The Economics of Density: Evidence from the Berlin Wall

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How do agglomeration and dispersion forces shape the internal structure cities?

- Research pioneered by Alonso (1964), Mills (1967), and Muth (1969) model of the mono-centric city.
- Lucas and Rossi-Hansberg (2002) solved for spatial model with endogenous firm location and agglomeration externalities under restrictive symmetric assumption.
- Brinkman (2016) estimates this model and studies transportation improvement.
- ARSW (2015) apply ideas from the trade literature (Eaton and Kortum, 2002) to develop and estimate a model of city structure that allows for asymmetric spatial development.

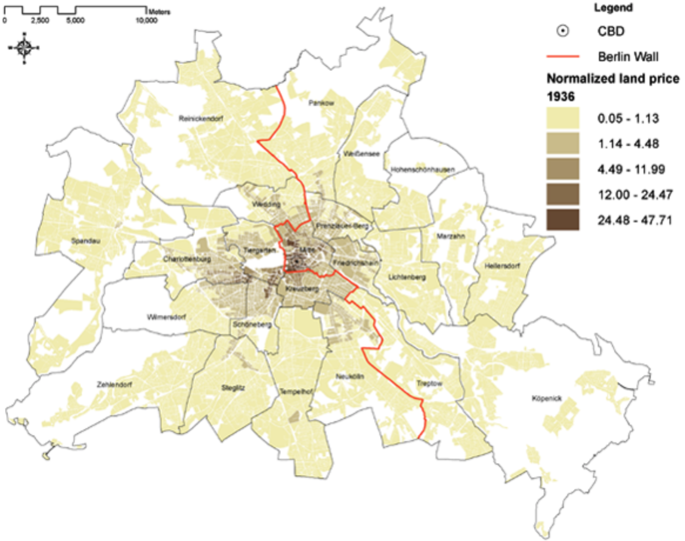
Contributions

- It is a tractable model that uses block-level data and allows for substantial spatial heterogeneity.
- In the spirit of trade models the paper ignores household heterogeneity (skills, gender, family size, wealth, etc).
- The paper exploits historical variation in city structure to identify the parameters that determine the endogenous amenities and agglomeration externalities.
- The estimation strategy deals with problems caused by multiplicity of equilibrium.
- The papers generates new empirical insights into the importance of agglomeration externalities.

Historical Background

- Berlin became the capital of a unified Germany in 1871.
- At the end of the Second World War Berlin was divided into four sectors. The Soviet sector became East Berlin (37% of population) and the capital of East Germany.
- The American, British and French sectors were combined into West Berlin (63% of population). The capital of West Germany was moved to Bonn.
- All economic and political ties between West and East Berlin were reduced by 1949, and severed in 1961 when the Berlin Wall was constructed.
- The Berlin Wall fell and East Germany collapsed in 1989.
- In 1990 Germany was unified and Berlin became the capital of a unified Germany again.

