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

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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
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.):

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

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

3) 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

8 / 44
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
1. Data and setting

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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 $j$

$$N_{ijt} = N_{ijt} \left( \theta_{it}(T_{it}), \omega_{jt}(T_{jt}), \tau_{ijt}(T_{it}, T_{jt}) \right)$$

- Residential
- Workplace
- Commuting costs

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:

1. O&D contain station
2. O&D $< 250m$ from station (if not i.)
3. O&D $< 500m$ from station (if not i. or ii.)
Commuting effect of transit

Isolate effect of transit connection \((T')\) on commuting from other margins

- **Outcome:** flow between residence \(i\) and workplace \(j\)

\[
N_{ijt} = N_{ijt} \left( \theta_{it}(T_{it}), \omega_{jt}(T_{jt}), \tau_{ijt}(T_{it}, T_{jt}) \right)
\]

(Log-linear specification with fixed effects:

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

- 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

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

- 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)
Identification: Gravity DinD (panel) estimator

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

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

**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)
Effects of stations on commuting flows; 1990–2000

<table>
<thead>
<tr>
<th>Subway Plan (All) Sample</th>
<th>(1)</th>
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<th>(4)</th>
<th>(5)</th>
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<tbody>
<tr>
<td>O &amp; D contain station</td>
<td>0.127*</td>
<td>0.147*</td>
<td>0.152*</td>
<td>0.162*</td>
<td>0.146*</td>
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<td></td>
<td>(0.044)</td>
<td>(0.044)</td>
<td>(0.044)</td>
<td>(0.046)</td>
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<td>O &amp; D &lt;250m from station</td>
<td>0.115*</td>
<td>0.122*</td>
<td>0.101*</td>
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<td>(0.049)</td>
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</tr>
<tr>
<td>O &amp; D &lt;500m from station</td>
<td>0.054</td>
<td>0.018</td>
<td>0.023</td>
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<tr>
<td>Tract Pair FE</td>
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<td>Y</td>
<td>Y</td>
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<tr>
<td>POW-X-Yr FE</td>
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<td>Y</td>
<td>Y</td>
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<tr>
<td>RES-X-Yr FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Sbcty-X-Sbcty-X-Yr FE</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Highway Control</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>Y</td>
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Metro increases commuting by **15% (10%)** between connected tracts

- Consistent across various strategies & PPML
- Effect spatially concentrated near workplaces
- Effect only along same line (transfers not important)
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)
  ⇒ Increasing capacity does not increase travel speed
  ⇒ 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

<table>
<thead>
<tr>
<th></th>
<th>$\tau_{ijt}^{\text{All}}$</th>
<th>$\ln(\tau_{ijt}^{\text{All}})$</th>
<th>$\tau_{ijt}^{\text{Car}}$</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Within 2km of tracks</td>
<td>-1.277**</td>
<td>-1.243**</td>
<td>-0.032*</td>
</tr>
<tr>
<td></td>
<td>(0.402)</td>
<td>(0.426)</td>
<td>(0.013)</td>
</tr>
<tr>
<td>Within 4km of tracks</td>
<td>-0.305</td>
<td>-0.304</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>(0.364)</td>
<td>(0.364)</td>
<td>(0.012)</td>
</tr>
</tbody>
</table>

Some evidence of small ($\sim$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
1. Data and setting

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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
What about welfare? Model summary

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

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

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

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

$$\nu_{ijo} \sim \text{Fréchet}(\epsilon, \Lambda_{ij}) \quad F_{ij}(\nu) = e^{-\Lambda_{ij} \nu^{-\epsilon}}$$
Model: Household problem

HHs choose place of residence (work) $i$ $(j)$, consumption, and housing:

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s.t. $C + Q_i H = W_j$

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

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

Shape parameter is key: $\epsilon$

- Homogeneity of location preference (higher=more homogenous)
- $\epsilon$ strength of comparative advantage
Model: Household problem (and gravity)

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

\[
\pi_{ij} = \frac{B_i E_j D_{ij} W_j^\epsilon \left(\delta_{ij} Q_i^{1-\zeta}\right)^{-\epsilon}}{\sum_{r=1}^{N} \sum_{s=1}^{N} B_r E_s D_{rs} W_s^\epsilon \left(\delta_{rs} Q_r^{1-\zeta}\right)^{-\epsilon}}
\]
Model: Household problem (and gravity)

