Public Transit Potential

NBER Conference on Transportation in the 21st Century

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Urban transportation during the last half century

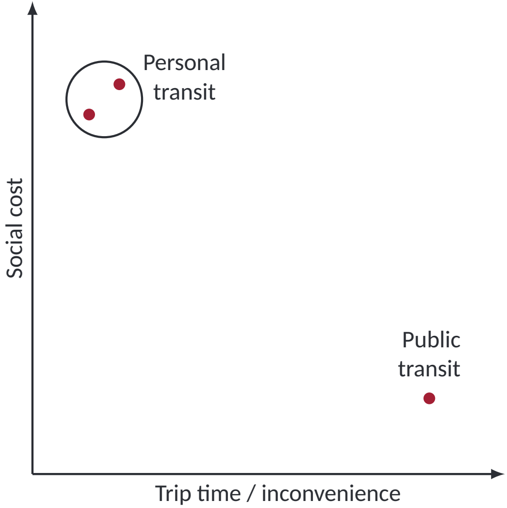
In the 1970s

Today

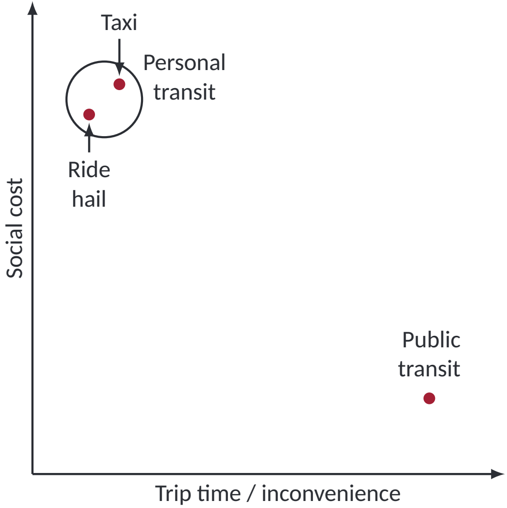
The Current State of Public Transportation

- Only 2.3% of personal trips in the US use public transit.
  Source: DOT, Numbers are for 2009
- A private car emits about twice the amount of CO2 per passenger mile as public transit.
  Source: DOT
- The average bus utilization rate is 28%.
  Source: DOT
- Customers only pay about 24% of the trip cost directly through fares.
  Source: newgeography.com

Technological advances and transportation



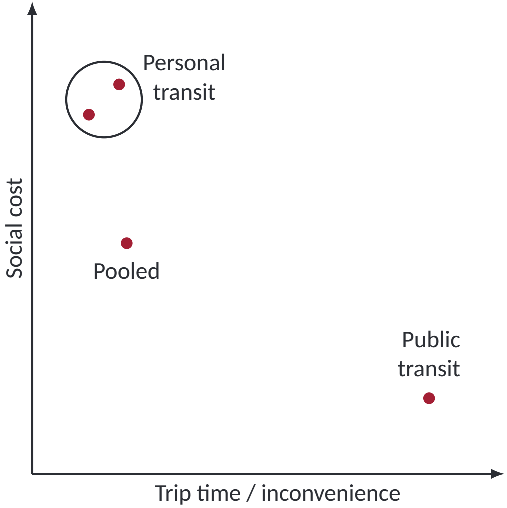
Technological advances and transportation



GPS, smartphones: lower coordination costs.

- Drivers $\leftrightarrow$ passengers.

Technological advances and transportation



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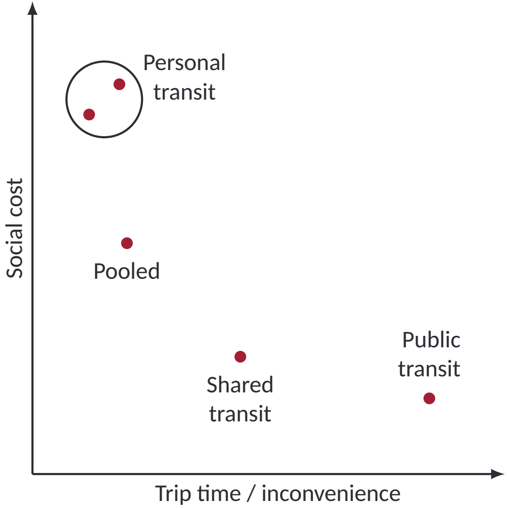

