Commuting, Labor, & Housing Market Effects of Mass Transportation: Welfare and Identification

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January 2019

Question: What are the welfare effects of urban rail infrastructure in car-oriented Los Angeles?

1. Establish the causal effect of rail transit on commuting flows between locations connected by LA Metro
2. Develop and estimate parameters of (relatively) simple quantitative, spatial GE model of internal city structure
   - Novel identification for elasticities (common in urban EG lit)
   - Disentangle commuting effect of transit from other margins
3. Quantify welfare effects of rail transit in Los Angeles

Why transit infrastructure?

Important **economic consequences**

- Trade between cities & growth (Fogel 1964; Donaldson 2018)
- Commuting within cities, urban form, neighborhood growth (Baum-Snow 2007; Bento et al. 2003; Gibbons & Machin 2005; Gonzalez-Navarro & Turner 2016)

Households care: high commuting costs limit residential/job access

- Households spend 10-15% of income & 220 hrs/yr commuting
- Increasing congestion (commutes times up 230% since 1985)

Rail is beneficial but expensive **policy option**

- Light rail is 10-20x cost of roadway, subway is 30-100x
- Large US cities on a transit building spree!
- US cities not dense, less monocentric (Anas, Arnott, Small 1998)
  - Especially Western/Sunbelt cities

Measuring the benefits of transit, I. Hedonics

Large literature studies indirect effects of commuting technology

- Housing/land prices, density, local income
- Hedonic DiD usually finds transit premium (Ahlfeldt 2009; Baum-Snow & Kahn 2005; Bowes & Ihlenfeldt 2001; Chen & Walley 2012; Gibbons & Machin 2005)
- Studies about LA (Redfearn 2009; Schuetz 2015; Schuetz, Giuliano, Shin 2018)

Hard to interpret or translate to welfare

i) Does not *directly* account for commuting
   - Agents make joint decision on where to live **and work**
   - Commuting can shift multiple channels (local characteristics)
   - What do asset prices represent? Expectations?

ii) General equilibrium effects
   - Even untreated locations are influenced

Measuring the benefits of transit, II. Market Access

Rise in quantitative spatial eq. models within city (Ahlfeldt, Redding, Sturm, Wolf 2015; Tsivanidis 2018)

- Effect at i is weighted average of change in travel time from ij and characteristics of j
- Can be implemented with (relatively) little data
- GE and counterfactuals (Donaldson & Hornbeck 2016)

Very (too?) model-dependent implementation (to evaluate urban trans.):

i) Model market access rather than commuting
   - Commuting typically not well measured well
   - Market access infers commuting from proximity

ii) Recover wages at place of work from commuting flows
   - Bakes in size/centrality

iii) Borrows parameters from trade literature

Contributions

1. Bring **new data** to bear on this topic
   - Panel of census of commuting flows between tracts
   - Average wage at place of work
2. Provide first direct evidence of **transit's effect on commuting**
   - Use panel data design with historical data to select controls
   - 'Sufficient' statistic to measure transportation impacts
3. Describe quantitative **spatial GE model** of city structure
   - Adapt ARSW (2015) to different data environment
4. Develop new **identification strategy** for key structural parameters
   - Clarify use of Bartik shocks within city
5. Use model to look for non-commuting effects
6. Calculate welfare: Does transit pass a **cost-benefit** test?
7. Assess some common methods in urban economic geography

Summary of Results

Increases **commuting** between close-connected tracts 15% by 2000

- Additional commuting growth by 2015

There is a lot of **heterogeneity** in where people want to live

- Within cities, commuting is lumpy (even after controlling for geography)
- Transit impacts correspond to large utility gains

Little evidence of non-commuting effects

- Small decrease in auto congestion nearby

Transit is **not cost-effective** after first decade or two, but may become cost-effective over **longer horizons**

1. Data and setting
2. Transit's effect on commuting flows (gravity)
3. Quantitative urban model with commuting
4. Structural identification and estimated elasticities
5. Non-commuting effects and welfare
6. Habituation and network returns
7. Assess quantitative economic geography models within cities

Setting: Commuting in Los Angeles

Setting: Los Angeles in 1990 and 2000

- No rail → 47 stations on 4 lines by 2000
- Historically automobile-oriented (Kelker, De Leuw and Co. 1925)
- Polycentric employment patterns (McMillen 2001; Redfearn 2007)

1963 Last LA area street/trolleycar shuts down
1980 Referendum over enabling sales tax (Prop A)
1990 SCRTD Blue line opens (July, downtown 2/1991)
1993 SCRTD becomes LACMTA, Red line opens
1995 LACMTA Green line opens
1996 LACMTA Red line expands
1999 LACMTA Red line expands
2000 Total: 3(4) lines, 47 stations
2015 Total: 6 lines, 81 stations ▸ Ridership

Data

Data: Census Transportation Planning Package (1990, 2000)

- Develop **panel** of all **bilateral commuting flows** for LA (tract-tract)
- Median wage at place (tract) of work

Other data sources

- LEHD LODES (2002, 2015) – not directly comparable to CTPP
- NHGIS/NCDB (1970-1990: housing values, covariates)
- IPUMS (wage shocks, commuting stats)
- LACMTA
- SCAG (misc. GIS data, zoning, land use)
- Historical document: Kelker, De Leuw and Company (1925)

  Comprehensive Rapid Transit Plan for the City and County of Los Angeles

Standardize main analysis to **1990 geographies**; counties:

- Los Angeles, Orange, Riverside, San Bernardino, Ventura

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Commuting effect of transit

Isolate effect of transit connection (T) on commuting from other margins

- **Outcome:** flow between residence i and workplace j

$$N_{ijt} = N_{ijt}\left(\underbrace{\theta_{it}(T_{it})}_{\text{Residential}}, \underbrace{\omega_{jt}(T_{jt})}_{\text{Workplace}}, \underbrace{\tau_{ijt}(T_{it}, T_{jt})}_{\text{Commuting costs}}\right)$$

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Log-linear specification with fixed effects:

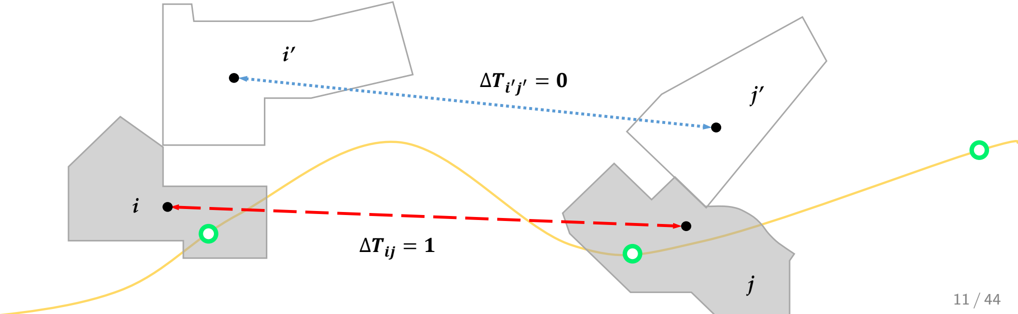
$$\ln(N_{ijt}) = \theta_{it} + \omega_{jt} + \delta_{ij} + T'_{ijt}\boldsymbol{\lambda} + \varepsilon_{ijt}$$

- FEs capture **non**-commuting effects of transit (e.g., on amenities)
- T_{ijt} is treatment – implicitly includes transit characteristics
- Three mutually exclusive definitions of treatment:
    i. O&D contain station
    ii. O&D <250m from station (if not i.)
    iii. O&D <500m from station (if not i. or ii.)

