Industrial Organization: Notes on the Literature

Luís Cabral

New York University and *CEPR*

May 1999, with a September 2015 post-script

In 1999, I was invited by Blackwell Publishers to put together a reader in Industrial Organization. In addition to collecting some 22 papers, I also wrote introductory notes to each chapter and a general preface. In September 2015, as I prepare to teach graduate IO for the first time in a long time, I decided to go back to these reading and accompanying notes.

With the benefit of another 16 years of experience, I might have chosen a different selection of papers. Also, a lot has been written since 1999. That notwithstanding, I think much — or even most — of what I wrote then still applies. For this reason, in what follows I transcribe the notes I put together in 1999. I didn't change any of the text, partly out of laziness, partly because, once you start making changes, there is no end point.

Paganelli-Bull Professor of Economics and International Business, Stern School of Business, New York University; luis.cabral@nyu.edu.

Preface

Industrial Organization has been a field of very intense and successful research over the past 25 years or so.[1] Assembling a reader with a page constraint of a few hundred pages is therefore a difficult task.

Some choices needed to be made. My first choice was to restrict the Reader to the core areas of IO. This excludes regulation and competition policy, auction theory, contracts and the theory of the firm, experiments, and other areas which, important as they are, would make the task of assembling this reader nearly impossible.

A second important choice pertains to the balance between theory and empirical analysis. A quick glance through the contents reveals a predominance of theory over empirical work. In addition to a possible bias resulting from the author's preferences, the mix theory/empirical work reflects the fact that IO work in the past twenty five years has been mostly of a theoretical nature.[2] I thus chose to include only one section on empirical work, containing three papers. I also make reference to a number of other empirical papers throughout the notes that precede each section.

Reader's intended readers

Several people may find this Reader useful. Students of graduate IO may prefer the Reader to a photocopy pack with the main papers discussed in the course. In fact, the Reader covers most of the papers "starred" in most of the course syllabus I had a chance to look at (by "starred" I mean papers that are studied in greater detail).

For the IO researcher, the Reader may be a useful reference point. Although I would expect IO researchers to be familiar with most of the papers included in the Reader, the possibility of quick, direct access to the original sources may prove useful in a variety of circumstances.

Finally, for the economist to whom IO is not the main field of research, I hope this Reader may serve as a useful point of entry to the IO literature. Having this in mind, I have started each section with a series of notes that place the papers within the context of the IO literature: which papers were written before and which papers were written after; what the important questions are and why the paper selected was an important step in answering those questions; and so forth.

1. Static oligopoly theory

The beginning of Oligopoly Theory — and, in fact, the beginning of Industrial Organization — can be traced back to the seminal book by Cournot (1838). Cournot considered a duopoly model where each firm chooses its output, the market price resulting from the aggregate output chosen by the duopolists. Cournot derived the equilibrium of this model, whereby

1. A recent ranking of field journals ranks IO as the third most important field of Economics research, Macro and Micro being the two first ones. Rankings are based on number and impact of papers listing the JEL IO code (L). See Barrett et al. (forthcoming).
2. Moreover, there seems to be less agreement over what the relevant empirical papers are than what the important theoretical papers are. This is based on a non-scientific survey of reading lists of various graduate courses in IO. The list of "usual suspects" in IO theory is much longer than that of empirical IO.

each firm chooses an optimal output level given the rival's output level (a concept which Nash (1951) later generalized). In this equilibrium, price is greater than marginal cost but lower than monopoly price.

Although output is the primary strategic variable in some oligopoly situations (e.g., the oil market), it is more common for firms to choose prices than to choose output levels. This observation formed the basis of Bertrand's (1883) criticism of the Cournot model. Bertrand further showed that, were firms to set prices, then the outcome would be quite different from the output-setting case: even if there are only two competitors (with equal, constant marginal cost), equilibrium price is equal to marginal cost.

Comparison of the Cournot and Bertrand models gives rise to a sort of "paradox:" although the Bertrand model is more realistic in assuming prices as the strategic variable, it gives rise to a result that seems a bit extreme: even if there are only two competitors, equilibrium price is the same as under perfect competition. The Cournot model, in turn, predicts that duopoly prices are between the monopoly and perfect competition prices, which seems more realistic; but it assumes that firms are output setters, not price setters.