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

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

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

$$
\ln(N_{ijt}) = -g_{1t} + \epsilon \ln(W_{jt}) + \ln(E_{jt}) - \epsilon(1 - \zeta) \ln(Q_{it}) + \ln(B_{it}) - \delta_{ij} + \ln(D_{ijt})
$$
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.

$$W_i = \alpha A_i \left( \frac{L^Y_i}{N^Y_i} \right)^{1-\alpha}$$

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 $C_i$

$$Q_i = C_i (H_i/L^H_i)^\psi$$
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:

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

Robustness and technical notes

▶ Eqbm. only defined for $\epsilon > 1$
  ▪ Can show that above expression is equivalent to multinomial logit
  ▪ Equivalent formulation valid for $\epsilon > 0$
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Model summary: Rosen-Roback with commuting

Labor

\[
\ln(W_{jt}) = \tilde{\alpha} \ln \left( \sum_r N_{rjt} \right) + \ln(A_{jt})
\]

Housing

\[
\ln(Q_{it}) = \psi \ln \left( \sum_s N_{ist}W_{st} \right) + \ln(C_{it})
\]
Model summary: Rosen-Roback with commuting

Labor
\[
\ln(W_{jt}) = \tilde{\alpha} \ln(\sum_r N_{rjt}) + \ln(A_{jt})
\]

Wage

Productivity

Commut. \[
\ln(N_{ijt}) = \epsilon \ln(W_{jt}) + \epsilon \zeta \ln(Q_{it}) + \delta_{ij} + \ln(B_{it} E_{jt} D_{ijt})
\]

Flow

Commuting and Amenities

Housing \[
\ln(Q_{it}) = \psi \ln(\sum_s N_{ist} W_{st}) + \ln(C_{it})
\]

H. Price

H. Eff.
Model summary: Rosen-Roback with commuting

Labor
\[ \ln(W_{jt}) = \tilde{\alpha} \ln(\sum_r N_{rjt}) + \ln(A_{jt}) \]

Wage

Commut.
\[ \ln(N_{ijt}) = \epsilon \ln(W_{jt}) + \epsilon \tilde{\zeta} \ln(Q_{it}) + \delta_{ij} + \ln(B_{it}E_{jt}D_{ijt}) \]

Flow

Housing
\[ \ln(Q_{it}) = \psi \ln(\sum_s N_{ist}W_{st}) + \ln(C_{it}) \]

H. Price

H. Eff.

Commuting and Amenities

\[ \text{Describes} \]

1. **Slopes**: \( \epsilon, \psi, \epsilon \tilde{\zeta}, \tilde{\alpha} \)
   - Local elasticities

2. **Shifts**: Changes to primitives \( A, B, C, D, E \)
   - Effects of transit
Identification of \( \epsilon \)

\( \epsilon \) 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
Identification of $\epsilon$

$\epsilon$ is key: 

*Location preference homogeneity* \iff *Local labor supply elast.*

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- Wage typically unobserved $\Rightarrow$ specter of simultaneity

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 $\epsilon$)

$$
\Delta z_{j,t}^{LD,R} = \sum_q \frac{\Delta R_t^{q,Nat}}{R_0^{q,Nat}} \times \frac{N_{q,j,0}}{N_{j,0}}
$$

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

Change in national ave. by 2-digit SIC (excl. CA) × 2-digit SIC at tract of work, 1990
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 $\epsilon$)

$$
\Delta z_{jt}^{LD,R} = \sum_q \frac{\Delta R_{Rq,Nat}^t}{R_{0q,Nat}^t} \times \frac{N_{qj,0}}{N_{j,0}}
$$

National-level industry trends 1990-2000 $\times$ Ex-ante industrial composition

Change in national ave. by 2-digit SIC (excl. CA) $\times$ 2-digit SIC at tract of work, 1990

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

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

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

$$
\Delta \tilde{\omega}_{jt} = \epsilon \Delta \ln(W_{jt}) + \Delta \ln(E_{jt})
$$
IV identification of $\epsilon$: labor supply & pref. homogeneity

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

- 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
- Preference homogeneity & Labor supply elasticity