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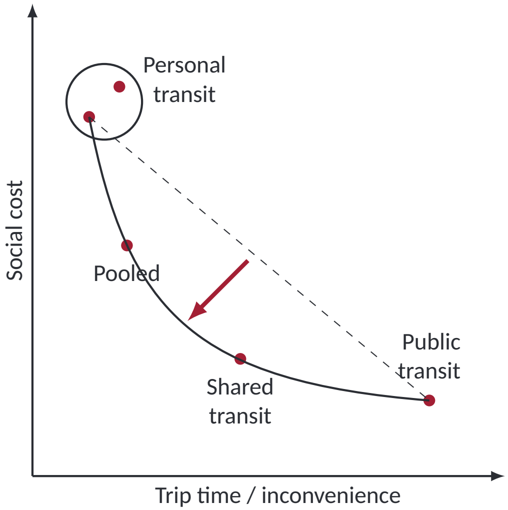
New possibility: **shared transit**

- Public transit that uses on-demand routes
- Vs. traditional fixed grid, fixed schedule

Technological advances and transportation



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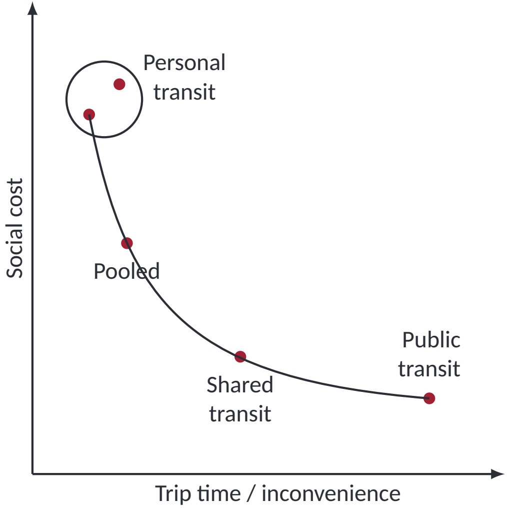
Technological advances and transportation



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New possibility: **shared transit**

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These new technologies push the frontier

- What is their potential?
- Should governments subsidize them?

This Study

Questions:

- How efficient is urban transportation given current technologies?
- What are the potential welfare gains from introducing new transportation technologies?

Roadmap:

1. Construct trip level dataset for all relevant modes for **Chicago** (January/February 2020).
2. Set up and estimate model of the transportation system in a city
   - Demand: discrete mode choice (McFadden 1974, Berry et al. 1995).
     - Estimate from congestion surcharge
   - Transit technology: cost, convenience, and network externalities
     - Estimate for current technology, (later) simulate for new technologies
3. Determine welfare effects of shared transit and optimal subsidies (max. welfare given budget)

Literature Review

1. **Transportation and the Value of Time:** Becker (1965), McFadden (1974), Small (1982), Small (2005), Kreindler (2017), Goldszmidt et al. (2020)

2. **Ride hailing and Taxi Industry:** Arnott (1996), Lagos (2003), Hall, Palsson, Price (2018), Frechètte, Lizzeri, and Salz (2019), Arora, Zheng, and Girotra (2020), Castillo (2020), Buchholz et al. (2020), Buchholz (2021), Cairncross, Hall and Palsson (2021), Rosaia (2021), Leccese (2021)

3. **Transportation in the Long-run:** Tsivanidis (2018), Allen and Arkolakis (2020), Barwick et al. (2021)

4. **Geo-location Data and Mobility:** Miyahuchi, Nakajima, and Redding (2020), Glaeser, Gorback, and Redding (2020), Couture et al. (2021)

Outline

1. Data
2. Model
3. Estimation

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Data Construction

Chicago, January-February 2020.

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Goal: Hourly flows by mode across community areas and times of the week.

