12 The Use of Game Theoretical Models for Empirical Industrial Organization

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1 The Aim Of This Paper

Game theoretical models have become the state of the art in industrial organization. This paper surveys the empirical research in industrial organization, inspired by non-cooperative game theoretical models. Empirical research motivated by game theory is in an "early stage of the product cycle", which implies that topics, and methodology, are not yet standardized. We specifically try to force structure into the existing literature and attempt to indicate into which direction research could go.

To make the task tractable, our approach will be restrictive in several respects. We exclude the growing literature concerning the testing of game theoretical predictions in experiments.[1] We do not report on applications of game theoretical models in some promising fields related to industrial organization. The behavior at auctions, methods of monitoring firms (agents), and the dynamics of innovation are popular fields in which non-cooperative game theory has gained importance for empirical research and as far as auctions are concerned, for policy as well. Although game theory has started to influence macroeconomics and public choice, these fields deserve separate surveys.[2]

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We focus on the testing of game theoretical models, making predictions for the core questions of industrial organization, concerning the relation between market structure and performance.[3] We focus on the application of game theory where it is really difficult, namely in the evaluation of the conduct and performance of *real world firms*. These are known to be complex decision making units usually producing a bulk of products for ill defined markets in unstable environments, while game theory has to be lauded for exactly defining the number of decision making units, strategy space, decision sequence, set of information, horizon etc. The gap between theoretical and empirical "environment" widens with the confrontation between game theoretical implications and the behavior of such ill-defined *aggregates* as industries.

We begin with the question dominating the first phase of applications, namely whether price-wars should occur in booms or recessions (Section 2). Then we report on papers investigating which of the model classes offered by theory could be played in the real world (Section 3). The following section includes a collection of rather diverse papers, thus leading to the critique that the "multiplicity" of models can result in an infinite number of predictions (Section 4). The countermove is to increase the usefulness of models by concentrating on robust predictions (the Sutton approach, Section 5). Conjectural variation models were popular in empirical research, but disdained by theoretical researchers. The main problems seem to have been solved by the latest research, and theoretically based empirical work will come up here (Section 6). Section 7 evaluates the impact of game-theoretical research on competition policy. Section 8 summarizes the areas covered, the problems involved, and sketches strategies for further research.

2 The Best Time For A Price-War

The granddaddy of empirical work on game theoretical models is the research area which deals with the question, whether collusion is more likely to break down during troughs or peaks. Porter started the empirical research founded on non-cooperative game theory, presenting supergame models in which collusion is monitored by trigger strategies.[4] He confronted the implications of the models with data from the Joint Executive Committee, a railroad cartel in the US in the 1880's.

Porter's models suggest that price-wars should occur during periods of weak demand. Although the prediction is in line with pre-game theoretical reasoning, some facets are very distinct. Porter's price-wars do not occur because firms are actually cheating, but rather, they occur when demand is unexpectedly low.[5] Firms in this situation do not know whether their own sales are low due to a general business trough, or due to the cheating of a defector. The resulting price-war is a necessary enforcement mechanism of optimal collusive arrangements. In pre-game theoretic literature, price-wars were seen as a sign of failure to collude. In his empirical analysis, Porter shows that price-wars occur (prices were 60% higher in cooperative periods), that they follow specific features implied by his model (they occur after a turbulent phase in the firms' market shares, and are more frequent when the number of firms increases). Of specific importance is that price-wars should not occur when demand is expected to decline (for example when the alternative lake route opens), but only in response to unexpected fluctuations.

Rotemberg and Saloner (1986) predict that price-wars should occur during peaks. Their strongest result is derived in a supergame for price-setting firms with constant marginal costs. Prices have to be lowered in booms to restrict the profitability of defection. Potential gains of defection are high in booms, the countervailing force of punishment remains constant, since demand shifts are assumed to be independently distributed (i.i.d.). So, we have a specific definition of price-wars (the maximal collusive prive is lower in relation to the unrestricted collusive price), we have a limited degree of uncertainty (firms set the price after the demand shift has become known), and we have the crucial assumption of uncorrelated demand. Similar (weaker) predictions can be derived for quantity setting, for the case of capacity restraints. Porter-like price-wars can exist if firms – after learning about actual demand – have to make a dichotomous decision whether or not to collude.

We may feel uncomfortable with the use of the term "price-war" or with the assumptions in the model of Rotemberg and Saloner, but the question whether price-wars occur in booms or troughs is, as the authors stress, empirical. Rotemberg and Saloner present some evidence that cement prices have a tendency to move counter-cyclically (regressing the relative cement price on changes in real GNP), and that pricing behavior in concentrated industries is rather smooth. The authors refer to Bresnahan's (see below) evidence that the automobile prices were lower in the booming year of 1955, and they interpret from Porter's data that the most severe price-wars occurred during periods of high demand (1981, 1984 and 1985).[6]

Many studies follow, which translate (and partly overinterpret) the price-war models into "peaks versus troughs" or even into the "procyclical versus anticyclical margins" issues. Domowitz, Hubbard and Petersen (1986 and 1987) test whether Porter's or Rotemberg and Saloner's prediction is more in line with empirical data (1958-81, 4 digit industries, US). Porter's model should provide procyclical prices and margins and some periods of large price cuts; Rotemberg and Saloner's model should yield some countercyclicality in the price-cost margin. The empirical evidence reveals that the price-cost margins are well below those implied by joint profit maximization, they are somewhat higher in concentrated industries, but still not fully collusive. Some prices drop in recession years, but far less than implied by a regime switch. Price-cost margins vary positively with capacity utilization, but less in "trigger price industries" (highly concentrated, large margins). Prices vary to some extent negatively with changes in capacity utilization (significantly in "trigger price industries"), this evidence is interpreted as favorable to the Rotemberg and Saloner model.