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<tr>
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<tbody>
<tr>
<td>$\ln(W_{jt})$</td>
<td>0.498</td>
<td>1.846*</td>
<td>1.830*</td>
</tr>
<tr>
<td></td>
<td>(0.411)</td>
<td>(0.835)</td>
<td>(0.783)</td>
</tr>
<tr>
<td>F-stat (KP)</td>
<td>15.277</td>
<td>16.883</td>
<td>17.328</td>
</tr>
<tr>
<td>$\hat{\omega}$ estimated:</td>
<td>Linear, Panel</td>
<td>PPML Yr-by-yr</td>
<td>PPML Panel</td>
</tr>
<tr>
<td>$N$</td>
<td>2354</td>
<td>2432</td>
<td>2433</td>
</tr>
</tbody>
</table>

- 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 ($\sim 6.7$); 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 \( \rho \)
- High-dimensional FE result in more plausible moment conditions

Combine to generate instruments; moments simplify to:

\[
\begin{align*}
\text{A1-a: } & \mathbb{E}[\Delta z_{jt}^{LD,R} \cdot \Delta \ln(E_{jt})] = 0, \ \forall \ j \\
\text{A2: } & \mathbb{E}[\Delta z_{jt}^{LD,R} \cdot \Delta \ln(C_{it})] = 0, \ \forall \ i, j \\
\text{A3-a: } & \mathbb{E}[\Delta z_{jt}^{LD,R} \cdot \Delta \ln(B_{it})] = 0, \ \forall \ ij' \neq ij \\
\text{A4: } & \mathbb{E}[\Delta z_{jt}^{LD,R} \cdot \Delta \ln(A_{jt})] = 0, \ \forall \ j' \neq j
\end{align*}
\]

**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

Labor Demand Shock

Tract A: Tech Companies
• Exogenous shift in Labor Demand
• Traces out Labor Supply
• Exogenous driver of Δ pop/wage

Tract B: Clothing Factories
• Relative wage/pop decreases
• Exogenous shift in Labor Supply
• Traces out Labor Demand

Tract H: Residential
Work in A
• Exogenous shift in Housing Demand
• Traces out Housing Supply
• Decreases available housing at each price

Work in B
• Exogenous shift to Housing Supply
• Traces out Housing Demand
Inverse housing supply elasticity

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

- Shocks only affect housing prices through housing demand
- Local adaptation of Saiz (2010); Guerrieri, Hartley, Hurst (2013)
- **Violations**: local construction costs correlated with shocks
Less elastic than longer run median across US cities (Saiz 2010)

CA has inelastic housing supply (Quigley & Raphael 2005)

Coefficient on land $\approx$ housing (matches model)
Moment conditions

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

- Informal overidentification test

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

- Labor demand shocks uncorrelated with changes in residential amenities *elsewhere*

- *Violations:* Endogenous spillovers in residential amenities, agglomeration
  
  \[ = \ -0.66, \ \text{se:} \ (0.35), \ \text{mobility responds as if housing exp. share is 36%} \]

\[ \mathbb{E}[\Delta z_{j't} \cdot \Delta \ln(A_{jt})] = 0, \ \forall j' \neq j: \text{labo} \]

- Valid if no changes in productivity spillovers

- *Violations:* agglomeration

  \[ = \ -0.23 \ \text{to} \ -0.33, \ \text{implies labor share of income is} \ 67-77\% \]
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:

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

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

\[
\hat{Y}_{it} = \lambda \text{Proximity}_{it} + \zeta_i + \epsilon_{it}
\]

to recover other effects \( \lambda = \lambda^A, \lambda^B, \ldots \)

- 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)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>0.680</td>
<td>0.680</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>1.830</td>
<td>1.830</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>0.650</td>
<td>0.650</td>
</tr>
<tr>
<td>$\psi$</td>
<td>1.693</td>
<td>1.693</td>
</tr>
<tr>
<td>$\epsilon\kappa$</td>
<td>-</td>
<td>-0.020</td>
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</table>

### Change in fundamentals

<table>
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<tr>
<th>Change in fundamentals</th>
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<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda^D$, O &amp; D contain station</td>
<td>0.146</td>
<td>0.146</td>
</tr>
<tr>
<td>$\lambda^D$, O &amp; D &lt;250m from station</td>
<td>0.101</td>
<td>0.101</td>
</tr>
<tr>
<td>$\lambda^\tau$, O &amp; D &lt;2km from station</td>
<td>-</td>
<td>-0.033</td>
</tr>
</tbody>
</table>

