Lecture 18 : Imperfect Competition
Ch. 11

Thus far we have studied consumer behavior (the origin of the demand curve), producer behavior (the origin of the supply curve), and the behavior of firms within perfectly competitive markets. In this final section of the course we will study the other market structures such as oligopoly and monopoly, and we will learn about how people and firms interact in strategic situations (Game Theory).

We learned that in a perfectly competitive market there are many firms producing identical products in a market with zero barriers to entry. Today we will begin discussion of <u>oligopoly</u>.

Oligopoly is a market structure in which few firms produce either identical or differentiated products in a market w/ some barriers to entry. Because oligopoly is one of the more complicated market structures, there is not

one single way to model oligopolistic situations. (1)
Hence, we will study oligopoly under a variety of different frameworks. we will learn about oligopoly situations in which few firms compete on quantity (Cournot oligopoly and Stackelberg oligopoly) and we will learn about a model in which few firms compete on price (Bertrand oligopoly). we will also study situations in which firms collude with one another and form cartels. oligopoly relies heavily on strategic ideas that we will more formalize when we cover game theory.

- The concept of Equilibrium in Oligopoly

In perfect competition we began to discuss the concept of Competitive Equilibrium. In PC it was pretty simple: goods sell at a price in which the quantity demanded equals the quantity supplied. In other words, the market "clears," and consumers and producers are content and do not want to change their decisions.

In oligopoly, the concept of equilibrium is more complex. In oligopoly, each firm's action influences what other firm's want to do. To arrive at an equilibrium outcome in which no firms want to deviate involves the use of a technique called backward induction. Backward induction is the process of reasoning backwords in time, from the end of a problem or situation, to determine what is the optimal outcome. If we weare a firm, what action would we choose conditional on the choices of other firms. In an oligopoly equilibrium, we need not only stability amongst consumers and producers through the model of supply and demand, but we also require stability in the strategic interaction of individual producers. When we talk about the concept of equilibrium in oligopoly, we are referring to the most important concept in Game Theory, the Nash Equilibrium. Nash equilibrium is named after John Nash. Nash won the Nobel Prize in Economics in 1994. Nash Equilibrium is a solution concept in non-cooperative games involving two or more players, in a situation of perfect information in which no player has any incentive to deviate. The Nash equilibrium concept was first put to use in 1838 by Antoine Augustin Cournot. Let's begin by formalizing a strategic situation in which firms compete on quantity, Cournot oligopoly.

- In Cournot oligopoly,
  - Firms sell identical products
  - Each firm has some market power
  - Firm's compete in quantities and choose quantities simultaneously
  - Firm's seek to maximize profits.
  - The market price is determined by the sum of all quantities produced in the mkt.

Let's consider a simple two-firm example of cournot oligopoly.

Suppose two firms compete with one another by simultaneously choosing levels of output, q_1 and q_2. Suppose demand is given by $P = 100 - Q$, where $Q = q_1 + q_2$, and $TC = 40q_i$

How much output should firms produce?

We know that demand is a function of both firms' output, i.e. $P = 100 - (q_1 + q_2)$

$$= 100 - q_1 - q_2$$

To determine what levels of output the firms should produce, we must think of this situation from the perspective of each firm. Let's consider this problem from the perspective of firm 1:

Firm 1 seeks to maximize profits:

$$\max_{q_1} \pi_1 = \underbrace{P \cdot q_1}_{TR} - \underbrace{40 \cdot q_1}_{TC} = P \cdot q_1 - 40 \cdot q_1$$

$q_1 \equiv$ Quantity produced by firm 1.