Identification: Gravity DinD (panel) estimator

$$\ln(N_{ijt}) = \theta_{it} + \omega_{jt} + \delta_{ij} + T'_{ijt}\boldsymbol{\lambda} + \varepsilon_{ijt}$$

- Origin-by-year, Destination-by-year FEs control for station location
- Pair-fixed effects capture time-invariant confounding factors (e.g., distance, completed highways connections)



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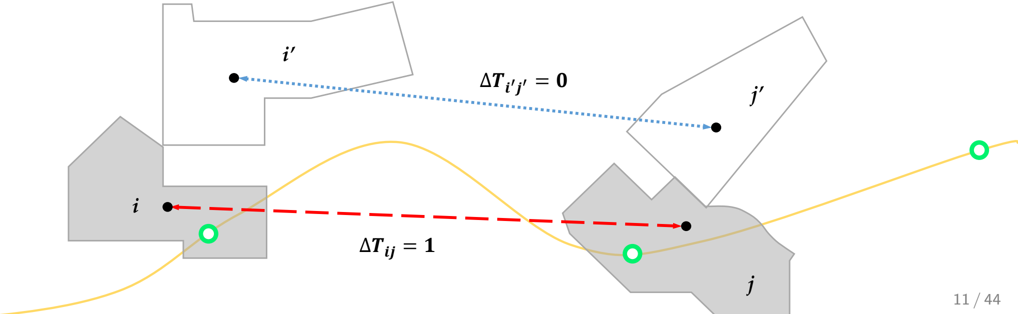
Identification: counterfactual commuting evolves in similar way between treated pairs & control pairs on average

- *Threat (e.g.):* Planners place lines along routes that would have experienced differential commuting changes



Controls for commuting flow DiD

1) Historical subway plan (Kelker, de Leuw and Co. 1925) ▸ Map

2) Red Car routes, Pacific Electric Railroad streetcar lines

3) Adjacencies (Dube, Lester, & Reich 2010)

Arguments:

- Many control pairs contain a treated 'end' (O or D)
- Similar evolution of built environment (Brooks & Lutz 2016)
- Placement: Routes connect political power centers (Elkind 2014)
- Timing: Staggered rollout based on political expediency

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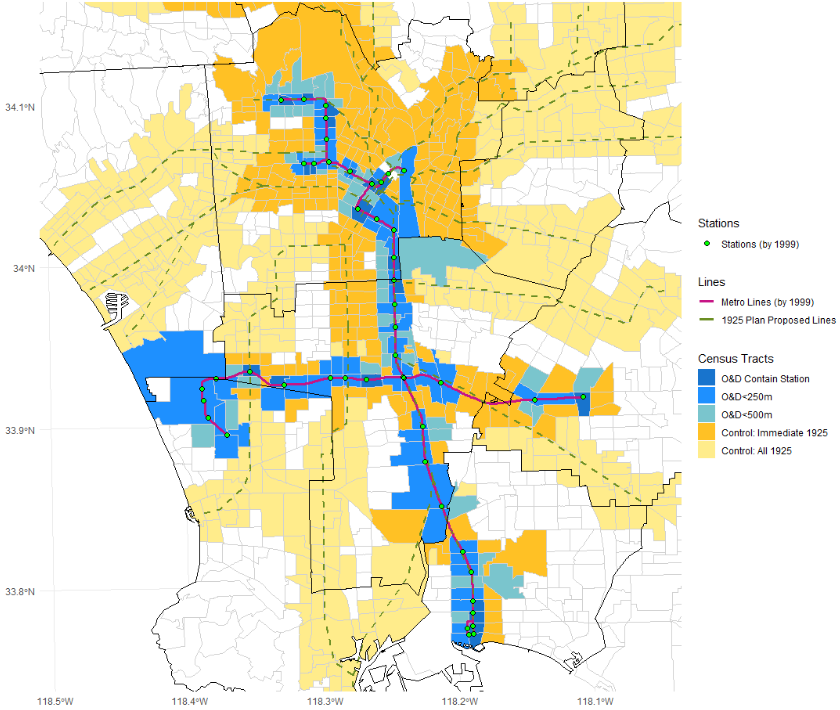
Pre-trends? Cannot directly test, but ...

- Parallel trends in pop/hous, but other tract chars. change Pre-trend 1
- Mostly parallel pre-trends in residential commuting Pre-trend 2
- Add Subcounty-by-Year FEs (Sbcty-x-Sbcty-x-Yr in gravity model)


34.1°N
34°N
33.9°N
33.8°N
118.5°W
118.4°W
118.3°W
118.2°W
118.1°W
Stations
Stations (by 1999)
Lines
Metro Lines (by 1999)
1925 Plan Proposed Lines
Census Tracts
O&D Contain Station
O&D<250m
O&D<500m
Control: Immediate 1925
Control: All 1925

Effects of stations on commuting flows; 1990–2000

	(1)	(2)	(3)	(4)	(5)
Subway Plan (All) Sample					
O & D contain station	0.127**	0.147**	0.152**	0.162**	0.146**
	(0.044)	(0.044)	(0.044)	(0.046)	(0.044)
O & D <250m from station			0.115*	0.122*	0.101*
			(0.049)	(0.050)	(0.051)
O & D <500m from station		0.054	0.018	0.023	0.013
		(0.035)	(0.044)	(0.042)	(0.042)
N	74046	74046	74046	74040	74040
Tract Pair FE	Y	Y	Y	Y	Y
POW-X-Yr FE	Y	Y	Y	Y	Y
RES-X-Yr FE	Y	Y	Y	Y	Y
Sbcty-X-Sbcty-X-Yr FE	-	-	-	Y	Y
Highway Control	-	-	-	-	Y

Metro **increases commuting by 15% (10%)** between connected tracts

- Consistent across various strategies & PPML
- Effect spatially concentrated near workplaces ▸ OD-distance interactions
- Effect only along same line (transfers not important) ▸ Line switching

Spillover effect on (non-transit) commute time

Transit often motivated as congestion relief

- Anderson (2014): *short run* 13% increase in travel speed b/c transit
  - Calibrates *long run* effect at about 1/2

Fundamental Law of Congestion – eqbm. travel in congested areas grows in lock-step with capacity expansions (Downs 1962)

$\Rightarrow$ Increasing capacity does not increase travel speed

$\Rightarrow$ Transit's purpose is to enable city growth

- Applies to any aggregate outcome (e.g., pollution)
  - even if per capita rate/dose improves

Evidence:

- Spending has very small effect on cong. costs (Winston & Langer 2006)
- On highways within MSAs, it holds (Duranton & Turner 2011)
- Public transit does not decrease highway travel (Duranton & Turner 2011)
- Travel demand increases exceed capacity increase (Hsu & Zhang 2014)
- Some persistence in reduced congestion near lines (Gu et al. 2018)

Spillover effect on (non-transit) commute time

	τ_{ijt}^{All}			$\ln(\tau_{ijt}^{All})$			τ_{ijt}^{Car}	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Within 2km of tracks	-1.277**	-1.243**	-0.748	-0.032*	-0.033*	-0.026	-1.417*	-0.766
	(0.402)	(0.426)	(0.481)	(0.013)	(0.014)	(0.016)	(0.631)	(0.719)
Within 4km of tracks	-0.305	-0.304	0.050	-0.006	-0.006	-0.002	0.150	0.293
	(0.364)	(0.364)	(0.398)	(0.012)	(0.012)	(0.013)	(0.556)	(0.612)
Control Network	All	All	All	All	All	All	All	All
Tract Pair FE	Y	Y	Y	Y	Y	Y	Y	Y
POW-X-Yr FE	Y	Y	Y	Y	Y	Y	Y	Y
RES-X-Yr FE	Y	Y	Y	Y	Y	Y	Y	Y
Near station control	-	Y	Y	-	Y	Y	-	-
Sbcty-X-Sbcty-X-Yr FE	-	-	Y	-	-	Y	-	Y
Highway Control	-	-	Y	-	-	Y	-	Y
N	311340	311340	310904	311314	311314	310878	96098	95884

