ECO 310: Empirical Industrial Organization

Lecture 8: Models of Competition in Prices or Quantities: Introduction

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Outline on today's lecture

1. **Introduction**
2. **Estimating Marginal Costs given a form of competition**
    2.1. **Perfect competition**
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1. Introduction

Introduction

- Firms' decisions of how much to produce (or sell) and the price to charge are fundamental determinants of firms' profits.
- These decisions are sources of **strategic interactions between firms**.

  ** In the market for an homogeneous good, the price depends on the total quantity produced by all the firms in the industry.*
  ** With differentiated products, demand for a firm's product depends on the prices of products sold by other firms in the industry.*

- These **strategic interactions** have first order importance to understand competition and outcomes in most industries.
- For this reason, models of competition where firms choose prices or quantities are at the core of Industrial Organization.

Equilibrium model of competition

- The answer to many economy questions require not only the estimation of demand and cost functions but also to know **how firms are competing with each other**.
- For instance, suppose we are interested in measuring the effects of:
  - a merger
  - a sales tax
  - the entry of a new firm or product in the market
  - ...
- The answers to these questions are very different depending on Perfect Competition, or Oligopoly Competition, or Collusion.

Empirical models of Price or Quantity competition

- We can distinguish three general classes of applications of empirical models of competition in prices or quantities.
- [1] Estimation of firms' marginal costs.
- [2] Identification of the "form of competition".
- [3] Joint identification of marginal costs and "form of competition"

Estimation of firms' marginal costs

- In many empirical applications, the researcher has information on firms' prices and quantities sold, but **information on firms' costs is not always available**.

- In this context, empirical models of competition in prices or quantities may provide an approach to obtain estimates of firms' marginal costs, and of the structure of these costs.

- Given an assumption about competition (e.g., Cournot, Bertrand, Stackelberg, Collusion), the model predicts that for every firm i, $MR_i = MC_i$, where the concept of MR_i depends on the assumption of the model of competition.

- Based on a estimation of demand, we can construct estimates of firms' MR. Then, the equilibrium conditions of the model imply and estimate of MCs.

Identification of the "Nature of competition"

- Suppose that the researcher has data to estimate separately the demand function and firms' marginal costs (e.g., from the production function and firms' input prices).
- Given an assumption about the form or nature of competition in this industry (e.g., Perfect competition, Cournot, Collusion), the researcher can use the demand to obtain firms' marginal revenues, MR_i, and check if they are equal to the observed marginal costs, MC_i
- That is, the researcher can test if a particular form of competition is consistent with the data.
- In this way, the researcher can find the form of competition that is more consistent the data, **e.g., identify if there is evidence of firms' collusion**.

Joint identification of MCs and Nature of competition

- Suppose that the researcher does not have data on firms' MCs (or estimates of these MCs from production function).
- We will see that, under some conditions, it is still possible to use the estimated demand and equilibrium conditions **to identify both firms' marginal costs and the form of competition**.
- This is the purpose of the **conjectural variation approach**.

Main References

- Bresnahan, T. (1982): “The Oligopoly Solution Concept is Identified,” Economics Letters, 10, 87-92.
- Bresnahan, T. (1987): “Competition and Collusion in the American Automobile Market: The 1955 Price War,” Journal of Industrial Economics, 35, 457-482.
- Genesove, D. and W. P. Mullin (1998): Testing static oligopoly models: Conduct and cost in the sugar industry, 1890-1914. The Rand Journal of Economics 29 (2), 355–377.
- Nevo, A. (2001): “Measuring Market Power in the Ready-to-Eat Cereal Industry," Econometrica, 69 (2), 307-342.

2.1. Estimating marginal costs given a form of competition: Perfect competition

Estimating MCs: Perfect competition

- We first illustrate this approach in the context of a **perfectly competitive industry for an homogeneous product**.
- The research has data on the market price and on firms' output for T periods of time (or geographic markets):

$$\text{Dataset } = \{p_t, \; q_{it} : \text{ for } i = 1, 2, ..., N_t \;\&\; t = 1, 2, ..., T\}$$

where N_t is the number of firms active at period t.

- The variable profit of firm i is:

$$\Pi_{it} = p_t \; q_{it} - C_i(q_{it})$$

- Under perfect competition, the marginal revenue of any firm i is the market price, p_t. Profit maximization implies:

$$p_t = MC_i(q_{it}) \quad \text{for every firm } i$$

where $MC_{it} \equiv C_i'(q_{it})$.

Estimating MCs: Perfect competition [2]

- Suppose that:
$$MC_i(q_{it}) = q_{it}^{\theta} \quad \exp\{\varepsilon_{it}^{MC}\}$$
where θ is a technological parameter and ε_{it}^{MC} is an unobservable that captures the cost efficiency of a firm.

