ECO 310: Empirical Industrial Organization

Lecture 9: Models of Competition in Prices or Quantities: Conjectural Variations

Victor Aguirregabiria (University of Toronto)

November 19, 2018

Outline on today's lecture

1. **Introduction**
2. **Estimating the form of competition when MCs are observed**
3. **An empirical application**

1. Introduction

Introduction

- In the previous lecture we saw how given a (estimated) demand system and an assumption about competition, **we can obtain (estimate) firms' marginal costs**.
- In today's lecture we will see how given a demand system and firms' marginal costs, **we can identify the form of competition in a market.**
- More specifically, we can identify firms' beliefs about how the other firms in the market respond strategically.
- This approach is called the **conjectural variation approach** or **conjectural variation model**.

2. Conjectural variation model: Homogeneous product markets

Conjectural Variation Model: Homogeneous product markets

- Consider an industry where, at period t, the inverse demand curve is $p_t = P\left(Q_t, X_t^D\right)$, and firms, indexed by i, have cost functions $C_i(q_{it})$.
- Every firm i, chooses its amount of output, q_{it}, to maximize its profit, $\Pi_{it} = p_t \; q_{it} - C_i(q_{it})$.
- Without further assumptions, the marginal condition for the profit maximization of a firm is **marginal revenue = marginal cost**, where the marginal revenue of firm i is:

$$MR_{it} = p_t + P_Q'\left(Q_t \; X_t^D\right) \; \left[1 + \frac{\partial Q_{(-i)t}}{\partial q_{it}}\right] \; q_{it}$$

- The term $\dfrac{\partial Q_{(-i)t}}{\partial q_{it}}$ represents the **belief** that firm i has about how the other firms in the market will respond if he changes its own amount of output marginally. We denote this **conjecture** or **belief** as the **conjectural variation of firm i, CV_i**

Conjectural Variations and Rational Beliefs

- As researchers, we can consider different assumptions about firms' beliefs or conjectural variations, CV_{it}.
- An assumption on CVs implies a particular model of competition.
- Different assumptions imply different equilibrium outcomes, q_{it}, Q_t, and p_t.
- However, not all the assumptions are consistent with an **equilibrium where firms have rational beliefs**, i.e., where the conjectural variations of all the firms are correct (hold) in equilibrium.
- In fact, most assumptions about CVs imply an equilibrium where firms are not rational in the sense that they have beliefs that do not hold in equilibrium.

Conjectural Variations and Nash Conjecture

- John Nash proposed the following conjecture: when a player constructs her best response, she believes that the other players will not response to a change in her decision.
- The very interesting property of the **Nash conjecture** is that it implies a type of equilibrium, the **Nash equilibrium**, with the important property that the Nash conjecture holds for every player.
- That is, Nash conjecture always implies an equilibrium where players have rational beliefs, i.e., conjectures that hold in equilibrium.

Conjectural Variations: Nash Conjecture & Cournot equilibrium

- In our model of firm competition, Nash conjecture implies that:

$$CV_{it} \equiv \frac{\partial Q_{(-i)t}}{\partial q_{it}} = 0$$

- This conjecture implies the Cournot equilibrium (or Nash-Cournot equilibrium).

- For every firm i, the "perceived" marginal revenue is:

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

and the condition $p_t + P'_Q \left(Q_t \; X_t^D \right) \; q_{it} = MC_i(q_{it})$ implies the Cournot equilibrium.

Other Rational Conjectural Variations: Perfect Competition

- Are other assumptions on firms' CVs that are consistent with a rational equilibrium?
- Yes, there are CVs that generate **perfect competition equilibrium** and the **collusive or monopoly equilibrium** which are consistent (rational) with the equilibrium outcome that they generate.
- **Perfect competition**. For every firm i, $CV_{it} = -1$.
- Note that this conjecture implies that:

$$MR_{it} = p_t + P'_Q\left(Q_t \; X_t^D\right) \; [1 - 1] \; q_{it} = p_t$$

and the conditions $p_t = MC_i(q_{it})$ imply the perfect competition equilibrium.

Other Rational Conjectural Variations: Collusion

- There are also beliefs that can generate the collusive outcome (monopoly outcome) as a rational equilibrium.
- **Collusion (Monopoly)**. For every firm i, $CV_{it} = N_t - 1$. This conjecture implies:

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

- This conjecture implies the equilibrium conditions:

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

- When firms have constant and homogeneous MCs, these conditions imply:

$$p_t + P'_Q\left(Q_t \ X_t^D\right) \ Q_t = MC$$

  which is the equilibrium condition for the Monopoly (collusive or cartel) outcome.