Several approaches have been attempted to solve this "paradox." One approach is given by the first paper in this Reader. **Kreps and Sheinkman (1983)** consider a two-stage model where firms set production capacities in the first period and prices in the second period. This game structure is consistent with the idea that capacity is a long-run variable, whereas price is a short-run variable. Kreps and Sheinkman obtain a remarkable result: In equilibrium, firms set the same price, the price that exactly clears the market (that is, the price such that total demand is equal to total capacity). Moreover, firms choose capacity level as the output they would choose if they were competing a la Cournot. In summary, the equilibrium of the two-period capacity and pricing game is isomorphic to that of Cournot competition.[3]

The idea of modeling price competition with capacity constraints dates back to Edgeworth (1897). Another important contribution prior to Kreps and Sheinkman (1983) is given by Levitan and Shubik (1972), who examine the case when both firms have the same capacity level. Two important papers have appeared since the 1983 paper was published. Davidson and Deneckere (1986) show that Kreps and Sheinkman's result depends critically on their assumption of how demand is rationed when capacity is not sufficient to satisfy all demand. Herk (1993), however, shows that Kreps and Sheinkman's assumption (namely that demand is efficiently rationed) is correct in a model with consumer switching costs.

The model introduced by Kreps and Sheinkman (1983) is a particular example of a more general framework where firms choose a long-run variable (first period) as well as a short-run variable (second period). In this context, first period decisions have both a direct effect on payoff and an indirect effect (also known as *strategic effect*) through changes in short-run (second-period) variables. A general analysis of this two-period framework was proposed by **Fudenberg and Tirole (1984)**. Their series of zoologic metaphors pertains to the nature of the strategic variables chosen by firms. A similar analysis was proposed by Bulow, Geanakoplos and Klemperer (1985a), to whom the terminology *strategic complements* and *strategic substitutes* is due.

3. An interesting coincidence: Kreps and Sheinkman's paper was published exactly one hundred years after Bertrand's.

2. Repeated games and oligopoly theory

Most real-world oligopoly interaction takes place over a number of periods. In this sense, static oligopoly models are of limited use: they either assume that decisions are taken once and for all, or that the same strategic choice is made in each period.

From a game theoretic point of view, the best way to analyze ongoing oligopoly interaction is to make use of repeated games. A repeated game, as the name suggests, is a game that is repeated—indefinitely, in the case of an infinitely repeated game, or for a fixed number of periods, in the case of a finitely repeated game.

It has long been known that there may exist equilibria in repeated games that do not correspond to equilibria in the respective static game.[4] For example, in the static Bertrand game the only equilibrium is for firms to set price equal to marginal cost. However, in the repeated Bertrand game, there may be equilibria where firms set prices above marginal cost. In fact, dynamic interaction is one of the solutions for the "paradox" alluded to in the previous section (namely, that in a price-setting context prices equal marginal cost even with only two competitors). The first formal application of the principles of repeated games to oligopoly theory is due to Friedman (1971), who examined a repeated Cournot game and confirmed the above results.

Repeated games provide a very reasonable explanation for cartels and collusion, one that static models cannot offer. In these repeated-game equilibria, notwithstanding the absence of explicit binding contracts, firms refrain from setting prices that would increase their short-run profits. The reason is that a short-run deviation from the equilibrium price is followed by a price war that creates greater harm for the deviant firm than the profits from deviation. However, in doing so, models like that of Friedman (1971) go a little too far in the opposite direction: they predict that, if firms interact frequently enough, then monopoly prices are set in every period (if firms pick the profit maximizing equilibrium). Moreover, although price wars are the deterrent of deviations from a collusive agreement, price wars do not actually take place along the equilibrium path. Such prediction fails to match the empirical observation that price wars do occur.

Inspired by Stigler's (1964) pioneering ideas, **Green and Porter (1984)** provide a formal, consistent repeated game where price wars take place along the equilibrium path. The key ingredient in the Green-Porter model is that firms cannot observe each other's actions (output level), only a public signal (price) which is a function of every players' actions and of exogenous noise. A firm that deviates by setting a high output will induce a lower price (stochastically speaking). In order to prevent this from happening, when price is sufficiently low firms revert into a (finite) price war, upon which they revert back to the cooperative phase of setting monopoly output levels.