- (i) Constant marginal cost: $\theta = 0$
(ii) Increasing marginal cost: $\theta > 0$
(iii) Decreasing marginal cost: $\theta < 0$.

- Using the equilibrium condition, we can estimate θ and the cost efficiency ε_{it}^{MC} of every firm i.

Estimating MCs: Perfect competition [3]

- The equilibrium condition $p_t = MC_i(q_{it})$ implies the following regression model in logarithms:

$$\ln(p_t) = \theta \ \ln(q_{it}) + \varepsilon_{it}^{MC}$$

- Using data on prices and quantities, we can estimate the slope parameter θ in this regression equation.

- Given an estimate of θ, we can estimate ε_{it}^{MC} as a residual from this regression, i.e., $\varepsilon_{it}^{MC} = \ln(p_t) - \theta \ \ln(q_{it})$.

- Therefore, we can estimate the marginal cost function of each firm, $MC_i(q_{it}) = q_{it}^{\theta} \ \exp\{\varepsilon_{it}^{MC}\}$.

Estimating MCs: Perfect competition [4]

$$\ln(p_t) = \theta \ \ln(q_{it}) + \varepsilon_{it}^{MC}$$

- Estimation of this equation by OLS suffers of an **Endogeneity problem**.
- The equilibrium condition implies that the less efficient firms (with larger value of ε_{it}^{MC}) have a lower level of output.
- Therefore, the regressor $\ln(q_{it})$ is negatively correlated with the error term ε_{it}^{MC}.
- This negative correlation between the regressor and the error term implies that the OLS estimator provides a downward biased estimate of the true θ, e.g., the OLS estimate can show IRS (i.e., $\theta < 0$) when the true technology has DRS (i.e., $\theta > 0$).

Estimating MCs: Perfect competition [5]

- This **Endogeneity problem** does not disappear if we consider the model in market means:

$$\ln\left(p_t\right) = \theta\ \overline{\ln q}_t + \overline{\varepsilon}_t^{MC}$$

where $\overline{\ln q}_t$ and $\overline{\varepsilon}_t^{MC}$ represents the means values of the variables $\ln(q_{it})$ and ε_{it}^{MC} over all the firms active at period t.

- We still have that $\overline{\ln q}_t$ and $\overline{\varepsilon}_t^{MC}$ are negatively correlated:
  - in time periods with larger aggregate cost shocks $\overline{\varepsilon}_t^{MC}$ there is lower average log-output $\overline{\ln q}_t$.

Estimating MCs: Perfect competition [6]

$$\ln(p_t) = \theta \; \overline{\ln q}_t + \overline{\varepsilon}_t^{MC}$$

- We can deal with this endogeneity problem by using **instrumental variables**.
- Suppose that X_t^D is a vector of observable variables that affect demand. These variables should be correlated with $\overline{\ln q}_t$ because demand shocks affect firms' output decisions.
- Under the assumption that these observable demand variables X_t^D are not correlated with $\overline{\varepsilon}_t^{MC}$, we can use these variables as instruments for $\overline{\ln q}_t$ for the consistent estimation of θ.

2.2. Estimating marginal costs given a form of competition: Cournot competition

Estimating MCs: Cournot competition

- We still have an homogeneous product industry and a researcher with data on quantities and prices over T periods of time: $\{p_t, q_{it}\}$ for $i = 1, 2, ..., N_t$ and $t = 1, 2, ..., T$.

- But now, the researcher assumes that the market is not perfectly competitive and that firms compete a la Nash-Cournot.

- The variable profit of firm i is $\Pi_{it} = p_t \; q_{it} - C_i(q_{it})$.

- The demand can be represented using the inverse demand function,

$$p_t = P\left(Q_t, X_t^D\right)$$

where $Q_t \equiv \sum_{i=1}^{N} q_{it}$ is the market total output, and X_t^D is a vector of exogenous market characteristic that affect demand.

Estimating MCs: Cournot competition [2]

- Each firm chooses its own output q_{it} to maximize profit.
- Since profit is equal to revenue minus cost, profit maximization implies the condition of **marginal revenue equal to marginal cost**.
- The marginal revenue function is:

$$
\begin{aligned}
MR_{it} &= \frac{d(p_t \ q_{it})}{dq_{it}} = p_t + \frac{dp_t}{dq_{it}} q_{it} \\
&= p_t + P'_Q\left(Q_t, X_t^D\right) \left[1 + \frac{dQ_{(-i)t}}{dq_{it}}\right] q_{it}
\end{aligned}
$$

where:
$P'_Q\left(Q_t, X_t^D\right)$ is the derivative of the inverse demand function with respect to total output;
$Q_{(-i)t}$ is the aggregate output of firms other than i.