Ellison (1994) reexamines the data with a more sophisticated model for the regime switch. He tests different "triggers" and utilizes the conflicting predictions made by Porter and Rotemberg and Saloner. Porter could not satisfactorily explain which events finally triggered the price-wars (demand played an ambiguous role). Ellison adds four trigger candidates (essentially indicators for unexpected high and low market shares), two of which are moderately significant. He shows that the unexpected component of demand is significant, while the full demand shock is not. This clearly favors Porter's story. Rotemberg and Saloner's specific version of the boom is that of "a period of high demand followed by a period of low demand". In his model, Ellison uses a variable which measures current to future demand, and makes use of the seasonal pattern of demand. The model implies that the highest incentive to deviate is given just before the alternative lake route opens. Ellison finds this variable to be insignificant; in particular, no countercyclical price response to seasonal cycles is shown. In his overall assessment, Ellison claims his "estimates provide some support for the predictions of the first theory" (i.e. Porter's), but is "not obviously supportive of the hypothesis that price-wars occur during booms" (Ellison 1994, p. 37, 48).[7] Another latecomer to this discussion is Hajivassiliou (1989), who uses the same data set to test the prediction by Abreu, Pearce and Stacchetti (1986) that price will switch across collusive/price warfare regimes according to a Markov process. The results favor the Abreu et al. prediction of Markovian switching behavior and "cast doubt on the key prediction of the Rotemberg-Saloner model" (Hajivassiliou 1989, p. 22).

Bagwell and Staiger (1997) offer a generalization of the Rotemberg and Saloner model. They show that the most collusive prices are weakly procyclical when demand growth rates are positively correlated through time. Secondly, the amplitude of the collusive pricing cycle is larger when the expected duration of boom phases decreases and when the expected duration of recession phases increases.

2.1 What Did We Learn From Game Theory?

The main contribution of game theory was to tell us that price-wars may happen not only in recessions but also in booms. The reason for this is that the gains from defection in this period may become so large that they outweigh future losses from cooperation. The concept of a price-war modeled in the supergame literature is a specific one: supergame literature defines the maximum price sustainable by implicit collusion for a given demand sequence. This maximum sustainable price is shown to be lower in booms, especially if they are quickly followed by recessions. As seen from the development of game theory today, we know that many different predictions can be made if we change the stochastics of the model, the information, and/or the punishment strategies. A search for robust predictions under different models would be an interesting task. A robust prediction of actual profits or prices which vary anticyclically has not been available up to now; the models reported here may more or less predict cyclicity or asymmetries, but not more.

2.2 How Will Empirical Research Develop?

On the empirical front, we learned that price-wars occur, but price differences in reality tend to be between the fully collusive scheme and the competitive model. There is some evidence that price decreases are steeper and more sudden than increases. The cyclicity of prices and margins is different across industries, but on average, the positive movements prevail. This is no surprise since even the Rotemberg-Saloner model does not predict countercyclical movements of actual prices. Suslow (1991) investigated the stability of cartels over the business cycle by examining 72 international cartel agreements covering 47 industries during the period 1920–1939. She reports that the cartels are more likely to fail in downturns. A similar study for the post World War II period would be interesting. The majority of experts in industrial organization seem still to believe that price-wars tend to occur in recessions.[8]

Empirical research now concentrates on cartel behavior in individual branches. Specifically, studies of the cement industry, the pharmaceutical industry and the oil industry have become very popular. Additionally, studies of the steel and paper industries appear interesting to me. In the European steel industry, the European Union favored cooperation and overt collusion in the sense of price floors and even quantity quotas or commitments to reduce capacities. It would be interesting to investigate the timing of successful government monitored cooperation and its recurrent breakdown. The paper industry, on the other hand, is an industry in which competition policy tries to prevent price collusion (as in the cement industry and in fertilizers). The opening of the borders to Eastern Europe led to a breakdown in prices in some concentrated industries (food, beverages, cement, fertilizers), sometimes without decreasing the market shares of the Western firms, and thus indicating the previous existence of high margins and collusion. Research on the topics mentioned here exists, but usually without reference to game theory. Further studies on the cyclical property of collusive pricing with industrial level data are recommended by Bagwell and Staiger (1997). More generally, the question whether price-cost margins move counter- or procyclically and whether cost differences between firms are this on the agenda.[9]

3 Which Game Is Played?

Game theory yields different predictions depending on the strategy used, the horizon of the play, the information available, and other specifications of the game. Empirical investigations may inform us which models are more likely to be played in real markets. The mechanism revealing this is whether predictions of a specific model class are observable in real world data. We present studies which investigate whether firms set prices or quantities, whether firms play static or dynamic games, and to what extent firms do coordinate.

Given the difference between the predictions of the Cournot and the Bertrand model at least in the static model, it is a shame that economists do not know which strategy prevails either in general or in specific industries. The mainstream presumption seems to be that the Bertrand model is "more relevant" if marginal costs are flat, while the Cournot model describes the situation with steep marginal costs. Haskel and Martin (1994) use this presumption to motivate the use of capacity utilization as a determinant of profit margins. If firms switch from Bertrand to Cournot when capacity utilization increases, then margins and capacity utilization should be positively related. This prediction is contrary to entry deterrence models in which profits and capacity utilization should at least temporarily be negatively related, and to price-war models in which margins depend on collusion. A specific difference to older models is that profits depend on the interaction term of concentration and capacity utilization, not on the level itself. Haskel and Martin find support in an UK industry sample, and enrich the model to include other variables (see Section 5).