Some evidence of small (∼3-5%) spillover effect on auto commute time

- About 1/4 of short run effect
- No effect on quantity/flow – use time to bound effect

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What about welfare? Model summary

To translate into welfare, need **quantitative, spatial GE model**

- HH dual location choice (similar to Ahlfeldt et al. 2015)
- **Bonus 1!** Generates reduced form commuting flow equation
- **Bonus 2!** Can test for other margins of effects from subway

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Locations: N locations (census tracts) in city

- Each containing a labor market, and a housing market
- Described by exogenous supply/demand fundamentals

Agents: Three types of agents (all massless)

- Workers/HHs: decide where to live and where to work
- Firms: hire workers
- Builders: use land & materials to produce housing

Model: Household problem

HH o choose place of residence (work) i (j), consumption, and housing:

$$\max_{\mathcal{C},H,ij} \frac{\nu_{ijo}}{\delta_{ij}} \left(\frac{\mathcal{C}}{\zeta}\right)^{\zeta} \left(\frac{H}{1-\zeta}\right)^{1-\zeta} \quad \text{s.t.} \quad \mathcal{C} + Q_i H = W_j$$

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$$\nu_{ijo} \sim \text{Fréchet}(\epsilon, \Lambda_{ij}) \qquad F_{ij}(\nu) = e^{-\Lambda_{ij}\nu^{-\epsilon}}$$

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$$\nu_{ijo} \sim \text{Fréchet}(\epsilon, \Lambda_{ij}) \qquad F_{ij}(\nu) = e^{-\Lambda_{ij}\nu^{-\epsilon}}$$

- $\Lambda_{ij} = B_i E_j D_{ij}$ describes *absolute advantage*
  - B_i: residential amenity
  - E_j: work amenity
  - D_{ij}: average utility of commute (net of time)
- δ_{ij} travel cost of commuting between i and j

Shape parameter is key: ϵ

- Homogeneity of location preference (higher=more homogenous)
- ϵ strength of *comparative advantage*

Model: Household problem (and gravity)

Share residing at i and POW j is $(\Pr[v_{ij} \geq \max\{v_{rs}\}; \forall rs])$

$$\pi_{ij} = \frac{B_i E_j D_{ij} W_j^{\epsilon} \left(\delta_{ij} Q_i^{1-\zeta}\right)^{-\epsilon}}{\sum_{r=1}^{N} \sum_{s=1}^{N} B_r E_s D_{rs} W_s^{\epsilon} \left(\delta_{rs} Q_r^{1-\zeta}\right)^{-\epsilon}}$$

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Commuting flows: $\pi_{ij} N_t = N_{ijt}$, (N_t is aggregate pop.)

$$\ln(N_{ijt}) = -g_{1t} + \underbrace{\epsilon \ln(W_{jt}) + \ln(E_{jt})}_{\omega_{jt}} - \underbrace{\epsilon(1-\zeta)\ln(Q_{it}) + \ln(B_{it})}_{\theta_{it}} - \underbrace{\delta_{ij} + \ln(D_{ijt})}_{\delta_{ij} + \lambda T_{ijt} + \varepsilon_{ijt}}$$

Closing the model

Production: Cobb-Douglas in labor and land

- Perfect competition, produce nationally trade good
- Multiplicatively separable productivity term A_i, can add agglomeration, etc.

$$W_i = \alpha A_i \left(L_i^Y / N_i^Y \right)^{1-\alpha}$$

Housing produced using land, materials

- Perfect competition among builders, Cobb-Douglas production
- No interaction with other land uses (restrictive zoning)
  - No evidence of any zoning changes
- Multiplicatively separable housing efficiency C_i

$$Q_i = C_i (H_i / L_i^H)^{\psi}$$

Equilibrium

City nested in closed economy with fixed population

- No spatial arbitrage condition
- Labor and housing markets clear
- Variant – open economy: population adjusts

Result 1: Equilibrium characterization
An equilibrium always exists, and is unique if

- *Housing supply elasticity is high enough*
- *Location preference is heterogeneous (small) enough*

Result 2: Recovering fundamentals (model inversion)
Given parameters and data, there exists a unique set of fundamentals $\mathbf{A}$, $\mathbf{C}$, *and* $\mathbf{\Lambda}$ $(\Lambda_{ij} = B_i E_j D_{ij})$ *consistent with a model equilibrium.*

Welfare

Simulate results of X', with $\hat{X} = X'/X$

- Plug in relative changes in primitives A, B, C, D, E
- Counterfactuals only require levels of wage, commuting
  - Both typically unobserved
- Find new fixed point of the system

Change in welfare in closed economy:

$$\ln \hat{\bar{U}} = \frac{1}{\epsilon} \ln \left(\frac{\hat{B}_i \hat{E}_j \hat{D}_{ij} \hat{W}_j^{*\,\epsilon} \hat{Q}_i^{*\,-\epsilon(1-\zeta)}}{\hat{\pi}_{ij}^{*}} \right)$$

Robustness and technical notes

- Eqbm. only defined for $\epsilon > 1$
  - Can show that above expression is equivalent to multinomial logit
  - Equivalent formulation valid for $\epsilon > 0$
- Land Use; Agglomeration

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Model summary: Rosen-Roback with commuting

Labor $$\underbrace{\ln(W_{jt})}_{\text{Wage}} = \tilde{\alpha} \ln\left(\sum_r N_{rjt}\right) + \underbrace{\ln(A_{jt})}_{\text{Productivity}}$$

Housing $$\underbrace{\ln(Q_{it})}_{\text{H. Price}} = \psi \ln\left(\sum_s N_{ist} W_{st}\right) + \underbrace{\ln(C_{it})}_{\text{H. Eff.}}$$

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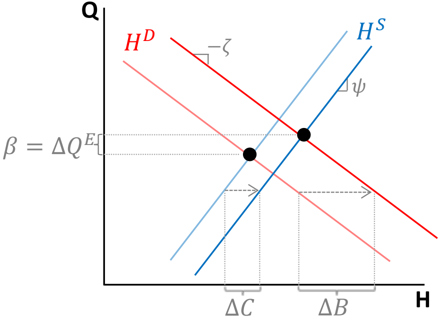
Describes

1. **Slopes**: ϵ, ψ, $\epsilon\tilde{\zeta}$, $\tilde{\alpha}$
   - Local elasticities
2. **Shifts**: Changes to primitives A, B, C, D, E
   - Effects of transit



Identification of ϵ

ϵ is key: *Location preference homogeneity* $\equiv$ ***Local labor supply elast.***

- **Extensive** margin of labor supply (HH's provide 1 unit of labor)
- Existing estimates use cross-sectional variation or calibrate (ARSW 2015; Monte, Redding, & Rossi-Hansberg 2018; Allen, Arkolakis, & Li 2018)
- Wage typically unobserved $\Rightarrow$ specter of simultaneity

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Here, two special ingredients:

1. Panel of median **wage at place (tract) of work**
2. Employment by industry at place (tract) of work

Bartik

Construct local variant of shift-share demand shock (Bartik 1991):

- Pred. growth in local (*census tract*) labor demand using nat. trends
- Plausibly exogenous local variation in labor demand (identifies ϵ)

$$\Delta z_{jt}^{LD,R} = \underbrace{\sum_q \frac{\Delta R_t^{q,Nat}}{R_0^{q,Nat}}}_{\text{Change in national ave. by 2-digit SIC (excl. CA)}} \times \underbrace{\frac{N_{j,0}^q}{N_{j,0}}}_{\text{2-digit SIC at tract of work, 1990}}$$

National-level industry trends 1990-2000 × *Ex-ante industrial composition*

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$$\underbrace{\textit{National-level industry trends 1990-2000}}_{\text{Change in national ave. by 2-digit SIC (excl. CA)}} \times \underbrace{\textit{Ex-ante industrial composition}}_{\text{2-digit SIC at tract of work, 1990}}$$

1. Recover place of work by year fixed effect (n.b. PPML)

$$\ln(N_{ijt}) = \omega_{jt} + \theta_{it} + \delta_{ij} - \tilde{\kappa} t_{ijt} + u_{ijt}$$

2. Use $\Delta z_{jt}^{LD,R}$ as an instrument for $\Delta \ln(W_{jt})$:

$$\Delta \widehat{\omega_{jt}} = \epsilon \Delta \ln(W_{jt}) + \Delta \ln(E_{jt})$$

IV identification of ϵ: labor supply & pref. homogeneity

$\mathbb{E}[\Delta z_{jt} \cdot \Delta \ln(E_{jt})] = 0, \ \forall j$

- Changes in (non-wage) workplace amenity orthogonal to shock:
  (i) national industry trends, (ii) ex-ante industrial composition
- Driving variation likely: Trade shocks & decline of garment industry

Flexible assumption, as compared with...