Estimating MCs: Cournot competition [3]

$$MR_{it} = p_t + P'_Q\left(Q_t, X_t^D\right) \left[1 + \frac{dQ_{(-i)t}}{dq_{it}}\right] q_{it}$$

- $\dfrac{dQ_{(-i)t}}{dq_{it}}$ represents the **belief** or **conjecture** that firm i has about how other firms will respond by changing their output when this firm changes marginally its own output.

- Under the assumption of Nash-Cournot competition, this *belief* or *conjecture is zero:*

$$Nash - Cournot \Leftrightarrow \frac{dQ_{(-i)t}}{dq_{it}} = 0$$

- Firm i takes as fixed the quantity produced by the rest of the firms, $Q_{(-i)t}$, and chooses his own output q_{it} to maximize his profit.

Estimating MCs: Cournot competition [4]

- Therefore, the first order condition of optimality under Nash-Cournot competition is:

$$MR_{it} = p_t + P'_Q \left(Q_t, X_t^D \right) \; q_{it} = MC_i(q_{it})$$

- Since $P'_Q \left(Q_t, X_t^D \right) < 0$ (downward sloping demand curve), it is clear that $MR_{it} < p_t$.

- Therefore, if the marginal cost $MC_i(q_{it})$ is a non-decreasing function, we have that the optimal amount of output q_{it} under Cournot is smaller than under perfect competition.

- Oligopoly competition reduces output and consequently increases price.

Estimating MCs: Cournot competition [5]

- Consider the same specification of the cost function as before, with $MC_i(q_{it}) = q_{it}^{\theta} \exp\{\varepsilon_{it}^{MC}\}$.
- Suppose that the demand function has been estimated in a fist step, such that there is a consistent estimate of the demand function.
- The researcher can construct consistent estimates of marginal revenues $MR_{it} = p_t + P'_Q\left(Q_t, X_t^D\right) q_{it}$ for every firm i.

Then, the econometric model can be described in terms of the following linear regression model in logarithms:

$$\ln\left(MR_{it}\right) = \theta \ \ln(q_{it}) + \varepsilon_{it}^{MC}$$

Estimating MCs: Cournot competition [6]

$$\ln\left(MR_{it}\right) = \theta \; \ln(q_{it}) + \varepsilon_{it}^{MC}$$

- OLS estimation of this regression function suffers of the same endogeneity problem as in the perfect competition case.
- To deal with this endogeneity problem, we can use instrumental variables.
- As in the case of perfect competition, we can use observable variables that affect demand but not costs, X_t^D, as instruments.
- In the case of Cournot competition we can have additional types of instruments.

Estimating MCs: Cournot competition [7]

- Suppose that the researcher observes also some exogenous characteristics of firms that affect the marginal cost.
- For instance, suppose that there is information at the firm level on the firm's wage rate, or its capital stock, or its installed capacity.
- Let us represent these variables using the vector Z_{it}.

Therefore, the marginal cost function is now $MC_i(q_{it}) = q_{it}^{\theta} \exp\{Z_{it}\gamma + \varepsilon_{it}^{MC}\}$, where γ is a vector of parameters. The marginal condition of optimality, in logarithms, becomes:

$$\ln\left(MR_{it}\right) = \theta\ \ln(q_{it}) + Z_{it}\ \gamma + \varepsilon_{it}^{MC}$$

Estimating MCs: Cournot competition [8]

$$\ln\left(MR_{it}\right) = \theta\ \ln(q_{it}) + Z_{it}\ \gamma + \varepsilon_{it}^{MC}$$

- Note that the characteristics Z_{jt} of firms j other than i have an effect on the equilibrium amount of output of a firm i.
- The smaller Z_{jt} the more cost efficient firm j, the larger its output, the smaller price p_t and the marginal revenue MR_{it}, and the smaller q_{it} for any firm i other than j.
- Under the assumption that the vector of firm characteristics in Z are exogenous, i.e., $E(Z_{jt}\ \ \varepsilon_{it}^{MC}) = 0$ for any (i, j), we can use the characteristics Z_{jt} of other firms as instrumental variables.

Estimating MCs: Cournot competition [9]

- For instance, we can use $\sum_{j \neq i} Z_{jt}$ as an instrumental variables, and estimate θ and γ using the moment conditions:

$$E\left(\left[\begin{array}{c} Z_{it} \\ \sum_{j \neq i} Z_{jt} \end{array}\right] \left[\ln\left(MR_{it}\right) - \theta \ \ln(q_{it}) - Z_{it} \ \gamma\right]\right) = \mathbf{0}$$

- Or equivalently, using a 2SLS estimator.

2.3. Estimating marginal costs given a form of competition: Bertrand with diff. product

Estimating MCs: Bertrand with diff. prod.

