Competition Among Spatially Differentiated Firms: An Estimator with an Application to Cement

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- Gas stations, fast food, theaters, cement, lumber, paper.
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Can we estimate the underlying parameters of supply & demand, exploiting variation in commonly available data?

Structural estimation would enable us to –
- Measure spatial differentiation, local market power
- Conduct new counterfactual policy experiments:
  - Gas tax & market power
  - Tariffs, duties
  - Geo. antitrust markets
  - Entry deterrence
Why is this challenging?

Most obvious way to estimate the costs of transportation:
- Observe distribution of shares
- Select costs that rationalize distribution

**Data Availability Problem:**
- This isn’t typically observed
- No studies do this (?)
- More common: firm-level shares and/or prices

*Figure: Market Shares over Space*
Another complication: spatial price discrimination

Some firms employ spatial price discrimination
  - E.g., charge higher prices to nearby “captive” consumers
  - Must account for geographic distributions of shares and prices
  - Exacerbates data availability problem

Some structural work on non-discriminatory spatial models
  - Thomadsen (2005), Davis (2006), McManus (2009)
  - But no structural work on spatial price discrimination
Two-part presentation

Estimator for models of spatial price differentiation, spatial price discrimination

- Flexible data requirements (e.g., regional prices/production)
- Extend estimation to settings previously too demanding
- Conditions for consistency, asymptotic normality
Introduction

Two-part presentation

1. Estimator for models of spatial price differentiation, spatial price discrimination
   - Flexible data requirements (e.g., regional prices/production)
   - Extend estimation to settings previously too demanding
   - Conditions for consistency, asymptotic normality

2. Empirical application to portland cement
   - Estimator works in real-world example
   - Fits the data well – in-sample, out-of-sample
   - Provide one counterfactual: merger harm over space
Main methodological insight

Numerical approximations to equilibrium relax data requirements

1. *Compute* distributions of shares & prices for a parameter vector
2. Construct aggregated equilibrium predictions at level of data
3. Repeatable: select parameters that match predictions to data
Main methodological insight

Numerical approximations to equilibrium relax data requirements

1. **Compute** distributions of shares & prices for a parameter vector
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3. Repeatable: select parameters that match predictions to data

**Identification:** predictions & data differ due to measurement error

- Orthogonal to plant locations, cost/demand shifters
- Multiple-equation nonlinear least squares ("RHS" computed)
- Each equation matches time-series of data to corresponding prediction
Part II

An Economic Model
A *geographic space* is a compact, connected set in $\mathbb{R}^2$

- Plants have fixed locations
- Continuum of consumers exists over the space
The geographic space

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*Consumer areas* are subsets of the geographic space
- Each firm sets different mill price to each area
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$\implies$ partition determines pattern of spatial price discrimination
A *geographic space* is a compact, connected set in $\mathbb{R}^2$

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*Consumer areas* are subsets of the geographic space

- Each firm sets different mill price to each area

$\implies$ partition determines pattern of spatial price discrimination

- One consumer area: no spatial price discrimination (arbitrage?)
- Lots of areas: firms discrimination finely
The geographic space: example

Figure: A Geographic Space.
Supply and demand

Multi-plant firms compete in prices, maximize variable profits:

\[
\pi_f = \sum_{j \in J_f} \sum_{n} p_{jn} q_{jn}(p_n; \theta_0) - \sum_{j \in J_f} \int_0^{Q_j(p; \theta_0)} c(Q; \theta_0) dQ
\]
Supply and demand

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variable revenues

variable costs

Conventional discrete-choice demand system. Indirect utility:

$$u_{ij} = \beta^c + \beta^p p_{nj} + \beta^d d_{jn} + \nu_{ij}$$

Logit or nested logit facilitates computation of equilibrium
Equilibrium

Get standard first-order conditions:

\[ f(p; \theta_0) \equiv p - c(Q(p; \theta_0); \theta_0) + \Omega^{-1}(p; \theta_0)q(p; \theta_0) = 0. \]
Equilibrium

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Bertrand-Nash equilibrium characterized by \( J \times N \) vector of prices

- Formally, \( p^*(\theta) : \mathbb{R}^K \rightarrow \mathbb{R}^{JN} \) such that \( f(p^*(\theta); \theta) = 0 \)
- Assume uniqueness, existence – come back to this
Part III

Estimation
Want to recover the structural parameters of supply and demand

Some more notation:
- Available endogenous data in vector $y_t$
  - Includes average firm prices, regional production, etc.
- Denote aggregated equilibrium predictions as $\tilde{y}_t(\theta; X_t)$
  - Construct at same level as data
- Put plant locations, cost/demand shifters in matrix $X_t$
The estimator

