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COURNOT AND THE OLIGOPOLY PROBLEM

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1. Introduction

Cournot's *Recherches sur les Principes Mathématiques de la Théorie des Richesses* (1838) contribution to economic theory ranges from the formulation of the concept of demand function to the analysis of price determination in different market structures, from monopoly to perfect competition. He is credited for being the pioneer in the use of mathematics in economic analysis. Nevertheless Cournot is most known for his theory of oligopoly.

Cournot claimed that prices would also be determined under oligopolistic rivalry. He envisioned firms (the celebrated mineral water producers) competing independently, deciding about their production levels, and bringing to the market the output, where a price emerges from the interaction of supply and demand. An equilibrium is reached when the output of any firm is a best response to the other firms' outputs. That is, when each firm chooses an output level that maximizes profits given the outputs chosen by the rivals. The equilibrium involves a price above the marginal cost of production. Cournot thought furthermore that this equilibrium would be stable in the sense that a departure from it would be self-correcting through a series of reactions of the firms. The disequilibrium dynamics would be governed by the best response functions of the firms, that is, by the functions that give the optimal output of a firm in terms of the outputs of the rivals. Cournot also evoked the question of why is it that firms do not come to an understanding and agree on sharing the market at the monopoly price. The answer is that from the point of view of a firm if the rivals follow the agreement it is in the interest of the firm to depart from it since this way it can increase its profits. In other words, there is an incentive to cheat. Cournot thought that monopoly or cartel type agreements could only be maintained by 'means of a formal engagement' (p. 83). Our author also considered competition of

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producers of complementary products. Interestingly, he assumed that firms would compete via prices and applied the same abstract solution concept, later formalized by Nash (1950). An equilibrium is characterized by actions, prices in this case, that are consistent in the sense that the action of a firm is a best response to the actions of the rivals. Furthermore he showed that the equilibrium price with competition in complementary products, and contrary to the case of substitutes, is larger than the monopoly or cartel price.[1]

Cournot's contribution went largely unnoticed by economists till the review of Bertrand in 1883. Bertrand, after noticing that the obvious choice for oligopolists is to collude, contended that in the homogeneous product market considered by Cournot the relevant strategies for firms where prices and not quantities. In modern language, Bertrand proposed the Nash solution concept in prices. If this is the case and production costs are constant, like in Cournot's mineral water example, price will equal marginal cost, the competitive solution.

Edgeworth remarked in his article on the pure theory of monopoly, published in 1897, that

> 'He (Cournot) concludes that a determinate proposition of equilibrium defined by certain quantities of the articles will be reached. Cournot's conclusion has been shown to be erroneous by Bertrand for the case in which there is no cost of production; by Professor Marshall for the case in which the cost follows the law of increasing returns; and by the present writer for the case in which the cost follows the law of diminishing returns' (1925, p. 117–118).

Edgeworth thought that the oligopoly problem was essentially indeterminate and that prices would never reach an equilibrium position in markets characterized by fewness in numbers, as opposed to what happens in competitive markets. He illustrated his theory examining price competition in a duopoly subject to capacity constraints and concluded that prices would oscillate and would not settle down, cycling indefinitely. Edgeworth also pointed out that the extent of indeterminateness diminishes as the goods become more differentiated, in the limit being the firms independent monopolies. His model has given rise to what now is called Bertrand–Edgeworth competition, where firms compete in prices but also where no firm is required to supply all the forthcoming demand at the set price. A firm will not have an incentive to supply more than its competitive supply (as determined by its marginal cost schedule) at any given price. In this model there need not exist a Nash equilibrium in pure strategies but, as it is well known, there always exists a Nash equilibrium in mixed strategies, where firms instead of choosing prices choose probability distributions over prices.

[1]This theme has been developed further recently by Singh and Vives (1984).

In this sense, up to a probability distribution, prices are determined in the Edgeworth model. Nevertheless, Edgeworth's analysis also could be interpreted as pointing towards the process of price formation in a *dynamic* context, which is not contemplated in the Bertrand–Edgeworth competition model as formulated above.