### Closed Economy

| Annual $\Delta$ in welfare                  | 0.051%  | 0.069%  |
| (in millions of $2016$)                      | $108.9$ mil. | $145.7$ mil. |

### Open Economy

| Population $\Delta$                          | 0.109%  | 0.146%  |

| Op. subsidy + capital cost (2.5%, $\infty$)  | -$380$ 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) $\sim$182 million p.y.
    - Generous estimates: (i) most variation from China, (ii) only follow 4-6 years after system opens
  - Congestion already incorporated; smaller $\kappa$ 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)

- Agglomeration: at most small multiplier

- Habituation ...
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
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

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
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<th>(6)</th>
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<tbody>
<tr>
<td>Subway Plan (All) Sample, $N = 385,290$</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>New: O &amp; D contain station</td>
<td>0.109**</td>
<td>0.102**</td>
<td>0.113**</td>
<td>0.106**</td>
<td>0.119**</td>
<td>0.112**</td>
</tr>
<tr>
<td></td>
<td>(0.031)</td>
<td>(0.031)</td>
<td>(0.032)</td>
<td>(0.031)</td>
<td>(0.032)</td>
<td>(0.031)</td>
</tr>
<tr>
<td>New: O &amp; D &lt;250m from station</td>
<td>0.041⁺</td>
<td>0.036</td>
<td>0.050⁺</td>
<td>0.044⁺</td>
<td>0.052⁺</td>
<td>0.046⁺</td>
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<tr>
<td></td>
<td>(0.023)</td>
<td>(0.023)</td>
<td>(0.024)</td>
<td>(0.023)</td>
<td>(0.024)</td>
<td>(0.023)</td>
</tr>
<tr>
<td>New: O &amp; D &lt;500m from station</td>
<td>0.019</td>
<td>0.016</td>
<td>0.034⁺</td>
<td>0.029</td>
<td>0.029</td>
<td>0.025</td>
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<tr>
<td></td>
<td>(0.020)</td>
<td>(0.020)</td>
<td>(0.020)</td>
<td>(0.020)</td>
<td>(0.020)</td>
<td>(0.020)</td>
</tr>
<tr>
<td>Existing: O &amp; D contain station</td>
<td>0.107**</td>
<td>0.098**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.033)</td>
<td>(0.032)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing: O &amp; D &lt;250m from station</td>
<td>0.066⁺</td>
<td>0.061⁺</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.035)</td>
<td>(0.035)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Existing: O &amp; D &lt;500m from station</td>
<td></td>
<td></td>
<td>0.056⁺</td>
<td>0.049⁺</td>
<td>0.035</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.023)</td>
<td>(0.023)</td>
<td>(0.025)</td>
<td>(0.025)</td>
</tr>
<tr>
<td>Tract Pair FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>POW-X-Yr FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>RES-X-Yr FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

- 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)
1. Data and setting

2. Transit’s effect on commuting flows (gravity)

3. Quantitative urban model with commuting

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7. Assess quantitative economic geography models within cities
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
   ⇒ 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 \( \kappa \)

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

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?
1. Market Access

How does market access compare with direct commuting flow measure?

- Define relative change in accessibility from residential places

\[
\Delta CF = \frac{\sum_s N_{is}}{\sum_s (1 - \lambda D T_{is}) N_{is}} - 1,
\]

\[
\Delta MA = \frac{\sum_s e^{-\tilde{\kappa} \tau_{is}} Y_s}{\sum_s e^{-\tilde{\kappa} \tau_{is}} (1 - \lambda D T_{is}) Y_s} - 1
\]

Benefits of CF terms:

1. No need to know \( \tilde{\kappa} \) or \( \tau \)
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
1. Market Access

How does market access compare with direct commuting flow measure?