Multiple-equation nonlinear least squares estimator

$$\hat{\theta} = \arg \min_{\theta \in \Theta} \frac{1}{T} \sum_{t=1}^{T} [y_t - \tilde{y}_t(\theta; X_t)]' C_T^{-1} [y_t - \tilde{y}_t(\theta; X_t)]$$

- Minimize deviations b/w data and equilibrium predictions
- Each element of $[y_t - \tilde{y}_t(\theta; X_t)]$ defines one nonlinear equation
- Matrix $C_T$ weights equations
- “Method of moments with optimal instruments”
Obtaining aggregate equilibrium predictions

Evaluation of objective function requires $\tilde{y}_t(\theta; X_t)$

1. Compute equilibrium as a vector $\tilde{p}^*$ that satisfies:

$$\frac{1}{JN} \| f(\tilde{p}^*; X_t, \theta) \| < \delta$$

- $\delta$ is user-specified tolerance; we use 1e-13
- Need fast nonlinear equation solver (e.g., DFSANE)

2. Use $\tilde{p}^*$ to calculate aggregated equilibrium predictions

3. Plug into objective function
Asymptotic properties


- Nested logit, single-plant firms (Mizuno 2003)
- Logit, multi-plant firms (Konovalov & Sándor 2010)
Asymptotic properties

**Assumption (A1):** A *unique* Bertrand-Nash equilibrium exists.
- Nested logit, single-plant firms (Mizuno 2003)
- Logit, multi-plant firms (Konovalov & Sándor 2010)

**Assumption (A2):** *The population parameter vector is globally identified.*
Asymptotic properties

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**Assumption (A2):** The population parameter vector is globally identified.

**Theorem 1:** The multiple-equation NLS estimate is consistent and asymptotically normal.
Part IV

Empirical Application
Portland cement industry: Basics

What is portland cement?

- Finely ground powder
- Portland Cement $+$ Water $=$ Ready Mix Concrete
- Shipped by truck from cement plants to concrete plants
- Consumers pay the transportation costs
- Contracts are individually negotiated with buyers
Map of cement production in 2003

Annual Portland Cement Production Capacity
- 0 - 800,000 metric tonnes
- 800,001 - 1,300,000 metric tonnes
- 1,300,001 - 1,800,000 metric tonnes

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Marginal cost specification (cont’d)
Demand specification

Demand is nested logit

- Plants differentiated by price, location, i.i.d. error
  \[ u_{ijt} = \beta^c + \beta^p p_{jnt} + \beta^d \text{MILES}_{jn} \ast \text{DIESEL}_t + \nu_{ijt} \]

- Two nests: inside goods vs. outside good
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Additional details:

- Use 90 counties to specify consumer areas
- Model competitive fringe of import suppliers
Endogenous data

Endogenous data from the U.S. Geological Survey, 1983-2003:

1. Average prices for NorCal, SoCal, and AZ-NV
2. Total production (same regions)
3. Total consumption for NorCal, SoCal, AZ, and NV

10 nonlinear equations, 21 time periods
Model fits

Panel A: Regional Consumption

Panel B: Regional Production

Panel C: Regional Prices

Panel D: Cross-Region Shipments

Empirical application

EstIMATION Results

Miller and Osborne (2010)
Estimated price elasticities

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate Elasticity</td>
<td>-0.12</td>
</tr>
<tr>
<td>Firm Elasticity</td>
<td>-4.27</td>
</tr>
</tbody>
</table>

- Wood, asphalt, steel are weak substitutes
- But firms compete – firm demand is more elastic
Empirical application

Estimated distribution of miles shipped in 2003

Transportation costs of $0.30 per tonne-mile (at 2000 diesel price)
- Consumers pay $24.61 for transportation per tonne
- 22% of total consumer expenditure
- Mean = 92 miles, 90% under 175 miles
Localized market power

Map A: Price

Map B: Shares

Counties By Price
- < 71
- 71 - 80
- 80 - 90
- > 90

Counties By Shares
- < .04
- .04 - .25
- .25 - .40
- > .40

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Empirical application

Merger simulation

Map A: No Divestiture

Map B: Optimal Divestiture

Loss of Consumer Surplus

- <2
- 2-20
- 20-50
- 50-250
- >250

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Closing thoughts

Estimator could define stage-game payoffs in dynamic routines
- Bajari, Benkard, Leven (2007 EMA), etc.
- Endogenize firm location choice
- Would have to solve state-space problem

Parallels to estimators for product space differentiation (BLP)
- BLP fully observe prices/shares but not characteristics
- M-O fully observe characteristics but not prices/shares
- Use numerical techniques to recover unobserved metrics