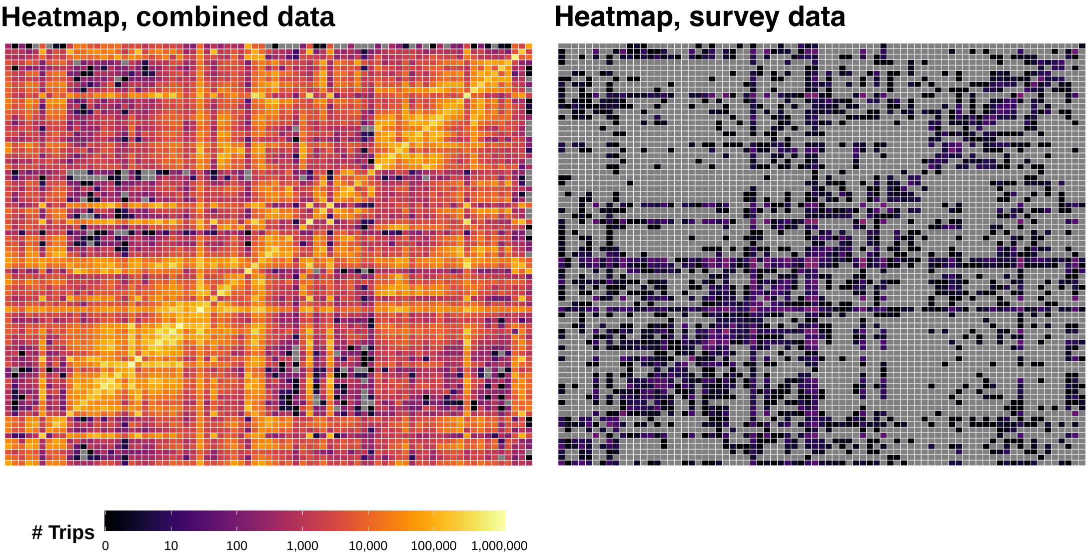
Raw data sets:

1. Universe of taxi and ride hailing (pooled + single rides) trips from the city of Chicago.
2. Universe of public transit trips through MIT-CTA partnership.
3. Individual cell phone location records: 40% of all devices. Representativeness
4. Block level census data.
5. 2019 Chicago transit survey for validation and calibration.

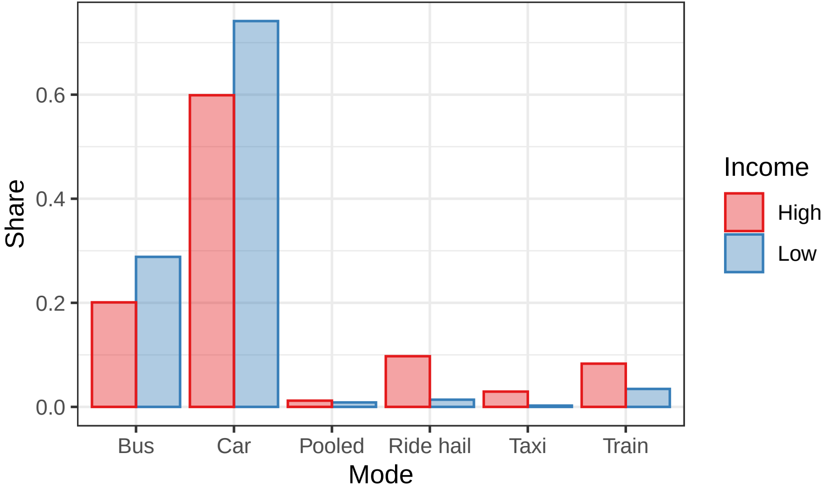
– Car trips are identified as:

$$\text{Car Trips} = \text{Cell Phone Trips} - \text{Public Transit Trips} - \text{Ride-hailing Trips} - \text{Taxi Trips}$$

Combined vs. survey data: flows across community areas



Mode market shares by income



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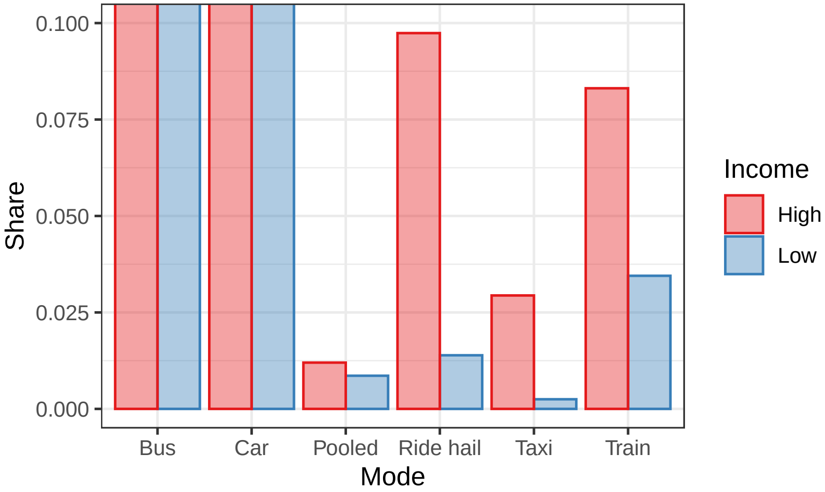

