Economies of Density in E-Commerce: A Study of Amazon's Fulfillment Center Network

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- This paper: examine the role of network expansion in Amazon's scale advantage.

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   - *Literature:* Holmes (2011), Zheng (2014), Hendricks, Piccone, Tan (1993, 1997), Ellickson, Houghton, Timmins (2013), Jia (2008), Nishida (2015)

Model

Amazon chooses the sequence of network expansion, $a = (a_0, a_1, ..., a_\infty)$, that solves:

$$\max_{a_t \forall t} \sum_{t=0}^{\infty} \beta^t \pi_t(a_t) \tag{1}$$

$$\pi_t(a_t) = \underbrace{R_t(a_t)}_{\text{Net revenue}} - \underbrace{\left[\sum_i Q_{it} \Omega_{ic}(a_t) g_{ic}(a_t)\right]}_{\text{Shipping cost}} - \underbrace{\sum_c L(q_{ct}, K_{ct}) w_{ct}}_{\text{Labor cost}} - F_{ct}$$

- Q_{it}: orders from county i
- $\Omega_{ic}(a_t)$: O-D matrix (order flow)
- q_{ct}, K_{ct}: orders and capacity at c

Main components to estimate:

- Revenue function: $R_t(a_t)$
- Cost of shipping an order: $g_{ic}(a_t) = \theta_o + d_{ic}\theta_x - \mathbf{1}^{VI}_{ic}(a_t)\theta_v$
- Labor demand function: $L(q_{ct}, K_{ct})$
- Fixed-cost: $F_{ct} = K_{ct} \times (r_{ct} + \kappa \text{PopDens}_{ct})$

Demand: Overview

Goal: Estimate demand for online and offline retail.

- Key objects: sensitivity to sales tax and convenience.
- Controls: product variety and platform quality.

Model: CES demand model for a representative consumer from county i, who chooses how much to spend on

1. Amazon (taxed depending on network).
2. Taxed online competitors (e.g., Walmart.com)
3. Non-taxed online competitors (e.g., overstock.com)
4. Offline competitors (e.g., Walmart)

Identification: Spending responses as network expands (changes in convenience and taxes).

Demand: Data

Data:

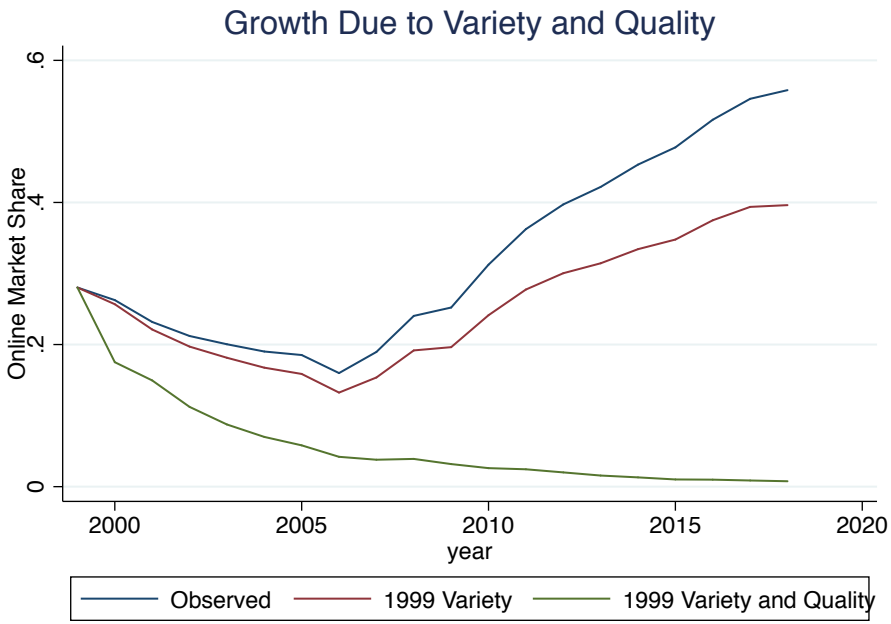
- Online spending 2006-2016: comScore, Forrester, financial statements.
- Offline spending: CEX.
- Taxes: TDS and various online sources.
- County level demand shifters: Census