By the time of the publication of Edgeworth's *Papers Relating to Political Economy*, 1925, it seems that Cournot's theory was widely criticized and discredited. In an introduction to his article on the theory of monopoly Edgeworth (1925, p. 111) writes:

> 'Cournot had represented the transactions between two parties to be determinate in the same sense as competitive prices. But heavy blows had been dealt on this part of his system by Bertrand in the *Journal des Savants*, 1883, and by Marshall, in an early edition of his Principles of Economics. Still in 1897 much of Cournot's construction remained standing; the large part which is based on the supposition that the monopolist's expenses of production obey the law of diminishing returns. Now the demolition of Cournot's theory is generally accepted'.

Some popular views on Cournot's theory and the oligopoly problem before the theory of games came into the scene are reflected in the influential book by Fellner, *Competition Among The Few* (1949). With respect to the oligopoly problem it is argued that with small numbers of competitors the usual supply and demand analysis does not work due to the interdependence of actions and that there exists a range of indeterminateness of prices. With respect to Cournot's theory two main criticisms are stated. First, that is 'right for the wrong reasons' since his stability argument makes no sense. Cournot's firms in the adjustment process to equilibrium see how their expectations are systematically falsified by the evidence. They expect rivals to maintain their outputs while in fact they are changing constantly. Only at the equilibrium point expectations are not falsified. Second, in small number situations there is a strong tendency for firms to collude.

The criticism of the Cournot tatonement is appropriate but this does not say anything about the solution concept proposed by Cournot: Nash in quantities. In a Cournot equilibrium firms anticipate correctly the production levels of rivals and optimize accordingly. The tendency towards collusion in oligopoly was argued forcefully by Chamberlin (1929). He thought that while in the 'large group' case the monopolistically competitive model was appropriate, in the 'small group' case firms would realize their interdependence and would act (implicitly) to maximize joint profits taking into account the possible use of retaliation strategies against defectors. This view has been endorsed by many influential economists, including Samuelson (1967) and Stigler (1964), and has been popularized in Industrial Organization textbooks like Scherer (1980).

In summary, the potential indeterminateness of prices emerges as a fundamental question in the oligopoly problem. Cournot's contention that under conditions of oligopoly prices would be determinate was strongly challenged by Edgeworth who thought that they were essentially indeterminate. Bertrand's opinion on this account falls on the Cournot side, while Chamberlin's leans towards Edgeworth's.

Von Neumann and Morgenstern's *Theory of Games and Economic Behavior* was published in 1944 and Nash article on noncooperative games in 1951 but although their influence is felt by some researchers in the oligopoly field, Shubik (1959), for example, the massive application of game theory to the analysis of competition among firms does not come till the late seventies. What have we learned about the oligopoly problem and what is the status of Cournot's contribution after approximately ten years of research efforts using the tools provided by game theory?

2. Statics

2.1. Cournot, Bertrand and Bertrand–Edgeworth competition

Let us consider a homogeneous product market. In Cournot competition, or Nash competition in quantities, the relative mark-up of firm i over marginal cost or Lerner index of firm i, $L(i)=(p-MC(i))/p$, will equal the market share of the firm, $s(i)$, divided by (the absolute value of) the market elasticity of demand. This is just the inverse of the elasticity of the perceived demand of the firm. The mark-up is thus directly related to the market share and to the productive efficiency of the firm and negatively related to the elasticity of demand. Weighting $L(i)$ by the market share of firm i and adding up across firms we get that the aggregate Lerner index of the industry $\sum s(i)L(i)$ equals the Herfindhal index (H), the sum of the squares of the market shares of the firms, divided by the elasticity of demand. The Cournot model is thus consistent with the idea that concentrated markets (with a higher H) will have larger departures from marginal cost. Notice that H may be higher because the number of active firms decreases or because the size distribution is more unequal. With identical firms at a symmetric equilibrium $s(i)=1/n$ and therefore the margin is inversely related to the number of firms in the market and $H=1/n$. For well behaved downward sloping demand (concave demand is sufficient but not necessary) a Cournot equilibrium exists for very general cost structures of the firms, including non-convex costs.[2] If firms have identical convex costs then the existence of equilibrium is guaranteed for general downward sloping demand.[3] In summary the

[2]See Bamon and Fraysee (1985) and Novsheck (1985).
[3]See McManus (1962) and Roberts and Sonnenschein (1976).

Cournot equilibrium exists in a wide range of circumstances and exhibits plausible properties.