Rotemberg and Saloner (1986) propose an alternative explanation for price wars. As in Green and Porter, they assume that demand fluctuates over time. However, they assume that both current demand and past prices are observable. In this context, "price wars" (specifically, periods of lower prices) result from the need to balance the benefits and costs of short-run deviations in prices. Specifically, the model predicts (under some assumptions) that prices are lower in periods of high demand, that is, periods when short-run deviations

4. Specifically, the *Folk theorem* (thus called on account of its uncertain origin) states that if players interact frequently enough then any payoff profile that is feasible and individually rational can be attained from an equilibrium of the repeated game.

would be more profitable.

Both the Green-Porter and the Rotemberg-Saloner papers have spawn a series of theoretical works that extend and generalize the original ideas. To mention a few, Porter (1983) extends Green and Porter (1984) to optimal cartel equilibria.[5] Abreu, Pearce and Stachetti (1991) propose a more general theory of collusion with imperfect observability. Haltiwanger and Harrington (1991) and Kandori (1992) extend Rotemberg and Saloner (1986) to more complex demand fluctuation patterns. On the empirical front, Porter (1983) (cf Section 4) and Ellison (1994) propose empirical specifications based on the theoretical models.

As mentioned above, collusive equilibria must balance the short-run benefits from deviation against the long-run costs from entering into a price war. When firms interact with each other in more than one market, the list of possible arrangements for stable collusive pricing increases. Or does it? Anecdotal evidence suggests that multi-market contact makes collusion easier to sustain. **Bernheim and Whinston (1990)** provide formal conditions such that collusion is indeed easier to sustain under multi-market contact. They also provide conditions under which multi-market contact is irrelevant from the perspective of collusion.

The idea that multi-market contact may facilitate collusion is not new: Scherer (1970) lists a series of examples and Telser (1980) briefly mentions the theoretical possibility. However, Bernheim and Whinston (1990) provided the first systematic analysis of the problem. Since then, a number of empirical papers have confirmed the theory's prediction, including Evans and Kessides (1994), Parker and Röller (1997), Fernández and Marín (1998). An interesting area for theoretical extension is the inclusion of incomplete observability of firms' actions, a possibility not considered by Bernheim and Whinston (1990).

3. Product differentiation

Section 1 of this reader introduced the "paradox" that results from contrasting assumptions and results of the Cournot and Bertrand models. Capacity constraints were then proposed as a first possible solution to the "paradox." In Section 2, a second solution was proposed: repeated interaction. A third possible solution to the Cournot-Bertrand "paradox" is given by product differentiation. In particular, the result that price competition leads to pricing at the level of marginal cost depends crucially on the assumption (common to the Cournot and Bertrand models) of product homogeneity.

The first attempt to formally model competition with differentiated products is due to Hotelling (1929). Hotelling went futher than the issue of equilibrium pricing with product differentiation. He was also interested in the equilibrium choice of products, in particular the equilibrium degree of product differentiation.[6] Hotelling considered a model where consumers are uniformly distributed along a segment and pay a total cost given by price plus transportation cost to the seller's location. Hotelling concluded that, in equilibrium, firms choose to locate very close to each other, in the middle of the segment — thence the principle of *minimum product differentiation.*

D'Aspremont, Gabszewicz and Thisse (1979) show that Hotelling's equilibrium

5. Other important references on optimal cartel equilibria, though not in an imperfect observability context, include Abreu (1989,1986).

6. This is another instance of the framework analyzed by Fudenberg and Tirole in the paper included in Section 1.

derivation is incorrect. In fact, for the case considered by Hotelling, no price equilibrium in pure strategies exists when the firms' products are similar. D'Aspremont et al. consider a slightly different version of the Hotelling model (quadratic transportation costs instead of linear transportation costs) and show that the equilibrium corresponds to firms *maximizing*, not minimizing, the degree of product differentiation. The importance of d'Aspremont et al.'s contribution lies more in the methodology (completely and correctly solving the two period model) than in the result itself (maximum differentiation). In fact, as de Palma et al. (1985) have shown, Hotelling's principle of minimum differentiation holds under sufficient consumer heterogeneity.