A second method of assessing the relevance of the models is to test whether, for example, the predictions of the Cournot model are consistent with the data. The Cournot model predicts higher market shares for more efficient firms, secondly it predicts the negative dependence of profit margins on the elasticity of demand and on market shares (firm level), respectively on the Herfindahl index (industry level). Aiginger (1996) reports that firm data – either individual firm data are used or data are grouped according to firm size – are consistent with the first prediction only in a very few industries. Secondly, market shares (resp. Herfindahls) plus demand elasticities can explain only a very small part of the profit variance. Unfortunately the data, while not corresponding very well to the Cournot model, are still more at variance with the Bertrand model. Profits are much higher than what a normal rate of return could reasonably be, the profit differences are large and very persistent over time.[10] The overall result is that other factors than those modeled in the homogeneous static Cournot models seem to be important.[11]

A third way is to ask firms directly whether they set quantities or prices. As known from the literature on business and consumer surveys, in which firms or consumers are asked about price and production expectations, this is not an easy task. If, however, no other methods are available, surveys may be a second or third best method of obtaining information. Aiginger tried to translate the notion of Cournot vs. Bertrand into the following question to the managers of manufacturing firms: "What is your main strategic variable: do you decide to produce a specific quantity, thereafter permitting demand to decide upon price conditions, or do you set the price, with competitors and the market determing the quantity sold?" The managers decided in favor of the Bertrand model (38.3% Cournot vs. 61.7% Bertrand, $n = 930$). This is in line with the prejudice of many economists (raised as a critique of the Cournot model) that firms determine prices and not quantities, a feeling that motivated the two stage interpretation of the Cournot model, with a quantity or capacity decision in the first phase and a price decision in the second period.

Rees (1993) confronts a static model with a supergame to investigate whether empirical data are more consistent with the first or the second. The static model chosen is a homogeneous price model with mixed equilibria yielding two testable predictions: a zero probability that firms will choose identical prices; and secondly, random price changes by each firm in case of the repetition of a specific market situation. The dynamic model is a supergame with a carrot and stick strategy. Using data on the UK salt monopoly, Rees reports that the data are consistent with the static model insofar as firms produced well below capacity and made profits (prices also exceeded marginal costs). The evidence is grossly at variance with the implications that prices were chosen randomly, as they were de facto "identical in each of the 17 times" (Rees 1993, p. 842). Furthermore, price leadership varied and the smaller firms did not produce at the capacity output. Evidence for an implicit collusion model comes from calculating the interest rates at which defection would have been profitable. Since quarterly rates had to be between 17% and 116% evidence on implicit collusion is given. However the data are not consistent with joint profit maximization, since production is not concentrated in the low cost plant.

In another paper on this line Slade (1987) uses data on the prices, costs and sales of individual service stations in the Vancouver gasoline market in the particularly unstable period of Summer 1983 to test whether continuous or discontinuous strategies prevailed.

3.1 *What Have We Learned From Game Theory?*

Game theory sharpened the method of analyzing the behavior of markets. We did know before that there are determinants of profit differences and we called them "structure"; the main candidates were the number of firms, and entry conditions (according to the Structure Conduct Performance Paradigm). Game theory stresses the importance of not only whether prices or quantities play the role of the decision variable, but also the significance of whether the play is static or dynamic, which firm decides when, and how many firms are willing to coordinate. Game theory helps to analyze industries according to these concepts and offers predictions or implications for a specific model which can be tested. We have, however, the problem of the multiplicity of the models; if we look at the test of Bertrand vs. Cournot, we could add Stackelberg or fringe models; if we look at the evidence of the static versus the dynamic model, we can devise models with asymmetric firms and/or product differentiation.

3.2 How Will Empirical Research Develop?

I hope that the question in which markets prices, resp. quantities, are the decision variable will become a central empirical issue. Game theory told us that this may be important for profits in static models, and stresses that the difference between "strategic complementarity" and "strategic substitutability" is important also for questions in the economics of information, uncertainty, innovation etc. The old stylized fact that profits differ across firms and industries in a surprisingly persistent way will be reinvestigated by the use of game theory. The role of strategic investment in research, skills, marketing, and reputation for persistency will be investigated. The reasons why cost differences across firms can persist, despite incentives to bridge them, will be reinvestigated under game theoretic perspectives.

4 Capacity And The Stability Of Regimes

In this chapter, we present a series of studies which deal with the importance of the type of game played, and its stability over time. I cannot help but say that the papers are very diverse indeed. While this is unpleasant for a reporter, it is a feature of research in a new field in which no seminal textbook and no systematic methodology exists. Some of the papers are related to the role played by capacity shortages and increases; the other recurrent issue is the reaction to other firms.

Gilbert and Lieberman (1987) confront two models for coordinating investment over time. In the first model[12] firms coordinate by not investing in capacity unit K+1 until all firms have installed capacity unit K. In the second model (following Dixit 1980 and Spence 1979), a firm successfully preempts to gain a first mover advantage. The data come from 24 chemical firms, the econometric model is binary (increase in investment larger/smaller than 5%). Industry capacity utilization proves to increase investment, the other firm's investment ("bandwagon") is positive for small and negative for large firms. Therefore, the authors believe that the results are "consistent with the hypothesis that firms can successfully preempt at least the larger firms" (Gilbert and Lieberman 1987, p. 26).[13] For smaller firms, the bandwagon effect is positive, supporting the maintained market share model.

Ghemawat (1984), Schwalbach (1984), Benoit and Krishna (1991), and Rosenbaum (1989) are papers which analyze specific industries with high capacity costs, by using the terminology of game theory. The first two papers refer to the US titanium dioxide industry. Ghemawat starts with the prediction that a low cost producer should deter entry, a strategy which however is limited by uncertainty and resource constraints. DuPont gained a cost advantage in the seventies and defined a growth strategy which fitted "well with our discussion of preemption driven by cost asymmetries". However, the results also "suggest that preemption is a hazardous process in which miscalculations can depress profitability" (Ghemawat 1984, p. 162). Benoit and Krishna use an entry deterrence game in which the post entry period is modeled by a supergame. This predicts that excess capacity will facilitate collusion, since flooding the market is possible. The anecdotal evidence comes from the US phosphorus industry, which was experiencing declining demand (and surprisingly stable prices and slow capacity reduction). A low cost producer entered in 1988, and capacity was increased by 10%. It was seen by the authors as very likely that "the new entrant would be accommodated with little decrease in prices". As a similar example, the authors cite that in the aluminum industry, the number of firms rose from three to twelve during a period of substantial excess capacity. Rosenbaum derives the prediction that the firm's margin should depend negatively on its own excess capacity and industry excess capacity (the latter facilitates punishment), for the industry, the sign is undetermined in the theoretical model. It was also insignificant for the US aluminum industry, which is seen as inconsistent with the non-collusive Bertrand oligopoly during periods of excess capacity, so that "industry excess capacity can bolster a non-cooperative oligopoly price" (Rosenbaum 1989, p. 241).