Conjectural Variations: Nature of Competition

- The value of the beliefs CV are related to the "nature of competition", i.e., Cournot, Perfect Competition, Cartel (Monopoly).

$$\begin{aligned}
\text{Perfect competition:} \quad & CV_{it} = -1; \quad MR_{it} = p_t \\
\text{Nash-Cournot:} \quad & CV_{it} = 0; \quad MR_{it} = p_t + P'_Q\left(Q_t\right)\ q_{it} \\
\text{Cartel all firms:} \quad & CV_{it} = N_t - 1; \quad MR_{it} = p_t + P'_Q\left(Q_t\right)\ Q_t
\end{aligned}$$

- Given this result, one can argue that CV is closely related to the **nature of competition**, and therefore with equilibrium price and quantities.
- If CV is negative, the degree of competition is stronger than Cournot. The closer to -1, the more competitive.
- If CV is positive, the degree of competition is weaker than Cournot. The closer to $N_t - 1$, the less competitive.

Conjectural Variations: Nature of Competition [2]

- Interpreting the beliefs CV as an **index of competition** is correct.
- However, it is important to take into account that for values of CV different to -1, or 0, or $N_t - 1$, the "Conjectural Variation" equilibrium that we obtain is not a rational equilibrium, in the sense that firms beliefs/conjectures do not hold in equilibrium.
- Note also that the "incentives to deviate" from a collusive outcome depend on our assumption on firms' beliefs.
- If firms have "collusive beliefs", $CV = N - 1$, then in the collusive equilibrium they do not have an incentive to deviate.
- If given this collusive equilibrium, then we modify firms' beliefs and consider Nash beliefs (i.e., $CV = 0$), then firms have incentives to deviate from collusion.

Conjectural Variation: Estimation

- Consider an homogeneous product industry and a researcher with data on firms' quantities and marginal costs, and market prices over T periods of time:

$$\text{Data} = \{p_t, \ MC_{it}, \ q_{it}\} \text{ for } i = 1, 2, ..., N_t \ \& \ t = 1, 2, ..., T$$

- Under the assumption that every firm chooses the amount of output that maximizes its profit given its belief CV_{it}, we have that the following condition holds:

$$p_t + P'_Q \left(Q_t \ X_t^D \right) \ [1 + CV_{it}] \ q_{it} = MC_{it}$$

- And solving for the conjectural variation,

$$CV_{it} = \frac{p_t - MC_{it}}{-P'_Q \left(Q_t \ X_t^D \right) \ q_{it}} - 1 = \left[\frac{(p_t - MC_{it}) \,/\, p_t}{q_{it} \,/\, Q_t} \right] |\eta_t| - 1$$

where η_t is the demand elasticity.

Conjectural Variation: Estimation [2]

$$CV_{it} = \left[\frac{(p_t - MC_{it}) \, / \, p_t}{q_{it} \, / \, Q_t} \right] |\eta_t| - 1$$

- This equation shows that, given data on quantities, prices, demand and marginal costs, we can identify the firms' beliefs that are consistent with these data and with profit maximization.
- Let us denote $\left[\frac{(p_t - MC_{it}) \, / \, p_t}{q_{it} \, / \, Q_t} \right]$ as the **Lerner-index-to-market-share ratio** of a firm.
- If the Lerner-index-to-market-share ratios are close zero, then the estimated values of CV will be close to -1, unless the absolute demand elasticity is large.
- If the Lerner-index-to-market-share ratios are large (i.e., larger than the inverse demand elasticity), then estimated CV values will be greater than zero, and can reject the hypothesis of Cournot competition.

Conjectural Variation: Estimation [3]

$$CV_{it} = \left[\frac{(p_t - MC_{it}) \, / \, p_t}{q_{it} \, / \, Q_t} \right] |\eta_t| - 1$$

- This equation shows that, given data on quantities, prices, demand and marginal costs, we can identify the firms' beliefs that are consistent with these data and with profit maximization.
- Let us denote $\left[\frac{(p_t - MC_{it}) / p_t}{q_{it} / Q_t} \right]$ as the **Lerner-index-to-market-share ratio** of a firm.
- If the Lerner-index-to-market-share ratios are close zero, then the estimated values of CV will be close to -1, unless the absolute demand elasticity is large.
- If the Lerner-index-to-market-share ratios are large (i.e., larger than the inverse demand elasticity), then estimated CV values will be greater than zero, and can reject the hypothesis of Cournot competition.

Conjectural Variation: Estimation [4]

$$CV_{it} = \left[\frac{(p_t - MC_{it}) \,/\, p_t}{q_{it} \,/\, Q_t} \right] |\eta_t| - 1$$

- Part of the sample variation of CV_{it} can be due to estimation error in demand and marginal costs.
- To implement a formal statistical test of the value of CV_{it} we need to take into account this error.
- For instance, let $\overline{CV}$ be the sample mean of the values CV_{it}. Under the null hypothesis of Cournot competition, $CV_{it} = 0$ for every (i, t) and $\overline{CV}$ has a Normal distribution $(0, , s^2)$. We can estimate s and implement a t-test based on the statistic $\overline{CV} / \widehat{s}$.

