Spatial Competition with Heterogeneous Firms

Jonathan Vogel

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I model endogenous product differentiation with heterogeneous firms.
Introduction

- I model endogenous product differentiation with heterogeneous firms
- Two branches of product differentiation literature
I model endogenous product differentiation with heterogeneous firms.

Two branches of product differentiation literature:

- Economists tend to hold product characteristics fixed when considering pricing decisions and firm behavior more generally → endogeneity bias.
Estimate the change in domestic-firm profit resulting from an increase in a tariff
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First step

\[
\begin{bmatrix}
\text{market shares} \\
\text{prices} \\
\text{product characteristics}
\end{bmatrix}
\rightarrow
\begin{bmatrix}
\text{demand system} \\
\text{marginal costs}
\end{bmatrix}
\]
Estimate the change in domestic-firm profit resulting from an increase in a tariff

First step

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\text{prices} \\
\text{product characteristics}
\end{bmatrix}
\Rightarrow
\begin{bmatrix}
\text{demand system marginal costs}
\end{bmatrix}
\]

Counter-factual exercise

\[
\begin{bmatrix}
\text{demand system} \\
\text{NEW marginal costs} \\
\text{FIXED product characteristics}
\end{bmatrix}
\Rightarrow
\begin{bmatrix}
\text{market shares} \\
\text{prices}
\end{bmatrix}
\]
Introduction

Endogenous differentiation and firm heterogeneity

- Markets are rarely perfectly competitive
  — Spence (1976), Dixit Stiglitz (1977), Salop (1979)
- Firm productivity differs significantly both within and across industries
  — Jovanovic (1982), Hopenhayn (1992)
- Models studying firm heterogeneity in monopolistically competitive industries abstract from or treat as exogenous product placement
Spatial competition models are ideally suited to answer: How does firm heterogeneity affect product placement in product space or firm location in geography?

Spatial competition literature dates back to Hotelling (1929)

- Two-stage model of Bertrand competition in which location differentiates otherwise homogeneous goods
While a spatial competition framework would be ideal, finding equilibria in "simple" symmetric-firm Hotelling-style models has proven difficult.
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Either assume that firms are homogeneous or abstract from location choice
I allow firms to randomize over prices
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Nevertheless, strategies are pure along equilibrium path
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- Tractability of framework allows me to answer questions of the form:
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- Tractability of framework allows me to answer questions of the form:
  - Will a firm locate closer to its relatively less productive neighbor?
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Tractability of framework allows me to answer questions of the form:

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- Does opening the black box of differentiation yield new insight into the mechanism linking productivity to profit and market share?
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- I allow firms to randomize over prices
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- Tractability of framework allows me to answer questions of the form:
  - Will a firm locate closer to its relatively less productive neighbor?
  - Does opening the black box of differentiation yield new insight into the mechanism linking productivity to profit and market share?
  - How does the productivity of direct competitors affect outcomes such as profit, market share, and the ease with which consumers substitute between goods?
A set of SPNE to a standard Hotelling-style model generalized in two ways:

1. firm heterogeneity
2. horizontal and vertical differentiation (vertical not in presentation)

Firms use pure strategies along the equilibrium path

There is a unique economic outcome in any strict SPNE under a simple refinement
A mass $L$ of consumers uniformly distributed along a unit circumference
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Each consumer inelastically demands one good
A mass $L$ of consumers uniformly distributed along a unit circumference. Each consumer inelastically demands one good. A consumer located at point $z$ buys from firm $i$ if

$$p_i + t \|z - i\| \leq \min_j \{p_j + t \|z - j\|\}$$

where $t > 0$.
A graphical representation of consumer preferences
Firm $i$ is associated with a constant marginal cost of production $k_i$. Additionally, the firm incurs a "shipping cost" of $\tau d$, with $\tau \in [0, t)$. The consumer located a distance $d$ from the firm's location.
Firm $i$ is associated with a constant marginal cost of production $k_i$.

