B STRATEGIC INTERACTION IN STATIC INDUSTRIES: OLIGOPOLISTIC COMPETITION

Above, we were concerned with the two extremes of market structures, i.e. monopoly with just one firm and perfect competition with many firms. Most markets in the real-world are in between these two extremes with a few firms being active in these markets. The situation in which there are a few competitors is called **oligopoly** (see, e.g., Cabral (2000: ch. 7) or Motta (2004: ch. 8.4)). The distinguishing feature of such oligopolies is the fact that firms in these industries take into account the (expected) behavior or their competitors when making their own strategic decisions. This is called the **strategic interdependence** of competitors. Decisions in such an interactive setting are called **strategic decisions**, and **game theory** is the branch of social science that formally analyzes and models strategic decisions. Therefore, section B.1 provides an introduction to game theory.

In case of the monopoly-model, it is easy to show that the market-outcome is the same when firms either set prices or quantities. However, once we leave the world of monopoly the equivalence of price and output strategies vanishes. In oligopolistic markets it matters very much whether firms compete in terms of quantities, as in Cournot, or in terms of price, as in Bertrand (Pepall et al. 2008: p. 224). In section B.2 , we present the Bertrand oligopoly-model, and turn to Cournot-competition in section B.3 .

B.1 Introduction to Static Game Theory

Game theory is divided into two branches: **non-cooperative** and **cooperative** game theory.[11] The essential difference between these two branches is that in non-cooperative games, the unit of analysis is the individual decision-maker or **player**, e.g., the firm. The non-cooperative setting means that each player is concerned only with doing as well as possible for herself, subject to the rules of the game. By contrast, cooperative game theory takes the unit of analysis to be a group or coalition of players, e.g., a group of firms. In section B , we concentrate on non-cooperative, static game. The term **static** means that firms only care about their payoffs in the current period. In section H.1 we turn to dynamic games. The term **dynamic** means that firms care about their payoffs in the current *and* in future periods.

Firms' strategic interaction can be **sequential** or **simultaneous**, i.e. a firm may, for example, decide on the price for its good after observing the price set by its rival, or it may set a price at the same time as its rival. In this lecture, we concentrate on simultaneous games.

Two basic assumptions underlie the application of non-cooperative game theory to oligopoly. The first is that **firms are rational**. They pursue well-defined goals, principally profit

11 Section B.1 is based on Pepall et al. (2008: ch. 9) and often quotes from this textbook.

maximization. Moreover, players' rationality is **common knowledge**. An event E is defined to be common knowledge if all players know E, all players know that all other players know E, all players all players know that all other players know that all other players know E, ad infinitum. The second basic assumption is that firms apply their rationality to the process of **reasoning strategically**. That is, in making its decision, each firm uses all the knowledge it has to form expectations regarding how other firms will behave. For example, an oligopolist can anticipate the response of its rivals by asking itself "What would I do if I were the other player?"

Each player's decision or plan is called a **strategy** (or: **action**), i.e. a firm, e.g., chooses a price p or a quantity q. A strategy is a fully-specified decision rule as to how to play the game. A **strategy set** S_i is the set of feasible strategies for player i. A list of strategies showing one particular strategy choice for each player is called a **strategy combination** (or: strategy profile). Any given strategy combination determines the **outcome** of the game that describes the **payoffs** or final gains earned by each player. In other words, a payoff function assigns a real number to each strategy profile. In the context of oligopoly theory, payoffs are often interpreted as firm i's profit π_i.

For a game to be interesting, at least one player must be able to choose from more than one strategy so that there will be more than one possible strategy combination, and more than one possible outcome of the game. Yet while there may be many possible outcomes, not all of these will be **equilibrium** outcomes. By equilibrium we mean a strategy combination that no firm has an incentive to change the strategy it is currently using given that no other firm changes its current strategy. This is called the **Nash equilibrium concept**. Hence, in the Nash-equilibrium each player's action is the **best response** to the actions of all other players. More formally, in a game with n players, denoting with S_i the set of actions available to player i (with $i = 1, ..., n$), and with player i's payoff $\pi_i(\sigma_1, ..., \sigma_i, ..., \sigma_n)$, the n-tuple $(\sigma_1^*, ..., \sigma_i^*, ..., \sigma_n^*)$ is a Nash equilibrium (Motta 2004: p. 543) if

$$\pi_i(\sigma_1^*, \dots, \sigma_i^*, \dots, \sigma_n^*) \geq \pi_i'(\sigma_1^*, \dots, \sigma_i', \dots, \sigma_n^*), \forall i=1,2,\dots,n \text{ and all } \sigma_i \in S_i \quad . \tag{18}$$