- vs. Urban economic geography literature
  - permits variation in workplace amenities (unlike ARSW), does not require correct travel costs (unlike all others) or rely on other model components
- vs. Standard MSA-level implementation of Bartik shift-share
  - doesn't require that residential amenities, commuting, and housing market innovations also be exogenous

ϵ – Preference homogeneity & Labor supply elasticity

	$\hat{\omega}_{jt}$ (1)	$\hat{\omega}_{jt}$ (2)	$\hat{\omega}_{jt}$ (3)
$\ln(W_{jt})$	0.498	1.846*	1.830*
	(0.411)	(0.835)	(0.783)
F-stat (KP)	15.277	16.883	17.328
$\hat{\omega}$ estimated:	Linear, Panel	PPML Yr-by-yr	PPML Panel
N	2354	2432	2433

- High degree of heterogeneity
  - embeds situational detail and **stickiness** of location decision
  - mobility frictions important **even within city**
- Smaller than cross-sectional trade-style estimates (~ 6.7); more similar to LS elasticity (Falch 2010; Suarez Serrato & Zidar 2014)

Moment conditions

Interact with distance between tracts

- Spatial structure generates variation in *local economic conditions*
- Strength of interaction governed by decay parameter ρ
- High-dimensional FE result in more plausible moment conditions

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Combine to generate instruments; moments simplify to:

A1-a: $\mathbb{E}[\Delta z_{jt}^{LD,R} \cdot \Delta \ln(E_{jt})] = 0, \ \forall \ j$

A2: $\mathbb{E}[\Delta z_{jt}^{LD,R} \cdot \Delta \ln(C_{it})] = 0, \ \forall \ i, j$

A3-a: $\mathbb{E}[\Delta z_{j't}^{LD,R} \cdot \Delta \ln(B_{it})] = 0, \ \forall \ ij' \neq ij$

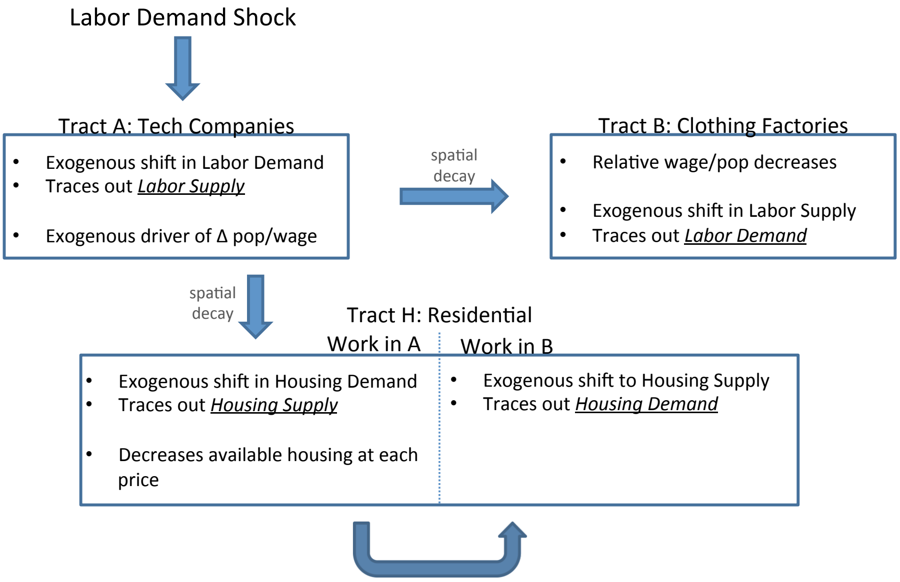
A4: $\mathbb{E}[\Delta z_{j't}^{LD,R} \cdot \Delta \ln(A_{jt})] = 0, \ \forall \ j' \neq j$

Result 3

Assume that moment conditions A1-a, A2, A3-a, and A4 are true, $\rho > 0$, and all instruments are relevant (housing and labor demand and supply slopes are well defined).

Elasticity identification: Toy example

Derive additional instruments by interacting with distance



ψ – Inverse housing supply elasticity

$\mathbb{E}[\Delta z_{jt} \cdot \Delta \ln(C_{it})] = 0, \ \forall i \neq j$: housing supply

- Shocks only affect housing prices through housing demand
- Local adaptation of Saiz (2010); Guerrieri, Hartley, Hurst (2013)
- *Violations:* local construction costs correlated with shocks

ψ – Inverse housing supply elasticity

	(1)	(2)	(3)	(4)	(5)	(6)
ln(Density)	2.221**	2.292**				
	(0.706)	(0.738)				
ln(Hous. Consump.)			1.693**	1.610**		
			(0.483)	(0.442)		
ln(Res. Land)			-1.396$^+$	-1.318$^+$		
			(0.790)	(0.778)		
ln(Hous. Density)					1.814**	1.693**
					(0.648)	(0.504)
Housing Supply Elasticity ($1/\psi$)	0.450**	0.436**	0.591**	0.621**	0.551**	0.591**
	(0.143)	(0.140)	(0.169)	(0.170)	(0.197)	(0.176)
F-stat (KP)	14.830	14.234	12.944	14.218	8.138	11.887
Empl. instrument	All	Not i	All	Not i	All	Not i
N	4550	4548	4500	4498	4500	4498

- Less elastic than longer run median across US cities (Saiz 2010)
- CA has inelastic housing supply (Quigley & Raphael 2005)
- Coefficient on land ≈ housing (matches model)

Moment conditions

Demand parameters can be taken from microdata, but can be estimated:

- Informal overidentification test ▸ Robustness

$\mathbb{E}[\Delta z_{j't} \cdot \Delta \ln(B_{it})] = 0,\ \forall ij' \neq ij$: housing demand elast. $-\epsilon(1-\zeta)$

- Labor demand shocks uncorrelated with changes in residential amenities *elsewhere*
- *Violations:* Endogenous spillovers in residential amenities, agglomeration

$=$ -0.66, se: (0.35), mobility responds as if housing exp. share is 36%

$\mathbb{E}[\Delta z_{j't} \cdot \Delta \ln(A_{jt})] = 0,\ \forall j' \neq j$: labor demand (share) $\alpha - 1$

- Valid if no changes in productivity spillovers
- *Violations:* agglomeration

$=$ -0.23 to -0.33, implies labor share of income is 67-77%

1. Data and setting
2. Transit's effect on commuting flows (gravity)
3. Quantitative urban model with commuting
4. Structural identification and estimated elasticities
5. Non-commuting effects and welfare
6. Habituation and network returns
7. Assess quantitative economic geography models within cities

Other margins and welfare effects

Test for transit effects on fundamentals (structural interp.), define:

$$\text{Proximity}_i^{500m} = \frac{\max\{0, 500m - \min_k\{\text{dist}_i(\text{MetroStation}_k)\}\}}{500m} \in [0,1]$$