3. An Empirical Application

An Application: US sugar industry 1890-1914

- Genesove and Mullin (GM) study competition in the US sugar industry during the period 1890-1914.
- Why this period? High quality information on the value of marginal costs because:

  (1) the production technology of refined sugar during this period was very simple;

  (2) there was an important investigation of the industry by the US anti-trust authority. As a result of that investigation, there are multiple reports from expert witnesses that provide estimates about the structure and magnitude of production costs in this industry.

The industry

- Homogeneous product industry.
- Highly concentrated during 1890-1914. The industry leader, American Sugar Refining Company (ASRC), had more than 65% of the market share during most of these years.
- Refined sugar companies buy "raw sugar" from suppliers in national or international markets, transformed it into refined sugar, and sell it to grocers.
- **Production technology.**
  - Raw sugar is 96% sucrose and 4% water. Refined sugar is 100% sucrose. Process of transforming raw sugar into refined sugar is called "melting".
  - Industry experts reported that the industry is a "fixed coefficient" production technology

Production technology: Costs

- "Fixed coefficient" production technology

$$q^{refined} = \lambda \ q^{raw}$$

where $q^{refined}$ is refined sugar output, q^{raw} is the input of raw sugar, and $\lambda \in (0,1)$ is a technological parameter.

- **Marginal cost function.** Given this production technology, the marginal cost function is:

$$MC = c_0 + \frac{1}{\lambda} \ P^{raw}$$

- P^{raw} is the price of the input raw sugar (in dollars per pound).
- c_0 is a component of the marginal cost that depends on labor and energy.

Production technology: Costs [2]

$$MC = c_0 + \frac{1}{\lambda} P^{raw}$$

- Industry experts unanimously report that the value of the parameter λ was close to 0.93, and c_0 was around \$0.26 per pound.
- Therefore, the marginal cost at period (quarter) t, in dollars per pound of sugar, was:

$$MC_t = 0.26 + 1.075 \; P_t^{raw}$$

Data

- Quarterly US data for the period 1890-1914.
- The dataset contains 97 quarterly observations on industry output, price, price of raw sugar, imports of raw sugar, and a seasonal dummy.

$$\text{Data} = \{\ Q_t,\ \ P_t,\ P_t^{raw},\ IMP_t,\ S_t : t = 1, 2, ..., 97\}$$

- IMP_t represents the imports of raw sugar from Cuba.
- And S_t is a dummy variable for the Summer season: $S_t = 1$ is observation t is a Summer quarter, and $S_t = 0$ otherwise.
- The summer was a high demand season for sugar because most the production of canned fruits was concentrated during that season, and the canned fruit industry accounted for an important fraction of the demand of sugar.

Estimates of demand parameters

- GM estimate four different models of demand. The main results are consistent for the four models. Here I concentrate on the linear demand.

$$Q_t = \beta_t \ (\alpha_t - P_t)$$

- GM consider the following specification for α_t and β_t:

$$\alpha_t = \alpha_L \ (1 - S_t) + \alpha_H \ S_t + e_t^D$$

$$\beta_t = \beta_L \ (1 - S_t) + \beta_H \ S_t$$

- α_L and β_L are the intercept and the slope of the demand during the "Low Season" (when $S_t = 0$).

- And α_H and β_H are the intercept and the slope of the demand during the "High Season" (when $S_t = 1$).

Estimates of demand parameters [2]

Demand Estimates		
Parameter	Estimate	Standard Error
α_L	5.81	(1.90)
α_H	7.90	(1.57)
β_L	2.30	(0.48)
β_H	1.36	(0.36)

- According to these estimates, in the high season the demand shifts upwards but it also becomes more inelastic.
- The estimated price elasticities of demand in the low and the high season are $\varepsilon_L = 2.24$ and $\varepsilon_H = 1.04$, respectively.
- According to this, any model of oligopoly competition where firms have some market power predicts that the price cost margin should increase during the price season due to the lower price sensitivity of

Estimates of CVs

- Given this estimated demand and the MCs, they obtain the following estimate of the CV parameter $\theta \equiv \dfrac{CV}{N}$.

Estimate of CV	
Parameter	Estimate (s.e.)
$\theta \equiv \dfrac{CV}{N}$	0.10 (0.02)

- Therefore, we can reject the null hypothesis of Cournot competition in favor of some form of collusion.
- Next week, we will see how it is possible to identify CVs even when the researcher does not have data on marginal costs, and needs to estimate marginal costs together with CVs.