Outline

Model: Outline

Transportation system of a city, 3 parts:

1. Commuters make mode choices: (prices and times) $\mapsto$ (# of people choosing each mode)
2. Transportation technology: (# of people choosing each mode) $\mapsto$ (time and cost)
3. City government: chooses prices and capacity of each mode, trades off welfare and budget

Outside our model (for now?):

- Supply side. Government hires taxi and ride-hailing drivers at market wage
- Long-term investments in infrastructure

Next few slides: simple theoretical model with one O-D pair, one time period

- We estimate main model for different O-D pairs and times of the week

Model: Demand

Agents choose across **modes of transportation** J

- Mode $j \in J$ has price p_j and total time (wait + trip time) T_j

Demand for mode j:

$$D_j(\mathbf{p}, \mathbf{T})$$

Model: Transportation technology

Mode j is described by three functions of quantity and capacity $(\mathbf{q}, \boldsymbol{\kappa})$:

1. $\tau_j(q_j, \kappa_j)$: Total time (wait + travel)
2. $C(\mathbf{q}, \boldsymbol{\kappa})$: Cost (fuel, depreciation, labor)
3. $E(\mathbf{q}, \boldsymbol{\kappa})$: Externalities ($CO_2$, congestion),

κ_j: Capacity of mode j, determines total times

- Taxis, ride-hailing, shared: Number of drivers working. More idle drivers $\rightarrow$ lower times.
- Buses, trains: Route frequency. More buses $\rightarrow$ lower times.

Model: City Government and Equilibrium

City government chooses prices and capacities $(\mathbf{p}, \boldsymbol{\kappa})$. Equilibrium $(\mathbf{q}, \mathbf{T})$ such that:

$$\underbrace{\mathbf{q} = \mathbf{D}(\mathbf{T}, \mathbf{p})}_{\text{demand}} \qquad \text{and} \qquad \underbrace{\mathbf{T} = \boldsymbol{\tau}(\mathbf{q}, \kappa)}_{\text{technology}}$$

Conditional on equilibrium, government's problem (Ramsey):

$$\max_{(\mathbf{p},\boldsymbol{\kappa})} \underbrace{CS\left(\mathbf{q}, \mathbf{p}(\mathbf{q}, \boldsymbol{\kappa})\right) + \overbrace{\mathbf{p} \cdot \mathbf{q} - C(\mathbf{q}, \kappa)}^{\text{Gov. revenue}} - E(\mathbf{q}, \kappa)}_{\text{Welfare}} \qquad \text{s.t.} \qquad \underbrace{\mathbf{p} \cdot \mathbf{q} - C(\mathbf{q}, \kappa) \geq B}_{\text{Budget constraint}}$$

Main result: Optimal tax/subsidy

FOCs can be rearranged to give the optimal tax/subsidy:

$$p_j - \underbrace{\tilde{C}_j}_{\text{Mg. cost}} = \underbrace{\tilde{E}_j}_{\substack{\text{Mg.} \\ \text{externality}}} + \underbrace{\bar{u}_j^T \cdot (\epsilon_j^{T,q} + \epsilon_j^{T,\kappa})}_{\substack{\text{Network} \\ \text{externalities}}} + \text{(Term due to budget constraint)}$$

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- Pigouvian tax/subsidy
- Higher subsidy to modes with larger network externalities / returns to scale (Arnott, 1996)
  - Such as taxis, ride hail and buses, but *likely larger for shared transit (coordinate 3+ people)*

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$$\frac{\lambda}{1+\lambda} \cdot \Big\{ -\tilde{E}_j - \underbrace{\sum_{k \in J} q_k \cdot \Omega_{kj}}_{\text{Market power distortion}} + \underbrace{(\tilde{u}_j^T - \bar{u}_j^T) \cdot (\epsilon_j^{T,q} + \epsilon_j^{T,\kappa})}_{\text{Spence distortion}} \Big\}$$