On a slightly more technical note, one interesting problem raised by the Hotelling model is that of equilibrium existence. Important results pertaining to a class of models that includes Hotelling were developed by Caplin and Nalebuff (1991).[7]

A distinction is normally made between horizontal and vertical differentiation. The Hotelling model is one of *horizontal* product differentiation: different consumers have different valuations for different products. Some consumers prefer A to B, other consumers prefer B to A. An example is given by the sweetness of a cola drink: different consumers have different ideas of what the ideal sugar content is, and so a little more sugar is a good think for some consumers and a bad thing for other consumers. In contrast, when all consumers agree that, conditional on price, product A is better than product B, then we have a case of *vertical* product differentiation. The durability of a battery might be an example: all consumers agree that longer lasting batteries are better.

The first models to examine the issue of competition with vertical product differentiation are Gabszewicz and Thisse (1979) and **Shaked and Sutton (1982)**. Gabszewicz and Thisse determine the price equilibrium for exogenously given product qualities. Shaked and Sutton examine in addition the endogenous choice of quality levels.[8]

Since these seminal papers in the late 1970s / early 1980s, a large amount of research has been devoted to modeling oligopoly competition with product differentiation. Many of these models are extensions or variations of the horizontal or vertical differentiation models. Specifically, Salop (1979) considers a version of the Hotelling model where consumers are located along a circumference — not a segment —, an alternative modeling strategy that has come to play an important role in economic analysis. Many of the models in this line of research are concerned with the issue of endogenous choice of the degree of product differentiation. However, in light of the ambiguity evidenced in the paper by de Palma et al. (1985), the value added by this literature seems questionable.

For all their differences, the vertical and the horizontal product differentiation models have one aspect in common: They are both "address" models. Each firm is located at a given "address," and has at most two direct competitors, its direct neighbors. A radically different approach to modeling product differentiation is that of "non-address" models. Under the latter approach, each product competes directly with all other products. Important contributions to this literature include Spence (1976a) and **Dixit and Stiglitz (1977)**. One question these authors are concerned with is the comparison of the equilibrium num-

7. An even more general set of results regarding existence of Nash equilibrium, with applications to a series of IO models, was developed by Dasgupta and Maskin (1986). The seminal contribution is, of course, Nash (1951).
8. One of the interesting results in Shaked and Sutton is that, with two competitors, the profits of the lower-quality firm decrease as the firm increases its quality, *even if quality is costless* — a result that runs counter to the "principle of minimum differentiation."

ber of product varieties to the socially optimal number of product varieties. The answer is — it depends. More on this in Section 5.

The address and the non-address approaches are both very extreme. The address approach exaggerates the extent of neighborhood effects. The non-address approach assumes no neighborhood effects. Reality is clearly somewhere in between. For this reason, a promising line of research is that of models based on the characteristics approach. Each products is defined by a number of characteristics, normally a number greater than one. Each consumer is defined by valuations for each of the product characteristics and maximizes the difference between utility and price. This approach, which dates back to at least Lancaster (1979), has been developed, inter alia, by Anderson et al. (1989). The approach has two advantages. First, it encompasses the models considered earlier in this section. For example, vertical product differentiation obtains when there is one characteristic only. Second, it has shown promising results in terms of empirical application, as we will see in Section 4.

4. Empirical analysis of oligopoly

It is fair to say that empirical work has lagged behind IO theory in the past twenty five years or so. To some extent, the "renaissance" of empirical IO, as it was once labeled, is still under way. This makes the task of selecting representative articles more difficult. To this is added the fact that there is less consensus about the main contributions than in the case of IO theory.

One of the main goals of empirical IO has been the estimation of market power. Until the 1970s, this was primarily done by means of cross-sectoral studies, that is, studies that pool data from various industries. This approach was however plagued by the economic and econometric problems of estimating reduced-form models and combining data from different industries. By contrast, the "New Empirical Industrial Organization" attempts to estimate the degree of market power in a particular industry and based on a structural model of oligopoly competition.

Estimating the degree of market power raises interesting identification problems. Suppose, for example, that there is a one-unit shift in the demand intercept and that demand is linear and sloped -1. A .5 shift in price is then consistent with both (a) monopoly pricing and constant marginal cost; and (b) competitive pricing and increasing marginal cost (such that the supply function has a slope of one). Is it possible to identify the degree of market power based on demand and cost data?[9] **Bresnahan (1982)** provides a set of conditions under which the answer is positive. In a companion paper, Lau (1982) generalizes these conditions.

