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

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Online Retailing: 1999-2018

- Increase in concentration (2006-2016): HHI of 400 to 1,900.
- Amazon’s sales growth: US revenue of $5.7bn to $80bn.
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  - Introduction of Sortation Centers (SCs) in 2011: 40 SCs by 2018.

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- Prior to 2017, sales tax is based on physical presence in state.
- Additional/higher rents and wages.

Benefits of expansion:
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- Shorter delivery routes.
- Vertical integration.

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3. **Distribution cost:** Quantify the fixed and variable cost savings from network expansion and vertical integration.
   - *Revealed preference trade-off:* Denser distribution network (lower distribution cost), is associated with revenue loss (from taxes) and higher operating costs (wage+land).
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Amazon chooses the sequence of network expansion, \( a = (a_0, a_1, ..., a_\infty) \), that solves:

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

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

- \( Q_{it} \): 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: \( g_{ic}(a_t) = \theta_o + d_{ic} \theta_x - 1_{ic}(a_t) \theta_v \)
- 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

**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:

\[ C_t(a_t) = \left[ \sum_i q_{it} \Omega_{ic}(a_t) g_{ic}(a_t) \right] + \left[ \sum_c L(q_{ct}, K_c) w_{ct} + F_{ct} \right] \]

Shipping cost

Labor cost

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: $\theta = (\theta_o, \theta_x, \theta_v, \kappa)$

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

Amazon chooses the optimal sequence of FC and SC openings:

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

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

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

Importantly:

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

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

Identification: revealed preference trade-offs

- Shipping distance: $\theta_x$
  - **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

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Next Steps and Conclusion

Next Steps:
- 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
- → Complementarity between SC and FC locations