- Estimate the effect of transit on these fundamentals, e.g., for $Y = \ln(A), \ln(B), \ln(C), \ln(E)$, estimate:

$$\hat{\mathbf{Y}}_{it} = \boldsymbol{\lambda}\text{Proximity}_{it} + \varsigma_i + \boldsymbol{\epsilon}_{it}$$

  to recover other effects $\boldsymbol{\lambda} = \lambda^A, \lambda^B, \ldots$
- Estimate separately to use historical DiD controls

No evidence of non-commuting effects ▸ Tables

- Commuting effect primary margin
- Structural interpretation: transit improves ij utility by 10-15%
  - Equivalent to 5-7 minute reduction in commute time

Welfare effects of system in 2000 (in $2016)

	(1)	(2)
Parameters		
α	0.680	0.680
ϵ	1.830	1.830
ζ	0.650	0.650
ψ	1.693	1.693
$\epsilon\kappa$	-	-0.020
Change in fundamentals		
λ^D, O & D contain station	0.146	0.146
λ^D, O & D <250m from station	0.101	0.101
λ^τ, O & D <2km from station	-	-0.033
Closed Economy		
Annual Δ in welfare	0.051%	0.069%
(in millions of $2016)	$108.9 mil.	$145.7 mil.
Open Economy		
Population Δ	0.109%	0.146%
Op. subsidy + capital cost (2.5%, ∞)	-$380 mil.	
Operation subsidy only	-$162 mil.	

Alternative cost: only deadweight loss from sales taxation (LA County)

- -$298 million py with mobility ($0.0045 increase)

Welfare effects of system, other margins

Benefits $<$ **Costs** by 2000

Other margins?

- If Fundamental Law of Congestion doesn't take hold (or slow):
  - Air pollution benefits a la (Gendron-Carrier et al. 2018) ∼\$182 million p.y.
    - Generous estimates: (i) most variation from China, (ii) only follow 4-6 years after system opens
  - Congestion already incorporated; smaller κ here than (Anderson 2014)
- Non-rail or non-commuter benefits
  - Unemployed/injured? Elderly/school? Other trips?
  - Better bus integration and service
  - Equity (though no differences income) Graph
- Agglomeration: at most small multiplier
- Habituation ...

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Effects of stations; 2002–2015

Full commuting effect may not occur from 199x by 2000:

- Path dependence in commuting choice/behavior
- Housing targeting specific transit routes (TOD)

Want to study changes after 2000, but:

P1 Data changes after 2000

P2 LA Metro Rail network has continued to grow

Solution: Assume $\{0\%, 100\%\}$ of future growth is *habituation*

- More recent data, LEHD LODES
  - not directly comparable to CTPP
- Allow different effects for already and connected pairs
- Else, growth due to *network returns*

Effects of stations; 2002–2015

	(1)	(2)	(3)	(4)	(5)	(6)
Subway Plan (All) Sample, $N = 385290$						
New: O & D contain station	0.109**	0.102**	0.113**	0.106**	0.119**	0.112**
	(0.031)	(0.031)	(0.032)	(0.031)	(0.032)	(0.031)
New: O & D <250m from station	0.041+	0.036	0.050*	0.044+	0.052*	0.046*
	(0.023)	(0.023)	(0.024)	(0.023)	(0.024)	(0.023)
New: O & D <500m from station	0.019	0.016	0.034+	0.029	0.029	0.025
	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)
Existing: O & D contain station					0.107**	0.098**
					(0.033)	(0.032)
Existing: O & D <250m from station					0.066+	0.061+
					(0.035)	(0.035)
Existing: O & D <500m from station			0.056*	0.049*	0.035	0.028
			(0.023)	(0.023)	(0.025)	(0.025)
Tract Pair FE	Y	Y	Y	Y	Y	Y
POW-X-Yr FE	Y	Y	Y	Y	Y	Y
RES-X-Yr FE	Y	Y	Y	Y	Y	Y
Sbcty-X-Sbcty-X-Yr FE	-	Y	-	Y	-	Y

- Assuming all benefits are habituation, adds about $70 million per year
- All in benefit is **$215 million per year** (still below break-even)

Discussion: Interpreting welfare numbers?

Positive benefits not small, *same order of magnitude as costs*

Tentative policy prescriptions (might improve outcomes):

1) Align transit routes to **commuting patterns**
   - E.g., the Purple line along dense Wilshire corridor
   - Lines connected ▸ Stats
     - 11-21% of workplace population
     - 3-8% of residential population
     - 1-3% of commuting flows
   - Cost unknown?

2) **Land use regulation** is very strict
   - CA as whole has tight dev. requirements
   - LA passed Prop U in 1986 ⇒ even less density permitted
   - Zoning seems to inhibit TOD Schuetz et al. (2018)
   - Low financial cost! (but local politics)

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Evaluating some assumptions in the new urban EG literature

1. How well do standard implementations of "market access" reflect observed commuting behavior?
   - Modeled commuting ignores persistent, pair-specific factors
   - Market access terms weight by market size of nearby locations & distance, not connectivity between

   $\Rightarrow$ Market access terms smooth local econ geography and effects

2. Are cross-sectional measures of local gravity reasonable?
   - Persistent, pair-specific confound cross-sectional estimates
   - Estimates of travel time disutility half the size in panel

3. How do model-derived wages accord with observed wages?
   - Not very well, simultaneity problem
   - Model-derived wages actually reflect population

1. Market Access

Market access terms summarize trade-cost weighted size of market:

$$MA_i = \sum_s e^{-\kappa \tau_{is}} Y_s$$

where Y_s is other market size (population, GDP, total consumer exp.)

Contribution of is and is' equivalent if $Y_s = Y_{s'}$ and $\tau_{is} = \tau_{is'}$

- What if observe greater flows between is and is'? Stronger connection? Random noise? Now what if is persistent? 0s?

"Standard approach" in urban EG:

i) Use travel survey to estimate κ
ii) Scrape travel times and travel times with transit change
iii) Predict changes in commuting from i) and ii)
iv) Use changes in market access implied by iii)

1. Market Access

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$$MA_i = \sum_s e^{-\kappa \tau_{is}} Y_s$$

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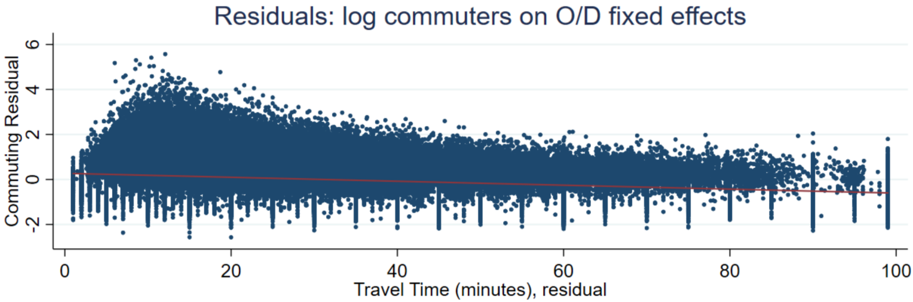

1. Market Access

How does market access compare with direct commuting flow measure?