Plugging in the inverse demand function we have:

$$\max_{q_1} \pi_1 = (100 - q_1 - q_2) \cdot q_1 - 40q_1$$

$$= \max_{q_1} \{100q_1 - q_1^2 - q_1 q_2 - 40q_1\}$$

$$= \max_{q_1} \{60q_1 - q_1^2 - q_1 q_2\}$$

$$\frac{\partial}{\partial q_1} = 60 - 2q_1 - q_2 = 0$$

$$2q_1 = 60 - q_2$$

$$q_1 = 30 - \frac{1}{2} q_2$$

This is Firm 1's <u>Reaction Function</u>

Firm 1's choice of q_1 depends directly on Firm 2's choice of q_2. i.e. $q_1(q_2)$ and $q_2(q_1)$.

Though this situation is symmetric (we know that firm 2's reaction function is the mirror image of firm 1's), lets solve for firm 2's reaction function.

Firm 2 seeks to maximize profits:

$$\max_{q_2} \Pi_2 = P \cdot q_2 - 40 q_2$$

$$= \max_{q_2} \{(100 - q_1 - q_2) \cdot q_2 - 40 q_2\}$$

$$= \max_{q_2} \{60 q_2 - q_1 q_2 - q_2^2\}$$

$$\frac{\partial}{\partial q_2} = 60 - q_1 - 2q_2 = 0$$

$$2q_2 = 60 - q_1$$

$$q_2 = 30 - \frac{1}{2} q_1$$ (symmetric to that of firm 1).

NOW we have a system of two equations and two unknowns. The reaction functions of the firms are the equations, and the output levels are the unknowns.

$$q_1 = 30 - \frac{1}{2} q_2$$

$$q_2 = 30 - \frac{1}{2} q_1$$

Let's solve this system of equations by plugging q_2 into q_1:

$$q_1 = 30 - \frac{1}{2}\left(30 - \frac{1}{2} q_1\right)$$

$$= 30 - 15 + \frac{1}{4} q_1$$

$$\frac{3}{4} q_1 = 15 \Rightarrow \boxed{q_1^* = 20}$$

$$q_2 = 30 - \frac{1}{2} q_1 = 30 - \frac{1}{2}(20) = 30 - 10$$

$$\boxed{q_2^* = 20}$$

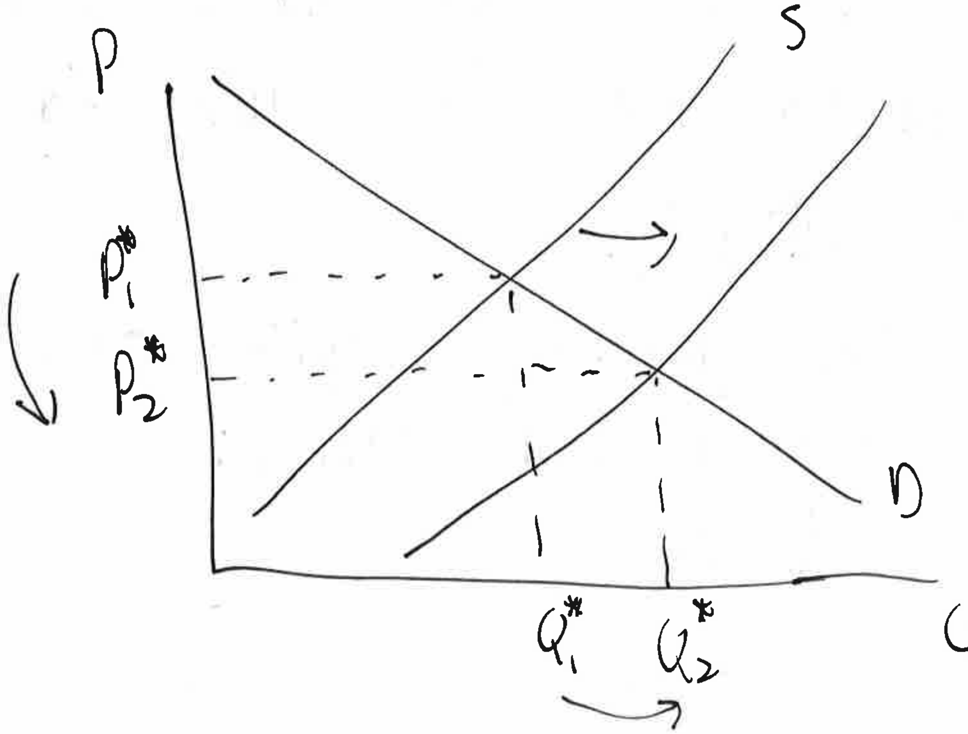
To solve for the market price:

$$p = 100 - q_1^* - q_2^* = 100 - 20 - 20$$

$$\boxed{p^* = 60}$$

Each firm's selection of output affects the market price, and hence the other firm's profit.

A real world example of Cournot oligopoly might be the market for crude oil. The United States has not always been a major player in crude oil production, but we experienced a shale oil boom in the late 2010's. Due to technological progress through hydraulic fracturing, the U.S. was able to supply substantially more oil to the global market. Hence, supply shifted outward:



This increase in supply led to a fall in the equilibrium price of oil. Saudi Arabia, a major supplier to the global crude oil market, have been under a lot of criticism for refusing to decrease their supply of oil (by decreasing supply, a higher equilibrium price can be maintained). Saudi Arabia has refused to scale back production, likely due to fears of losing out on market share to the U.S. Gas prices have fallen from \$3.32 per gallon in late 2014 to \$1.69 per gallon in early 2016. We can model what we observe in the real world using the Cournot model of oligopoly.

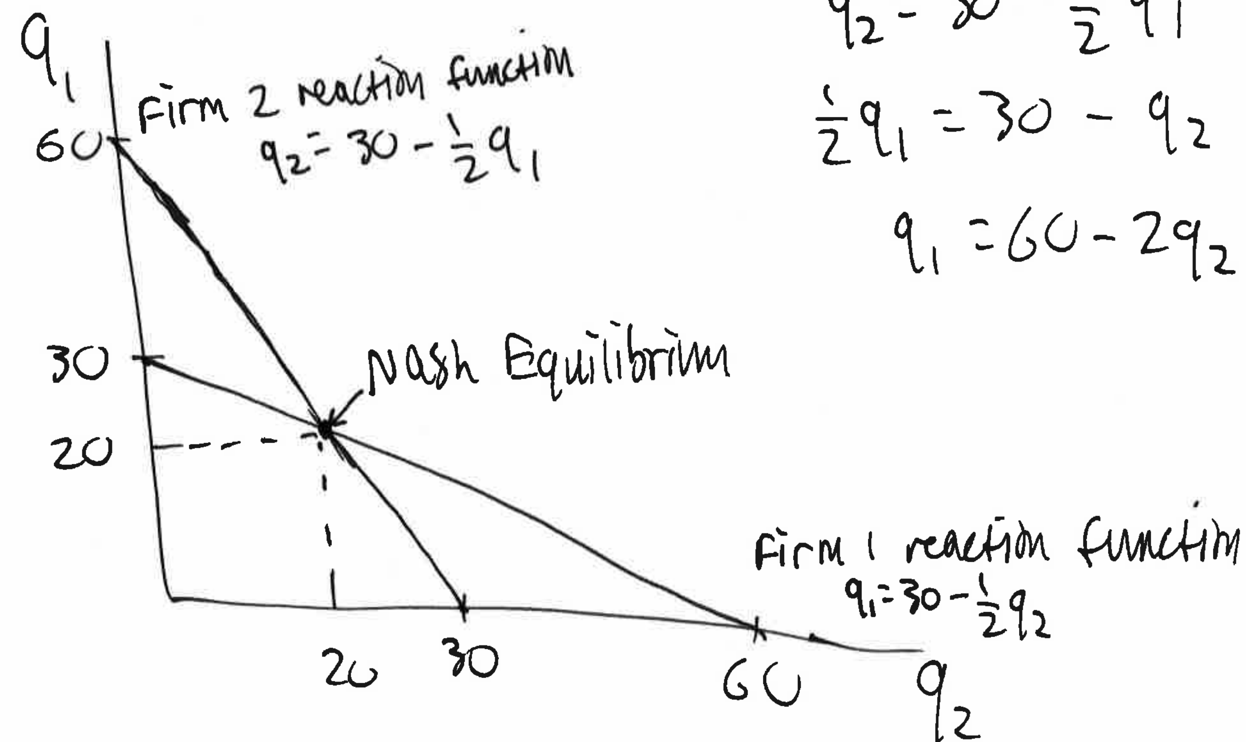
• we can graphically depict each firm's reaction function from earlier:

$$q_1 = 30 - \frac{1}{2} q_2$$

$$q_2 = 30 - \frac{1}{2} q_1$$

Let's put q_1 on the y-axis and q_2 on the x-axis.

$$q_2 = 30 - \frac{1}{2} q_1$$
$$\frac{1}{2} q_1 = 30 - q_2$$
$$q_1 = 60 - 2q_2$$



From the graph, anywhere along each firm's reaction function is its best response to the other firm's production decision. Notice that the two curves cross at (20, 20) (recall that we solved for this earlier: $q_1^* = 20$, $q_2^* = 20$). This point is the Nash Equilibrium, i.e. the point at which both competitors are simultaneously producing optimally given the other's best response, i.e. the mutual best response.

what happens if there are more than two firms in a Cournot oligopoly? The more firms that exist within a Cournot oligopoly, the closer the outcome begins to resemble that of perfect competition with price equaling marginal cost and with the industry operating at zero economic profit. Having more and more firms results in each individual firm's supply decision becoming less and less influential on the market as a whole. With many firms in the market, each firm essentially becomes a price taker, and they produce at a level such that $P = MC$. In a typical Cournot environment, however, $P > MC$.

Stackelberg competition

Now we will study a version of oligopoly that is very similar to Cournot, and that is Stackelberg competition.

In many ways, Stackelberg oligopoly is identical to Cournot. It differs in that firms do not choose output levels simultaneously, they instead choose output sequentially. One firm acts as the Stackelberg leader and chooses its level of output, while all following firms observe this choice and later choose their own output levels. Let's consider the same example as earlier, except now this is a Stackelberg game with Firm 1 as the Stackelberg leader. Recall that $P = 100 - Q$, where $Q = q_1 + q_2$, and each firm has a total cost given by $TC = 40q_i$. How much output should both the leader and follower produce?

To solve this, we must use backward induction and begin by analyzing the choice of the follower, Firm 2.

Firm 2 seeks to maximize profits:

$$\max_{q_2} \{P \cdot q_2 - 40q_2\}$$

$$= \max_{q_2} \{(100 - q_1 - q_2) \cdot q_2 - 40q_2\}$$

$$= \max_{q_2} \{100q_2 - q_1q_2 - q_2^2 - 40q_2\}$$

$$= \max_{q_2} \{60q_2 - q_1q_2 - q_2^2\}$$

$$\frac{\partial}{\partial q_2} = 60 - q_1 - 2q_2 = 0$$

$$2q_2 = 60 - q_1$$

$$q_2(q_1) = 30 - \frac{1}{2}q_1$$

→ Firm 2's reaction function. Note that it is a function of Firm 1's output.