Note that every player is solely interested in choosing the action (subject to the actions chosen by the other players) that maximizes his own payoff, i.e. the player is rational because his behavior maximizes his payoff given his beliefs over unknown variables such as the other players' strategies. In the words of the US-American financier and political consultant Bernard Baruch (1870-1965) this objective may be stated as follows: You don't have to blow out the other fellow's light to let your own shine (cited according to Brandenburger and Nalebuff 1996: 4). Hence, competition among firms, which is a central concept of this lecture, does not emerge from firms' interest to harm their rivals but from their interest to do as well as possible for themselves.

A core objective of game theory is to **solve games**, i.e. to determine their Nash equilibria. In other words, our objective is to describe what strategies players will choose and what the resulting outcome will be. Sometimes Nash equilibria are easy to determine. This is because some of a firm's possible strategies may be dominated. For example, suppose that we have two firms *A* and *B*, in a market whose set of possible strategies is S_i (with $i = A, B$). Suppose that one of *A*'s strategies $\underline{\sigma_i}$ is such that it is never a profit-maximizing strategy regardless of the choices (σ_j) made by *B*, i.e. there is always a strategy σ_i' such that

$$\pi_i(\sigma_i', \sigma_j) > \pi_i(\underline{\sigma_i}, \sigma_j) \forall \sigma_j \text{ with } (i \neq j) \tag{19}$$

applies. Then we say that the strategy in question is **strictly dominated**: rationally speaking, it will never be chosen. Dominated strategies cannot be part of the equilibrium outcome and can be eliminated one by one. Similarly, a **dominant strategy** is one that outperforms all of a firm's other strategies no matter what its rivals do. That is, it leads to higher profits than any other strategy the firm might pursue regardless of the strategies selected by the firm's rivals.

This section B shows that competing firms rarely end up with the highest payoffs that they could theoretically make. Brandenburger and Nalebuff (1996: 10) suggest that you "can play the game extremely well, and still fare terribly. That's because you're playing the wrong game: you need to change it." The remainder of this lecture is concerned with an analysis of the ways firms attempt to change the game. Some of these strategies are legal and benefit consumers such as research and development that creates more efficient production technologies or better products (section C). Other strategies can be illegal like attempts of a dominant firm to exclude its rivals from the market (section J.3). Sometimes, governments attempt to change the game by granting aid to domestic firms at the expense of foreign firms (section K). In Europe, such state aid can be illegal if the positively and negatively affected firms do business in European member states such that the aid would have adverse effects within the European Union.

B.2 Pricing in Bertrand-Competition with Homogeneous Products

In Bertrand-competition, firms reason what price to choose in order to sell the output produced. Cournot-competition takes this analysis one step back and asks what output capacity-constrained firms should optimally produce. Although the Bertrand model was published about 50 years after the Cournot model (see section B.3), we present both models in reverse order because the Bertrand model shares more similarities with perfect competition.

The Basic Bertrand Model

The characteristic feature of the Bertrand model is its assumption that firms use price as strategic variable. The model rests on the following assumptions.

1. The market consists of ***n*** **identical** firms (set of players). The marginal costs of firm i are constant in output and equal those of firm j ($c_i=c_j\ \forall\ i,j$). The firms do not incur fixed costs.
2. The firms supply a **homogeneous product**, i.e. the firms' products are perfect substitutes.[12]
3. The firms face a **downward-sloping demand** $D(p)$, which is continuous and bounded. Demand is perfectly observed by all firms. The consumers demand from the firms with the lowest price. If there is more than one firm with the lowest price, demand is equally divided among them.
4. Firms' strategic variable is price. They **simultaneously set prices**. The strategy set for each firm is $[0,\bar{p}]$ with $D(p)=0$ if $p\geq\bar{p}$.
5. The firms are **not capacity-constrained**, i.e. each firm would be able to supply the entire market.[13]
6. The firms play a **one-shot game**, i.e. they are only interested in the profits of the current period.