- Define relative change in accessibility from residential places

$$\Delta CF = \frac{\sum_s N_{is}}{\sum_s (1-\lambda^D T_{is}) N_{is}} - 1 \, , \quad \Delta MA = \frac{\sum_s e^{-\tilde{\kappa}\tau_{is}} Y_s}{\sum_s e^{-\tilde{\kappa}\tau_{is}} (1-\lambda^D T_{is}) Y_s} - 1$$

1. Market Access

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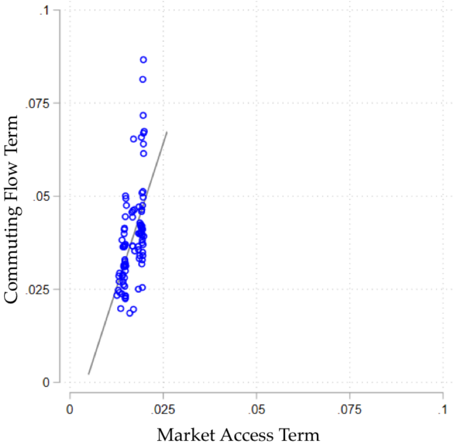
$$\Delta CF = \frac{\sum_s N_{is}}{\sum_s (1-\lambda^D T_{is}) N_{is}} - 1 \,, \quad \Delta MA = \frac{\sum_s e^{-\tilde{\kappa}\tau_{is}} Y_s}{\sum_s e^{-\tilde{\kappa}\tau_{is}} (1-\lambda^D T_{is}) Y_s} - 1$$



Benefits of CF terms:

1. No need to know $\tilde{\kappa}$ or τ
2. Preserves heterogeneity; idiosyncratic factors (besides distance) determine commuting
3. "**Observed**" accessibility

Benefits of MA terms:

1. Can scrape/model travel time data
2. Smooths spatial economy, like spatial weights? (Sp. E/metrics)
3. "**Potential**" accessibility

2. Commuting disutility not measured well in cross-section

Consider panel gravity equation:

$$\ln(N_{ij}) = \theta_i + \omega_j - \tilde{\kappa}\tau_{ijt} + u_{ij} \quad \text{(A)}$$

$$\ln(N_{ijt}) = \theta_{it} + \omega_{jt} + \delta_{ij} - \tilde{\kappa}\tau_{ijt} + u_{ijt} \quad \text{(B)}$$

- R^2 without δ_{ij} is 0.20 in (B), R^2 with δ_{ij} 0.80
  - Time-invariant characteristics of pairs $\gg$ changes in travel time
- Two step estimator (not much time variation in τ)
  1. Run (B) excluding τ_{ijt} and estimate δ_{ij}
  2. Run following:

     $$\hat{\delta}_{ij} = \alpha - \tilde{\kappa}\tau_{ij} + u_{ij}$$

  - $R^2 \approx 0.20$, travel time $\ll$ time-invariant determinants of flows

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  - $R^2 \approx 0.20$, travel time $\ll$ time-invariant determinants of flows

Different estimates of $-\tilde{\kappa}$:

LA 1-yr	LA Panel	**LA 2-step**	ARSW Gravity	ARSW GMM	MRR-H
-0.053	0.000	**-0.024**	-0.077	-0.099	≈ -0.1
(0.002)	(0.000)	**(0.001)**	(0.003)	(0.002)	

3. Model wages vs. observed wages

(Step 1) $$\ln(N_{ij}) = \omega_j + \theta_i - \epsilon\kappa\tau_{ij} + d_{ij}$$

(Step 2: Standard) $$\omega_j = \epsilon w_j$$

(Step 2: Here) $$\omega_{jt} = \epsilon w_{jt} + e_{jt}$$
$$0 = \mathbb{E}[\Delta z_{jt} \cdot \Delta \ln(E_{jt})]$$

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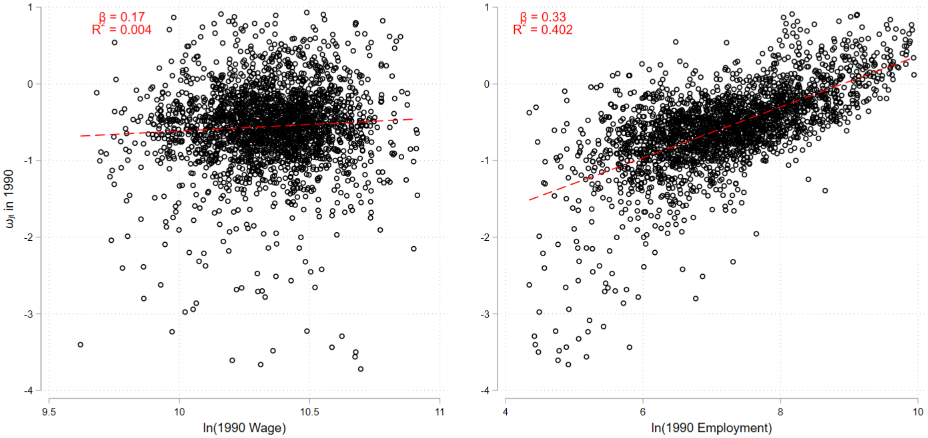


Summary

Develop new data sources to estimate effects of LA Metro:

- **Positive** effect on commuting between connected tracts
- Little adjustment on other margins

Carefully identify elasticities that populate econ. geo. model

- New identification strategy based on tract-level shift-share instrument
- Local stickiness, limited mobility even within city
- Permits more retention of unmodeled heterogeneity

Calculate welfare benefits of LA Metro

- Significant benefits, but **costs are larger**
- Even after 25 years...