Now, lets look at the Stackelberg leader's profit maximization problem:

$$\max_{q_1} P \cdot q_1 - 40q_1$$

$$= \max_{q_1} \{(100 - q_1 - q_2) \cdot q_1 - 40q_1\}$$

Let's plug in firm 2's reaction function:

$$= \max_{q_1} \{(100 - q_1 - (30 - \tfrac{1}{2}q_1)) \cdot q_1 - 40q_1\}$$

$$= \max_{q_1} \{(100 - q_1 - 30 + \tfrac{1}{2}q_1) \cdot q_1 - 40q_1\}$$

$$= \max_{q_1} \{70q_1 - \tfrac{1}{2}q_1^2 - 40q_1\}$$

$$= \max_{q_1} \{30q_1 - \tfrac{1}{2}q_1^2\}$$

$$\frac{\partial}{\partial q_1} = 30 - q_1 = 0$$

$$\Rightarrow q_1^* = 30$$

$$q_2 = 30 - \frac{1}{2} q_1^* = 30 - \frac{1}{2}(30)$$

$$q_2^* = 15$$

$\Rightarrow$ Here, the follower produces less output than the leader. Recall, under the Cournot case, $q_1^* = q_2^* = 20$.

Under the Stackelberg case, firm 1 has a <u>First-mover advantage</u>. Firm 1 is able to backwardly induct the decision of firm 2, and by doing so Firm 1 can produce output strategically, and make more profit. How much profit does each firm earn in this example?

$$\Pi_1(q_1, q_2) = (100 - q_1 - q_2) \cdot q_1 - 40 q_1$$
$$= (100 - 30 - 15) \cdot 30 - 40 \cdot 30$$
$$= 450$$

$$\Pi_2(q_1, q_2) = (100 - 30 - 15) \cdot 15 - 40 \cdot 15$$
$$= 225$$

Firm 2 (the follower) makes less profit.

Let's compare to profit from Cournot:

$$\Pi_{1,2}(q_1, q_2) = (100 - 20 - 20) \cdot 20 - 40 \cdot 20$$
$$= 400$$

Each firm in Cournot makes $\Pi = 400$.

Total industry profit:

Stackelberg $= 450 + 225 = 675$

Cournot $= 400 + 400 = 800$

There is more industry profit in Cournot than Stackelberg. The stackelberg leader makes more profit than if it were in a Cournot situation.

We observe some Stackelberg-like situations in the real world. For example, Apple ~~history~~ releasing the iPhone to the market before any other firm had a smartphone in the market.

Thus far we have looked at two standard forms of oligopoly, Cournot and Stackelberg competition. We showed that depending on whether firms act simultaneously or sequentially, both firm-specific and industry profits can differ. It is easy to imagine a scenario in which firms might collude, If firms agree to coordinate their quantity and pricing decisions, then we call this <u>collusion</u>. Suppose we are in a two firm world and each firm agrees to collude and split the industry profits? What type of market structure would this create? The answer is <u>monopoly</u>. Though we will formally introduce monopoly later on, solving oligopoly models in which there is collusion is very much like solving a model of monopoly. When firms collude, it is often called a <u>cartel</u>. In most countries, this type of anti-competitive behavior is illegal. Most cases of collusion are done secretly.

(We will find out later that in a monopoly equilibrium, firms produce at an output level in which marginal revenue equals marginal cost and the price is determined by the demand curve)

Cartels are also theoretically unstable. Think about a situation in which Firm 1 and Firm 2 agree to collude. Assume that they each have the same constant marginal cost c. If the firms act collectively, they will produce at a level such that $MR = MC$. With an inverse demand function of $p = a - bQ$,

$MR = MC$

$$\Rightarrow \quad a - 2bQ = c$$

solving for Q:

$$a - c = 2bQ$$

$$Q = \frac{a-c}{2b}$$

This is industry output when firms collude and act like a monopolist. If we plug this into the inverse demand function above we have

$$p = a - \cancel{b}\left[\frac{a-c}{2\cancel{b}}\right] = \frac{2a - a + c}{2}$$

$$p = \frac{a+c}{2} \longrightarrow \text{The market price at the collusive quantity}$$

In a cartel, individual firms have the incentive to deviate, in other words, collusion is never part of a Nash Equilibrium. If both firms are colluding and restricting output, then an individual firm has the incentive to expand output and make more individual profits. This type of problem increases as a cartel grows larger.