In Bertrand competition with constant unit costs the outcome is the competitive one. With general convex costs there is typically a range of Bertrand equilibria. For example with increasing marginal costs there is an interval of prices around the competitive price all supported by Bertrand equilibria. It is important to remark that in Bertrand competition a firm by setting a price is committed to supply all the forthcoming demand at that price. This is what explains the multiplicity of equilibria.[4] With fixed costs Bertrand equilibria typically do not exist since firms can not cover their unit costs. To see this just add a fixed cost of production to the constant marginal cost case. Quite a few researchers think that two features of the Bertrand model are unrealistic: the resulting competitive outcome with only two firms and constant unit costs and the fact that one firm by undercutting slightly its rival obtains all the market demand, implying discontinuous profit functions. This difficulty is overcome considering differentiated products.[5]

As remarked above the Bertrand–Edgeworth model needs to resort to mixed price strategies to establish the existence of equilibrium. The characterization of equilibria is consequently much more difficult to attain and the plausibility of such randomizing behavior is still debated. Furthermore, and contrary to common belief, product differentiation does not solve the existence problem since the root of the difficulty is the lack of quasiconcavity and not the lack of continuity of payoffs.[6]

2.2. *Conjectural variations and supply functions*

There have been several attempts to integrate the different oligopoly theories into a general framework. The oldest one goes back to Bowley (1924) with the theory of conjectural variations. This approach tries to consider dynamic effects in a static setting and is based on the idea that a firm when choosing its output level takes into account the 'reaction' of rival firms. No reaction, or zero conjectural variation, would correspond to the Cournot case while an output contraction so as to leave the market price constant would correspond to the competitive case. A continuum of possibilities from collusion to perfect competition can be contemplated. The problem is that we are in the context of one shot simultaneous move games and therefore there is no opportunity for the rivals of the firm to react to its move. Restricting attention to Nash equilibria and quantity strategies only

[4] See Vives, forthcoming.

[5] Nevertheless the location-type models à la Hotelling may yield discontinuous demands. Existence of Bertrand–Nash equilibria in product differentiation models can be established using methods developed in Vives (1988).

[6] See Vives, forthcoming.

Cournot equilibria can be the outcome of the game played by firms. As envisioned by Cournot, only Nash equilibria can constitute self-enforcing agreements. Furthermore, the only plausible *equilibrium* concept in situations of strategic conflict is the Nash one since it is the only prescription of how to play the game that when anticipated is self-fulfilling. Abandoning equilibrium analysis other possibilities arise. Requiring strategies to be 'rationalizable' for example yields in general a wide range of possible outcomes other than the Cournot equilibrium.[7]

Grossman (1981) and Hart (1982) proposed the supply function approximation to the oligopoly problem. In this approach the strategy for a firm is a supply function, $S(\cdot)$, the interpretation being that the firm is committed to select a price–quantity pair (p,q) satisfying $q=S(p)$. The commitment to a supply function is explained in terms of the capacity of firms to establish binding contracts with consumers or in terms of internal organizational factors, like incentive structures and operating systems. Horizontal supply functions would correspond to price strategies while vertical ones would correspond to quantity strategies. The payoff to a firm is found computing the market clearing price that equates demand and total supply. The market outcome is then given by a Nash equilibrium in supply functions. The problem is that there is an enormous multiplicity of equilibria. In general any individually rational point, where any firm earns at least its minmax payoffs, can be supported as a supply function equilibrium. Two ways have been proposed to limit the number of equilibria. The first uses a competitive pricing assumption which pins down the supply function of the firm, corresponding to the short run cost schedule, via a capacity choice [Dixon (1985) and Vives (1986)]. The second introduces demand uncertainty to induce forms to favor ex-ante certain supply schedules over others [Klemperer and Meyer (1987)]. In supply function models the mark-up over marginal costs $(p-MC(i))/p$ is given by a similar expression than in the Cournot case. It equals the inverse of (the absolute value of) the elasticity of the residual demand faced by the firm. The difference is that the residual demand to a firm depends on the market price on two counts since both market demand and the supply decisions of other firms depend on the market price.