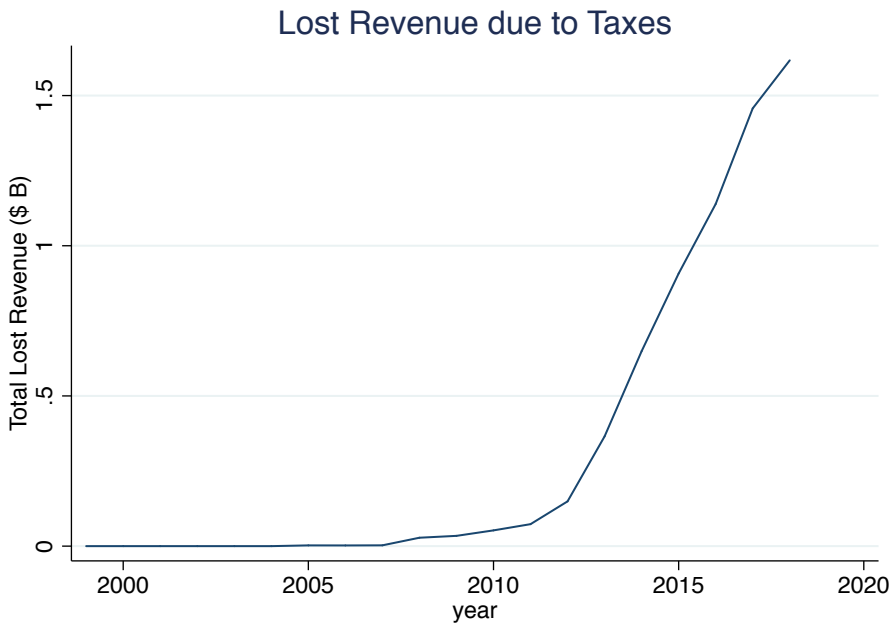
Projections: Use estimates, Census data and financial statements to project demand 1999-2005 and 2017-2018.

Demand: Results

Key Results:

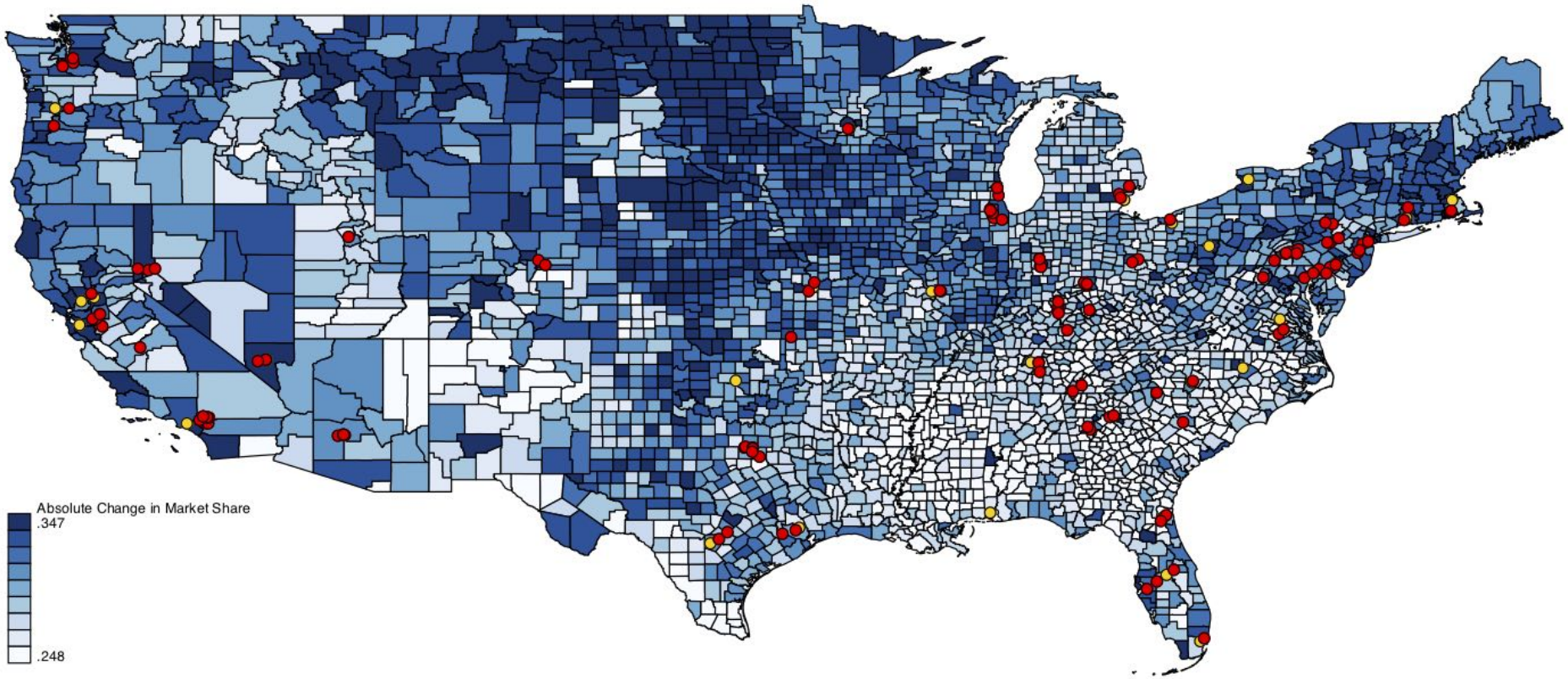
- Descriptive transaction level regression: consumers sensitive to tax, no **local** convenience.
- CES model: elasticity of substitution=-1.4.