Slade (1992) investigates the stability of price determinants, starting from an intertemporal reaction function encompassing behavior from Bertrand to monopoly. The characteristics of the reaction function remain stable in times of price-wars; the reactions are asymmetric in a somewhat unexpected direction. Major gasoline stations react to price cuts by the independent stations more strongly than to increases (this is expected). But independents react to price increases by majors more strongly than to price decreases. Slade's interpretation of this unexpected result is that price-wars were usually ended by the majors. When the major stations send a signal by raising prices considerably, the independents follow immediately.

Brander and Zhang (1993) investigate the behavior of United Airlines and American Airlines on duopoly routes, to see whether the dynamic path of prices and quantities could be characterized by the mere repetition of Bertrand, Cournot or cartel solutions. The results reject this, regime switching seems to be the case. The evidence depends crucially on the starting point (Bertrand or Cournot), but "the data seem more consistent with the quantity setting regime switch model than with the other alternatives considered here" (Brander and Zhang 1993, p. 434).

4.1 *What Did We Learn From Game Theory?*

Game theory in these papers provides analytic concepts; most of them are not new, but the analyst learned that it is important whether it is a two-stage game or a super-game, whether firms want to coordinate or to preempt, that large capacity can not only lead to intensive competition, but can also facilitate collusion. In some cases, as in the investment game, two alternatives lead to two diverse predictions, and we can determine whether the evidence is more in line with one or the other. One problem of the studies reported is that they convey the impression that the evidence presented may be explained by other factors than those modeled here. For example, the negative bandwagon of large firms may stem from the lumpiness of investment in large firms, while the cooperative movements of small firms may be the result of the strict dependence of investment on short run industry profits in small firms. The games selected as starting points look arbitrarily from today's knowledge of available models. The next section reports on the reaction to this multiplicity of models.

4.2 *How Will Empirical Research Develop?*

It would be fruitful for empirical research if lists of predictions for game theoretical models were to be supplied. Which menu of predictions for investment is available for which kind of models, differing with respect to number, size, symmetry of firms, to the horizon, and to the information set? Which menu for entry, which for price dispersion etc.? If such menus were available, the flair of ambiguity which is present in today's empirical studies, where each author or analyst picks up one or two models out of many, would be decreased. Later on, such a survey like that of Schmalensee (1989) will follow, summarizing stylized facts arising from empirical studies and relating to game theoretically founded hypotheses. This could lead to a feedback of modifying models in a way most consistent with real behavior.

5 In Search Of Robustness: The Sutton Strategy

Sutton (1990, 1992 and 1993) evaluates the merits and problems of game theory: on the one hand, game theory has proved immensely flexible insofar as there is at least some model capable of explaining any observable facet of behavior.[14] On the other hand, multiple equilibria are endemic, and there is considerable scope for designing the structure of the moves and the toughness of competition. The old threat that "everything is possible under oligopoly" reappears. Sutton proposes focusing on the question what is excluded in a relatively broad class of models.

The usual response of empirical research to the plethora of game theoretical models is to concentrate on very specific and narrow markets. The knowledge of specific market characteristics facilitates the exclusion of some classes of models. This may allow us to narrow down the "candidate models" – in the optimal case – to one specific preferred model, which yields "a menu of qualitative predictions" (Sutton 1990, p. 508).[15] Even if the range of possible models is narrowed down, several specifications remain feasible. It is advisable to start with a model which encompasses several underlying games, which seem plausible, and let the data decide which one is realistic. Sutton cites a paper on the price and advertising competition between Coca Cola and PepsiCo as an example. The value of this approach depends heavily on the extent to which a specification can be found which is rich enough to span the range of models to be tested. If only two models are tested against each other, there may be a third which better explains the behavior.

The alternative is to explore theory to determine whether there are (probably weak) results which might hold across a broad class of model specifications. While the exact specification may differ across industries, some robust results may provide a game theoretic basis for certain cross industry studies.[16]

5.1 Robust Predictions Tested By Sutton

As an example of a robust prediction which can be tested empirically, Sutton (1992) proposes the difference in the size concentration schedule in industries with exogenous sunk costs, and in industries exhibiting the endogenous sunk cost case. In homogeneous industries, where the only sunk costs to entrants is the cost of building a MES plant (the exogenous sunk cost case), concentration will monotonically decrease with increasing market size).[17] On the other hand, in markets in which advertising and other endogenous sunk costs are important, these outlays may be used to enhance consumers' willingness to pay. In this case, there exists no monotonic relationship between concentration and market size and no picture of a fragmented industry will arise however large the market size grows.

Sutton (1992, pp. 33) shows that the split between the exogenous sunk costs class and the endogenous sunk cost class holds for a broad range of models. For a given market size, prices depend on the number of competitors and on the "toughness of competition". As competition becomes tougher (in the sense of moving from joint profit maximization to Cournot, and then to Bertrand)[18] the "equilibrium structure" becomes more concentrated (e.g. under the prospect of price competition in the second stage, only one firm enters in the first stage and then enjoys monopoly.

In the case of sunk costs, but now with product differentiation, multiple equilibria become endemic. But there exists a lower bound to equilibrium concentration. Concentrations below this bound cannot be supported as equilibria. The bound is negatively sloped in the size- concentration plane, but monotonically in the exogenous sunk cost case, while a horizontal or even increasing segment can occur in the endogenous sunk cost case (Sutton 1992, pp. 60).