The supply function approach predicts that the slope of marginal costs is a crucial determinant which indicates whether the Cournot or Bertrand models are more appropriate descriptions of the competitive process. Steep (flat) marginal costs, linked to inflexible (flexible) technologies, are conducive to Cournot (Bertrand) type behavior. Other factors come also into play, supply functions tend to be flatter for less differentiated products, for example. In

[7]A strategy of a player is rationalizable if there is a subjective assessment of the other player's moves for which the strategy is a best response. Nash strategies are obviously rationalizable. See Bernheim (1984) and Pearce (1984).

simple models where firms can choose only price or quantity strategies the type of uncertainty, the curvature of demand and the nature of the products influence the choice of firms. Prices are shown to be preferred when uncertainty relates only to the size of the market in contrast to the case where the distribution of reservation prices is uncertain also and when demand is convex (concave demand tends to favor quantities) [Klemperer and Meyer (1986)]. When firms can commit to a price type or a quantity type supply function before the market period Singh and Vives (1984) show that with substitute (complementary) products it is a dominant strategy to choose a quantity (price) strategy. It is worth remarking that Cournot assumed firms would compete in quantities in the (perfect) substitute goods case and in prices in the complementary goods case. With respect to the departure from efficiency in general supply function models, the magnitude of the price-(marginal) cost margin is seen to be of the order of $1/n^2$ provided marginal costs have bounded slope. Supply function competition dissipates quickly the monopoly power of firms in contrast to the Cournot model where the margin is typically of the order of $1/n$.

3. Dynamics

The disequilibrium dynamics, with its series of myopic reactions, introduced by Cournot have been widely criticized with good reason. Nevertheless the Cournot tatonement has been studied extensively. Furthermore, the stability properties of the Cournot equilibrium have been shown to have important implications for comparative statics. In essence, stability is a necessary condition for a Cournot equilibrium to enjoy 'plausible' or 'intuitive' comparative static properties.

The analysis of dynamic games has developed in important ways recently: two-stage, repeated and more fully dynamic games have received a lot of attention. Two-stage games have contributed in particular to our understanding of the quantity versus prices issue. Repeated and other dynamic games have helped to explain the mechanisms necessary to support collusion but have left us with a host of other possible equilibria.

In the supply function it is assumed that firms are able to choose between quantity or price strategies or, more generally, between alternative supply schedules. There are circumstances though that the basic structure of the market dictates the relevant strategic variables. Firms make in general decisions about both prices and quantities. The variable that is more difficult to adjust, like output in agricultural or automobile markets or prices when production is to order, can be seen as the dominating strategic variable. This situation is naturally modelled in a two-stage game. Kreps and Scheinkman (1983) show that if firms compete first in capacity followed by price (Bertrand–Edgeworth) competition the outcome is Cournot. In equilibrium firms do not use mixed strategies and price at the Cournot level. This result holds if unsatisfied demand at the second stage is rationed according to the surplus-maximizing rule. Otherwise the outcome tends to be more competitive than Cournot, first stage capacities are larger than Cournot levels, and mixed price strategies are used in equilibrium [Davidson and Deneckere (1986)]. Friedman (1986) studies similar models in a product differentiation context. These analyses suggest that the Cournot and Bertrand models are better viewed as reduced forms of more complex and realistic multistage games. It is worth emphasizing that the quantity setting model may be a good description of market behavior even in pure price setting models. Holt and Scheffman (1987) show how facilitating practices, like most-favored-customer and meet-or-release clauses, transform a price setting game into a quantity setting one.

Firms compete repeatedly in the marketplace making quantity and price decisions (with inventory adjustments), which affect short term prospects, and making investment decisions, which affect long term prospects. Two-stage games illustrate the effect of a state (first stage) variable in the overall competition process. Supergames take another approach, there is no state variable and a one-shot game is repeated indefinitely. Friedman (1971) showed that any vector of payoffs that give every firm more than the static Nash profits can be supported as a (subgame perfect)[8] Nash equilibrium of the repeated game if the firms do not discount the future too much. In fact the multiplicity of equilibria extends to support any individually rational payoff in the one-shot game provided certain conditions are met.[9] Firms' strategies typically specify punishments for the deviating firms and for the firms failing in punishing the deviator and so on. The maximal degree of collusion will be achieved when defectors are punished in the most severe way possible.[10] It is worth noting that price setting models may tend to support more collusive outcomes than quantity setting models precisely because credible punishments can be more severe.

