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Testing Oligopoly Theory in the Lab

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Abstract

Previous experimental results are reviewed to address the extent to which oligopolistic equilibria are good predictors of behavior observed in laboratory experiments with human agents. Although the theory is unrealistically demanding with respect to the agents' informational and rational endowments, experimental results obtained in more realistic settings with subjects using trial-and-error decision mechanisms tend to confirm predictions of simple symmetric theoretical models. However, in the presence of more complex and/or asymmetric environments, systematic deviations are observed between theoretical predictions and experimental results. Certainly, more effort should be made by all parties involved to build a bridge between theoretical predictions and the behavior observed in the lab in order to assist both the theorist and the policy maker; the former to enrich theoretical models including the behavioral factors identified by experimentalists and the latter to gain insights on the strengths and weaknesses of theory in predicting human behavior in the marketplace.

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I Introductory Methodological Thoughts

Since more than half a century ago, the use of the experimental method in economics has been inspired by the endeavor to bring theory closer to reality. It may seem risky to claim that oligopoly theory was the first among all theoretical economic paradigms whose predictions were tested in the lab. However, this claim is anything but false, if one goes back to the origins of experimental economics when Chamberlin (1948) and Smith (1962, 1964) ran the first experiments designed to study whether a market with few trading agents[1] would reach the competitive equilibrium. However, rather than reviewing all experiments assuming few agents on the supply side, in this article I adopt a more narrow definition of the term, focusing on experiments which have been directly inspired on the basic oligopoly models by Cournot (1838), Bertrand (1883), Hotelling (1929), Stackelberg (1934), and some of their most immediate extensions, omitting other experiments like the aforementioned seminal ones by Chamberlin and Smith which in fact were designed to test the predictive power of the competitive equilibrium.

Most of the experiments which are designed to test the predictions of oligopoly theory in the laboratory, implicitly or explicitly address the following question:

Q: *Are oligopolistic equilibria —derived in abstract settings under the assumption of fully rational, risk neutral, perfectly informed agents with infinite calculus capacity— good predictors of behavior in oligopolistic environments with human agents?*

In most of the cases, this question is answered together with some of its natural extensions, two of which are especially interesting for our review:

Q1: *If the answer to* ***Q*** *is negative, which are the main reasons of deviation between theoretical predictions and behavior by experimental subjects acting in similar settings in the lab?.*

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[1] According to the Greek etymology of the word, oligopoly is a market with *few* (ὀλίγοι) *sellers* (πωληταί).

or

Q2: *If the answer to **Q** is negative, which are the implications of this finding for the relation between the prediction of oligopoly theory and the functioning of real-world markets?*

The question formulated in **Q2** is a moderate version of the most frequent criticism received by economists who use the lab in order to reach policy and strategy-relevant conclusions. Trying to aggregate all the anecdotal information and personal experience from *sceptical peers'* comments on this issue in one sentence, I summarize below this critique:

C: *Given that all experiments on oligopoly models have been run with inexperienced subjects recruited among populations of young university students motivated with small amounts of money, what can be learned from their observed actions which could be applicable in real-world markets oligopolized by big companies managed by high-level CEO's and managers whose wealth and happiness critically depend on their decisions' implications for their firms' performance?*

Arguably this criticism is often expressed in less aggressive ways or is correctly inspired by the impossibility or at least difficulty of implementing specific non-monetary motivations of subjects in the lab. This is especially the case when *over-realistic* designs are implemented in order to replicate a manager's status, workers' retirement plans, promotion possibilities, ethical issues, environmental externalities and other non-neoclassical sources of motivation for oligopolists. I do not imply that such over-realistic designs are wrong or hopeless, but an experimentalist should think twice before trying to bring such factors in the lab.[2] Also, we must admit that some oligopoly experiments may be wrongly designed or wrongly focused. Except for these cases, in all other cases the criticism in **C** is *wrong* and *unfair*.

Wrong: The fact that a critical reader finds it difficult or impossible to draw

[2] Such issues have been successfully addressed in other areas of experimental research within less orthodox economic domains like economic psychology when studying, for example, phenomena like cognitive dissonance and reciprocity.

meaningful and policy relevant conclusions from a certain experiment is not by itself a proof of the fact that the experiment is wrongly designed or irrelevant, because it may be the result of the critique's unwillingness to interpret the results or lack of imagination.

