A Quantitative Framework for Evaluating the Impact of Urban Transport Improvements

Gabriel M. Ahlfeldt
London School of Economics and CEPR
Stephen J. Redding
Princeton University, NBER and CEPR
Daniel M. Sturm
London School of Economics and CEPR

Motivation

- Organization of economic activity within cities is crucially dependent on the transportation of people
- The London Underground
  - Handles 3.5 million passenger journeys a day
  - Trains travel 76 million kilometers each year (200 times distance between earth and moon)
- Public policy typically involved in transport infrastructure
- Transport for London
  - Annual operating expenditure of around £6bn in 2014-15
  - £1.7bn direct government grants
  - Remainder largely funded by charges to users
  - Annual capital investment program of around £1.7bn
- Determining the economic impact of transport infrastructure investments is of public policy relevance

Challenges

- Economic evaluation of transport infrastructure improvements is subject to theoretical and empirical challenges
- A growing reduced-form literature provides quasi-experimental evidence on the impact of transport improvements
  - Cannot identify spatial equilibrium effects
  - Cannot distinguish reallocation from creation of economic activity
  - Typically abstracts from heterogeneous treatment effects
  - Substitution between alternative modes of transport
- Most existing theoretical models of internal city structure make simplifying assumptions such as monocentricity or symmetry
  - Locations within cities differ substantially in productivity, amenities and access to transport infrastructure
- Evaluations of transport infrastructure often
  - Adopt partial equilibrium cost-benefit approaches
  - Assume mechanical input-output relationships

Challenges

- Substantial uncertainty surrounding existing estimates of the impact of transport infrastructure improvements

KPMG to face MPs again over HS2 report

Consultants to defend forecast of £15bn economic boost following claims that calculation was 'essentially made up'

  - "The KMPG partners behind the report said their work was robust and stood by the £15bn forecast, despite admitting it did not have a firm statistical foundation."
  - "Henry Overman, professor of economic geography and a former adviser to HS2 Ltd, said the figure was arrived at using a procedure that was 'essentially made up'."

This Paper

- Quantitative framework for evaluating urban transport improvements building on Ahlfeldt, Redding, Sturm & Wolf (2015)
- Capture first-order features of the data such as locations differ in
  - Production and residential fundamentals
  - Production and residential externalities
  - Inelastic supply of land and commuting costs
  - Transportation infrastructure
- Parsimonious and tractable and requires only data on
  - Land prices and area
  - Employment by workplace and employment by residence
  - Travel times
- We use our framework for a quantitative evaluation of the U5 underground line in Berlin (under construction)
  - Relative land values
  - Reallocation of workplace and residence employment
  - Aggregate effects (e.g. city size and productivity)

Related Literature

- Size and internal structure of cities
  - Alonso-Mills-Muth, Fujita & Ogawa (1982), Fujita & Krugman (1995), Lucas & Rossi-Hansberg (2002), Ahlfeldt et al. (2015), Arkolakis et al. (2015)
- Agglomeration economies
  - Fujita et al. (1999), Duration and Puga (2004), Rosenthal and Strange (2004), Moretti (2004), Combes et al. (2010), Greenstone et al. (2010), Kline and Moretti (2014), Arkolakis and Allen (2014)
- Transport infrastructure and development
  - McDonald & Osuji (1995), Baum-Snow & Kahn (2005), Gibbons & Machin (2005), Baum-Snow(2007), Michaels (2008), Donaldson (2014), Duranton & Turner (2012), Donaldson & Hornbeck (2013), Faber (2014), Fajgelbaum & Redding (2014), Baum-Snow et al (2014)
- Economics of transportation
  - Beckman et al. (1956), Fogel (1964), McFadden (1974), Parry and Small (2005, 2009), Small, Winston and Yan (2005), Small and Verhoef (2007), Anderson (2014), Couture et al. (2014)

Road Map

- Theoretical Model
- Data and Calibration
- Results

Consumption

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

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

  - Consumption of the final good (c_{ij}), chosen as numeraire ($p_i = 1$)
  - Residential floor space (ℓ_{ij})
  - Residential amenity B_i
  - Commuting costs $d_{ij} = e^{\kappa \tau_{ij}}$
  - Idiosyncratic shock z_{ijo} that captures idiosyncratic reasons for a worker living in block i and working in block j
- Indirect utility