Demand: Absolute Change in Amazon's Market Share

Period: 1999-2018



Cost Function Estimation

Cost function:

$$C_t(a_t) = \underbrace{\left[\sum_i q_{it}\Omega_{ic}(a_t)g_{ic}(a_t)\right]}_{\text{Shipping cost}} + \underbrace{\sum_c L(q_{ct}, K_c)w_{ct}}_{\text{Labor cost}} + F_{ct}$$

Data:

- Employment, size, entry date, location of each FC and SC from 1999-2018.

Estimation:

- $\Omega_{ic}(a_t)$ and $L(q, K)$: Employment data
- $g_{ic}(a_t)$ and F_{ct}: Revealed-preference inequalities

Profit Function and Optimal Rollout

Amazon's NPV of profits: $\theta = (\theta_o, \theta_x, \theta_v, \kappa)$

$$\Pi(\mathbf{a}; \theta) = \sum_{t=0}^{\infty} \beta^t \pi(a_t; \theta)$$

Amazon chooses the optimal sequence of FC and SC openings:

$$\mathbf{a}^0 = \arg\max_{\mathbf{a} \in \mathcal{A}} \Pi(\mathbf{a}; \theta)$$

Choosing a counter-factual sequence in which the opening date of FC c is swapped with c' must be suboptimal:

$$\Pi(\mathbf{a}^0; \theta) - \Pi(\mathbf{a}^{c,c'}; \theta) \geq 0$$

Importantly:

- These inequalities are independent of the continuation value in $T + 1$
- NPV differences are linear in the parameters: $\Pi(\mathbf{a}^0) - \Pi(\mathbf{a}^{c,c'})$

Moment Inequalities

Use estimates to calculate profit components under observed and perturbed network.