Additionally, firm incurs a "shipping cost" of $2\tau d$, with $\tau \in [0, t)$, to ship a good to a consumer located a distance $d$ from its location.
Firms play a two-stage game of complete information
The game

- Firms play a two-stage game of complete information

- Location stage
The game

- Firms play a two-stage game of complete information
  1. Location stage
  2. Price stage
The game
Stage one: location stage

- There is a set of $n \geq 2$ firms
- The vector of marginal costs $(k_1, \ldots, k_n)$ is common knowledge
- All firms simultaneously choose locations along the circumference of the circle
The game
Stage two: price stage

- All locations and marginal costs are common knowledge at the beginning of the price stage
- All firms simultaneously choose their prices
No SPNE

A simple game without a simple solution

Market share is discontinuous in price
No pure-strategy equilibrium

Firms' profits are not globally continuous or quasi-concave

\[ p_B^* = p_A - td \]

\[ p_B^{**} = p_A + td \]
For any subgame, there exists a mixed-strategy equilibrium - Reny (1999)
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Suppose firm \( i \) unilaterally deviates in the location stage from conjectured equilibrium and in subsequent price stage there exists no pure strategy equilibrium in prices
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Upper bound on \( i \)’s profit strictly less than profit had it not deviated
Proof strategy

Let \( \pi_i^* \) (\( \pi_i^{A*} \)) denote firm \( i \)'s profit in the real game ("auxiliary" game) if firms follow eqm strategies.
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- Let $\pi_i^{A'} (E[\pi_i'])$ denote firm $i$’s profit in the auxiliary game (expected profit in the real game) if $i$ unilaterally deviates.
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- I prove that there exists a $\phi > 0$ s.t. if $k_i \in [k, k + \phi]$ for all $i$: 
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  3. Either $\pi_i^{A'} \geq E[\pi'_i]$ or $\pi_i^* > E[\pi'_i]$
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3. Either $\pi_i^{A'} \geq E[\pi_i']$ or $\pi_i^* > E[\pi_i']$

$\implies$ Either $\pi_i^* > E[\pi_i']$ or $\pi_i^* = \pi_i^{A*} \geq \pi_i^{A'} \geq E[\pi_i']$
Firm $i$’s strategy space is $\Omega_i$ and a strategy is $\omega_i \in \Omega_i$

Let $\Omega^n \equiv \Omega_1 \times \ldots \times \Omega_n$ and denote $\tilde{\omega} \in \Omega^n$ by a *strategy vector*. 
Proposition

Suppose $\tau \geq 0$. For any set of parameters $\theta \equiv (n, t, \tau, L)$ and $k \geq 0$ there exists a $\phi(\theta, k) > 0$ such that if $k_i \in [k, k + \phi(\theta, k)]$ for all $i$, then there is a non-empty set $O^* \in \Omega^n$ such that any $\tilde{\omega} \in O^*$ is a SPNE and strategies are pure along the equilibrium path for all $\tilde{\omega} \in O^*$. 
Proposition

For an arbitrary order in which firms locate, label any firm 0 and label subsequent firms in a clockwise direction (to firm \( n - 1 \)). This order corresponds to an equilibrium in \( O^* \). For any \( \tilde{\omega} \in O^* \) the distance between each pair of neighbors, firms \( i \) and \( i + 1 \), is

\[
d_{i,i+1}^* = \frac{1}{n} + \frac{2}{3t + 2\tau} \left( \bar{k} - \frac{k_i + k_{i+1}}{2} \right)
\]

Firm \( i \)'s price, market share, and profit are

\[
p_i^* = (t + \tau) \left( \frac{1}{n} + \frac{2}{3t + 2\tau} \bar{k} \right) + \frac{t}{3t + 2\tau} k_i
\]

\[
x_i^* = \frac{1}{n} + \frac{2}{3t + 2\tau} (\bar{k} - k_i)
\]

\[
\pi_i^* = Lt \left(x_i^* \right)^2
\]
Suppose there are four firms: two relatively unproductive firms and two productive firms.
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The two productive firms could be separated by the unproductive firms:
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- The two productive firms could be separated by the unproductive firms:

- The two productive firms could neighbor each other:
Isolation between two neighbors is strictly decreasing in their average marginal cost \( \frac{k_i + k_{i+1}}{2} \).
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2. More productive firms have larger market shares; a firm’s market share is greater than average if and only if $k_i < \bar{k}$

Novel mechanism linking productivity to firm size
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2. More productive firms have larger market shares; a firm’s market share is greater than average if and only if \( k_i < \bar{k} \).