Example of Collusion

Suppose that two firms ~~agree to~~ are the only two that exist in a particular industry w/ inverse demand given by $P = 32 - 2Q$. Assume that both firms have the same constant marginal cost of \$16.

a) under an outcome of collusion, find the level of output for each firm, the ~~equilibrium~~ price of the good resulting from those levels of output, and profit for each firm.

(11)

~~If~~ the ~~firms~~ behave like a monopolist through collusion, they will produce at a level such that $MR = MC$.

To solve for marginal revenue,

$$TR = P \cdot Q = (32 - \cancel{2}Q) \cdot Q$$

$$= 32Q - \cancel{2}Q^2$$

$$MR = \frac{dTR}{dQ} = 32 - \overset{4}{\cancel{8}}Q$$

$$MC = 16$$

$$32 - 4Q = 16$$

$$4Q = 16$$

$Q = 4$, Hence each firm that is colluding will produce $\frac{Q}{2} = 2$

To find price: $P = 32 - 2(4) = \$24$

$\pi_1 = \cancel{24(2)} - 16 = 24(2) - 16(2)$

$\pi_1 = 48 - 32 = 16$

b) Does either firm have the incentive to defect by producing higher output?

Suppose firm 1 produces 3 units instead of 2: so now $Q = 3 + 2 = 5$

$P = 32 - (2) \cdot 5 = 22$

Profit for firm 1 becomes:

$\pi_1 = 22 \cdot 3 - 16 \cdot 3$

$= 18$

Since firm 1's profit is larger if it deviates from the agreement, then it has the incentive to defect.

c) Does firm 1's decision to cheat affect firm 2's profit?

$\pi_2 = 22 \cdot 2 - 16 - 2$

$= 12$

Yes, it lowers firm 2's profit from 16 to 12.

~~d) Suppose that each firm agrees to produce 1 more unit than they were in a) How much profit will each firm earn~~

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Bertrand Oligopoly

- Firms compete by choosing price as opposed to choosing quantity.
- Firms set their prices simultaneously.

Assuming identical products, consumers will purchase whichever is cheaper.

Suppose two stores such as Wal-mart and Target compete with each other by selling playstations.

Consumers will purchase whichever playstation is cheaper.

Demand for playstations at Wal-mart / Target

Q, if $P_W < P_T$	0, if $P_W < P_T$
$\frac{Q}{2}$, if $P_W = P_T$	$\frac{Q}{2}$, if $P_W = P_T$
0, if $P_W > P_T$	Q, if $P_W > P_T$

1'

Each store chooses its price to maximize profit. Here, we assume that the number of consoles sold, Q, doesn't depend on the price charged.

To think about the Nash Equilibrium of a Bertrand game, first assume that the marginal cost of a playstation is $150.

Suppose Wal-mart charges $175 for a playstation, what should Target charge? They should undercut Wal-mart's price and charge $174.99. But then Wal-mart would undercut target and charge $174.98. The process of undercutting would repeat itself until $P = MC$, or $P = 150$. The equilibrium of this Bertrand oligopoly occurs when each firm charges a price of 150, each obtains half the market share, and each earns zero economic profit. (If wal-mart or Target drop the price below marginal cost, then they would be selling consoles at a loss.

Note that the Bertrand oligopoly equilibrium w/ identical goods is the same as the perfectly competitive outcome, $P = MC$.

Thus far we have shown the outcome of Bertrand oligopoly to be the same as perfect competition, and the collusive Cournot outcome is the same as monopoly. The standard Cournot outcome is somewhere in the middle of the two in terms of competitiveness.