In terms of applications, the literature on identification of market power goes back at least to Iwata (1974). Bresnahan (1982), however, was the first to tackle the problem in a systematic way. Since then, many applications of his framework and variations thereon have been performed with data from different industries and different countries.

For all their variety, most of these applications have the common feature of being static models. **Porter (1983)** provides the first attempt at estimating an econometric model that is inspired by a dynamic model, specifically, the model developed in Green and Porter

9. The above is not a great example since the change in output together with the change in price would select between (a) and (b). However, it illustrates the fact that variable market power introduces an added degree of freedom that has to be taken into account in econometric estimation.

(1984). As seen in Section 2, this is a game of collusion with price wars, that is, with phases of "cooperative" pricing and phases of "non-cooperative" pricing. Obviously, a model of this sort cannot be estimated based on an econometric specification that implies a unique (static) solution. Porter's (1983) model has become a source of inspiration for other attempts at estimation of dynamic models. The number of such attempts is still relatively low; it includes Ellison (1994) (an extension of Porter's (1983) paper, based on the same dataset), Bresnahan (1987), Roberts and Samuelson (1988) and Slade (1992), among others.

In Section 3, we depicted the dilemma between address and non-address models of product differentiation, concluding that empirical analysis should be the way forward — based on models following the characteristics approach. That is what **Barry, Levinson and Pakes (1995)** do, together with the contemporaneous Goldberg (1995). The Barry-Levinson-Pakes framework, which follows an earlier contribution by Berry (1992), has spawned a respectable number of similar applications to other industries. These empirical models of product differentiation have been used to address a number of important issues where theory has essentially reached its limits; for example, the question of selection bias in the provision of differentiated products (cf the papers by Spence and Dixit and Stiglitz cited in Section 3).

One of the troublesome features of oligopoly theory is the variety of solutions that can be supported as an equilibrium; and the sensitivity of equilibria to apparently small changes in the assumptions. Witness, for example, the contrast between Green and Porter (1984) and Rotemberg and Saloner (1986).[10] For empirical economists, this implies the choice between two possible paths. One is to study individual industries, determining their particular institutional features and estimating specialized models. Porter (1983) would be an example of this. An alternative path is to look for empirical implications of oligopoly theory that are sufficiently robust, that is, common to a reasonably wide class of models.

Prominent among the second path is the "bounds" approach, pioneered by Sutton (1991) and extended in Sutton (1999). The idea of this approach is to derive the set of empirical observations that are consistent with theory and test whether the data are consistent with the theory. A related line of research is that of Bresnahan and Reiss (1991) who, like Sutton, look at the relation between market size and market structure.

Another strand of recent empirical IO literature pertains to competitive industry dynamics. Strictly speaking, this would not fit under the current section heading, as most of this literature assumes competitive markets, not oligopoly competition. However, it forms part of the "renaissance" of empirical IO, and is thus worth mentioning. This new literature is possible thanks to the availability of novel, comprehensive firm-level or plant-level datasets, together with the remarkable improvement in computing resources. The result is a series of studies that document important regularities regarding firm entry, growth and exit. To cite only a few, Dunne, Roberts and Samuelson (1988), Evans (1987) and Hall (1987).

Unusually for Economics, this is an area where theoretical work trails behind empirical work. Some of the theoretical contributions are reviewed in the last part of Section 5. I would expect them to occupy an entire new section in a future edition of this reader.

10. The problem is especially apparent in the context of repeated-game oligopoly theory, but is true more generally.

5. Entry

Monopolies are more profitable than oligopolies. This simple fact provides the motivation for the strategy of entry preemption. Incumbent monopolists will do all they can in order to maintain their dominant position. In a seminal work, Sylos-Labini (1962) proposed the strategy of limit pricing as a positive theory of entry preemption (the idea goes back at least to Bain (1949)). By setting a low price, an incumbent discourages entry by potential rivals. The latter, taking the incumbent's price as given, finds it unprofitable to enter. The incumbent, in turn, sacrifices short-run profits (lower than monopoly price) for the maintenance of a monopoly situation.