- Pigouvian tax/subsidy
- Higher subsidy to modes with larger network externalities / returns to scale (Arnott, 1996)
  - Such as taxis, ride hail and buses, but *likely larger for shared transit (coordinate 3+ people)*
- Government cares about **budget**, so it behaves like a **monopolist** to some extent

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Identifying Variation for Price Elasticity: Ride-hailing Trip Surcharge

Challenge: finding exogenous price variation

- Bus/train prices fixed, taxi prices follow fixed schedule
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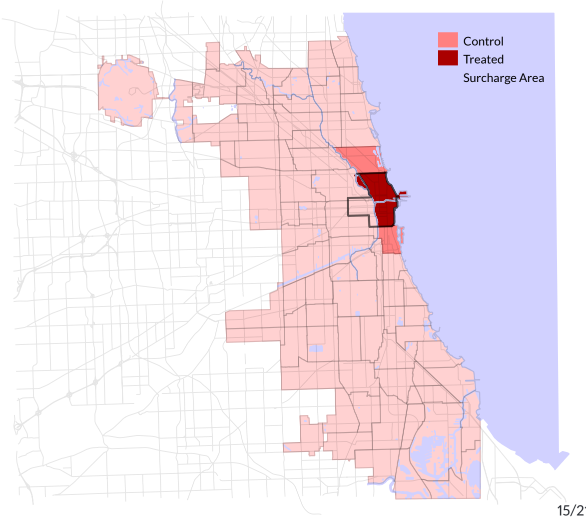
We exploit a tax to ride-hailing that offers *temporal* and *spatial* price discontinuities:

- Surcharge (higher tax) for trips to/from "Surcharge area".
- Active weekdays 6am-10pm.
- $1.75 for "standard", $0.65 for pool trips

Surcharge Areas (Treated) and Neighboring Areas (Control)
by Community Area



Identifying Variation for Price Elasticity: Ride-Hailing Trip Tax

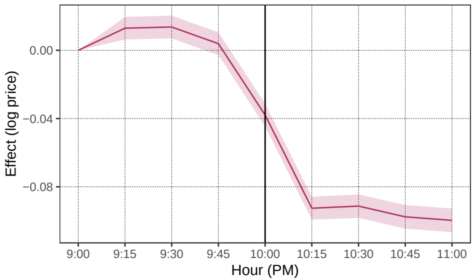
Specification:

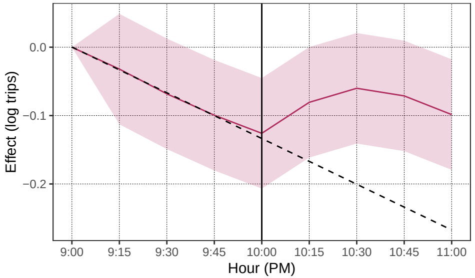
$$y_{o,d,t} = \mu_{o,d} + \alpha_t + \beta_t \cdot treat_{o,d} + \epsilon_{o,d,t}$$

where:

- $y_{o,d,t}$: Log price, log trips
- o, d: origin/destination community area
- t: Time of the day (15-min intervals)
- $treat_{o,d}$: Are $o \to d$ trips subject to surcharge?

Figures plot coefficients β_t





Taking the model to the data: Demand

Setup:

- Arrival rate λ_{odt} of agents who want to go from o to d at time t
- Mode j has price p_{odtj} and total time (wait + trip time) T_{odtj}

Utility of agent i:

$$u^i_{odtj} = -\underbrace{\beta_i \cdot p_{odtj}}_{\text{Disutility of price}} - \underbrace{\gamma_i \cdot T_{odtj}}_{\text{Disutility of time}} + \underbrace{\xi_{odtj}}_{\text{Market-level unobservables}} + \underbrace{\epsilon^i_{odtj}}_{\text{Idiosyncratic error}}$$

- ξ_{odtj}: Fixed effects + residual demand shifter
- ϵ^i_{odtj}: Nested logit, nests are (car), (bus, train), (taxi,ride-hail,pooled).
- $\frac{\gamma_i}{\beta_i}$ is the **value of time**.