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

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

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

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

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

- Commuting market clearing

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

Residential Amenities

- Expected utility of moving to the city

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

- Residential choice probabilities:

$$\frac{B_i T_i^{1/\epsilon}}{\bar{U}/\gamma} = \left(\frac{H_{Ri}}{H} \right)^{\frac{1}{\epsilon}} \frac{Q_i^{1-\beta}}{W_i},$$

$$W_i = \left[\sum_{s=1}^{S} E_s \left(w_s / d_{is} \right)^{\epsilon} \right]^{1/\epsilon}, \qquad d_{is} = e^{\kappa \tau_{is}}.$$

- Solve for adjusted residential amenities ($\tilde{B}_i$):

$$\ln\left(\frac{\tilde{B}_i}{\bar{\tilde{B}}} \right) = \frac{1}{\epsilon} \ln\left(\frac{H_{Ri}}{\bar{H}_R} \right) + (1-\beta) \ln\left(\frac{Q_i}{\bar{Q}} \right) - \ln\left(\frac{W_i}{\bar{W}} \right),$$

Productivity

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

$$X_j = A_j H_{Mj}^{\alpha} L_{Mj}^{1-\alpha}, \qquad 0 < \alpha < 1,$$

- Profit maximization and zero profits:

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

- Solve for adjusted productivity ($\tilde{A}_i$):

$$\ln\left(\frac{\tilde{A}_{it}}{\bar{\tilde{A}}_t}\right) = (1-\alpha)\ln\left(\frac{Q_{it}}{\bar{Q}_t}\right) + \alpha\ln\left(\frac{\tilde{w}_{it}}{\bar{\tilde{w}}_t}\right),$$

General Equilibrium

- Model parameters: $\{\alpha, \beta, \mu, \epsilon, \kappa\}$
- Exogenous location characteristics: $\{\boldsymbol{T}, \boldsymbol{E}, \boldsymbol{A}, \boldsymbol{B}, \boldsymbol{\varphi}, \boldsymbol{K}, \boldsymbol{\xi}, \boldsymbol{\tau}\}$
- Equilibrium vector: $\{\boldsymbol{\pi_M}, \boldsymbol{\pi_R}, \mathbf{Q}, \boldsymbol{q}, \boldsymbol{w}, \boldsymbol{\theta}\}$ and total population H

Proposition

Assuming exogenous, finite and strictly positive location characteristics $(T_i \in (0, \infty), E_i \in (0, \infty), \varphi_i \in (0, \infty), K_i \in (0, \infty), \xi_i \in (0, \infty),$ $\tau_{ij} \in (0, \infty) \times (0, \infty))$*, and exogenous, finite and non-negative final goods productivity* $A_i \in [0, \infty)$ *and residential amenities* $B_i \in [0, \infty)$*, there exists a unique equilibrium vector* $\{\boldsymbol{\pi_M}, \boldsymbol{\pi_R}, H, \mathbf{Q}, \boldsymbol{q}, \boldsymbol{w}, \boldsymbol{\theta}\}$.

▸ More

Introducing Agglomeration Forces

- Allow productivity to depend on
  - Exogenous production fundamentals
  - Endogenous production externalities

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

- Allow amenities to depend on
  - Exogenous residential fundamentals
  - Endogenous residential externalities

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

Recovering Location Characteristics

- Adjusted location characteristics

$$\begin{aligned} \tilde{A}_i &= A_i E_i^{\alpha/\epsilon}, & \tilde{a}_i &= a_i E_i^{\alpha/\epsilon}, \\ \tilde{B}_i &= B_i T_i^{1/\epsilon} \zeta_{Ri}^{1-\beta}, & \tilde{b}_i &= b_i T_i^{1/\epsilon} \zeta_{Ri}^{1-\beta}, \\ \tilde{w}_i &= w_i E_i^{1/\epsilon}, \\ \tilde{\varphi}_i &= \tilde{\varphi}_i \left(\varphi_i, E_i^{1/\epsilon}, \xi_i \right), \end{aligned}$$