How can low prices be an entry deterrent? After all, once entry is a *fait accompli*, the incumbent will find out that it is in its best interest to raise price to more reasonable levels. In other words, if the incumbent cannot commit to set a low price for a long-period, then low prices should not be a entry deterrent. The game-theoretic development of this idea owes much to the work of Selten (1965), who argues that the threat of maintaining low prices after entry is not a credible threat.

As a reaction to this criticism, Spence (1977) proposed a reinterpretation of the Sylos-Labini model whereby the incumbent expands its capacity, possibly to the point of holding excess capacity, and threatens to use such excess capacity were entry to take place. This seems like a more credible strategy. After all, capacity costs are mostly sunk; it would thus seem that the monopolist has an incentive to use its capacity were entry to take place.

Not necessarily, argues **Dixit (1981)**. In a model with linear demand and costs, Dixit shows that an incumbent may increase capacity to (successfully) deter entry. However, the incumbent never holds excess capacity in equilibrium. Bulow et al. (1985b) qualify this assertion: if demand is non-linear (constant elasticity, for example), then excess capacity may indeed be an equilibrium entry deterring strategy, as suggested by Spence (1977).

Sunk capacity costs are not the only source of credible commitment.[11] Schmalensee (1978), for example, shows that product proliferation may deter entry in a similar way. Another important instance of credible deterrence is given by contracts. For example, in anticipation of the expiry of its patent, Monsanto (the producer of Nutrasweet) signed long-term contracts with its main customers (Coca-Cola and Pepsi-Cola), making life more difficult for entrant Holland Sweetner Company. On the eve of entry deregulation in Portuguese TV broadcasting, the incumbent monopolist signed a series of contracts with suppliers of movie and sports programs, the most important items — financially speaking — in TV broadcasting.

Can such an outcome result from rational behavior on the part of customers and suppliers? Why didn't Coca-Cola, for example, wait for Holland Sweetner to enter the market and then benefit from lower prices resulting from duopoly competition? **Aghion and Bolton (1987)** make the point that a long-term contract of the sort considered above may be in the joint-interest of incumbent and buyer (or incumbent and supplier); that is, can be an equilibrium phenomenon. Suppose the entrant's cost is unknown to incumbent and buyer. When the entrant's cost is lower than the incumbent's, entry takes place absent any contract between incumbent and buyer. In this case, the entrant prices below the incumbent's cost and makes a profit. It's precisely because of this "entrant's surplus" that incumbent

11. In fact, aside from Dupont's strategy of capacity expansion in the market for Titanium Dioxide in the 1970s, it is remarkably difficult to find an example of preemption by capacity expansion.

and buyer find it optimal to write a contract. Such contract, including a liquidated damages clause (if the buyer decides to switch to the entrant) effectively extracts some of the entrant's surplus, to the benefit of incumbent and buyer. The inefficiency that the contract causes (deterred entry when the incumbent is less efficient) is analogous to the inefficiency caused by monopoly pricing. In fact, crucial to the Aghion-Bolton result is the fact that the entrant's cost is unknown to the incumbent, just like a monopolist lacks information on each buyer's valuation.

Another question of interest in the context of entry is whether the equilibrium number of entrants is too small or too large from a social welfare point of view. In a seminal paper, von Weizsacker (1980) showed that entry barriers may be welfare enhancing, for otherwise the equilibrium number of entrants would be too large from a social welfare point of view. A more general analysis of this problem was developed by **Mankiw and Whinston (1986)**, who characterize an important externality in the entry decision — the "business stealing" effect. The idea is that, when there is market power, part of the profits earned by an entrant correspond to earnings transfered from incumbent firms, earnings which do not correspond to an increase in social welfare. A analysis similar to Mankiw-Whinston's is presented by Suzumura and Kiyone (1987).

In the context of free entry with product differentiation, early attempts at solving the free-entry-and-welfare question include Spence (1976a) and Dixit and Stiglitz (1977) (cf Section 3). An important recent contribution is Anderson et al. (1995). A general feature of all these models is that there is a conflict between the business-stealing effect and the opposite externality that an entrant is only able to capture a fraction of the consumer surplus it generates. General results regarding the relative weight of these two effects seem difficult to obtain. The way forward would seem to be empirical analysis (see the third paper in Section 4).