Unfair: If this critique were decisively applicable to oligopoly experiments, it should automatically invalidate also the underlying theoretical model which inspired the design. In that case, the critique would hold *a fortiori* in the following form: *What can we learn on real-world markets and real firms' strategies from abstract models assuming that managers write down deterministic profit functions in order to make their decisions by solving equations which result from equalizing first derivatives to zero?* The absurdity of this argument shows the unfairness of the critique in **C**. This is so, because it is a well-known fact that, although managers follow different decision rules from those assumed in oligopoly models, many of the theoretical predictions of oligopoly theory are adopted world wide as the basis for market regulation and policy towards collusion, dumping, best price guarantees, advertising, vertical restrictions, market segmentation and a plethora of phenomena of which an exhaustive list is beyond the scope of the present paper. Therefore, if abstract models making the aforementioned unrealistic assumptions are so useful to the policy maker, then testing the performance of these models in equally abstract environments inhabited by real human agents deciding and learning from trial-and-error processes should imply some value added to our knowledge on the economics and regulation of strategic interaction in markets with few sellers.

We do not disregard here the possibility or even the need of re-making the whole paradigm of oligopoly theory by incorporating a number of non-standard behavioral assumptions.[3] Yet, doing so would not imply that traditional non-behavioral oligopoly theory is wrong or useless, provided that some simple, clear cut predic-

[3]For example, almost nothing has been done by oligopoly theorists to accommodate Simon's (1991) approach to the links between individual and organizational decision making as a result of the interaction among many economic agents.

tions receive favorable evidence in markets with human -thus, imperfect, complex and heterogeneous- agents. Producing this evidence is a primary task that should be undertaken in the lab, which would be equivalent to testing whether simple abstract models can be used to study more complex real-world markets. This brings us to the main question addressed in this article: *To what extent can simple oligopoly models predict behavior observed under more realistic rules governing the informational and rational endowments of agents?*

Answering this question is crucial for both theorists and policy makers. The former could be helped to write new, more complete models aimed at mitigating the factors which are responsible for the deviations between observed behavior and the corresponding theoretical predictions; the latter could be warned on the weaknesses of theoretical predictions when used to organize behavior by less than perfectly rational, fully strategic and mathematically competent agents.

The remaining part of this paper is organized as follows. Section II presents an overview of experiments designed to test the predictive power of standard oligopoly models and some of their immediate extensions. Section III concludes.

II The Resurrection of Oligopoly Experiments

We present here a series of experiments, most of which were run over the last decade.[4] This strand in the literature can be considered as a new wave of experimental papers reporting results on experimental tests of the basic oligopolistic models. I am referring here to this research line as the *the resurrection of oligopoly experiments*, because it represents a more recent and systematic effort by experimentalists to study an issue which is similar but not identical to that addressed in the seminal papers by Chamberlin (1948) and Smith (1962, 1964) who also studied markets with

[4] Earlier experimental tests of Industrial Organization Theory are thoroughly reviewed by Plott (1982). Later, Holt (1995) presented an overview of more recent experimental results from oligopolistic markets.

few sellers. While these two early contributions compared human behavior in the laboratory with the competitive equilibrium prediction, the series of experiments reviewed here are designed to compare the observed behavior with the corresponding oligopolistic equilibria.

The section is divided in self-contained subsections referring to different parts of oligopoly theory including monopoly as well as a number of extensions of the basic models, which are selected in order to have a representative but not exhaustive list of insights that can be gained from oligopoly experiments.

II.1 Monopoly

The simplest issue which can be addressed in the spirit of the question formulated in **Q** is whether the optimal price corresponding to a static monopoly with linear demand and costs can be reached —and if so, how fast— by limit strategies of unexperienced and uninformed monopolist-subjects who learn from trial-and-error mechanisms. This could be the simplest experimental design which could be used to test the aforementioned intuitive conjecture. To my knowledge, this experiment has not been run so far, or if it has, the results have not been reported in any of the usual outlets, probably due to the almost trivial findings. Full convergence is always achieved, although the time of full convergence may vary depending mainly on the *grid* of the strategy space available to the subjects. For example, a monopolist faced with a demand function $Q = 100 - 2p$ without knowing the exact form of it and costs $C = 0$ should learn to set the optimal price $p^* = 25$. Undergraduate students offered a strategy space ranging between 0 and 500 with an unlimited number of decimal digits will consciously tend to adopt exactly this price after $6 - 10$ trials of experimenting with initially random prices which are later improved using feedback from past periods as the only relevant information available.