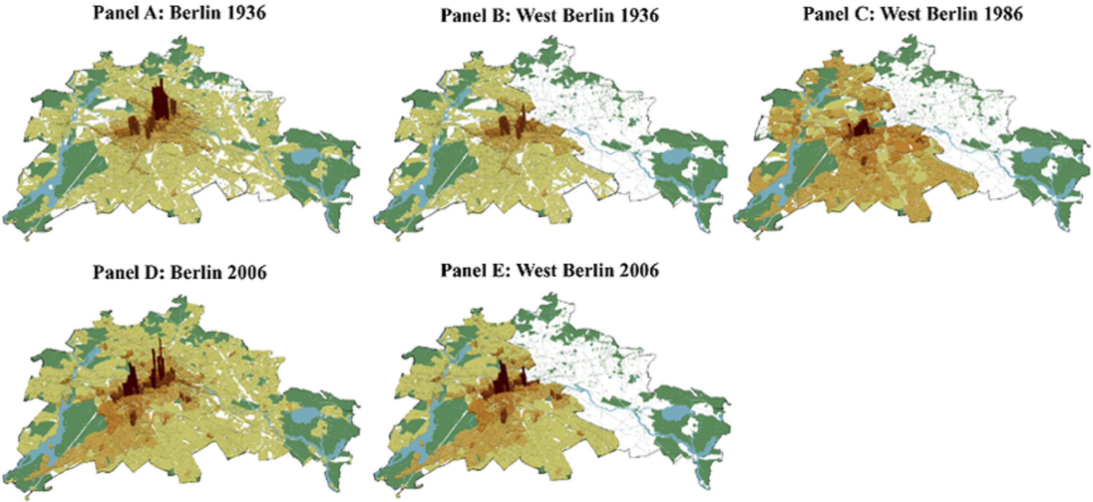
Pre-war Land Price Gradient in 1936



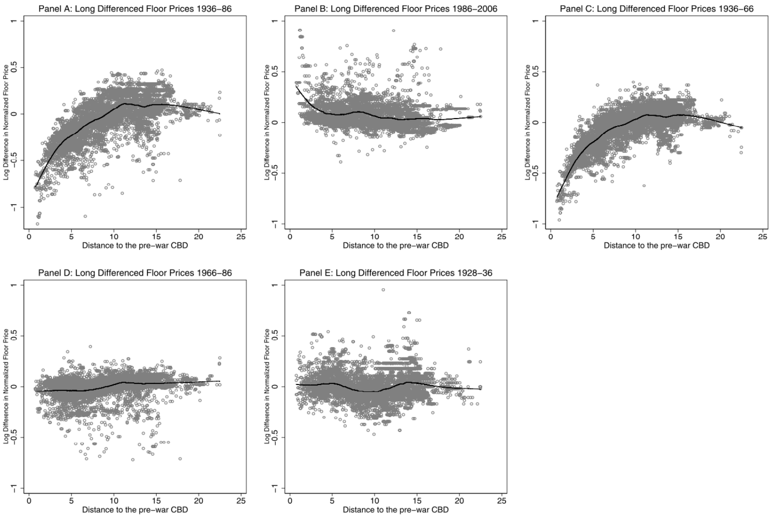
Data

- Three snapshots: 1936, 1986, 2006.
- To estimate the model, the authors collect the following data:
  - Employment at block level,
  - Number workers living in block,
  - Land prices (and therefore, using their model, floor prices) at block level,
  - Construct travel times between blocks using historical public transit and road networks,
  - Wages at block level,
  - Commuting time survey at district level.
- Supplemental data on local amenities, destruction during WWII, and urban renewal projects.

Spatial Price Evolution in Berlin



Land Price changes by Distance from Pre-war CBD



Notation

- City with discrete blocks indexed by i in $1, \ldots, S$.
- Endogenous share of floor space θ_i used for commercial purposes. (ignore)
- H is the mass of *ex-ante* identical workers.
- Reservation utility is exogenously given by $\bar{U}$. (plays no role in estimation)
- Simplifying assumption: only one price for floor space: q_i

Worker's Problem

Utility for worker o residing in block i and working in block j is given by:

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

where

- B_i is the neighborhood amenity.
- $d_{ij} = \exp(\kappa\tau_{ij}) \in \{1, \infty\}$ is an iceberg commuting cost. The Berlin Wall will cause $\kappa \to \infty$ for blocks across the border from each other.
- c_{ijo} is the consumption good and ℓ_{ijo} is residential floorspace.
- z_{ijo} is a Fréchet-shock with distribution $F(z_{ijo}) = \exp(-T_i E_j z_{ijo}^{-\varepsilon})$, where T_i and E_j determine the mean of the shock for residents of block i and workers of block j and ε determines the dispersion.
- Simplify $T_i = 1 = E_j$ since these means are really not identified.

Conditional Indirect Utility

Working in j and living i, indirect utility is given by:

$$u_{ijo} = \frac{z_{ijo}\, B_i\, w_j}{q_i^{1-\beta} d_{ij}}$$

where

- w_j is the wage at block j;
- q_i is the floorspace price; and
- the price of the consumption good is normalized to 1.

Conditional Choice Probabilities & Population Shares

Given the Frechet assumption, the probability of living in block i and working in block j given by:

$$\pi_{ij} = \frac{(d_{ij} q_i^{1-\beta})^{-\varepsilon} (B_i w_j)^{\varepsilon}}{\sum_{r=1}^{S} \sum_{s=1}^{S} (d_{rs} q_r^{1-\beta})^{-\varepsilon} (B_r w_s)^{\varepsilon}}$$

Block-level residential and worker populations are given by:

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

Production

Output for block j is given by:

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

where L_{Mj} is the commercial floorspace and a_j is the productivity shock.