6 The Lost Son: Conjectural Variation Models

6.1 Empirical Attractiveness And Theoretical Shortcomings

Conjectural variation (CV) models incorporate the strategic interdependence of firms in a market by a term which describes the reactions of other firms' decision variables to changes in the own decision variable. These models are popular in empirical research because they allow the data to decide upon the degree of market power, the empirical coefficient can reveal that the static Bertrand game is being played, that Cournot is consistent with the data, or any degree of collusion up to joint profit maximization. However, CV models are disdained by theoretical researchers specifically because reactions are forced into a static model (the strategy space and the horizon are loosely defined). A second line of criticism refers to the arbitrariness of the hypothesis, no theoretical arguments are available to predict strong or weak reactions; everything is possible.

Bresnahan (1987) investigates whether the US automobile industry colluded in the fifties. The data suggest a price-war in 1955. In this year of moderate business expansion, auto sales increased by 45%, and prices decreased (after adjustment for quality changes) by 2.5%. Bresnahan estimates a model for a differentiated product market, with a demand function and a supply relation. The crucial variable is how strongly a specific firm reacts to the marginal revenue term of a close substitute. He estimates four models: one for (price) collusion, one for competition, a hedonic price model, and a product model.[21] For 1954 and 1956, the collusion model cannot be rejected, for 1955 however, collusion is rejected in favor of any alternative, the competitive model in favor of none. The data, Bresnahan concludes, can be explained by the "hypothesis that tacit collusion among automakers broke down in 1955". Although the paper seeks to detect price-wars, the implied model and the technique are much different from studies in the Porter tradition. The model is essentially static (firms for some reason include or exclude the impact on rivals revenue in their own maximization), and no foundation for a supergame is given. The technique was the starting point, or at least provided new impetus, for a research line that was labeled "New Empirical Industrial Organization" by Bresnahan. It combines a demand function and a supply relation to estimate a market power parameter (essentially a CV parameter). In contrast to "cross section studies", no information is needed on profit margins and marginal costs, but only on prices and output over time. Therefore, this method of revealing market power is also called the "time series approach". The economic mechanism for the identification of market power comes from the fact that firms under competition and monopoly react differently to changes in demand. The econometric identification requires that the inverse industry demand function is not separable into its components. One exogenous variable has to interact with the output term, so that it shifts and rotates the demand function.[22]

6.2 Callback No 1: Theoretical Underpinnings For The CV Parameter

Most economists believe that the conjectural variation parameter is not really exogenous. How strongly firms react to each other's decisions depends on several economic parameters. Haskel and Martin (1994) start from the result of Bresnahan's consistent conjectural variation model in which the CV parameter is related to marginal costs in a specific nonlinear way. Marginal costs are low, if capacity is unconstrained, and high if capacity limits are binding. Therefore, the consistent CV parameter (and profits) depend on capacity utilization. The authors use a qualitative survey of the Confederation of British industry to measure this influence for a panel of UK industries. They add in the econometric estimation variables for exports and unemployment, and discuss demand uncertainty, two stage games, and supergames on a theoretical level. The approach has been applied to model the influence of union power (Haskel 1994), of labor flexibility (Aiginger and Weiss 1997), and of financial status as an indicator of the ability to react on the degree of interaction (Haskel and Scaramozzini 1996). The crucial feature of this approach is that it is usually not the level of a specific variable (such as capacity), which the theory predicts to be important, but the interaction terms between concentration and that economic variable. This is the difference between "pre-game theoretic" and "game theoretically founded" profit explanation.

This research line is open to many additions. Every economic variable which enters the profit function or the cost function can exert an influence on the interaction between the decision variables of two firms, and thus become part of or rational for a conjectural variation parameter. This overcomes the critique that the parameter is arbitrary, but not the critique that dynamics is forced into a static model.

6.3 Callback No 2: Equivalence With Dynamic Models

Cabral (1995) and Dockner (1992) make important steps to rationalize the use of CV models in empirical research by showing that they can be considered as a reduced form of dynamic games. Cabral (1995) proves that for each linear oligopoly model there exists an equivalent "optimal collusive equilibrium" that maximizes total industry profits in a supergame (in which collusion is sustained by a stick and carrot strategy). In the simplest case, the correspondence reads $\gamma/2 = \delta\sqrt{1+\delta}$, where γ is the CV parameter and δ is the discount factor. Dockner (1992) – focusing on the market segment between Bertrand and Cournot – proved that the subgame perfect steady state equilibrium of an infinite horizon model with adjustment costs is identical to that of a static CV model.

The papers demonstrate the equivalence for two classes of dynamic models, each of which has its advantages. Cabral's model is easier to implement empirically, since it facilitates comparative static analysis and concentrates on the more collusive

Therefore, with endogenous sunk costs, an industry will not converge to a fragmented structure (deconcentration) however large the market grows. Increased market size is associated with escalating levels of outlays by some firms. The location of the lower bound depends on the shape of the advertising response function. The market size/market structure relationship is not monotonic, concentration may first decline and then increase. This prediction is different from the traditional view, that advertising costs add up to a fixed cost, thereby increasing the entry barrier and shifting the size concentration relationship to the right (without changing its monotonicity).

The empirical data consists of 20 sub industries within the food and drink industry (for six countries). These are industries in which homogeneity or heterogeneity can be assessed by the amount of advertising outlays spent.

The relationship between concentration (CR4) and market size (Size/MES) is strongly negative (Sutton 1992, p. 113), and minimal concentration falls to levels below 5% for industries representing the exogenous sunk costs case. Among advertising intensive industries, the lowest concentration is 25%, for very large market sizes it is in the 25%-30% range. The formal proof uses a maximum likelihood estimator to approximate the lower bound of concentration. The pool of the advertising intensive industries generates a limit for the CR4 of 19%, the other group generates a CR4 limit of 0.06%. The shift of the size concentration schedule due to increased advertising is not horizontal (as the old hypothesis for an exogenous determination of advertising would propose).[19]

5.2 In Search Of Robust Determinants Of Profitability

The "Bain story" in industrial organization has told us that profits depend on concentration (and entry). This story initiated a long and critical literature, and to some extent became the core of the Structure Conduct Performance Paradigm. In the game theoretical literature, new determinants of profits or profit margins have become interesting. We have already mentioned that in a two stage game with free entry, profits depend on the toughness of competition, and on the existence of sunk costs.

