Microeconomics III

Oligopoly – preface to game theory
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• Oligopoly is a market in which only a few firms compete with one another, and entry of new firms is impeded.

• The situation is known as the Cournot model after Antoine Augustin Cournot, a French economist, philosopher and mathematician (1801-1877).

• In the basic example, a single good is produced by two firms (the industry is a “duopoly”).
Cournot’s oligopoly model (1838)

- A single good is produced by two firms (the industry is a “duopoly”).

- The cost for firm \( i = 1, 2 \) for producing \( q_i \) units of the good is given by \( c_i q_i \) (“unit cost” is constant equal to \( c_i > 0 \)).

- If the firms’ total output is \( Q = q_1 + q_2 \) then the market price is

\[
P = A - Q
\]

if \( A \geq Q \) and zero otherwise (linear inverse demand function). We also assume that \( A > c \).
The inverse demand function

\[ P = A - Q \]
To find the Nash equilibria of the Cournot’s game, we can use the procedures based on the firms’ best response functions.

But first we need the firms payoffs (profits):

\[ \pi_1 = Pq_1 - c_1q_1 \]
\[ = (A - Q)q_1 - c_1q_1 \]
\[ = (A - q_1 - q_2)q_1 - c_1q_1 \]
\[ = (A - q_1 - q_2 - c_1)q_1 \]

and similarly,

\[ \pi_2 = (A - q_1 - q_2 - c_2)q_2 \]
Firm 1’s profit as a function of its output (given firm 2’s output)

\[ \text{Profit 1} \]

\[ \text{Output 1} \]

\[ A - c_1 - q_2 \]

\[ A - c_1 - q'_2 \]

\[ q'_2 < q_2 \]
To find firm 1’s best response to any given output $q_2$ of firm 2, we need to study firm 1’s profit as a function of its output $q_1$ for given values of $q_2$.

If you know calculus, you can set the derivative of firm 1’s profit with respect to $q_1$ equal to zero and solve for $q_1$:

$$q_1 = \frac{1}{2}(A - q_2 - c_1).$$

We conclude that the best response of firm 1 to the output $q_2$ of firm 2 depends on the values of $q_2$ and $c_1$. 
Because firm 2’s cost function is \( c_2 \neq c_1 \), its best response function is given by

\[ q_2 = \frac{1}{2}(A - q_1 - c_2). \]

A Nash equilibrium of the Cournot’s game is a pair \((q_1^*, q_2^*)\) of outputs such that \( q_1^* \) is a best response to \( q_2^* \) and \( q_2^* \) is a best response to \( q_1^* \).

From the figure below, we see that there is exactly one such pair of outputs

\[ q_1^* = \frac{A + c_2 - 2c_1}{3} \quad \text{and} \quad q_2^* = \frac{A + c_1 - 2c_2}{3} \]

which is the solution to the two equations above.
The best response functions in the Cournot's duopoly game

Output 2

$\frac{A - c_1}{2}$

$\frac{A - c_2}{2}$

$BR_1(q_2)$

$BR_2(q_1)$

Nash equilibrium
A question: what happens when consumers are willing to pay more ($A$ increases)?
In summary, this simple Cournot’s duopoly game has a unique **Nash equilibrium**.

Two economically important properties of the Nash equilibrium are (to economic regulatory agencies):

[1] The relation between the firms’ equilibrium profits and the profit they could make if they act collusively.

[1] **Collusive outcomes**: in the Cournot’s duopoly game, there is a pair of outputs at which both firms’ profits exceed their levels in a Nash equilibrium.

[2] **Competition**: The price at the Nash equilibrium if the two firms have the same unit cost $c_1 = c_2 = c$ is given by

$$P^* = A - q_1^* - q_2^*$$

$$= \frac{1}{3}(A + 2c)$$

which is above the unit cost $c$. But as the number of firm increases, the equilibrium price deceases, approaching $c$ (zero profits!).
Stackelberg’s duopoly model (1934)

How do the conclusions of the Cournot’s duopoly game change when the firms move sequentially? Is a firm better off moving before or after the other firm?

Suppose that \( c_1 = c_2 = c \) and that firm 1 moves at the start of the game. We may use backward induction to find the subgame perfect equilibrium.