Profit maximization implies that the optimal labor demand is given by:

$$H_{Mj} = \left(\frac{\alpha A_j}{w_j}\right)^{1/(1-\alpha)} L_{Mj}$$

The Price for Floor Space

- The zero-profit assumption implies that the bidding function for floor prices q_j is given by:

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

  It increases in A_j and decreases in w_j.
- We need the zero profit assumption because we do not observe output and cannot directly measure the residuals from the production function.

The Production Function of Floor Space

Cobb-Douglas production of floor space L_i

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

where

- M_i is capital at common price P,
- $M_i^{\mu} = \varphi_i$ is the density of development,
- K_i is land which can be purchased at price R_i

We will ignore the equilibrium conditions for floor space since it plays no role for estimation. It only matters for counterfactuals.

Industrial Agglomeration Forces

Now, endogenize agglomeration externalities as

$$A_j = a_j \; \Upsilon_j^{\lambda}$$

where a_j are exogenous production fundamental and Υ_j capture production externalities given by

$$\Upsilon_j = \sum_{s=1}^{S} \exp\left(-\delta \; \tau_{js} \; \frac{H_{Ms}}{K_s}\right)$$

where δ defines the spatial rate of decay and H_{Ms}/K_s is the worker employment density per unit of land.

Residential Agglomeration Forces

Residential endogenous amenities are defined as

$$B_i = b_i \, \Omega_i^{\eta},$$

where b_i captures fundamentals and Ω_i endogenous agglomeration externalities given by

$$\Omega_i = \sum_{r=1}^{S} \exp\left(-\rho \tau_{ir} \frac{H_{Rr}}{K_r}\right)$$

where ρ defines the spatial rate of decay and H_{Rr}/K_r is the residential employment density. Berlin wall causes $\delta \to \infty, \rho \to \infty$ for blocks across the border from each other.

Data

We observe for each block i:

- price of floor space, q_i,
- wages, w_i,
- workplace employment, H_{Ri},
- residential employment, H_{Mi},
- the amount of land use in each block, K_i, and
- residential and commercial floor space, L_i^R and L_i^C
- as well as the matrix of commuting distances between blocks, τ_{ij}.

Recovering Location Characteristics from Observed Outcomes

The following identification result is shown in Proposition 2 of the paper:

Given known values for the parameters $\{\alpha, \beta, \mu, \varepsilon, \kappa\}$ and the observed data there exists a unique vector of the unobserved location characteristics $\{\boldsymbol{w}, \boldsymbol{A}, \boldsymbol{B}, \boldsymbol{\varphi}\}$ that are consistent with the data being an equilibrium of the model.

Intuition I

We treat the parameters $\{\alpha, \beta, \mu, \varepsilon, \kappa\}$ as known.

1. Given observed workplace and residence employment, and our measures of travel times, worker commuting probabilities can be used to solve for unique wages consistent with commuting market clearing.

$$H_{Mj} = \sum_{i=1}^{S} \frac{(w_j/d_{ij})^{\epsilon}}{\sum_{s=1}^{S} (w_s/d_{is})^{\epsilon}} H_{Ri}$$

2. Given wages and observed floor prices, the firm cost function can be used to solve for the unique productivity consistent with zero profits.

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

Intuition II

3. Given wages, floor prices and residence employment shares, worker utility maximization and population mobility can be used to solve for the unique amenities consistent with residential choice probabilities:

$$\pi_{Ri} = \sum_{j=1}^{S} \pi_{ij}, \quad \text{where} \quad \pi_{ij} = \frac{(d_{ij} q_i^{1-\beta})^{-\varepsilon} (B_i w_j)^{\varepsilon}}{\sum_{r=1}^{S} \sum_{s=1}^{S} (d_{rs} q_r^{1-\beta})^{-\varepsilon} (B_r w_s)^{\varepsilon}}$$

4. Given observed land area, the implied demands for commercial and residential floor space can be used to solve for the density of development consistent with market clearing for floor space.

$$L_i^R + L_i^C = \varphi_i K_i^{1-\mu}$$

Gravity Equation

- They can determine the commuting parameters $\nu = \epsilon\ \kappa$ using only information on commuting probabilities.
- Note that substituting $d_{ij} = \exp(\kappa\tau_{ij})$ into the conditional choice prob and taking logs, we obtain the following gravity equation:

$$\ln \pi_{ij} \quad = \quad -\nu\tau_{ij} + FE_i + FE_j \ \ (+e_{ij})$$

- Where is error term coming from? Measurement error in these probabilities? (Inconsistent with previous assumption?!)
- Table III of the paper suggests that estimate of ν is about 0.07.