Aiginger (1996) and Aiginger and Pfaffermayr (1997b) propose exploiting the prediction of supergames with a given number of firms. This model class – which by no means is the only sensible one – enables us to derive easy formulas for the minimum value of the discount factor (δ), which is necessary to facilitate collusion at a specific price (e.g. the monopoly price). Alternatively, we can calculate the maximum price which may be supported by a trigger strategy for a given discount factor.

Two predictions are specifically robust in this model class: growing markets should be more collusive and therefore more profitable, and markets with greater uncertainty should be less collusive and profitable. This is easy to see, since any market growth leads to larger future gains as compared to present gains. Anything which may be gained by defection is less important if compared to ever increasing future losses from punishment. The opposite is true, if we introduce uncertainty in such a way that the survival probability (λ) from period to period is lowered: any future loss has to be given a decreasing weight, since the probability of future profits falls. The robustness can be attributed to the fact that growth and uncertainty can be seen as a constituent part of the discount factor.[20]

The influence of other factors is not so easy to understand. The collusive properties of quantity and price competition varies with the number of firms; product differentiation and efficiency influence the sustainability of collusion in two ways (influencing gains and losses of defection).

Aiginger (1996) tests whether the determinants of the collusion feasibility can also explain the profit differences, in a panel of 97 industries, as well as in a panel of 300 manufacturing firms. He looks for proxies for these theoretical determinants, and uses the variance of production, imports and exports (over time) as empirical candidates for the uncertainty group. Demand growth and export growth are used as proxies for the growth group.

The data show that price cost margins depend negatively on market instability and positively on market growth. On the other hand, profits do not depend on concentration (the old Bain story) and profits do not follow portfolio theoretical predictions (higher profits for industries with non-diversifiable risk). The results are empirically robust (they hold for different specifications of the equation, different points of time, different data sets, and different definitions of the profit margin).

5.3 What Is Achieved And Where To Go

What is achieved by this approach? Robust predictions are derived by Sutton for the relationship between concentration and market size, and for the influence of endogenous sunk costs. The predictions are relatively weak, but different from pre-game theoretical literature (monotonic vs. non-monotonic size concentration schedule) and supported by the data (what should not exist in one market class does not exist in this class). Relatively robust predictions for profits in supergames are that they should be higher in growing markets and lower in markets with a higher probability of exit (Aiginger 1996). These predictions are not identical with pre-game theoretical models, but replicated by data.

The robustness approach seems to be a fruitful one. Nearly everything can be predicted by choosing the appropriate assumptions, and if we do not know which specific model is correct, it makes sense to start from robust predictions. The disadvantage is that the predictions will necessarily be weak. Additionally, supergames outline the limits (lower bound) on the feasibility of collusion, while the data report actual profits. Further work may model the two stages separately: the feasibility of collusion first, and then the dependence of profits on some feasibility index.

should emerge: which industries tend to play which type of games under which circumstances? This would help for competition policy, and give new answers to the question of the persistency of profit differences.

8.2 How Game Theory Changed Empirical Research

Game theory offered some new hypotheses for empirical research. The ultimate reason for the price-war in the Porter model is surprising, as is the definition of a price-war in the model of Rotemberg and Saloner. The importance of interaction terms, rather than the significance of the level of a variable, is a specific feature in conjectural variation models with economic interpretation. The dependence of market fragmentation on endogenous sunk cost has not been stressed before, the same holds to some extent for the dependence of profits on growth and uncertainty. The changing nature of variables between static and dynamic models (topsy turvy results) are new.

We cannot say that the empirical tests of game theoretical models were an unambiguous success up to now. We do not have a final verdict on which price-war model is correct, or as to under which circumstances wars will occur, but our knowledge has been broadened. We have learned about theoretical determinants, such as expected vs. unexpected demand, market share stability, and types of demand shifts. We have learned from the data that price-wars are not occurring too frequently, that there is a surprising downward rigidity of prices in sectors with underutilized capacity. We have learned that prices do not rise in booms, especially in concentrated industries. Studies have confirmed that profits and prices tend to be procyclical and vary positively with capacity utilization, as does investment. However, in all these cases, there are exceptions and subsets of periods or industries in which other factors work.

8.3 Problems Inherent To The Testing Of Game Theoretical Models

The multiplicity of models is stunning. Depending on the strategic variable, the horizon, the information available, the timing of the decision, the extent of coordination, and the feasibility to change the environment nearly everything can happen. Fisher (1989) calls this the exemplifying character of game theory, originating from very narrow assumptions and illustrating "what could happen". Nevertheless, this seems to me no return to the old notion that "under oligopoly everything can happen", since we now know what happens under which – narrowly specified – circumstances. The multiplicity of equilibria is a specific feature of game theoretical models. It can be best dealt with the strategy proposed by Sutton: looking at what cannot happen, what is excluded by the models.[25]

An empirical application of game theoretical models does not mean testing whether the model is correct, since it is – hopefully – correct on its own assumptions. Predictions arrived at in game theoretical models, as those in other models, are conditional to assumptions. If a prediction is falsified, it can be that (i) the hypothesis was wrong, (ii) that the assumptions were not fulfilled, (iii) that the data were faulty, (iv) or bad luck (type one error) was encountered.[26] In game theoretical models, the probability that a prediction did not follow from the assumptions is narrowed down by careful specification of the circumstances and by strict logical reasoning. If there are *n* firms, if prices are set simultaneously, if the product is homogeneous, if firms play a static non-cooperative game, and so on, then the outcome is more or less strictly logically determined. This leads many authors to speak of testing the "implications" of models, rather than predictions[27], as is usual in pre-game theoretical industrial organization.