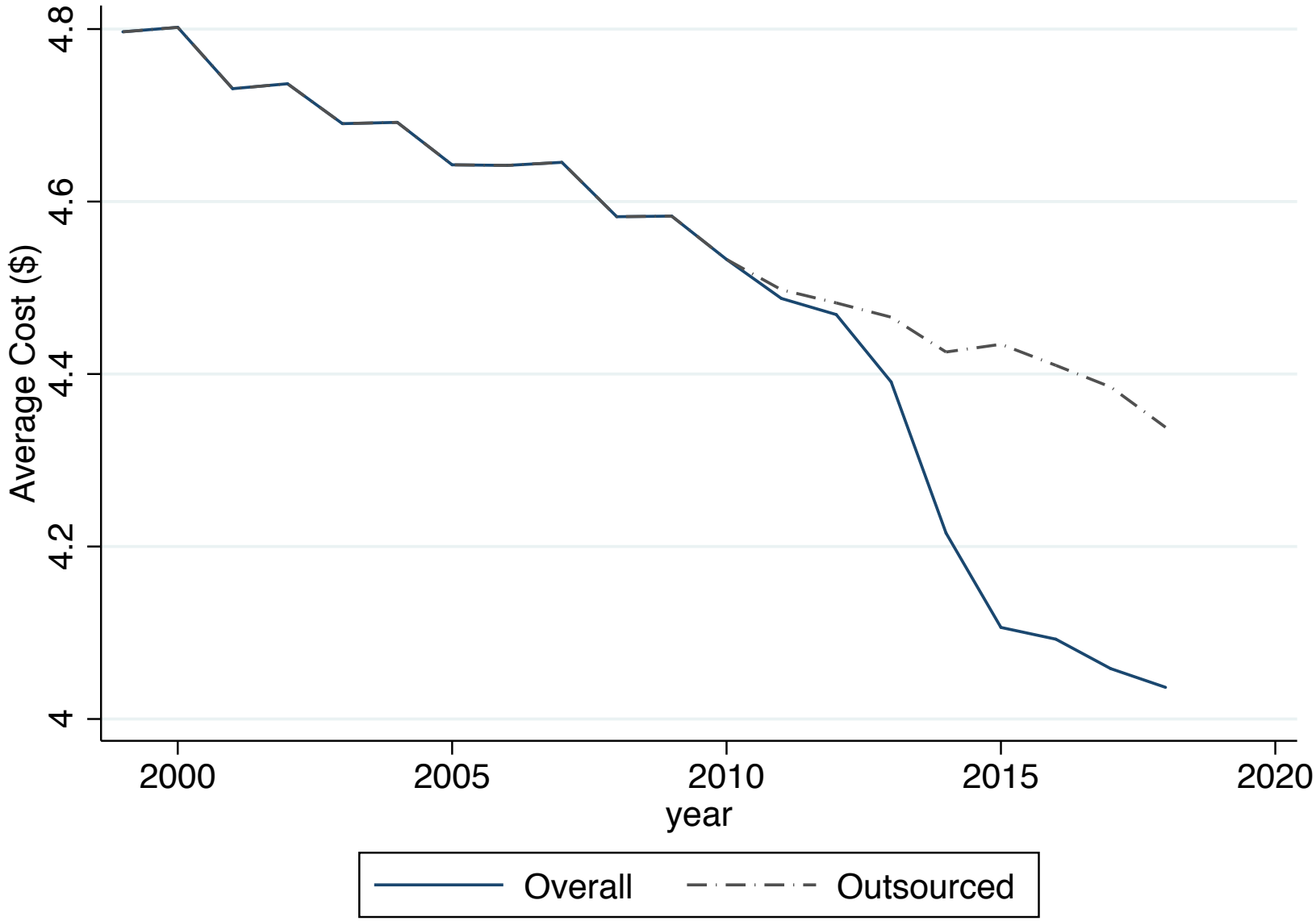
- Assume components are measured with error: $\tilde{\Pi}(a;\theta) = \Pi(a;\theta) + \varepsilon$
- Form a set of moment inequalities.

$$\frac{1}{M}\sum_{c,c'} \tilde{\Pi}(\mathbf{a}^0;\theta) - \tilde{\Pi}(\mathbf{a}^{c,c'};\theta) = \tilde{m} \geq 0$$

Identification: revealed preference trade-offs

- Shipping distance: θ_x
  - *Lower bound:* Enter high tax/cost areas in order to decrease distance
    - ★ *Simplified example:* $y - \theta x \geq 0 \rightarrow \frac{y}{x} \leq \theta$
  - *Upper bound:* Enter rural areas to avoid taxes or save on costs
    - ★ *Simplified example:* $y - \theta x \geq 0 \rightarrow \frac{y}{x} \geq \theta$
- Similar trade-offs help to identify other parameters.

Impact of Expansion



Next Steps and Conclusion

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- Distortion of cost savings from tax laws.

Conclusion: quantified the trade-off associated with the expansion of FC network.

- Consumers sensitive to sales tax.
- Significant cost savings from density and VI into sorting
- $\rightarrow$ Complementarity between SC and FC locations