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

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Research question

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- Gas stations, fast food, theaters, cement, lumber, paper.

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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

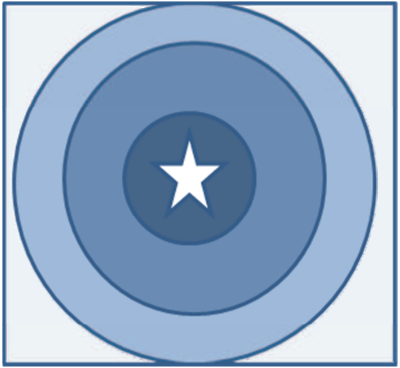

Figure: Market Shares over Space

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

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

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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

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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

The geographic space

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

The geographic space: example

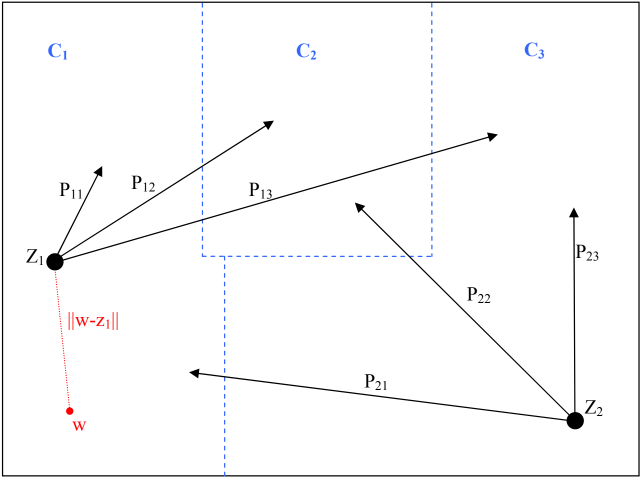

Figure: A Geographic Space.

Supply and demand

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

$$\pi_f = \underbrace{\sum_{j \in \mathbb{J}_f} \sum_n p_{jn} q_{jn}(\mathbf{p_n}; \boldsymbol{\theta}_0)}_{\text{variable revenues}} - \underbrace{\sum_{j \in \mathbb{J}_f} \int_0^{Q_j(\mathbf{p};\, \boldsymbol{\theta_0}))} c(Q; \boldsymbol{\theta}_0) dQ}_{\text{variable costs}}$$

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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:

$$\mathbf{f}(\mathbf{p};\theta_0) \equiv \mathbf{p} - \underbrace{\mathbf{c}(\mathbf{Q}(\mathbf{p};\theta_0);\theta_0)}_{\text{marginal cost}} + \underbrace{\mathbf{\Omega}^{-1}(\mathbf{p};\theta_0)\mathbf{q}(\mathbf{p};\theta_0)}_{\text{markup}} = \mathbf{0}.$$

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

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

Part III

Estimation

Overview

Want to recover the structural parameters of supply and demand

Some more notation:

- Available endogenous data in vector $\mathbf{y}_t$
  - Includes average firm prices, regional production, etc.
- Denote aggregated equilibrium predictions as $\widetilde{\mathbf{y}}_t(\theta; \mathbf{X}_t)$
  - Construct at same level as data
- Put plant locations, cost/demand shifters in matrix $\mathbf{X}_t$

The estimator

Multiple-equation nonlinear least squares estimator

$$\widehat{\theta} = \arg\min_{\theta \in \Theta} \frac{1}{T} \sum_{t=1}^{T} [\mathbf{y}_t - \widetilde{\mathbf{y}}_t(\theta; \mathbf{X}_t)]' \mathbf{C}_T^{-1} [\mathbf{y}_t - \widetilde{\mathbf{y}}_t(\theta; \mathbf{X}_t)]$$

- Minimize deviations b/w data and equilibrium predictions
- Each element of $[\mathbf{y}_t - \widetilde{\mathbf{y}}_t(\theta; \mathbf{X}_t)]$ defines one nonlinear equation
- Matrix $\mathbf{C}_T$ weights equations
- "Method of moments with optimal instruments"

Obtaining aggregate equilibrium predictions

Evaluation of objective function requires $\widetilde{\mathbf{y}}_t(\boldsymbol{\theta}; \mathbf{X}_t)$

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

$$\frac{1}{JN} \parallel \mathbf{f}(\widetilde{\mathbf{p}}^* ; \mathbf{X}_t, \boldsymbol{\theta}) \parallel < \delta$$