- Consider the industry of a differentiated product.
- The researcher has data on prices, quantities, and product characteristics for the J products in the industry, where J is large: $\{p_i, \ q_i, \ X_i\}$ for $i = 1, 2, ..., J$.
- For the moment, we consider that each product is produced by only one firm and each firm produces only one product.
- The profit of firm i is $\Pi_i = p_i \ q_i - C_i(q_i)$.

Estimating MCs: Bertrand with diff. prod. [2]

- The demand system comes from a discrete choice model of demand:

$$q_i = H\ s_i = H\ \sigma_i(\mathbf{p}, \mathbf{X})$$

- H is the number of consumers in the market, s_i is the market share of product, i.e., $s_i \equiv q_i / H$.

- $\sigma_i(\mathbf{p}, \mathbf{X})$ is the market share function in the demand model, and $\mathbf{p}$ and $\mathbf{X}$ are the vectors of prices and characteristics.

- For instance, under a logit demand system we have that,

$$\sigma_i(\mathbf{p}, \mathbf{X}) = \frac{\exp\left\{-\alpha\ p_i + X_i\ \beta\right\}}{1 + \sum_{j=1}^{J} \exp\left\{-\alpha\ p_j + X_j\ \beta\right\}}$$

Estimating MCs: Bertrand with diff. prod. [3]

- Under Bertrand competition, each firm chooses its price p_i to maximize its profit.
- The marginal condition of optimality implies that $\frac{d\Pi_i}{dp_i} = 0$, or equivalently, $\frac{d(p_i q_i)}{dp_i} = \frac{dC_i(q_i)}{dp_i}$.
- Note that profit Π_i depends on price p_i both directly and indirectly through q_i. Then we have that

$$\frac{d(p_i q_i)}{dp_i} = q_i + p_i \frac{dq_i}{dp_i}$$

And

$$\frac{dC_i(q_i)}{dp_i} = MC_i(q_i)\ \frac{dq_i}{dp_i}$$

Estimating MCs: Bertrand with diff. prod. [4]

- Combining these equations, $\dfrac{d(p_i q_i)}{dp_i} = \dfrac{dC_i(q_i)}{dp_i}$, we have:

$$MR_i = p_i + \frac{q_i}{dq_i / dp_i} = MC_i(q_i)$$

- And taking into account that $q_i = H\ s_i = H\ \sigma_i(\mathbf{p}, \mathbf{X})$:

$$MR_i = p_i + \frac{s_i}{d\sigma_i / dp_i} = MC_i(q_i)$$

- The term $\dfrac{s_i}{d\sigma_i / dp_i}$ is negative. Therefore, $\dfrac{-s_i}{d\sigma_i / dp_i}$ is the price-cost margin $p_i - MC_i(q_i)$ in equilibrium.

- For instance, for the Logit demand system, we have that $d\sigma_i / dp_i = -\alpha\ s_i(1 - s_i)$, such that:

$$p_i - \frac{1}{\alpha(1 - s_i)} = MC_i(q_i)$$

Estimating MCs: Bertrand with diff. prod. [5]

- In general, we have that the marginal revenue,

$$MR_i = p_i + \frac{s_i}{d\sigma_i / dp_i}$$

only depends on p_i, s_i, and the demand function $\sigma_i(\mathbf{p}, \mathbf{X})$.

- After estimating the demand function, the researcher knows (or has estimates) of the marginal revenues MR_i for every firm/product in the market.

Estimating MCs: Bertrand with diff. prod. [6]

- Suppose that the marginal cost function is $MC_i(q_{it}) = q_{it}^{\theta} \exp\{X_{it} \gamma + \varepsilon_{it}^{MC}\}$.
- The marginal cost of producing a product depends on the characteristics of this product.
- Suppose that the demand function has been estimated in a fist step, such that there is a consistent estimate of the demand function.
- Then, the econometric model is:

$$\ln (MR_{it}) = \theta \ \ln(q_{it}) + X_{it} \ \gamma + \varepsilon_{it}^{MC}$$

Estimating MCs: Bertrand with diff. prod. [7]

$$\ln\left(MR_{it}\right) = \theta \ \ln(q_{it}) + X_{it} \ \gamma + \varepsilon_{it}^{MC}$$

- OLS estimation of this regression function suffers of the same endogeneity problem as in the PC or Cournot.
- To deal with this endogeneity problem, we can use instrumental variables.
- We can use the characteristics of products other than i, X_{jt} $j \neq i$, as instruments.

$$E\left(\begin{bmatrix} X_{it} \\ \sum_{j\neq i} X_{jt} \end{bmatrix} \left[\ln\left(MR_{it}\right) - \theta \ \ln(q_{it}) - X_{it} \ \gamma\right]\right) = \mathbf{0}$$