Suppose, the number of firms in the market is $n=2$. Every firm is concerned with determining a best price response given its expectation of the other firm's price. For determining this best response, consider that the firm which sets the lowest price may supply the entire demand. This is because the homogeneity of products (assumption 2) implies that customers always buy at the cheapest offer. If both firms set the same price p, the market is split evenly and both firms receive half of the demand $D(p)/2$. Assumption 5 (no capacity constraints) ensures that every firm would be able to serve the entire market. What is the best strategy in this context?

(i) If firm 1 conjectures that firm 2 sets a price above the monopoly price p_m, firm 1 should set the monopoly price. With this strategy, it gets all of the demand and receives the maximum possible (i.e. monopoly) profits π_m while firm 2 makes zero profits.

(ii) Now, firm 1 conjectures that firm 2 sets a price p_2 below the monopoly price but above marginal costs. If firm 1 sets $p_1=p_2$ it receives half of the demand at this price $D(p_2)/2$, as shown in Figure 8. Therefore, firm 1 should set a somewhat lower price, $p_1{*}=p_2-\varepsilon$. With this strategy, it receives the entire demand at this price and makes profits π_1 while firm 2 makes zero profits. This is (almost) a doubling in profits as compared to setting the same price as

12 The assumption of homogeneous products is relaxed in section G.2 .

13 Further below in this section the case of constrained capacities is analyzed.

firm 2. Firm 1's demand is discontinuous as shown by the solid line in Figure 8 (Pepall et al. 2008: p. 225).

$$D_1(p_1, p_2) = \begin{cases} D(p_1), & \text{if } p_1 < p_2 \\ D(p_2)/2, & \text{if } p_1 = p_2 \\ 0, & \text{if } p_1 > p_2 \end{cases} \tag{20}$$

(iii) If firm 1 expects firm 2 to set a price below marginal costs c it should set a price at the level of marginal costs in order to avoid losses $\pi_1<0$.

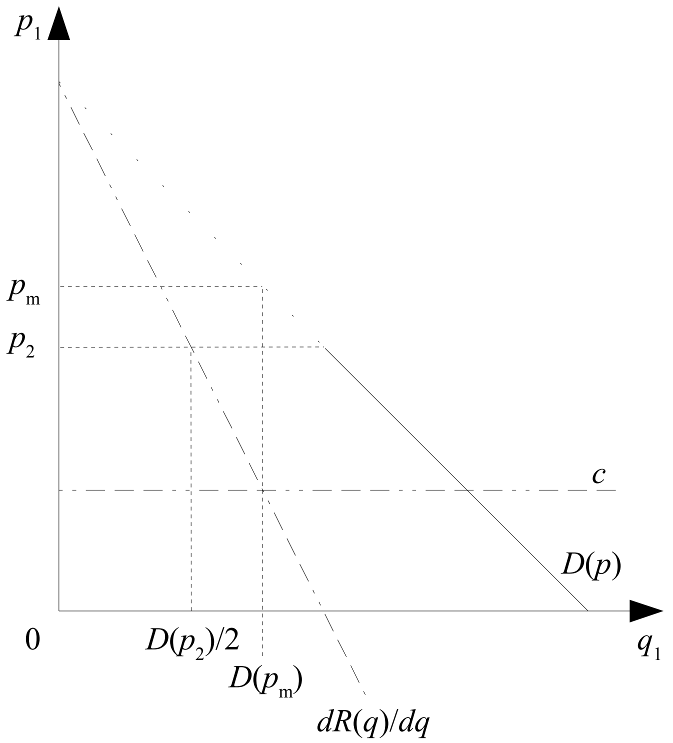

Figure 8: Demand Curve in the Bertrand Model

The **best responses** (or reaction functions) of firms 1 and 2 are shown in Figure 9. A reaction function is a function $p_i*(p_j)$ that shows firm i's optimal price for each price of firm j. A **Nash equilibrium** is a pair of strategies (here: a pair of prices) such that no firm can increase profits by unilaterally changing price (Motta 2004: ch. 8.4.1).