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

2. Use $\widetilde{\mathbf{p}}^*$ to calculate aggregated equilibrium predictions
3. Plug into objective function

Asymptotic properties

Assumption (A1): *A unique Bertrand-Nash equilibrium exists.*

- Nested logit, single-plant firms (Mizuno 2003)
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Theorem 1: *The multiple-equation NLS estimate is consistent and asymptotically normal.*

Part IV

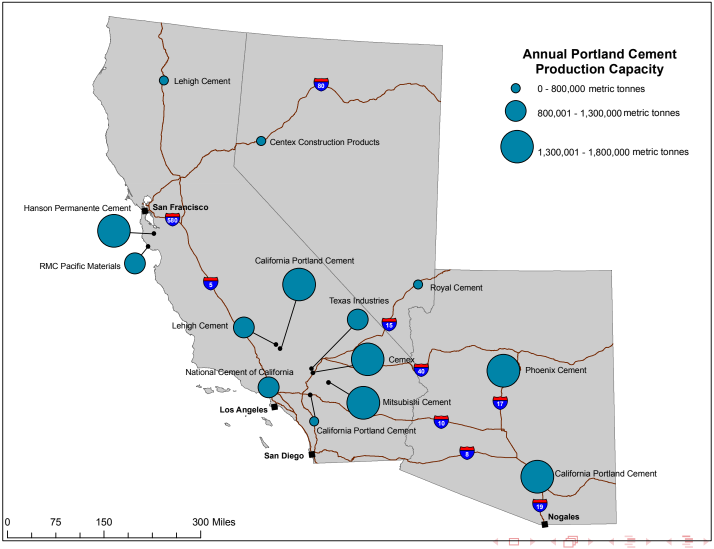
Empirical Application

Portland cement industry: Basics

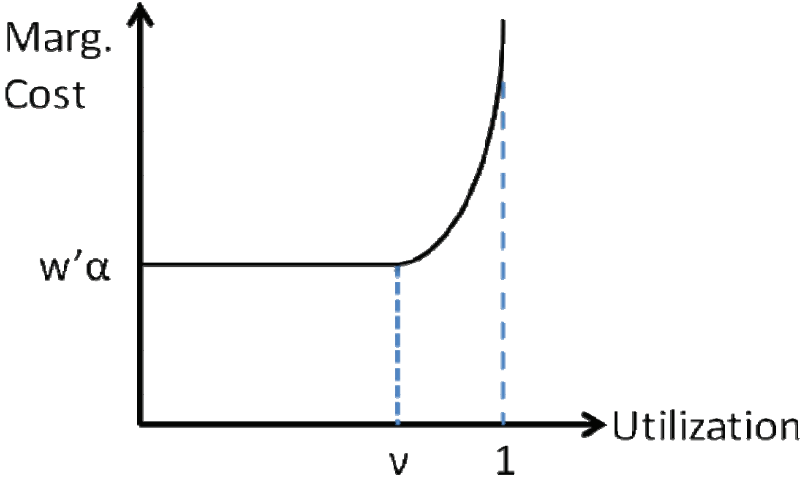
What is portland cement?

- 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



Marginal cost specification (cont'd)



Demand specification

Demand is nested logit

- Plants differentiated by price, location, i.i.d. error

$$u_{ijt} = \beta^c + \beta^p p_{jnt} + \beta^d MILES_{jn} * DIESEL_t + \nu^*_{ijt}$$

- 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

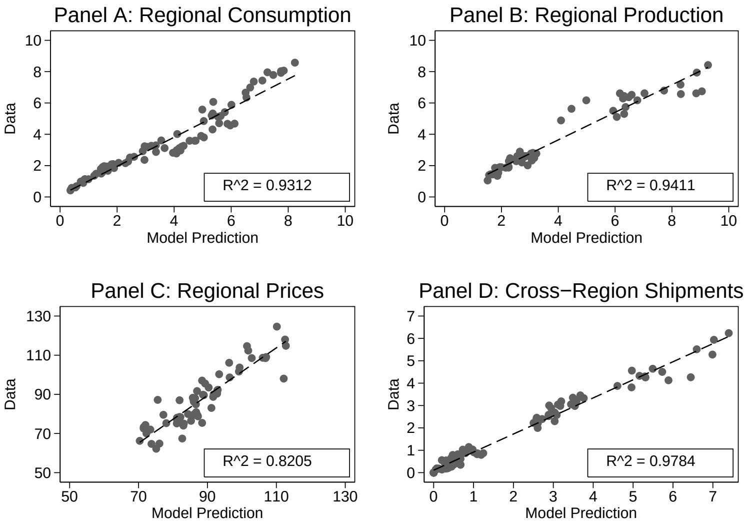
Endogenous data

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
4. Cross-region shipments 1990-2003