- Define relative change in accessibility from residential places

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

**Benefits of CF terms:**

1. No need to know \( \tilde{\kappa} \) or \( \tau \)
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:

\[
\ln(N_{ij}) = \theta_i + \omega_j - \tilde{\kappa}\tau_{ijt} + u_{ij} \tag{A}
\]
\[
\ln(N_{ijt}) = \theta_{it} + \omega_{jt} + \delta_{ij} - \tilde{\kappa}\tau_{ijt} + u_{ijt} \tag{B}
\]

- \(R^2\) without \(\delta_{ij}\) is 0.20 in (B), \(R^2\) with \(\delta_{ij}\) 0.80
  - Time-invariant characteristics of pairs \(\gg\) changes in travel time
- Two step estimator (not much time variation in \(\tau\))
  1. Run (B) excluding \(\tau_{ijt}\) and estimate \(\delta_{ij}\)
  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
2. Commuting disutility not measured well in cross-section

Consider panel gravity equation:

\[
\ln(N_{ij}) = \theta_i + \omega_j - \tilde{\kappa} \tau_{ijt} + u_{ij} \tag{A}
\]
\[
\ln(N_{ijt}) = \theta_{it} + \omega_{jt} + \delta_{ij} - \tilde{\kappa} \tau_{ijt} + u_{ijt} \tag{B}
\]

- \( R^2 \) without \( \delta_{ij} \) is 0.20 in (B), \( R^2 \) with \( \delta_{ij} \) 0.80
  - Time-invariant characteristics of pairs \( \gg \) changes in travel time

- Two step estimator (not much time variation in \( \tau \))
  1. Run (B) excluding \( \tau_{ijt} \) and estimate \( \delta_{ij} \)
  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

Different estimates of \(-\tilde{\kappa}\):

<table>
<thead>
<tr>
<th></th>
<th>LA 1-yr</th>
<th>LA Panel</th>
<th>LA 2-step</th>
<th>ARSW Gravity</th>
<th>ARSW GMM</th>
<th>MRR-H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.053</td>
<td>0.000</td>
<td>-0.024</td>
<td>-0.077</td>
<td>-0.099</td>
<td>≈ -0.1</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.000)</td>
<td>(0.001)</td>
<td>(0.003)</td>
<td>(0.002)</td>
<td></td>
</tr>
</tbody>
</table>
3. Model wages vs. observed wages

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

(Step 2: Standard) \hspace{1em} \omega_j = \epsilon w_j

(Step 2: Here) \hspace{1em} \omega_{jt} = \epsilon w_{jt} + e_{jt}

\hspace{1em} 0 = \mathbb{E}[\Delta z_{jt} \cdot \Delta \ln(E_{jt})]
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) \[ \omega_{jt} = \epsilon w_{jt} + e_{jt} \]

\[ 0 = \mathbb{E}[\Delta z_{jt} \cdot \Delta \ln(E_{jt})] \]
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
Extra slides
Ridership

A. Total Rail Ridership

B. Ridership by Line

- Blue
- Red/Purple
- Green
- Gold
- Expo

(Av. Weekday Boardings (1000s/day))
### Pre-trends in Residential Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Model-type variables</th>
<th>Other characteristics</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In Res. Emp. (1)</td>
<td>In #HHs (2)</td>
<td>In HHI (3)</td>
</tr>
<tr>
<td>Subway Plan (Immediate) Sample</td>
<td>Proximity\textsubscript{500m} × t</td>
<td>0.029 (0.020)</td>
<td>-0.011 (0.017)</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>1629</td>
<td>1629</td>
</tr>
<tr>
<td>Subway Plan (All) Sample</td>
<td>Proximity\textsubscript{500m} × t</td>
<td>0.012 (0.020)</td>
<td>-0.031* (0.017)</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>3786</td>
<td>3786</td>
</tr>
<tr>
<td>PER Sample</td>
<td>Proximity\textsubscript{500m} × t</td>
<td>0.002 (0.021)</td>
<td>-0.032* (0.017)</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>4631</td>
<td>4629</td>
</tr>
<tr>
<td>Full Sample</td>
<td>Proximity\textsubscript{500m} × t</td>
<td>0.025 (0.020)</td>
<td>-0.027 (0.017)</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>11651</td>
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<tr>
<td>Tract FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Sbcty-X-Yr FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