$$\pi_i(p_i*, p_j*) \geq \pi_i'(p_i, p_j*) \tag{21}$$

In Bertrand competition, the market is at equilibrium when both firms charge a price that equals marginal costs.

$$p_1*(p_2) = p_2*(p_1) = c \tag{22}$$

The equilibrium is not defined by first-order conditions because the discontinuity in residual demand implies that a firm's payoff function is not differentiable everywhere. Neither firm would charge a price below marginal costs as this would imply making losses. However, unilaterally charging a higher price is not possible, either, because the firm with the higher price looses all demand to the firm with the lower price. Therefore, the existence of just two firms, which are not constrained in capacity, would be enough to cause a perfectly competitive market-outcome. This is called the **Bertrand paradox**. The equilibrium price is independent of the number of firms when there are at least two firms.

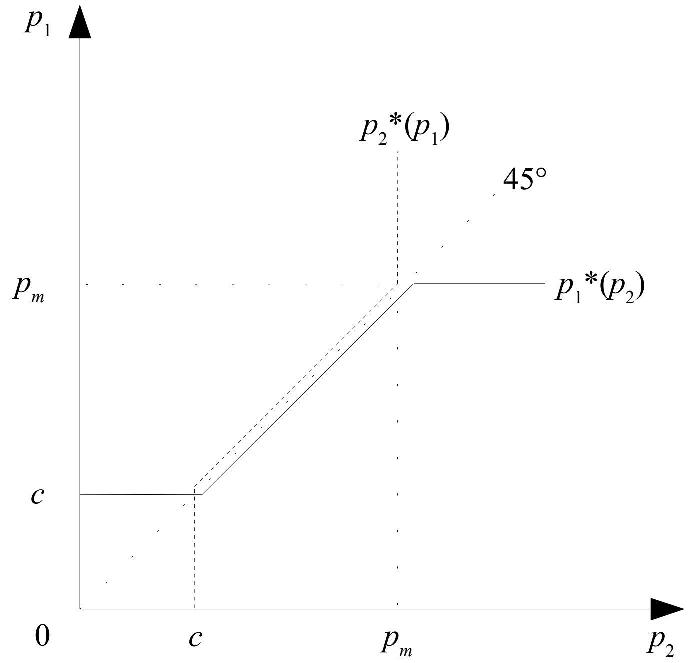

Figure 9: Best Responses in Bertrand Competition

Pepall et al. (2008: 228) provide the following example of Bertrand competition:

> *"Perhaps one of the most dramatic examples of Bertrand competition comes from the market for flat screen TVs. Such screens use one of three basic technologies [(LCD, DLP or plasma). ... Over] time, the differences between the three types have diminished. The result has been the eruption of a severe price war. From mid-2003 to mid-2005, prices for new TVs based on these technologies fell by an average of 25 percent per year. Fifty-inch plasma TVs that sold for $20,000 in 2000 were selling for $4,000 in 2005. Nor has this pressure let up. In November 2006, Syntax-Brillian cut the price on its 32-inch LCD TV by 40 percent. Sony and other premium brands were forced to follow suit. Prices on all models fell further. Indeed, when Sony was rumored to be thinking of further reducing its 50-inch price to $3,000, James Li, the chief executive of Syntax-Brillian, was quoted as saying, "If they go to $ 3,000, I will go to $ 2,999." Bertrand would have been proud."*

Another example for intense price competition among capacity-unconstrained firms is the US-American industry for solar panels:[14]

> *In November 2011 the US-American commerce department opened an investigation into the market for solar panels because American producers accuse Chinese producers of being subsidized[15] and dumping solar panels into the US-market at prices even below production costs. Despite demand for solar panels in USA has been growing since 2008 at a rate of 70% per year, Chinese producers have grown faster to export about 95% of their production built up a US market share of more than 50%. As a consequence, prices of solar panels per watt of capacity have been falling from USD 3.30 in 2008 to USD 1.00-1.20 in November 2011.*

Solving the Bertrand-Paradox

The result of prices equaling marginal costs is not necessarily realistic because in most real-world oligopolies firms may be assumed to make more than zero profits. This Bertrand-paradox is caused by the strong assumptions of the Bertrand-model (Cabral 2000: p. 105).