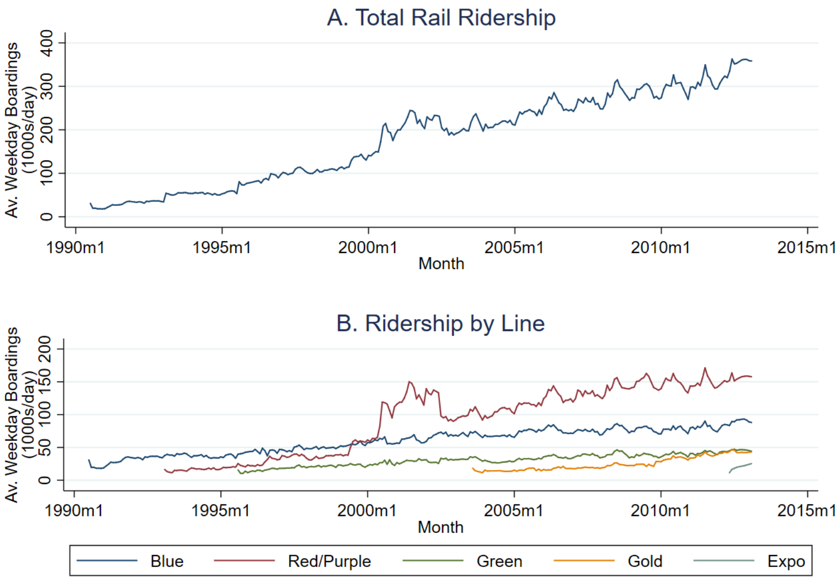
Critically examine urban EG modeling

Thank you

Metro Rail & Busway
metro.net
Chatsworth
Nordhoff
Roscoe
Sherman Way
Warner Ctr
SAN FERNANDO VALLEY
Canoga
De Soto
Pierce College
Tampa
Reseda
Balboa
Woodley
Sepulveda
Van Nuys
Woodman
Valley College
Laurel Canyon
North Hollywood
Universal City/Studio City
Hollywood/Highland
Hollywood/Vine
Hollywood/Western
Vermont/Sunset
Vermont/Santa Monica
Vermont/Beverly
Wilshire/Vermont
Westlake/MacArthur Park
Wilshire/Western
Wilshire/Normandie
CENTRAL LA
WESTSIDE
Lake
Allen
Sierra Madre Villa
Arcadia
Monrovia
Duarte/City of Hope
Irwindale
Azusa Downtown
APU/Citrus College
Memorial Park
Del Mar
Fillmore
South Pasadena
Highland Park
Southwest Museum
Heritage Sq
Lincoln/Cypress
Chinatown
Union Station
SAN GABRIEL VALLEY
LAC+USC Medical Ctr
Cal State LA
El Monte
Civic Ctr/Grand Park
Pershing Square
7th St/Metro Ctr
Pico
Little Tokyo/Arts Dist
Pico/Aliso
Mariachi Plaza
Soto
Indiana
Maravilla
East LA Civic Ctr
Atlantic
EASTSIDE
DOWNTOWN LA
LATTC/Ortho Institute
Grand/LATTC
San Pedro St
Downtown Santa Monica
17th St/SMC
26th St/Bergamot
Expo/Bundy
Expo/Sepulveda
Westwood/Rancho Park
Palms
Culver City
La Cienega/Jefferson
Expo/La Brea
Farmdale
Expo/Crenshaw
Expo/Western
Expo/Vermont
Expo Park/USC
Jefferson/USC
37th St/USC
Slauson
Manchester
Washington
Vernon
Slauson
Florence
Firestone
103rd St/Watts Towers
Willowbrook/Rosa Parks
SOUTH LA
LAX
Mariposa
El Segundo
Douglas
Redondo Beach
Aviation/LAX
Hawthorne/Lennox
Crenshaw
Vermont/Athens
Harbor Fwy
Avalon
Long Beach Bl
Lakewood Bl
Norwalk
Rosecrans
Harbor Gateway Transit Ctr
Carson
Pacific Coast Hwy
San Pedro
Compton
Artesia
Del Amo
Wardlow
Willow St
Pacific Coast Hwy
Anaheim St
Pacific Av
5th St
Downtown Long Beach
1st St
GATEWAY CITIES
SOUTH BAY
Metro
N
Rail Station
Transfer Station
Busway Station
Metro Rail
Red Line
Purple Line
Blue Line
Expo Line
Green Line
Gold Line
Metro Busway
Orange Line
Silver Line
Regional Rail
Amtrak
Metrolink
Airport Shuttle
LAX FlyAway
MAY 2016
Subject to Change

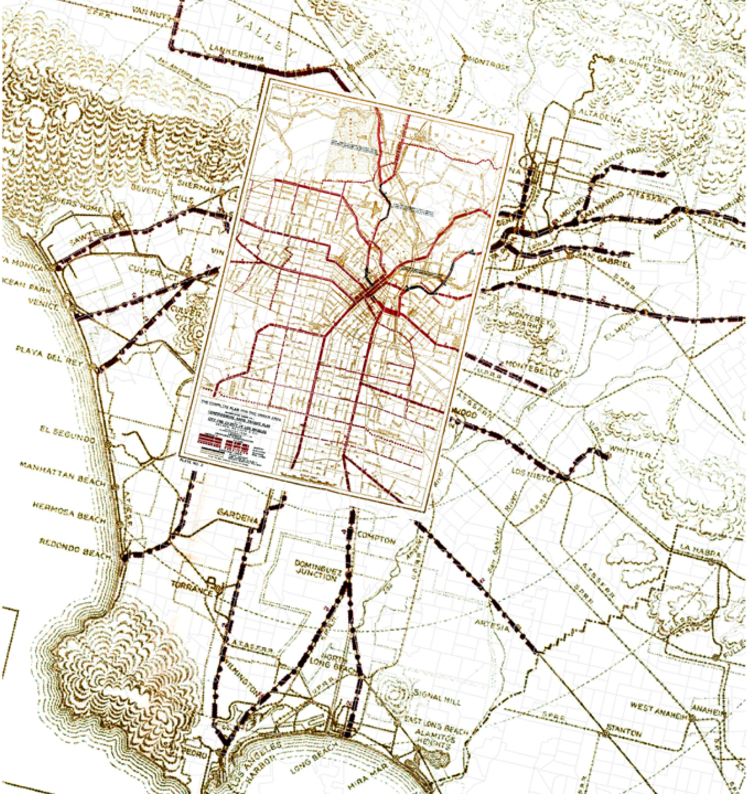
Extra slides

Ridership



▸ Return

Return



VAN NUYS
VALLEY
LANKERSHIM
MONTROSE
ALPINE TAVERN
ALTADENA
SIERRA MADRE
SHERMAN
BEVERLY HILLS
SAWTELLE
CULVER JCT
CULVER CITY
VENICE
PLAYA DEL REY
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
GARDENA
TORRANCE
COMPTON
DOMINGUEZ JUNCTION
NORTH LONG BEACH
SIGNAL HILL
EAST LONG BEACH
ALAMITOS HEIGHTS
LONG BEACH
SAN PEDRO
ARTESIA
LA HABRA
WHITTIER
LOS NIETOS
MONTEBELLO
MONTEREY PARK
EL MONTE
SAN GABRIEL
ARCADIA
WEST ANAHEIM
ANAHEIM
STANTON

Pre-trends in Residential Characteristics

	Model-type variables				Other characteristics		
	ln Res. Emp. (1)	ln #HHs (2)	ln HHI (3)	ln House Value (4)	% Coll. Grads (5)	Pov. Rate (6)	% Moved <5yrs (7)
Subway Plan (Immediate) Sample							
$\text{Proximity}_i^{500m} \times t$	0.029	-0.011	-0.013	-0.002	-0.008*	0.008+	-0.011*
	(0.020)	(0.017)	(0.013)	(0.019)	(0.004)	(0.005)	(0.006)
N	1629	1629	1628	1555	1629	1629	1629
Subway Plan (All) Sample							
$\text{Proximity}_i^{500m} \times t$	0.012	-0.031+	-0.019	-0.017	-0.013**	0.012**	-0.014**
	(0.020)	(0.017)	(0.012)	(0.018)	(0.003)	(0.004)	(0.005)
N	3786	3786	3779	3688	3786	3786	3786
PER Sample							
$\text{Proximity}_i^{500m} \times t$	0.002	-0.032+	-0.020	-0.034+	-0.015**	0.013**	-0.014**
	(0.021)	(0.017)	(0.013)	(0.018)	(0.004)	(0.004)	(0.005)
N	4631	4629	4619	4502	4631	4632	4631
Full Sample							
$\text{Proximity}_i^{500m} \times t$	0.025	-0.027	-0.016	-0.022	-0.015**	0.015**	-0.016**
	(0.020)	(0.017)	(0.012)	(0.017)	(0.003)	(0.004)	(0.005)
N	11651	11641	11567	11407	11657	11733	11659
Tract FE	Y	Y	Y	Y	Y	Y	Y
Sbcty-X-Yr FE	Y	Y	Y	Y	Y	Y	Y

▸ Return (DiD) ▸ Return (Fundamentals)

Pre-trends in Commuting Characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. Total workers								
$\text{Proximity}_i^{500m} \times t$	-0.263**	0.025	0.014	0.029	0.011	0.012	-0.018	0.002
	(0.021)	(0.020)	(0.021)	(0.020)	(0.020)	(0.020)	(0.021)	(0.021)
N	11685	11643	1632	1629	3792	3786	4643	4631
B. Commuting by automobile								
$\text{Proximity}_i^{500m} \times t$	-0.002	-0.001	-0.003	-0.001	0.000	-0.000	0.001	-0.002
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
N	11686	11644	1632	1629	3792	3786	4643	4631
C. No car households								
$\text{Proximity}_i^{500m} \times t$	-0.146**	-0.012	-0.006	0.014	-0.028	0.021	-0.044	0.007
	(0.035)	(0.036)	(0.040)	(0.040)	(0.055)	(0.038)	(0.055)	(0.037)
N	7720	7692	1086	1084	2524	2520	3086	3078
D. Transit (rail and bus) commuters, >0								
$\text{Proximity}_i^{500m} \times t$	-0.204**	0.023	0.043	0.042	-0.117**	-0.007	-0.135**	0.010
	(0.038)	(0.044)	(0.040)	(0.043)	(0.040)	(0.043)	(0.040)	(0.044)
N	9708	9669	1617	1614	3726	3721	4459	4448
E. Transit (rail and bus) commuters, all								
$\text{Proximity}_i^{500m} \times t$	-0.001	0.101**	0.098**	0.089**	0.051*	0.088**	0.022	0.097**
	(0.020)	(0.022)	(0.021)	(0.022)	(0.020)	(0.023)	(0.021)	(0.023)
N	11261	11195	1626	1623	3786	3776	4629	4617
Sample	All	All	Sim	Sim	Sal	Sal	PER	PER
Tract FE	Y	Y	Y	Y	Y	Y	Y	Y
Sbcty-X-Yr FE	-	Y	-	Y	-	Y	-	Y