**Return (DiD)**  
**Return (Fundamentals)**
### Pre-trends in Commuting Characteristics

<table>
<thead>
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<th>(1)</th>
<th>(2)</th>
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<tbody>
<tr>
<td><strong>A. Total workers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Proximity $\times t$</td>
<td>-0.263**</td>
<td>0.025</td>
<td>0.014</td>
<td>0.029</td>
<td>0.011</td>
<td>0.012</td>
<td>-0.018</td>
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<td></td>
<td>(0.021)</td>
<td>(0.020)</td>
<td>(0.021)</td>
<td>(0.020)</td>
<td>(0.020)</td>
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<td>(0.021)</td>
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<td>3792</td>
<td>3786</td>
<td>4643</td>
<td>4631</td>
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<tr>
<td><strong>B. Commuting by automobile</strong></td>
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<td>-0.003</td>
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<td><strong>C. No car households</strong></td>
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<tr>
<td>Proximity $\times t$</td>
<td>-0.146**</td>
<td>-0.012</td>
<td>-0.006</td>
<td>0.014</td>
<td>-0.028</td>
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<td><strong>D. Transit (rail and bus) commuters, &gt;0</strong></td>
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<tr>
<td>Proximity $\times t$</td>
<td>-0.204**</td>
<td>0.023</td>
<td>0.043</td>
<td>0.042</td>
<td>-0.117**</td>
<td>-0.007</td>
<td>-0.135**</td>
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<td></td>
<td>(0.038)</td>
<td>(0.044)</td>
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<td>(0.043)</td>
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<td><strong>E. Transit (rail and bus) commuters, all</strong></td>
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<tr>
<td>Proximity $\times t$</td>
<td>0.001</td>
<td>0.101**</td>
<td>0.098**</td>
<td>0.089**</td>
<td>0.051*</td>
<td>0.088**</td>
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<td>(0.021)</td>
<td>(0.022)</td>
<td>(0.020)</td>
<td>(0.023)</td>
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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: $^+ p < 0.10$, $^* p < 0.05$, $^{**} p < 0.01$.
# O-D distance interactions

<table>
<thead>
<tr>
<th></th>
<th>D contains station</th>
<th>D&lt;250m from station</th>
<th>D&lt;500m from station</th>
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<tbody>
<tr>
<td>O contains station</td>
<td>0.140**</td>
<td>0.078</td>
<td>0.083</td>
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<td>(0.045)</td>
<td>(0.079)</td>
<td>(0.113)</td>
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<td>O&lt;250m from station</td>
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<td>0.018</td>
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<tr>
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<td>(0.051)</td>
<td>(0.066)</td>
<td>(0.057)</td>
</tr>
<tr>
<td>O&lt;500m from station</td>
<td>0.197*</td>
<td>-0.100</td>
<td>0.059</td>
</tr>
<tr>
<td></td>
<td>(0.077)</td>
<td>(0.089)</td>
<td>(0.064)</td>
</tr>
</tbody>
</table>

**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
## Same vs. different line analysis

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<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O &amp; D contain station, same line</td>
<td>0.205**</td>
<td>0.192**</td>
<td>0.153*</td>
<td>0.144*</td>
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<tr>
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<td>(0.077)</td>
<td>(0.064)</td>
<td>(0.062)</td>
<td>(0.059)</td>
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<tr>
<td>O &amp; D contain station, not same line</td>
<td>0.075</td>
<td>0.089</td>
<td>0.058</td>
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<td></td>
<td>(0.091)</td>
<td>(0.079)</td>
<td>(0.078)</td>
<td>(0.076)</td>
</tr>
<tr>
<td>O &amp; D &lt;250m from station, same line</td>
<td>0.145*</td>
<td>0.112*</td>
<td>0.093+</td>
<td>0.062</td>
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<tr>
<td></td>
<td>(0.066)</td>
<td>(0.055)</td>
<td>(0.054)</td>
<td>(0.051)</td>
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<tr>
<td>O &amp; D &lt;250m from station, not same line</td>
<td>0.105</td>
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<td></td>
<td>(0.078)</td>
<td>(0.068)</td>
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<td>(0.065)</td>
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<tr>
<td>O &amp; D &lt;500m from station, same line</td>
<td>0.041</td>
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<td>(0.041)</td>
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<td>(0.038)</td>
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<tr>
<td>O &amp; D &lt;500m from station, not same line</td>
<td>-0.048</td>
<td>-0.052</td>
<td>-0.037</td>
<td>-0.073</td>
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<td>(0.066)</td>
<td>(0.054)</td>
<td>(0.054)</td>
<td>(0.052)</td>
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### Control Network