1. The above assumption 2 implies that all firms supply a homogeneous product. However, when firms sell **differentiated products** and consumers possess a love for this variety, firms can charge prices above marginal costs. The idea of this result is that firms specialize on different segments of the market which lowers competition in each of these segments. Therefore, the firms may charge prices above marginal costs. Bertrand-competition with differentiated products is introduced in section G.2 .

2. The above assumption 6 implies that the firms play a one-shot game. This prevents retaliatory actions by the competitors. Consider the case of a **dynamic game** where firms interact over many periods. In this case, firms could set a price above marginal costs. If one firm decided to unilaterally lower its price in order to gain additional demand the other firms could lower their prices in the following even further in order to punish the deviator. In sections H.1 and H.2 , we explore the conditions under which firms can sustain such supracompetitive prices.

3. The above assumption 5 implies that firms are not **capacity-constrained**. Thus, by setting a lower price than its rivals, a firm wins the entire demand. In section B.3 , we show one way how capacity-constraints affect the competitive market-outcome, i.e. we assume that firms compete in quantities.

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14 http://www.nytimes.com/2011/11/10/business/global/us-and-china-on-brink-of-trade-war-over-solar-power-industry.html?pagewanted=1#

15 The economic analysis of state aid in the European Union is described in section K .

A second possibility for considering capacity-constraints is to model them explicitly in the Bertrand-model (see Cabral (2000: p. 105) and Motta (2004: p. 555)). Thus, consider the industry shown in Figure 10. Market demand $D(p)$ is assumed to be downward sloping. Marginal costs c are assumed to be zero. Firm 1 is capacity-constrained and cannot sell more than quantity k_1. Firm 2 is capacity-constrained and cannot sell more than quantity k_2. The capacity-constraints are binding because $k_i<D(p_i=c)$.

Now, consider the profit-maximization problem of firm 2. If firm 2 sets a price $p_2 \leq p_u$ firm 1 will set a price $p_1=p_2-\varepsilon$ and sell as much quantity as possible, i.e. it will sell the quantity k_1. The residual demand of firm 2 $D_2(p_2)$ equals the market demand at price p_2 minus the quantity supplied by firm 1, i.e. $D_2(p_2)=D(p_2)-k_1$. Moreover, we show firm 2's marginal revenue $dR_2(q_2)/dq_2$.

What price should firm 2 optimally choose? For any price $p_2>p_l$ makes a marginal revenue above zero. Consequently, a capacity-unconstrained firm would set an optimal price p_l. However, at this price firm 2 would have to supply a greater quantity than it can produce. Given its capacity-constraint, firm 2 sets an optimal price price p_{opt}. We find that, if total industry capacity is low in relation to market demand, equilibrium prices are greater than marginal cost and every firm sells an output equal to its capacity.

