s|i], \mathbb{Q}_i, \theta_i\}$$

5. Counterfactuals

1. Use 1936 values to simulate land prices in 1986
   - Simulate **division**
2. Use 1986 values to simulate land prices in 2006
   - Simulate **reunification**

TABLE VII

COUNTERFACTUALS[a]

	(1) $\Delta \ln QC$ 1936–1986	(5) $\Delta \ln QC$ 1986–2006
CBD 1	−0.836***	0.363***
	(0.052)	(0.041)
CBD 2	−0.560***	0.239***
	(0.034)	(0.028)
CBD 3	−0.455***	0.163***
	(0.036)	(0.031)
CBD 4	−0.423***	0.140***
	(0.026)	(0.021)
CBD 5	−0.418***	0.177***
	(0.032)	(0.032)
CBD 6	−0.349***	0.100***
	(0.025)	(0.024)
Counterfactuals	Yes	Yes
Agglomeration Effects	Yes	Yes
Observations	6,260	7,050
R^2	0.11	0.12

- Land prices are close to RF-results
- Agglomeration economies are important!

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- Goals of this lecture

  1. You should understand the model structure of ARSW
     - Simple CD productivity and utility,
     - Workers and productivity interact via commuting and agglomeration economies
     - Inelastic land market

- Goals of this lecture

  2. You should be able to estimate ARSW model
     - Straightforward recursive estimation using OLS/2SLS
     - *OR* more advanced GMM techniques
     - Gravity commuting equation is key!

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6. Summary

- **Goals of this lecture**

3. You should understand the pros and cons of applying the ARSW model
   – Model structure is quite restrictive and does not include other urban frictions
   – Workers and firms are unlikely to be fully rational
   – Estimation can take a long time
   + Combines a structural model with proper empirical identification
   + The model seems to replicate reality quite well
   + It relies on data sources that are widely available
   + The model estimates spatial friction/decay parameters directly from the data

Quantitative spatial economics

Applied Econometrics for Spatial Economics

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