Example

Suppose inverse demand is given by $P = 10 - 0.05Q$. and we have constant $MC = 1$.

a) solve for the equilibrium price and quantity in a perfectly competitive world.

$$P = MC \implies 10 - 0.05Q = 1$$

$$0.05Q = 9$$

$$Q^* = 180$$

$$P = 10 - 0.05(180) \qquad P^* = 1$$

2'

b) In monopoly, $MR = MC$

$$TR = P \cdot Q = (10 - 0.05Q) \cdot Q$$

$$TR = 10Q - 0.05Q^2$$

$$MR = 10 - 0.1Q = 1 = MC$$

$$9 = 0.1Q$$

$$Q^* = 90 = 90$$

$$p = 10 - 0.05(90)$$

$$p^* = 5.5$$

c) $p = MC$, i.e. $Q^* = 180$

$$p^* = 1$$

Example

Suppose there are n firms in a Cournot oligopoly. Let q_i denote the quantity produced by firm i, and let $Q = q_1 + \ldots + q_n$ denote the aggregate quantity in the market. Let P denote the market clearing price and assume that inverse demand is given by $P(Q) = a - Q$ (assuming $a > Q$). Assume that the total cost of firm i from producing q_i is $C_i(q_i) = c q_i$. Suppose that firms choose output simultaneously. What is the Nash Equilibrium? What happens as n approaches infinite?

n firms $\quad P = a - Q \quad , \quad Q = q_1 + \ldots + q_n$

$C(q_i) = c q_i \quad , \quad$ let $q_{-i} = \sum_{j \neq i} q_j$

Profit Firm i:

$$\pi_i(q_i, q_{-i}) = (a - q_i - q_{-i}) \cdot q_i - cq_i$$

$$= (a - c - q_{-i} - q_i) \cdot q_i$$

$$\frac{\partial \pi_i}{\partial q_i} = a - c - q_{-i} - 2q_i^*(q_{-i}) = 0$$

$$2q_i^*(q_{-i}) = a - c - q_{-i}$$

$$q_i^*(q_{-i}) = \frac{a-c}{2} - \frac{1}{2} q_{-i}$$

→ Firm i's best response function

Now, in a NE:

$$q_1^* = \frac{a-c}{2} - \frac{1}{2}(q_2^* + \dots + q_n^*)$$

$$q_2^* = \frac{a-c}{2} - \frac{1}{2}(q_1^* + \dots + q_n^*)$$

$$\vdots$$

$$q_n^* = \frac{a-c}{2} - \frac{1}{2}(q_1^* + \dots + q_{n-1}^*)$$ summing

$$Q^* = n\left(\frac{a-c}{2}\right) - \frac{(n-1)}{2}(Q^*)$$

solving for Q^*:

$$\frac{2 + n - 1}{2} Q^* = n\left(\frac{a-c}{2}\right)$$

$$\frac{1+n}{\cancel{2}} Q^* = n\left(\frac{a-c}{\cancel{2}}\right)$$

$$Q^* = n\left(\frac{a-c}{n+1}\right)$$ This is market output in equilibrium.

In a symmetric NE, $q_1^* = q_2^* = \ldots = q_n^* = \frac{1}{n} Q^*$

So $q_i^* = \frac{a-c}{n+1}$.

To show that this is a NE, show that it is a mutual best response for firm i and all firms other than i.

Spps $j \neq i$, choose $q_j^* = \frac{a-c}{n+1}$

i's BR is:

$$q_i^*(q_{-i}^*) = \left(\frac{a-c}{2}\right) - \frac{1}{2}(n-1)\left(\frac{a-c}{n+1}\right)$$

$$= \frac{(n+1)(a-c)}{2(n+1)} - \frac{(n-1)(a-c)}{2(n+1)}$$

$$= \frac{(\cancel{n}+1-\cancel{n}+1)}{2}\left(\frac{a-c}{n+1}\right)$$

$$= \frac{a-c}{n+1}$$

So no firm has incentive to deviate.

As $n \to \infty$, $Q^* \to a-c$

$\hookrightarrow$ as the # of firms goes to ∞, we get the result from perfect competition.