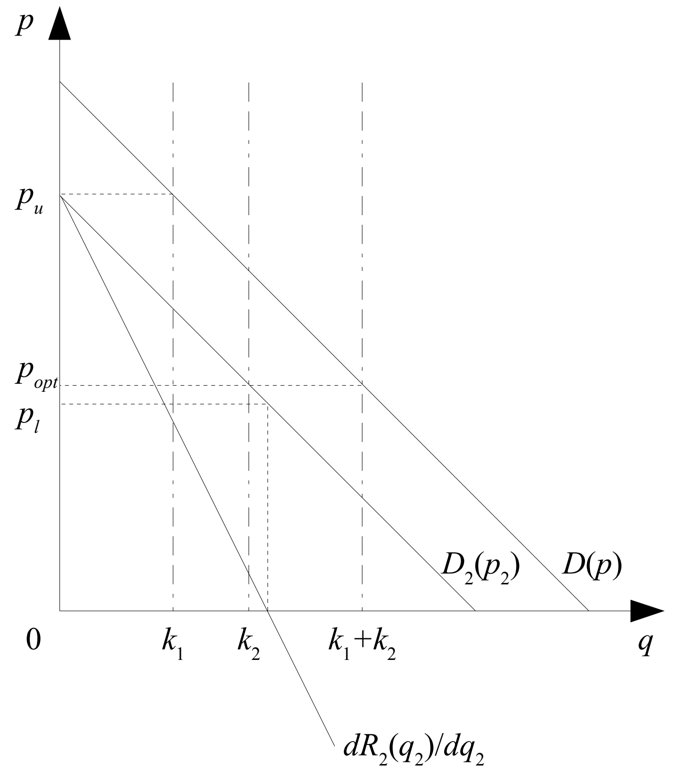

Figure 10: Bertrand Competition with Capacity Constraints

B.3 Pricing in Cournot-Competition with Homogeneous Products

In Bertrand-competition, firms reason what price to choose in order to sell the output produced. Cournot-competition asks what output capacity-constrained firms produce and what price they charge. In a Cournot-model one can, e.g., answer the question: What is the effect of the number of firms on price?

The Basic Cournot-Model

A simple Cournot-model is characterized by the following assumptions.

1. The market consists of ***n*** **identical firms**. The marginal costs of firm i are constant in output and equal those of firm j ($c_i = c_j \; \forall \; i,j$).
2. The firms supply a **homogeneous product**.
3. Firms' strategic variable is quantity. They **simultaneously set quantities**. The price is set as to clear the market.
4. The firms face a **downward-sloping demand** $D(p)$, which is perfectly observed by all firms.
5. The firms are **capacity-constrained**, i.e. neither firm would be able to supply the entire market.
6. The firms play a **one-shot game**, i.e. they are only interested in the profits of the current period.

The output q supplied by all firms is the sum of the output of all other firms q_{-i} plus the output of firm i, i.e. q_i. Given the inverse demand function (2), the market clearing price at total output q is

$$p = p\left(q_{-i} + q_i\right) \quad . \tag{23}$$

Hence, the profit function of firm i may be denoted as follows.

$$\pi_i = \left(p\left(q_{-i} + q_i\right) - c\right) \cdot q_i \tag{24}$$

Assume for the moment that n=2 applies. Thus, the two firms 1 and 2 choose quantities q_1 and q_2 in order to maximize their profits.

$$\pi_1 = \left(p\left(q_1 + q_2\right) - c\right) \cdot q_1$$
$$\pi_2 = \left(p\left(q_1 + q_2\right) - c\right) \cdot q_2$$

To illustrate firm 1's decision consider the demand curve $D^{-1}(q)$ as shown in Figure 11. When firm 2 decides to supply quantity q_2, firm 1's **residual demand** curve $D_1^{-1}(q_1, q_2)$ moves to the left by exactly this amount. Firm 1's best response to firm 2's output choice is determined by its first-order condition

$$\begin{array}{rcll} \frac{d\pi_1}{dq_1} & = & p(q_1+q_2)+\frac{dp(q_1+q_2)}{dq_1}\cdot q_1 - c & \overset{!}{=} 0 \\ & & dR_1(q_1)/dq_1 & = c \end{array} , \tag{25}$$

i.e. firm 1 chooses an optimal quantity $q_1*(q_2)$ such as to equalize marginal cost and marginal revenue. Re-arranging equation (25) for the optimal price yields

$$p = c - \frac{dp}{dq_1}\cdot q_1 \quad . \tag{26}$$

Because of $dp/dq<0$, the market **price** in Cournot-competition **is above marginal costs**.