Proposition

(i) *Given known values for the parameters* $\{\alpha, \beta, \mu, \epsilon, \kappa\}$ *and the observed data* $\{\mathbb{Q}, \boldsymbol{H_M}, \boldsymbol{H_R}, \boldsymbol{K}, \boldsymbol{\tau}\}$*, there exist unique vectors of the unobserved location characteristics* $\{\tilde{\boldsymbol{A}}^*, \tilde{\boldsymbol{B}}^*, \tilde{\boldsymbol{\varphi}}^*\}$ *that are consistent with the data being an equilibrium of the model.*
(ii) *Given known values for the parameters* $\{\alpha, \beta, \mu, \epsilon, \kappa, \lambda, \delta, \eta, \rho\}$ *and the observed data* $\{\mathbb{Q}, \boldsymbol{H_M}, \boldsymbol{H_R}, \boldsymbol{K}, \boldsymbol{\tau}\}$*, there exist unique vectors of the unobserved location characteristics* $\{\tilde{\boldsymbol{a}}^*, \tilde{\boldsymbol{b}}^*, \tilde{\boldsymbol{\varphi}}^*\}$ *that are consistent with the data being an equilibrium of the model.*

Road Map

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Data

- Data on land prices, workplace employment, residence employment and bilateral travel times
- Data for Greater Berlin in 2006
- Data at the following levels of spatial aggregation:
  - Districts (“Bezirke”), 12 post-2001 reform
  - Statistical blocks, 15,937
  - Around 254 million bilateral connections
- 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
- Data on employment by residence and workplace
- Geographical Information Systems (GIS) data on:
  - Land area and geographical boundaries
  - U-Bahn (underground) and S-Bahn (suburban) lines and stations, bus and tram network

Parameters

- Assumed parameters from Ahlfedlt, Redding, Sturm & Wolf (2015)

Parameter	Definition	Value
$(1-\beta)$	Consumer expenditure residential floor space	0.25
$(1-\alpha)$	Firm expenditure commercial floor space	0.20
$(1-\mu)$	Share of Land in Construction Costs	0.25
ν	Semi-elasticity Commuting Flows and Travel Times	0.07
ϵ	Fréchet Shape Parameter Commuting Decisions	6.83

Parameter	Definition	Value
λ	Production Externalities Elasticity	0.05
δ	Production Externalities Decay	0.05
η	Residential Externalities Elasticity	0.05
ρ	Residential Externalities Decay	0.05

Road Map

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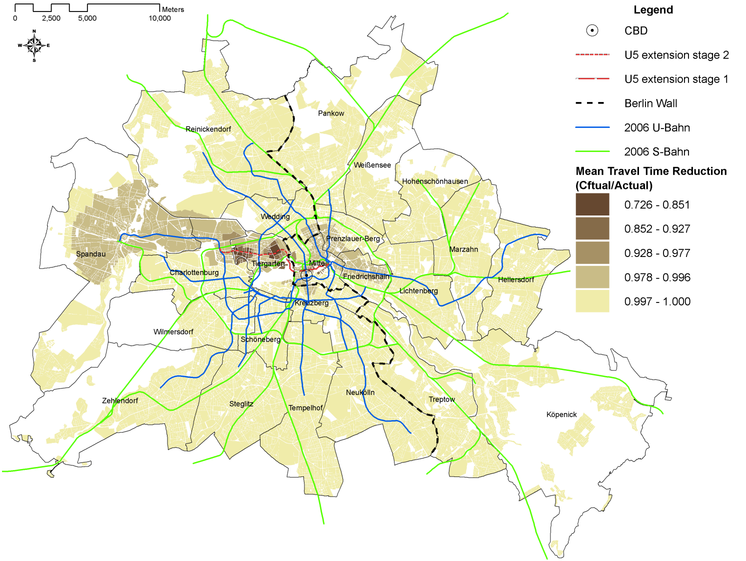
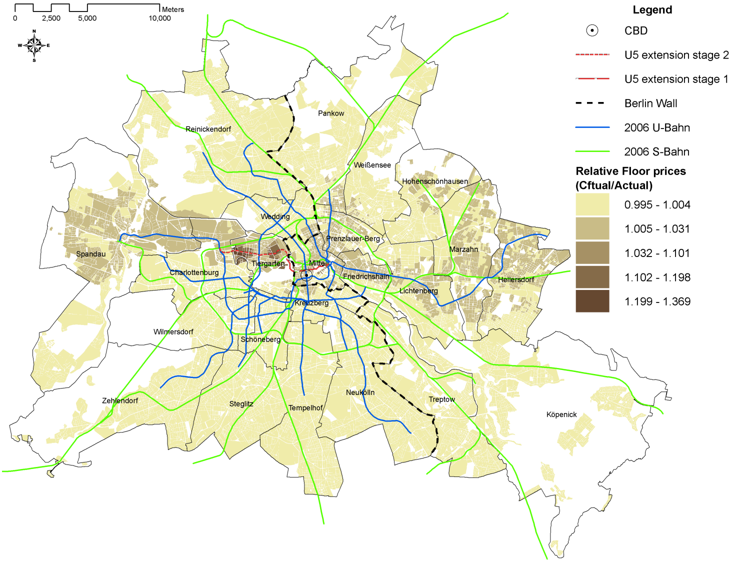
Mean Relative Travel Time Reduction