Not every industry has "large" incumbent firms playing strategies of entry preemption. At the opposite extreme of the spectrum, we have perfect competition, where entry is "easy" and incumbent firms' profits are zero in the long-run equilibrium. The problem with the perfect competition "story" is that it does not fit the data. In theory, we should observe entry *or* exit, depending on whether the number of firms is lower or greater than the long-run equilibrium, respectively. But typically one observes both entry *and* exit in any given industry or time period. A first attempt at a model that is consistent with price-taking equilibrium behavior and with the above stylized fact was developed by **Jovanovic (1982)**. Jovanovic's seminal paper has spawned an interesting literature on industry dynamics, including important contributions by Hopenhayn (1992) and Ericson and Pakes (1995).

6. Technology and dynamics

Considering how important technical progress is, considering the dramatic impact that new products and production processes can have on industry structure, it is surprising how little attention IO has devoted to this issue. One of the central points of the Schumpeterian school (and, to some extent, of the Chicago school) is that economists pay much too attention to the problem of (static) market power. Because of technical progress and entry, market power is inherently a temporary phenomenon. Or is it?

This question motivates an analysis that goes beyond the measurement of market power and instead focuses on the *persistence* of market power. Do dominant firms tend to maintain, or even increase, their market dominance? Is market power temporary or is it permanent?

R&D-intensive industries are a natural context in which to address this question. New products or production processes provide a channel through which new firms might supplant old ones. This could then justify Schumpeter's assertion that technical progress is nothing but a process of *creative destruction* in which firms have at most transitory market power.

Gilbert and Newbery (1982) develop a strong argument against this view. Although their paper is posed in a particular context (the incentive of an incumbent monopolist to acquire "sleeping patents"), their point is more general: a monopolist has more to lose from letting competition in than a potential entrant has from challenging the monopolist. As a result, the tendency should be towards persistence, not alternation, of market dominance.

Reinganum (1982) makes the point that Gilbert and Newbery's (1982) result depends on their assumptions, especially the assumption that there is no uncertainty in the R&D process. Under uncertainty, with positive probability the potential entrant does not succeed in inventing a new product, even though it invests a positive amount. When this happens, a successful incumbent would only be replacing its monopoly product with another monopoly product. This is basically Arrow's (1962) "replacement" effect. Arrow argues that, because of this effect, a monopolist has less incentive to engage in R&D that a competitive firm has. Along the same lines, Reinganum (1982) shows that, with uncertainty, there are cases when the probability the monopolist is replaced by an entrant is greater than the probability of persistence.

Gilbert and Newbery (1982) and Reinganum's (1982) models are static models. Even though the latter introduces time (the time before an invention is made), they only consider one innovation. But the problem of the persistence of dominance is an inherently dynamic one. A potential entrant that challenges the monopolist should take into account that, if successful, it will be playing the same game that the monopolist is playing now — including the fact that it will be challenged.

Cabral and Riordan (1994) develop a "truly" dynamic model where two duopolists compete in an infinite series of periods. Technology dynamics are given by a learning curve, a particular but important case of R&D where R&D is complementary with production. They provide sufficient conditions for increasing dominance to hold, that is, for the probability that the leader gets ahead to be greater than 50%. A similar set of conditions is presented in Budd et al. (1994). Early contributions to the literature on competition with a learning curve inlcude Spence (1976b) and Fudenberg and Tirole (1983), who consider two-period models.

It is not enough for technologies to be developed. They also need to be employed. **Fudenberg and Tirole (1985)** analyze the strategic issues involved in the adoption of a new technology. One of the stylized facts of technology adoption is that of diffusion: not all firms adopt a new technology at the same time. Many authors attribute this feature to adopter heterogeneity: not all firms have the same incentive to adopt a given technology. Fudenberg and Tirole (1985) propose an explanation for diffusion based on strategic behavior by adopters who compete in the product market. Under some conditions, equilibrium implies that two otherwise symmetric firms decide to adopt a new technology at different times.

The paper by Fudenberg and Tirole (1985) is also interesting for the methodological contribution it makes to the study of games in continuous time. Previous research, e.g., Reinganum (1981), considered a solution where firms precommit to an adoption time (open-loop solution). Fudenberg and Tirole (1985) consider the alternative case when firms can react instantaneously to the other firm's moves. Several papers have extended this methodology in the context of technology adoption games, e.g., Riordan (1992).