The danger that assumptions are not fulfilled is eminent in game theoretical models, since the assumptions are extremely narrow and at the same time, from the very outset, at variance with real world characteristics (market definition, entry, complex decision units, substitution, unstable environment etc.). Considering the near certainty that assumptions are violated, as well as the near certainty that the internal logic of the model is correct, the testing of game theoretical models is a joint test of its predictions and assumptions, with a large weight on the latter. If the model predicts that price-wars will occur under some conditions, data revealing such events guarantee that the theory cannot be falsified. If, on the other hand, the data do not show price-wars, it can be that the theory was wrong or that the assumptions were not fulfilled (with more weight on the latter; data problems and bad luck may also play a role).

8.4 Availability Of Data

The data problems seem to differ little between game theoretically founded tests and traditional ones. Perhaps the pressure to examine firm data (instead of industry data) is more imminent. Game theoretical models encourage focusing on narrow, well-defined markets. It has become customary to exploit the time series properties of prices and quantities, to infer margins from the data instead of measuring profits and marginal costs. However, some of the late papers compare behavior in concentrated versus non-concentrated industries, in high margin versus low margin branches. Sutton (1991) confronts industries with exogenous and endogenous sunk cost, Aiginger (1996) compares margins across industries and over time. Panel data are increasingly available and will prove useful for future research (Haskel and Martin 1994; Aiginger and Pfaffermayr 1997b). A problem which is not confined to the testing of game theory is that cost data, and specifically the split between fixed costs and marginal costs, are extremely difficult to obtain.

spectrum of results. Dockner's model focuses on market segments between Bertrand and Cournot. What is most important is that more bridges between the conjectural variation models and the dynamic models will follow, and that the architecture of the bridges will grow in sophistication and beauty. Aiginger and Pfaffermayr (1997b) developed a bridge along the Cabral line, demonstrating an equivalence for models with market growth and product differentiation.[23]

6.4 *What We Learned And Where To Go*

The papers reported in this chapter open the door for eventually growing empirical research with good conscience. The conjectural variation models supply the flexibility needed for empirical research on profits in different industries and countries, the bridges to economic determinants and to dynamic models allows interpretations of the results which are in line with mainstream theory. The importance of the effects of interaction is a specific feature of game theoretically founded models, which allows this generation the research to be distinguished from its predecessors.

This line of research is complementary to that proposed by Sutton. It does not start with a very narrow industry about which the researcher knows a lot, it does not start from robust but necessarily narrow predictions, but it starts with a menu of models or even with a bundle of empirical presumptions. Some of the flair of the deductive vs. inductive issue returns, where the Sutton path is more typical for the first, and the equivalence approach more typical for the second. We should not now use conjectural variation models without keeping in mind that they may be too eclectic or too ad hoc, but "call back one" has reduced the degree of arbitrariness, and "call back two" the problem of dynamics within statics.

7 The Impact on Competition Policy

It is beyond the scope of this survey to evaluate the overall impact of game theory on competition policy. I suspect that the trend will be that the multiplicity of models will increase the uncertainty and the dissense among economists to recommend under which circumstances economic policy should intervene and in which direction. An example for this trend is that the exchange of information had been considered long as *per se* evidence of collusion in antitrust, while game theory offers models in which the exchange of information is also profitable in non-collusive equilibria. Another impact is a redefinition of the yardstick for competition policy. Phlips (1995) proposes to choose the non-collusive equilibrium of a non-cooperative game as the new yardstick. This implies that the supernormal profits should not be a sufficient justification for intervention, if these profits are predicted in a model as a non-collusive equilibrium.

On the other hand, supergames can offer some rationale for long lasting profit differences and for the reluctance of firms agressively to install the best technology. If an industry has reached a collusive equilibrium with cost asymmetries, the less efficient firms can survive without adopting the best technology, and the incentive to invest in the best technology is weakened by the threat that this could destabilize collusion. Aiginger and Pfaffermayr (1997a) use such a constellation to extent the concept of social losses due to oligopoly by a cost side effect, and prove that the cost side effect (called the staircase because the cost curve depicts a staircase if firms are ordered from low costs to high costs) is empirically larger than the demand side effect ("the deadweight triangle"). The policy implication is that competition policy should focus on industries in which large cost differences do not evaporate even if the best technology is freely available on the market. This conclusion fits into the calculations in Neumann (1998), who shows that the dynamic losses of monopoly are much larger than the static ones.

8 Summary and Prospects for Future Research

The theoretical development in industrial organization has increased our understanding of strategic behavior in real markets, and it has increased the importance and the reputation of industrial economics within economics. The game theoretic revolution has a significant impact on the empirical research, if game theoretical models can be given enough structure to yield testable predictions even if the predictions are only robust insofar as they exclude a certain behavior.[24] This evaluation is maintained even if the problems of empirical testing of game theoretical models are numerous and the empirical papers using sound game theoretical foundations are not too widespread.

8.1 The Areas Covered

In the past – and we followed the sequence chronologically – the most popular research topic concerned the question whether and when price-wars will occur. A second theme was the influence of capacity utilization on pricing and more generally on strategies. The third area concerned investigations of reactions to rivals and types of coordination. All these areas are part of the wider question which asks, how competitive industries really are. Game theory favored the tendency to investigate specific narrow industries with rather few players. Regarding future research, I think it would be particularly interesting to learn about the types of games played in real industries. Are prices set, or quantities; is horizontal or vertical product differentiation more relevant; do firms play strategic two stage games, finite horizon games or infinite horizon games? There will be no general answers, but some structure

8.5 Strategies For Future Research

There are two strategies suitable for dealing with the multiplicity of models. One is to concentrate on a specific narrow industry or event, the other is to screen models for robust predictions. The first has dominated research up to now, the second will hopefully prove fruitful in the future. Menus of robust predictions for classes of models should be supplied for areas such as entry, mergers, profit differences, growth of firms etc. The problem that data never replicate the concepts of variables in the models and that markets never resemble those modeled, will best be dealt with by the Schmalensee postulate, which demands reports on the robustness of the results. Using different concepts for the variables, different specifications for the functional forms, testing intervening variables, instrumenting for endogeneity and replicating empirical strategies for different industries and different countries will help in the testing of an idea, when the theoretical concepts and the empirical data differ. The bridges built between the conjectural variation models and the dynamic models will prove specifically encouraging for future empirical research.