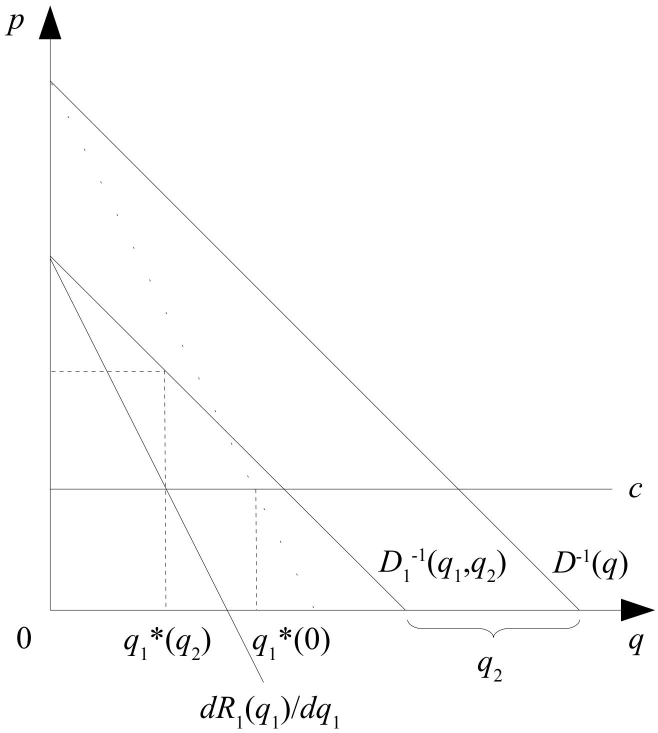

Figure 11: Cournot Optimum

$q_1*(q_2)$ is firm 1's best-response or **reaction function** given 2's choice of quantity q_2. Suppose firm 2 chose a quantity $q_2=0$ so that $D_1^{-1}(q_1,q_2)=D^{-1}(q_1)$. Using first-order condition (25), it is easy to show that firm 1's best response is setting $q_1*(0)$. Given that firm 2 sets a quantity $q_{2,c}$ such that $p=c$, firm 1 should set $q_1*(q_{2,c})=0$. This reaction function of firm 1 is shown in Figure 12. Because firm 2 is assumed to be symmetric to firm 1, the above reasoning applies to firm 2 as well. Therefore, the reaction-function of firm 2 is also shown in Figure 12. The **Nash-equilibrium** of this game is at the point where both reaction functions intersect. To see this, suppose firm 2 sets quantity $q_{2,A}$. In this case, it would be optimal for firm 1 to set $q_{1,A}$. This would induce firm 2 to set $q_{2,B}$ so that firm 1 optimally chooses $q_{1,B}$ (Cabral 2000: p. 123). The combination of quantities $q_{1,opt}$ and

$q_{2,opt}$ is the only set of quantities where neither firm would have an incentive to adjust its output.

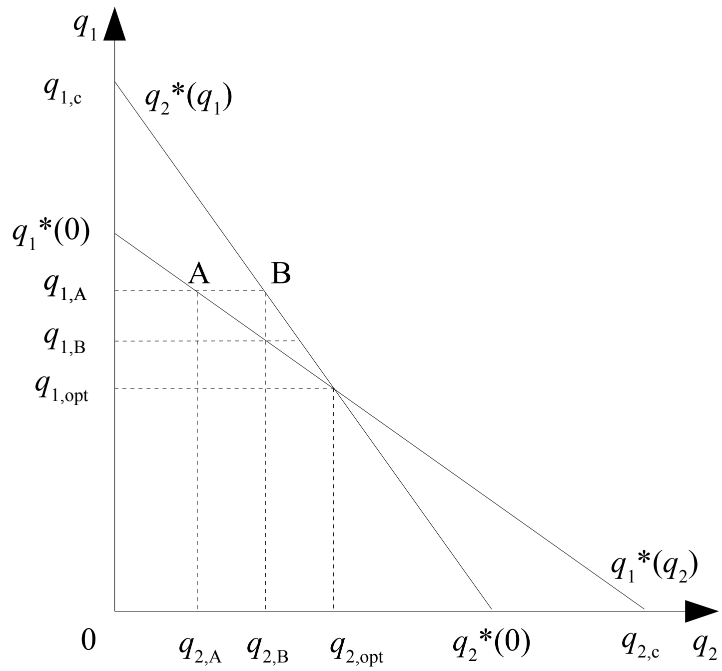

Figure 12: Cournot Reaction-Functions

Comparing the Cournot-Model to other Models

Monopoly is the extreme case of a Cournot-model with n=1 sellers. Consider that $q_1^*(0)=q_2^*(0)$ is the quantity that a profit-maximizing monopolist would set. Therefore, the line that connects these points in Figure 13 shows all divisions of the quantities of firm 1 and firm 2 that add up to the monopoly quantity. We find that the aggregate quantity supplied by the Cournot-duopolists exceeds the quantity of a monopolist.