First, for any output \( q_1 \) of firm 1, we find the output \( q_2 \) of firm 2 that maximizes its profit. Next, we find the output \( q_1 \) of firm 1 that maximizes its profit, given the strategy of firm 2.
**Firm 2**

Since firm 2 moves after firm 1, a strategy of firm 2 is a *function* that associate an output \( q_2 \) for firm 2 for each possible output \( q_1 \) of firm 1.

We found that under the assumptions of the Cournot’s duopoly game Firm 2 has a unique best response to each output \( q_1 \) of firm 1, given by

\[
q_2 = \frac{1}{2} (A - q_1 - c)
\]

(Recall that \( c_1 = c_2 = c \)).
Firm 1

Firm 1’s strategy is the output $q_1$ the maximizes

$$
\pi_1 = (A - q_1 - q_2 - c)q_1 \quad \text{subject to} \quad q_2 = \frac{1}{2}(A - q_1 - c)
$$

Thus, firm 1 maximizes

$$
\pi_1 = (A - q_1 - (\frac{1}{2}(A - q_1 - c)) - c)q_1 = \frac{1}{2}q_1(A - q_1 - c).
$$

This function is quadratic in $q_1$ that is zero when $q_1 = 0$ and when $q_1 = A - c$. Thus its maximizer is

$$
q_1^* = \frac{1}{2}(A - c).
$$
Firm 1’s (first-mover) profit in Stackelberg’s duopoly game

\[ \pi_1 = \frac{1}{2} q_1 (A - q_1 - c) \]
We conclude that Stackelberg’s duopoly game has a unique subgame perfect equilibrium, in which firm 1’s strategy is the output

\[ q_1^* = \frac{1}{2}(A - c) \]

and firm 2’s output is

\[
q_2^* = \frac{1}{2}(A - q_1^* - c) \\
= \frac{1}{2}(A - \frac{1}{2}(A - c) - c) \\
= \frac{1}{4}(A - c)
\]

By contrast, in the unique Nash equilibrium of the Cournot’s duopoly game under the same assumptions \((c_1 = c_2 = c)\), each firm produces \(\frac{1}{3}(A - c)\).
The subgame perfect equilibrium of Stackelberg's duopoly game

Nash equilibrium (Cournot)

Subgame perfect equilibrium (Stackelberg)
Bertrand’s oligopoly model (1883)

In Cournot’s game, each firm chooses an output, and the price is determined by the market demand in relation to the total output produced.

An alternative model, suggested by Bertrand, assumes that each firm chooses a price, and produces enough output to meet the demand it faces, given the prices chosen by all the firms.

⇒ As we shall see, some of the answers it gives are different from the answers of Cournot.
Suppose again that there are two firms (the industry is a “duopoly”) and that the cost for firm \( i = 1, 2 \) for producing \( q_i \) units of the good is given by \( c q_i \) (equal constant “unit cost”).

Assume that the demand function (rather than the inverse demand function as we did for the Cournot’s game) is

\[
D(p) = A - p
\]

for \( A \geq p \) and zero otherwise, and that \( A > c \) (the demand function in PR 12.3 is different).
Because the cost of producing each unit is the same, equal to $c$, firm $i$ makes the profit of $p_i - c$ on every unit it sells. Thus its profit is

$$\pi_i = \begin{cases} 
(p_i - c)(A - p_i) & \text{if } p_i < p_j \\
\frac{1}{2}(p_i - c)(A - p_i) & \text{if } p_i = p_j \\
0 & \text{if } p_i > p_j 
\end{cases}$$

where $j$ is the other firm.

In Bertrand’s game we can easily argue as follows: $(p_1, p_2) = (c, c)$ is the unique Nash equilibrium.
Using intuition,

- If one firm charges the price $c$, then the other firm can do no better than charge the price $c$.

- If $p_1 > c$ and $p_2 > c$, then each firm $i$ can increase its profit by lowering its price $p_i$ slightly below $p_j$.

$\implies$ In Cournot’s game, the market price decreases toward $c$ as the number of firms increases, whereas in Bertrand’s game it is $c$ (so profits are zero) even if there are only two firms (but the price remains $c$ when the number of firm increases).