GMM Estimation: Inversion

- They use estimates of $\{\alpha, \beta, \mu\}$ taken from literature (See p 2167).
- The purpose is to estimate $\{\nu, \epsilon, \lambda, \delta, \eta, \rho\}$
- Given ν, ϵ we can use the inversion result from proposition 2 and recover $(A_1, ..., A_S, B_1, ..B_S)$ for each time period t=1936, 1986, 2006.
- Technically these inputed variables are functions of ν, ϵ, i.e

$$A_j \equiv A_j(\nu, \eta | data)$$
$$B_j \equiv B_j(\nu, \eta | data)$$

but we will suppress this dependence for notational convenience.

GMM Estimation: Moments

- Having recovered overall adjusted productivity and amenities, we can use our spillovers specification to decompose these variables into their two components of externalities and adjusted fundamentals:

$$
\begin{aligned}
\ln(A_{jt}) &= \ln(a_t) + \lambda \ln\left(\sum_{s=1}^{S} \exp\left(-\delta\ \tau_{jst}\ \frac{H_{Mst}}{K_{st}}\right)\right) + u_{jt} \\
\ln(B_{it}) &= \ln(b_t) + \eta \ln\left(\sum_{r=1}^{S} \exp\left(-\rho \tau_{irt} \frac{H_{Rrt}}{K_{rt}}\right)\right) + v_{it}
\end{aligned}
$$

  where error terms are defined as $\ln(a_{jt}) = \ln a_t + u_{jt}$ and $\ln(b_{it}) = \ln(b_t) + v_{it}$.
- The paper then differences the above equations across time.

GMM Estimation: Instruments

- Need to find instruments such that $E[\Delta u_{jt}|z_{jt}] = 0$ $E[\Delta v_{it}|z_{it}] = 0$.
- The first set of moment conditions impose that the changes in adjusted production and residential fundamentals are uncorrelated with the exogenous change in the surrounding concentration of economic activity induced by Berlin's division and reunification. (NLLS?)
- Another moment conditions requires that the total number of workers commuting for less than 30 minutes in the model is equal to the corresponding number in the data
- The last moment is formed based on the squared difference between the variances across districts of log adjusted wages in the model and log wages in the data.

Parameter Estimates

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)

[a]Generalized Method of Moments (GMM) estimates. Heteroscedasticity and Autocorrelation Consistent (HAC) standard errors in parentheses (Conley (1999)). * significant at 10%; ** significant at 5%; *** significant at 1%.

Interpreting the Parameter Estimates

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: $\delta = 0.3617$, $\rho = 0.7595$, $\kappa = 0.0148$.

Counterfactual Policy Analysis

- Two classes of counterfactuals: with and without externalities.
- Because the model with externalities allows for multiple equilibria, we need an equilibrium selection rule to do comparative static analysis.
- The authors claim that the "closest" equilibrium is chosen.

Counterfactual Change in Floor Prices

Table 1: Change in Floor Prices, 1936-1986

Distance to pre-war CBD	Data	Exogenous location characteristics	Endogenous location characteristics
<1.25 km	-0.800	-0.408	-0.836
	(0.071)	(0.038)	(0.052)
1.25-1.75 km	-0.655	-0.348	-0.560
	(0.042)	(0.017)	(0.034)
1.75-2.25 km	-0.543	-0.353	-0.455
	(0.034)	(0.022)	(0.036)
2.25-2.75 km	-0.436	-0.378	-0.423
	(0.022)	(0.021)	(0.026)
2.75-3.25 km	-0.353	-0.380	-0.418
	(0.016)	(0.022)	(0.032)
3.25-3.75 km	-0.291	-0.354	-0.349
	(0.018)	(0.018)	(0.025)

Analogous finding for reunification.

Conclusions

- Develop a tractable model of discrete city blocks to study the importance of residential externalities and industrial agglomeration effects.
- Parameter estimates fit into the existing literature on agglomeration and residential externalities.
- Some heroic assumptions are needed such time invariant parameters of preferences and technology.
- They find that is is necessary to consider agglomeration spillovers to explain observed changes in Berlin after division and reunification.