3. Novel mechanism linking productivity to firm size.

4. Firm \( i \) earns more profit than average if and only if \( k_i < \bar{k} \).
Uniqueness

- A SPNE is *strict* if a unilateral deviation along the equilibrium path by firm $i$ strictly decreases firm $i$’s profit
  - This is not the standard definition of strict. A more accurate term would be "strict along the equilibrium path"
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**Proposition**

If $\tau > 0$ and $k_i \in [k, k + \phi(\theta, k)]$ then $\tilde{\omega}$ is a strict SPNE if and only if $\tilde{\omega} \in O^*$. 
Given locations, firm’s $i$’s best-response in prices is

$$p_i = \frac{2(\tau + 2t)}{(t + \tau)} p_i = p_{i-1} + p_{i+1} + t(d_{i-1,i} + d_{i,i+1}) + \frac{2t}{t + \tau} k_i$$
Uniqueness
Auxiliary game and refinement

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- This implies the system
  \[A \bar{\rho}' = \bar{b}'\]
  where
  \[
  A \equiv \begin{bmatrix}
  \frac{2(2t+\tau)}{t+\tau} & -1 & 0 & 0 & -1 \\
  -1 & \frac{2(2t+\tau)}{t+\tau} & -1 & 0 & 0 \\
  \vdots & \vdots & \vdots & \vdots & \vdots \\
  -1 & 0 & 0 & -1 & \frac{2(2t+\tau)}{t+\tau}
  \end{bmatrix}
  \]

  and
  \[b_i \equiv t(d_{i-1,i} + d_{i,i+1}) + \frac{2t}{t + \tau} k_i\]
In the auxiliary game firm $i$’s price is:

$$p_i = \beta_1 (d_{i-1,i} + d_{i,i+1}) + \beta_2 (d_{i-2,i-1} + d_{i+1,i+2}) + \ldots + \delta_0 k_i + \delta_1 (k_{i-1} + k_{i+1}) + \ldots$$

Its market share and profit are

$$x_i = \frac{1}{2t} \left( p_{i-1} + p_{i+1} - 2p_i + t \left( d_{i-1,i} + d_{i,i+1} \right) \right)$$

$$\pi_i = L \left[ x_i (p_i - k_i) - \tau (x_{i,i-1}^2 + x_{i,i+1}^2) \right]$$
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\]

- Refinement intuition: want to be "centered in market share"
Extensions

- Consider both horizontal differentiation and (arbitrarily many dimensions of) vertical differentiation

\[
p_i + t \|z - i\| - \sum_{k=1}^{K} q_{k,i}^\gamma \leq \min_j \left\{ p_j + t \|z - j\| - \sum_{k=1}^{K} q_{k,j}^\gamma \right\}
\]

Allow consumers to vary in value they place on quality, \(\theta\), where \(\theta \in [\theta_L, \theta_H]\):

Prove that there exist equilibria when the cost of transportation is convex (concave) that limit to my class of equilibria as the convexity (concavity) limits to linearity.
Consider both horizontal differentiation and (arbitrarily many dimensions of) vertical differentiation

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Empirical implementation

- Central prediction is that the distance between two neighbors is a decreasing function of their average marginal cost \( \frac{k_i + k_{i+1}}{2} \).
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Empirical implementation

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- Empirically testing this prediction requires a measure of physical productivity and a measure of distance
- Can be tested in two types of industry:
  - homogeneous good industry in which firms are differentiated by location
  - examples of industries:
    - movie theaters (Davis (2005))
    - motels (Mazzeo (2002))
    - video retail (Seim (2001))
    - eyeglass retail (Watson (2004))
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Spatial price discrimination

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    - Mill pricing: firm charges one price to all consumers and consumers pay the cost of transportation
    - Spatial p.d.: firm chooses a price schedule that lists the prices that the firm charges consumers at each location in space

Relevance of frameworks to industries

1. Mill pricing: appropriate for modeling differentiation in geographic and product-characteristics space
2. Spatial p.d.: most appropriate for geographic differentiation and for differentiation of intermediate inputs that must be tailored to exact specifications of final good producers
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  2. SPD most appropriate for geographic differentiation and for differentiation of intermediate inputs that must be tailored to exact specifications of final good producers
Spatial Price Discrimination

SPD relative to mill pricing: results

● Similarities

1. All economically relevant firm outcomes are uniquely determined across all SPNE in undominated strategies.
2. A firm's neighbor has no stronger effect on its market share and profit than a distant firm.
3. More productive firms are more isolated in product or geographic space, all else equal.

Diﬀerences

1. Results hold not only in a neighborhood of symmetry, but for arbitrary distribution of m.c.'s.
2. A unique characterization of SPNE in undominated, pure strategies without imposing any assumptions on the allocation of transportation costs.
3. Equilibria with SPD are all welfare maximizing (solve social planner's prob).
Spatial Price Discrimination

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- **Differences**
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Conclusions

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- Whether predictions are borne out remains to be seen