The multiplicity of equilibria in repeated games, where periods are independent and history matters only because firms threaten it to matter, carries over to full fledged dynamic games. In the latter context it has been proposed to restrict attention to strategies that depend only on state variables. Using this approach Maskin and Tirole (1988) have studied alternating moves price and quantity duopoly games following a model developed by Cyert and De Groot (1970). In simple contexts they are able to show the existence of a unique (Markov perfect) equilibrium for the quantity game, which is more competitive than Cournot, but a multiplicity of

[8] In dynamic games Nash equilibrium must be refined in order to avoid incredible threats. The appropriate concept is then perfect equilibrium [Selten (1965)].
[9] See Fudenberg and Maskin (1986).
[10] This way Abreu (1984) identifies optimal punishment strategies.

equilibria, including cycles à la Edgeworth and kinked demand curve prices,[11] is found for the price game.

4. Conclusion

After one hundred and fifty years the Cournot model remains the benchmark of price formation under oligopoly. Nash equilibrium has emerged as the central tool to analyze strategic interactions and this is a fundamental methodological contribution which goes back to Cournot's analysis. Furthermore the properties of the Nash equilibrium in quantity strategies, the solution proposed by Cournot for the homogeneous product market, are generally viewed as plausible and more relevant empirically than their Bertrand counterpart. The links between price-cost margins, market shares and the different efficiencies of the firms or the implied relationship between the Lerner and concentration indexes coupled with payoffs that are continuous in actions give the Cournot model its 'realistic' flavor to the sizeable amount of economists that do not agree with the lemma that 'two is enough for competition'. The fact that the Cournot model does not explain the way prices are set, the implicit assumption that output is auctioned efficiently, is certainly a drawback in descriptive terms but we have seen how price setting models may boil down to Cournot outcomes. The quantity setting model can then be viewed as a reduced form of a more complex and realistic multistage game.

What is the balance of the recent game theory research on the indeterminacy issue?

We understand much better now in what circumstances the Cournot or the Bertrand model are appropriate descriptions of the competition in the marketplace. Sometimes the basic technological or institutional conditions, relating in particular to the relative flexibility of prices and quantities, dictate which is the relevant model. Sometimes firms can choose between price-type and quantity-type strategies and then factors like the steepness of marginal costs play a crucial role. Nevertheless the investigation of dynamic games and the strategies by which firms may support collusive agreements has offered a great multiplicity of possible equilibria. In this sense if we interpret Edgeworth's analysis as hinting at an essential indeterminacy when considering pricing in a dynamic context then the theoretical evidence as of today is in his favor. If we interpret Edgeworth's contribution in a static context, and this corresponds better to the formal statement of his model, then the indeterminacy is greatly reduced.

[11] For sufficiently low discount rates the authors argue that the only equilibrium which is robust to renegotiation attempts is a kinked demand curve price at the monopoly level.

How much of this indeterminacy is due to small numbers? In other words, does equilibrium become determinate with a large number of firms?

Cournot thought of perfect competition as the limit of his oligopoly model as individual production tends to be negligible and does not affect the market price.[12] Chamberlin proposed his monopolistic competition model to deal with the large numbers case in a differentiated product context. He also thought that collusion would break down with many firms. This has been and is still the prevalent view although collusion can also be supported with a large number of firms.[13] The limits of many models as the number of firms grows large or, more precisely, as firms become small in relation to the market are either the perfectly or the monopolistically competitive outcomes. The crucial difference with small numbers markets is that the action of a firm has a negligible impact on the aggregate market action, overcoming this way the 'oligopoly problem'.

The research agenda of oligopoly theory is not exhausted yet after one hundred and fifty years since Cournot's book.[14] The application of the tools provided by game theory has proven fruitful but still we have a lot to learn about pricing in a dynamic context, both from the theoretical and from the empirical points of view. The resurgent interest in empirical tests of market power and of oligopoly pricing[15] models allows us to be optimistic about future developments.

[12] This idea gives rise to the noncooperative approach to build proper foundations for perfect competition. See Mas-Colell (1982).

[13] See, for example, Green (1982).

[14] In this paper we have sketched only some of the recent research in oligopoly theory. For more complete surveys, including the applications developed from games of incomplete information, see, for example, Fudenberg and Tirole (1986), Shapiro (1987) and Tirole (1988).

[15] See Bresnahan (1987).

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