Relative Increase Floor Prices



Aggregate Effects (Immobile Population)

	Counterfactual / Actual	
Percentage Increase	Exogenous	Endogenous
Utility	0.22%	0.33%
Net City Employment	0%	0%
Value Total City Income	0.02%	0.11%
Value Total City Land Rents	0.02%	0.11%
Total Factor Productivity	0.03%	0.13%
Sum of Absolute Changes as Percent of Aggregate	Exogenous	Endogenous
Workplace Employment	0.70%	0.92%
Residence Employment	0.36%	0.44%
Output	0.58%	0.78%

Aggregate Effects (Mobile Population)

	Counterfactual / Actual	
Percentage Increase	Exogenous	Endogenous
Utility	0%	0%
Net City Employment	0.55%	1.06%
Value Total City Income	0.46%	1.01%
Value Total City Land Rents	0.46%	1.01%
Total Factor Productivity	0.03%	0.18%
Sum of Absolute Changes as Percent of Aggregate	Exogenous	Endogenous
Workplace Employment	0.58%	1.06%
Residence Employment	0.55%	1.06%
Output	0.49%	1.01%

Aggregate Effects (Mobile Population)

Variable	Exogenous	Endogenous
Berlin GDP (2012 1,000s Euro)	105,148,850	
Increase GDP (2012 1,000s Euro)	479,421	1,056,767
Increase Land Rents (2012 1,000s Euro)	39,952	88,064
NPV Increase GDP (60 year, 3%)	13,747,679	30,303,380
NPV Increase GDP (60 year, 5%)	9,554,528	21,060,609
NPV Increase GDP (60 year, 10%)	5,257,890	11,589,726
NPV Increase Land Rents (60 year, 3%)	1,145,640	2,525,282
NPV Increase Land Rents (60 year, 5%)	796,211	1,755,051
NPV Increase Land Rents (60 year, 10%)	438,157	965,811
Construction U5 (2012 1,000s Euro)	650,000	
Operating U5 (2%, 2012 1000s Euro)	13,000	
NPV Total Cost (3% discount rate)	1,022,782	
NPV Total Cost (5% discount rate)	909,081	
NPV Total Cost (10% discount rate)	792,573	

Conclusion

- Determining the economic impact of transport infrastructure improvements is an important public policy issue
- Evaluations of the economic impact of such transport improvements face a number of theoretical and empirical challenges
- We develop a theoretical framework for undertaking counterfactuals for the spatial equilibrium impact of transport improvements
- Rich spatial structure with locations differing in productivity, amenities and access to transport infrastructure
- Framework remains tractable and amenable to quantitative analysis
- Find substantial effects of empirically plausible transport infrastructure improvements on land rents, internal city structure and aggregate city economic activity

Thank You