Estimation by GMM. Two types of moments:

1. Orthogonality of T_{odtj} and residual demand shifter
2. Demand responses to surcharge

Simple Demand Results

	(1)	(2)	(3)	(4)	(5)
Trip Time (in hours)	-4.051***	-1.632***	-2.002***	-1.717***	-1.722***
	(0.127)	(0.315)	(0.187)	(0.264)	(0.275)
Price	-0.219***	-0.128***	0.00829*		
	(0.00806)	(0.00938)	(0.00470)		
VOT	$18.49	$12.79	-241.57	$19.07	$19.14
Price Elasticity	-1.56	-.91	.06	-1.42	-1.42
Hour FE	No	Yes	Yes	Yes	Yes
Day of Week FE	No	Yes	Yes	Yes	Yes
O-D FE	No	Yes	Yes	Yes	Yes
Mode FE	No	No	Yes	Yes	Yes
Elasticity from Policy	No	No	No	Yes	Yes
Mode-Hour-We FE	No	No	No	No	Yes
R_a^2	0.653	0.398	0.630	0.552	0.583
Observations	743046	742803	742803	742803	742803

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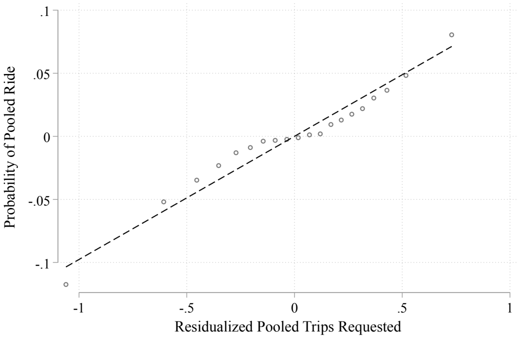
Transportation Technology: Pooling Network Externalities

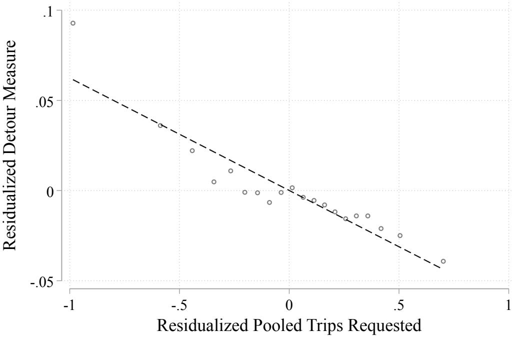
What is the optimal subsidy for shared transit? $\leftrightarrow$ How large are the network externalities?

Doubling the number of trip requests leads to:

Extensive margin: 10% Increase in match probability

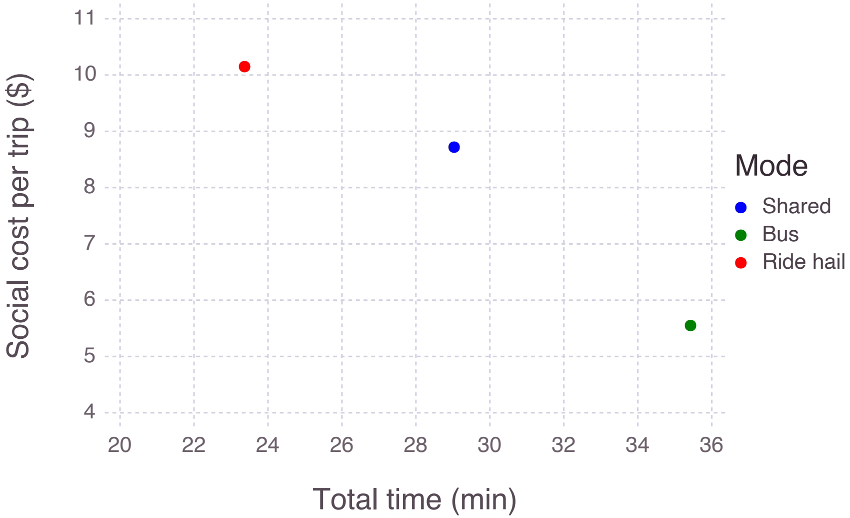


Intensive margin: 8% reduction in detour



We fit a microfounded pooling technology with 4 parameters to match both levels and slopes.