Perfect competition is the extreme case of Cournot-competition with infinitely many sellers. The quantity $q_{1,c}=q_{2,c}$ implies a price p equaling marginal costs c. This is the condition for a short-run equilibrium in perfect competition (see equation (12)). Therefore, the line that connects these quantities in Figure 13 shows all divisions of the quantities of firm 1 and firm 2 that add up to the competitive quantity.

We find that the aggregate quantity supplied by the Cournot-duopolists is below the quantity in a perfectly competitive market. Likewise, the Cournot-price is lower than the monopoly-price and greater than the price in perfect competition.

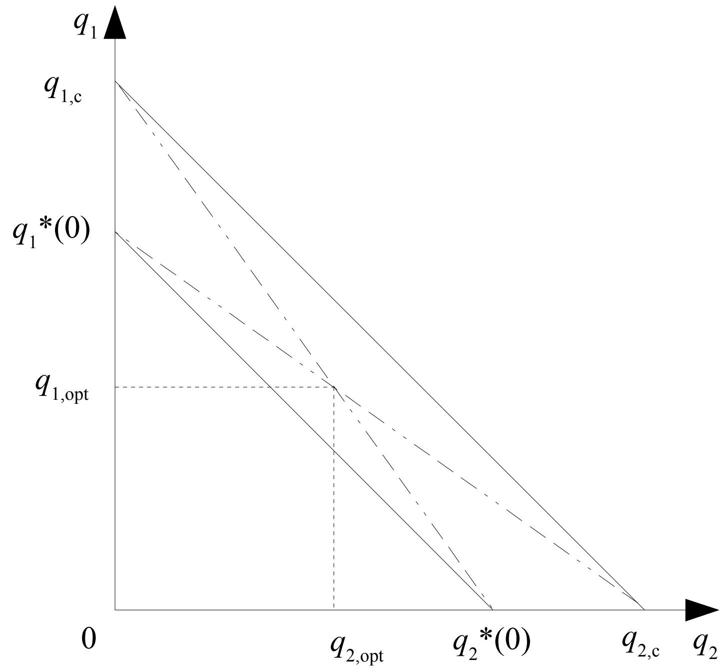

Figure 13: Oligopoly, Monopoly, Competition

In contrast to the Cournot-model, the Bertrand-model predicts that duopoly competition is sufficient to drive prices down to the level of marginal costs. Hence, two firms are enough to achieve the perfectly competitive price level. This decisive difference implies that the two models describe two very different sorts of industries. If capacity and output can be easily adjusted (→ no capacity constraints), the Bertrand model is a better approximation of duopoly competition. Examples include software, insurance, and banking. If output and capacity are difficult to adjust (→ existence of capacity constraints), the Cournot model is a good approximation of duopoly competition. Examples include wheat, cement, steel, cars, and computers (Cabral 2000: 113).

Kreps and Scheinkman (1983: 326) show that the outcomes of a Cournot-model are identical to those of a "two-stage oligopoly game where, first, there is simultaneous production, and, second, after production levels are made public, there is price competition." The first stage can also be interpreted as one where the firms choose a production capacity. The second stage, corresponds to Bertrand-like price competition where production of a homogeneous good is carried out subject to the capacity constraints generated by the first-stage decisions. The size of these capacities is assumed to be common knowledge. The results provided by Kreps and Scheinkman (1983) provide a justification for applying the quantity game to industries in which firms are choosing price.

Lessons Learned

After reading this section you should be able to answer the following questions.

1. What is meant by a Nash-equilibrium?
2. Define the term *dominant strategy*.
3. In what way do the assumptions of the Bertrand model affect its outcome?
4. What is the most important characteristic that distinguishes the Bertrand model from the Cournot model?
5. Calculate the Cournot-equilibrium for a duopoly and an inverse demand function $p(q)=a-bq$ (Cabral 2000: p. 110).
6. Explain why welfare in at a Cournot-equilibrium is lower than welfare in perfect competition.

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