7. Asymmetric information

One of the most important aspects of the game-theory "revolution" in IO has been the formal introduction of imperfect information, in particular asymmetric information. Prominent contributions in this area are the papers by Kreps and Wilson (1982) and Milgrom and Roberts (1982). These papers are motivated by the so-called chain-store paradox, first proposed by Selten (1978). Consider a simple game where an entrant decides whether or not to enter a market that is initially monopolized. In case of entry, the incumbent decides whether or not to prey on the entrant. If entry costs are sunk, no amount of predation will lead the entrant to exit. A simple backwards induction argument implies that the *threat* of predation will not work either — at least not between rational players. The force of backwards induction works equally well when we consider a finite series of games of this sort played between a chain-store owner and a series of potential entrants.

This result is a paradox because one would have thought that the perspective of facing a large number of potential entrants would induce the incumbent to respond aggressively to entry, in the hope of creating a reputation for being a "tough" player. But how can we model the idea of reputation? **Kreps and Wilson (1982)** and Milgrom and Roberts (1982) propose the following framework: with a small probability, an incumbent is of a type — the "crazy" type — that derives positive utility from fighting an entrant (even though this may imply negative profits). The entrants don't know the incumbent's type (the incumbent does). In this context, by fighting early entrants, a "normal" incumbent increases the entrant's posterior that the incumbent is of the "crazy" type. This "investment" in reputation is costly, since "normal" incumbents derive negative utility from predation. But it may pay off in the long run as it preempts entry: eventually, entrants will hold a posterior of the incumbent being "crazy" so high that no entry is the optimal strategy.

The papers by Kreps, Milgrom, Roberts and Wilson (1982) were important for two reasons. First, they proposed a very reasonable solution to an important paradox in the IO theory of strategic entry and predation. Second, they set up a framework that has proved to be very useful in addressing a number of related issues (not only in IO but also in other areas of Economics, including Macroeconomics).

As mentioned in Section 5, the Sylos-Labini model suffers from the criticism that firms usually cannot commit to prices. However, anecdotal evidence suggest that low prices are an important deterrent. As recently as a few months ago, the Wall Street Journal Europe pointed France Telecom as a successful case of an ex-monopolist reacting to potential competition. France Telecom lowered its telephone rates by so much that it discouraged most potential entrants, the argument goes. How can theory and empirical observation be reconciled?

Milgrom and Roberts (1982) propose a solution based on asymmetric information. Suppose the entrant does not know the incumbent's cost, only the distribution of possible cost values. Before deciding whether to enter, the entrant observes the price set by the incumbent. In a signalling equilibrium, a lower-cost incumbent sets a lower price. If price is sufficiently low, then the entrant infers that the incumbent's cost is very low and decides not to enter. In other words, a low price effectively deters entry, even though there is no commitment to keep that price low upon entry.

Milgrom and Roberts (1982) follow the framework of signalling equilibria first proposed by Spence (1971). Many other papers have applied Spence's ideas. Milgrom and Roberts' was one of the first applications in an IO context. Other important applications include Wolinsky (1983), a paper that derives conditions under which prices can signal product quality, and Khilstrom and Riordan (1984), who show that advertising can also be a signal of product quality. The latter follow the ideas first put forward by Nelson (1970, 1974), who argues that, in a model of repeat customers, introductory advertising may function as a signal of product quality. The idea is that a high-quality firm has a greater incentive to advertise because it has more to gain from attracting first customers (the reason being they will be repeat customers).

It is apparent from this literature that there are various possible signalling equilibria. In particular, different actions (e.g., price, advertising level) may function as signal of the same private information (e.g., quality level). Which signal is best? Which signal should we expect to be used in equilibrium? **Milgrom and Roberts (1986)** propose an answer to this question in the context of the price-advertising-quality framework. The answer is, both advertising and price should be used as signals of product quality. Specifically, the most efficient signalling equilibrium is one where both strategic variables are used as a signal. This result is important not only for the particular application (which is, again, in the Nelson tradition), but also for the methodological contribution to modeling multi-dimensional signalling.

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