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<th>1925 Imm</th>
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<th>PER Lines</th>
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<tr>
<td>Tract Pair FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>POW-X-Yr FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>RES-X-Yr FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Sbcty-X-Sbcty-X-Yr FE</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Highway Control</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td><strong>N</strong></td>
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## Ridership

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<th>(6)</th>
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<tbody>
<tr>
<td><strong>A. Effect on productivity $\Delta A$, $\alpha - 1 = -0.226$</strong></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Proximity(_{500m}^t)</td>
<td>-0.089**</td>
<td>0.009</td>
<td>-0.009</td>
<td>0.008</td>
<td>-0.034</td>
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<td>-0.050(^+)</td>
<td>0.011</td>
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<td>(0.030)</td>
<td>(0.031)</td>
<td>(0.034)</td>
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<td>N</td>
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<td>4858</td>
<td>780</td>
<td>776</td>
<td>1828</td>
<td>1826</td>
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<td>2284</td>
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<td><strong>B. Effect on residential amenity $\Delta B$, $\epsilon(1 - \zeta) = 0.662$</strong></td>
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<tr>
<td>Proximity(_{500m}^t)</td>
<td>0.107**</td>
<td>-0.002</td>
<td>0.030</td>
<td>-0.042</td>
<td>0.070(^*)</td>
<td>-0.007</td>
<td>0.076(^{**})</td>
<td>0.012</td>
</tr>
<tr>
<td></td>
<td>(0.029)</td>
<td>(0.032)</td>
<td>(0.032)</td>
<td>(0.035)</td>
<td>(0.029)</td>
<td>(0.033)</td>
<td>(0.029)</td>
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<td><strong>C. Effect on inverse housing efficiency $\Delta C$, $\psi = 1.693$</strong></td>
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<tr>
<td>Proximity(_{500m}^t)</td>
<td>0.070(^+)</td>
<td>0.006</td>
<td>-0.096(^*)</td>
<td>-0.044</td>
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<td>-0.025</td>
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<td>692</td>
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<td><strong>D. Effect on workplace amenity $\Delta E$, $\epsilon = 1.83$</strong></td>
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<tr>
<td>Proximity(_{500m}^t)</td>
<td>-0.203**</td>
<td>-0.058</td>
<td>-0.092</td>
<td>-0.154(^*)</td>
<td>-0.103(^+)</td>
<td>-0.103</td>
<td>-0.104(^+)</td>
<td>-0.115(^+)</td>
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<td>(0.066)</td>
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<td>776</td>
<td>1830</td>
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<th>Sim</th>
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<th>Sal</th>
<th>Sal</th>
<th>PER</th>
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<tr>
<td>Tract FE</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>Y</td>
<td>-</td>
<td>Y</td>
<td>-</td>
<td>Y</td>
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</tbody>
</table>
Model robustness

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

- 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 $\epsilon$ and $\psi$
Mode use by income

Transit Use: LA County

Train Use: LA County
### Descriptive statistics (1990)

<table>
<thead>
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<td>Centroid</td>
<td>Any</td>
<td>Centroid</td>
<td>Any</td>
</tr>
<tr>
<td></td>
<td>&lt; 500m</td>
<td>&lt; 500m</td>
<td>&lt; 500m</td>
<td>&lt; 500m</td>
</tr>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td></td>
</tr>
<tr>
<td>% workers receiving transit, POW</td>
<td>11.3%</td>
<td>20.7%</td>
<td>7.2%</td>
<td>13.1%</td>
</tr>
<tr>
<td>% workers receiving transit, RES</td>
<td>2.7%</td>
<td>8.1%</td>
<td>1.6%</td>
<td>4.8%</td>
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<tr>
<td>% workers receiving transit, RES&amp;POW</td>
<td>0.6%</td>
<td>3.1%</td>
<td>0.4%</td>
<td>1.7%</td>
</tr>
<tr>
<td>% workers commuting via: Drive alone</td>
<td>71.8%</td>
<td></td>
<td>74.5%</td>
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</tr>
<tr>
<td>% workers commuting via: Carpool</td>
<td>15.8%</td>
<td></td>
<td>15.8%</td>
<td></td>
</tr>
<tr>
<td>% workers commuting via: Bus</td>
<td>6.9%</td>
<td></td>
<td>4.6%</td>
<td></td>
</tr>
</tbody>
</table>

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%