Transportation technology: Mode comparison



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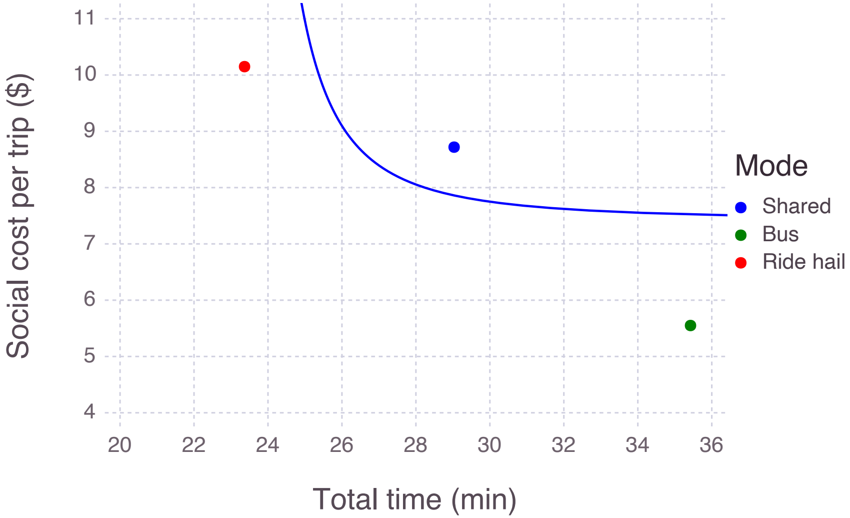

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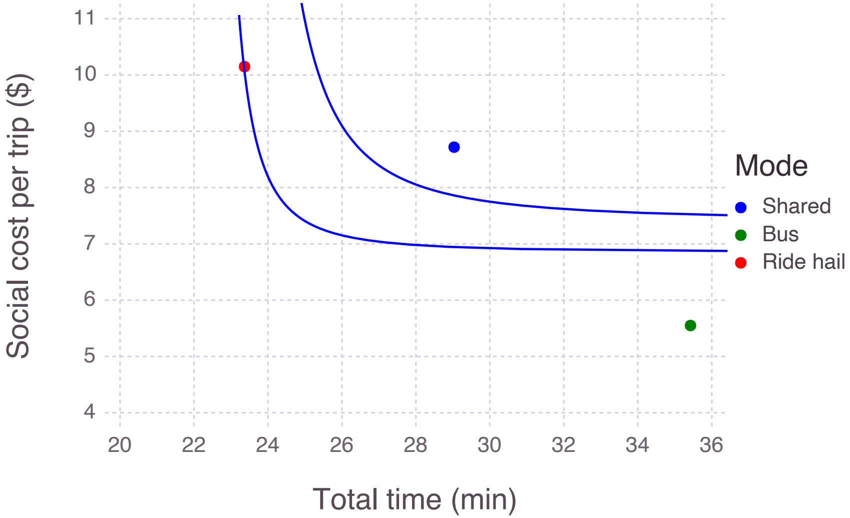


Conclusions

Key results:

- Demand: Value of time of $\sim$ \$20 /h, demand elasticity of ~ -1.5
- Substantial network externalities of shared transit $\rightarrow$ need for subsidies
- Shared transit can become viable alternative if scaled up

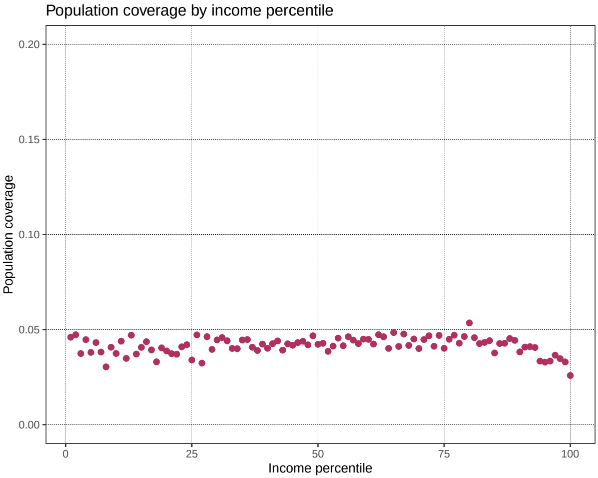
Future steps:

- Finish estimating model
- Run counterfactuals
- Focus on:
  - Spatial heterogeneity (e.g., find spatially optimal prices)
  - Distributional consequences of policies

Thank you!

Cell phone data is balanced over income

- Assign home census tract to cellphone id
- Construct population coverage relative to census tract population in census
- Order tracts by income percentiles



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