$\Longrightarrow$ 10 nonlinear equations, 21 time periods

Model fits


Panel A: Regional Consumption
Data
Model Prediction
R^2 = 0.9312
Panel B: Regional Production
Data
Model Prediction
R^2 = 0.9411
Panel C: Regional Prices
Data
Model Prediction
R^2 = 0.8205
Panel D: Cross−Region Shipments
Data
Model Prediction
R^2 = 0.9784

Estimated price elasticities

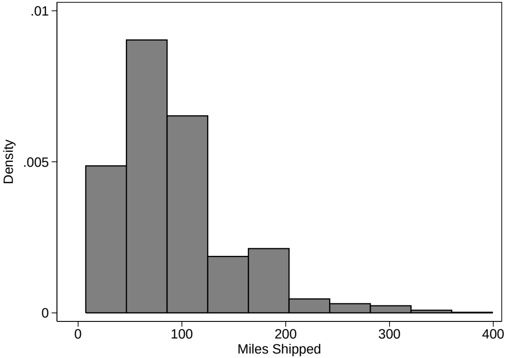
	Mean
Aggregate Elasticity	-0.12
Firm Elasticity	-4.27

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

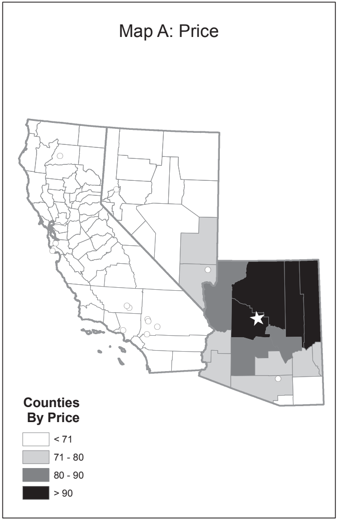
Estimated distribution of miles shipped in 2003

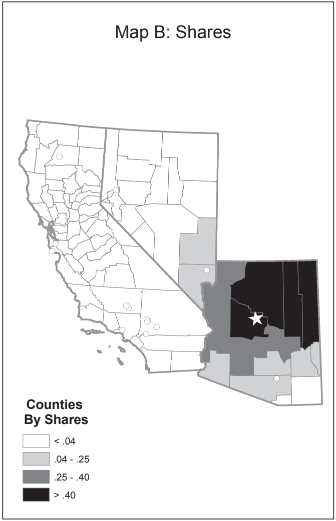
Transportation costs of \$0.30 per tonne-mile (at 2000 diesel price)

- Consumers pay \$24.61 for transportation per tonne
- 22% of total consumer expenditure
- Mean = 92 miles, 90% under 175 miles

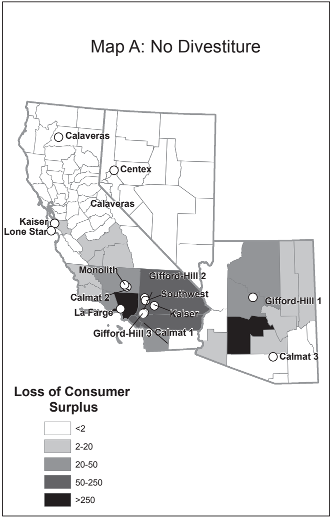


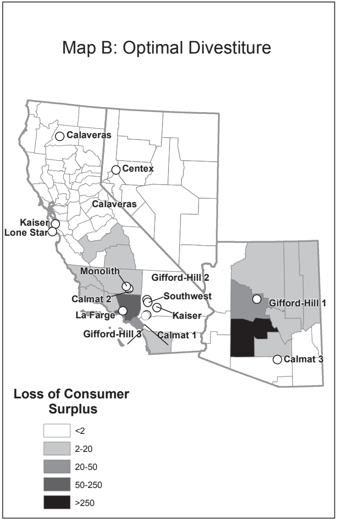
Localized market power





Merger simulation





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