Game theory has enlarged and sharpened our theoretical knowledge and our analytic tools, for example by bringing in concepts such as self-commitment, subgame perfectness, and strategic substitutes into the toolbox of Industrial Organization. On the empirical side, game theory provided us with predictions of rational behavior, which differ widely depending on very specific circumstances. We have surveyed here an application of non-cooperative game theory in the core fields of market structure and performance. Applications to analyze auctions, incentives, and innovation were outside the scope of this article. I believe that the decades of theoretical progress will now be followed by a decade during which theory-based empirical work will blossom.

Notes

1 See Davis and Holt (1993) for a survey, Hey (1994) for a recent contribution. One could argue that since games have distinctive features which can be replicated only in experiments, class–room experiments are the "natural" method of testing game theoretical models. Only here do we have single decision units, an identifiable number of players, well defined strategies, a fixed horizon, and exact payoffs. The focus of this survey, however, is to investigate the application of game theoretical models to real world data.

2 Surveys on behavior at auctions are available in Porter, Hendricks and Boudreau (1987), Domberger and Hensher (1994), Holmstrom and Milgrom (1994). For a survey of game theory in monetary economics see Canzeroni and Henderson (1992), for applying game theory in public choice see Pardo and Schneider (1996), for the policy of central banks see Hochreiter et al. (1996). An early application on the macroeconomic effects of oil price cartels is Johannsen and Karakitsos (1992), who examine the macroeconomic effect of UK oil production strategies under three different model classes.

3 European experts in industrial organization were asked to classify their own research according to the classifications of The Journal of Economic Literature. Oligopoly and other forms of market imperfections came out first (44 %), followed by innovation and inventions and firm organization.

Interestingly, non-cooperative games were choosen as an "own research topic" by only 15 %, and therefore was not among the top ten areas. The research project is decribed in Aiginger et al. (1998).

4 Porter (1983 a, b), Porter (1985), Green and Porter (1984) and Lee and Porter (1984).

5 Adherence to the collusion strategy is guaranteed by the incentive constraint. The methodology explicitly investigates under which circumstances defection is not profitable, and firms stick to collusion forever.

6 According to Rotemberg and Saloner (1986, p. 407), "The authors conclude that they have "presented a variety of simple tests capable of discriminating between industrial organization folklore and our theory. Since none of them favored the folklore, it may well be without empirical content. On the other hand, our theory deserves to be tested more severely."

7 Ellison stresses three testable implications of Porter's model. First that price wars should occur, second that they should occur when the random shocks resemble a signal, which can be used as a trigger, and finally that secret price cuts should not occur. Ellison focuses on the second point. Other innovations are that (i) the industry was nearer monopoly than earlier studies had calculated (demand elasticity is found to be larger than one) (ii) that there are some signs of price cutting (which is at variance with the literal model forecast) and (iii) that the punishment (in fact the increase in the probability of starting a price war in response to a price cut) may have been too low.

8 See Aiginger et al. (1998).

9 See Oliveira Martins (1998), Aiginger and Pfaffermayr (1997, 1998).

10 Cf. Mueller (1990), Aiginger and Pfaffermayr (1996 a).

11 Candidates for these other factors are product differentiation, entry barriers, type of industry (consumer good dummy) and the degree of collusion.

12 Cf. Gilbert and Harris (1984).

13 The bandwagon variable is defined as the capacity increase of all other firms than firm *i*.

14 See Sutton (1990, p. 506).

15 Along this path, a successful field is given in studies of auctions. Here, the rules of the game, the timing of the decisions, and the payoffs are easy to find. Explicit collusion can be ruled out, implicit cooperation can be analyzed. Game theoretic predictions differ from other (non game theoretic) descriptions of bidding behavior. See Hendriks and Porter (1988) for an empirical analysis of public auctions for offshore drilling rights.

16 See Sutton (1990, p. 511).

17 A MES plant is a plant equal or larger than minimum efficient scale requires.

18 It does not hold for the limit case of Bertrand itself. Here the tough competition in the second stage allows only one firm to enter, which then enjoys monopoly profit.

19 This leads to Sutton's claim that the data are not only consistent with his game theoretical model class, but that they also indicate the rejection of an alternative hypothesis (exogeneous advertising levels). Proponents of the older models could object (as D.C. Mueller in a comment on this paper), that the predictions tested were not key predictions of the models and that the differences between the old models and the new one would not be great.

20 Let us define δ^*, δ as the comprehensive discount factor and the discount factor proper; g is growth and λ the probability of a firm to survive; then $\delta^* = \delta(1+g)\,\lambda$.

21 The reason for these two alternatives is that Bresnahan wanted to test the collusion and the competition model against "outside alternatives". The product model assumes that each make competes with each of the others, independently of whether they are produced by the same firm. The collusion model assumes that coordination exists within a firm, but tests whether this is the case outside the firm.

22 See Lau (1982), Bresnahan (1982) and Aw (1992). Overviews in studies of this type can be found in Bresnahan (1989), Martin (1993) and Aiginger et al. (1995). Note that most authors do not interpret their work as test of game theoretical models and that game theorists criticize that this approach models dynamics in a static context.

23 They used a firm panel to estimate a supergame founded CV model.

24 See Aiginger et al. (1998) for the degree of agreement with these conclusion among IO experts.

25 The provocative assertion that "Game theory is not of much practical use, since ...we can get any result we want" is approved only by one third of the researchers, Sutton's strategy to look for robust predictions is approved by a large majority in Aiginger et al. (1998).

[26] We should add that the concept of the Nash equilibrium itself is not without problems, since we do not know how the coordination problem is solved and the requirements posed for the players are very demanding. I owe this point to a conversation with Egbert Dierker.

[27] Implication is a mathematical term. A implies B means, that for A to be true, B is a necessary condition. If B is wrong, there is no chance for A to be correct (and no probability of an error). If B is true, A may still not be true. Predictions, on the other hand, is a statistical term. If a set of conditions in A is given, B will be found with some probability.

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