Each column of each panel presents the results of a different regression, for forty total. Estimates show pre-trends from 1970-1990 for tracts treated by 1999, except for Panel c, which only covers 1980-1990. Panels A and D are log-linear; Panels B, C, E estimated by PPML with exposure set to relevant tract population. All regressions include tract fixed effects. Tracts are 2010 geography. Standard errors clustered by tract in parentheses: $^{+}$ $p < 0.10$, * $p < 0.05$, **

▸ Return

O-D distance interactions

	D contains station	D<250m from station	D<500m from station
O contains station	0.140**	0.078	0.083
	(0.045)	(0.079)	(0.113)
O<250m from station	0.024	0.018	0.054
	(0.051)	(0.066)	(0.057)
O<500m from station	0.197*	-0.100	0.059
	(0.077)	(0.089)	(0.064)
Control Network	1925 Plan (All), Loose		
Tract Pair FE	Y		
POW-X-Yr FE	Y		
RES-X-Yr FE	Y		
Sbcty-X-Sbcty-X-Yr FE	Y		
Highway Control	Y		
N	74040		

▸ Return

Same vs. different line analysis

	(1)	(2)	(3)	(4)
O & D contain station, same line	0.205**	0.192**	0.153*	0.144*
	(0.077)	(0.064)	(0.062)	(0.059)
O & D contain station, not same line	0.075	0.089	0.058	0.042
	(0.091)	(0.079)	(0.078)	(0.076)
O & D <250m from station, same line	0.145*	0.112*	0.093+	0.062
	(0.066)	(0.055)	(0.054)	(0.051)
O & D <250m from station, not same line	0.105	0.093	0.085	0.047
	(0.078)	(0.068)	(0.067)	(0.065)
O & D <500m from station, same line	0.041	0.045	0.046	0.014
	(0.054)	(0.041)	(0.040)	(0.038)
O & D <500m from station, not same line	-0.048	-0.052	-0.037	-0.073
	(0.066)	(0.054)	(0.054)	(0.052)
Control Network	1925 Imm	1925 All	PER Lines	All
Tract Pair FE	Y	Y	Y	Y
POW-X-Yr FE	Y	Y	Y	Y
RES-X-Yr FE	Y	Y	Y	Y
Sbcty-X-Sbcty-X-Yr FE	Y	Y	Y	Y
Highway Control	Y	Y	Y	Y
N	19222	74040	99054	290580

Return

Ridership

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. Effect on productivity ΔA, $\alpha - 1 = -0.226$								
$\text{Proximity}_i^{500m} \times t$	-0.089**	0.009	-0.009	0.008	-0.034	0.006	-0.050+	0.011
	(0.027)	(0.030)	(0.031)	(0.034)	(0.028)	(0.030)	(0.027)	(0.030)
N	4882	4858	780	776	1828	1826	2288	2284
B. Effect on residential amenity ΔB, $\epsilon(1-\zeta) = 0.662$								
$\text{Proximity}_i^{500m} \times t$	0.107**	-0.002	0.030	-0.042	0.070*	-0.007	0.076**	0.012
	(0.029)	(0.032)	(0.032)	(0.035)	(0.029)	(0.033)	(0.029)	(0.033)
N	4534	4518	712	710	1700	1700	2094	2092
C. Effect on inverse housing efficiency ΔC, $\psi = 1.693$								
$\text{Proximity}_i^{500m} \times t$	0.070+	0.006	-0.096*	-0.044	0.024	-0.025	0.051	0.003
	(0.041)	(0.046)	(0.047)	(0.054)	(0.042)	(0.048)	(0.042)	(0.048)
N	4484	4476	694	692	1670	1670	2058	2056
D. Effect on workplace amenity ΔE, $\epsilon = 1.83$								
$\text{Proximity}_i^{500m} \times t$	-0.203**	-0.058	-0.092	-0.154*	-0.103+	-0.103	-0.104+	-0.115+
	(0.058)	(0.062)	(0.066)	(0.073)	(0.060)	(0.066)	(0.059)	(0.062)
N	4866	4842	780	776	1830	1828	2286	2282
Sample	All	All	Sim	Sim	Sal	Sal	PER	PER
Tract FE	Y	Y	Y	Y	Y	Y	Y	Y
Sbcty-X-Yr FE	-	Y	-	Y	-	Y	-	Y
Controls	-	Y	-	Y	-	Y	-	Y

Return

Model robustness

Agglomeration: $A_i = \tilde{A}_i \Upsilon_i^{\mu}$

- Does not change equilibrium conditions
- May change identification
- But little observed effect here: agglomeration is a (smallish) multiplier, and changes in population concentration are not large

Endogenous land use change

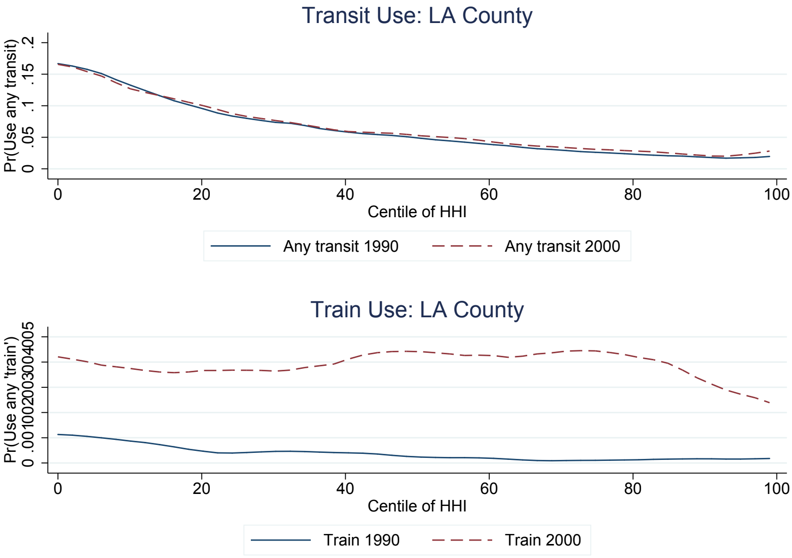
- Model describes in terms of density, so no effect on identification
- Does change equilibrium description (ARSW 2015)

Both?

- Equilibrium description is different
- Can still identify ϵ and ψ

▸ Return, Welfare ▸ Return, Moments

Mode use by income



▸ Return

Descriptive statistics (1990)

	LA County		Full Sample	
	Centroid $< 500m$ (1)	Any $< 500m$ (2)	Centroid $< 500m$ (3)	Any $< 500m$ (4)
% workers receiving transit, POW	11.3%	20.7%	7.2%	13.1%
% workers receiving transit, RES	2.7%	8.1%	1.6%	4.8%
% workers receiving transit, RES&POW	0.6%	3.1%	0.4%	1.7%
% workers commuting via: Drive alone	71.8%		74.5%	
% workers commuting via: Carpool	15.8%		15.8%	
% workers commuting via: Bus	6.9%		4.6%	

POW tract of work; RES tract of residence; *Source:* CTPP, IPUMS Census microdata

Mobility (Census Mobility Report 1995)

- Moving hazard rate (annual): 0.16
- Moving hazard rate in West (annual): 0.21
- Portion of movers that move within county, West: 69%

Return