However, things drastically change once some degree of complexity is introduced to the monopolist's problem by asking subjects to submit simultaneously prices for two products. In such a framework, Kelly (1995) reports significant deviations of subjects' strategies from the monopolistic optimum. García-Gallego, Georgantzís and Sabater-Grande (2004) design a two-product monopoly setting, assuming that a monopolist's products i and j are demand substitutes as denoted by the asymmetric demand system, $q_i = a_i - bp_i + gp_j$ and that production costs are constant and equal to C. The predicted optimal monopoly price pair (p_1^*, p_2^*) is confirmed by subjects' limit choices averaged per product, but convergence is slower than in the single product case, especially if monopolists do not receive feedback containing additional information enabling them to distinguish between the direct and indirect effects of price changes on each product's demand.

A complex dynamic water market is managed by the participants acting as monopolists in the basic treatment of the experiments reported by García-Gallego, Georgantzís, Kujal (2006a, 2006c) and Georgantzís, García-Gallego, Fatás, Kujal and Neugebauer (2004). It is found that subjects systematically fail to learn and converge towards the optimal level of stocks even after 50 periods of learning from their feedback on past strategies. On the contrary, the existence of a sufficient level of reasoning is confirmed in terms of the subjects' understanding of the hydrological properties and equilibrium of the aquifer system implemented. Thus, subjects achieve a sustainable flow of water supplied to the market, although they seem to be reluctant to let stocks fall too much due to an unfounded fear of scarcity and high extraction costs in the future.

Summary: *The strategies of monopoly subjects who decide based on trial-and-error converge to the equilibrium prediction of the corresponding full information static monopoly model, although the speed and precision of the convergence process decrease when monopolists are faced with more complex problems, like for example, multiproduct decision making. In that case, appropriately modifying the feedback received from past strategies improves the convergence to the equilibrium prediction. As the complexity of the set up increases and subjects are asked to deal with the* *dynamic aspects of their markets, systematic learning failures are observed. In such cases, decisions based on learning from feedback in past periods are significantly different from the corresponding monopoly optimal solutions.*

II.2 Price-setting oligopoly

The earliest experiments reported on this issue go back to Fouraker and Siegel's (1963) seminal work. In fact, these authors pay special attention to the issue which is central in the present review of oligopoly experiments, namely the role of more realistic assumptions concerning the agents' informational endowments on the likelihood that oligopolistic equilibria are a good predictor of the behavior observed in an experimental market. The authors confirmed that agents who are privately informed on their own payoff structures will tend to converge to the full information Bertrand Nash equilibrium, while having information on the competitor's payoff structure leads a subject to set higher prices than those predicted by the non-cooperative equilibrium.

A second, much more recent wave of oligopoly experiments have adopted market clearing mechanisms in which buyer behavior is based on a simulated continuous demand function.[5] In fact, given the well-known discontinuity of payoff functions of price setting firms in homogeneous product markets, experimentalists have tested the Bertrand equilibrium prediction in the laboratory assuming differentiated products. For example, García-Gallego (1998) uses a symmetric demand system consisting of n equations of the type $q_i = \alpha - \beta p_i + \theta \sum_{j \neq i} p_j$, where p_i is the price of variety i, n is the number of varieties available in the market, whereas j represents each one of variety

[5] Accounting for systematic shortcomings observed with respect to the subjects' ability to deal with continuous strategy spaces, several authors have opted for presenting subjects with payoff matrices corresponding to discrete games resulting from the combination of discrete strategy spaces available to the players. We will not insist here on whether this practice artificially facilitates the emergence of candidate equilibria in the laboratory, which would be an interesting issue to address in an appropriately designed experiment. Generally speaking, it is a matter of the experimentalist's taste whether a better chance should be given to the theory by design or, alternatively, a more realistic setting should be implemented.

i's substitutes. The parameter θ determines the degree of interdependence among varieties. This type of demand system corresponds to the case in which each variety can be imperfectly substituted to the same degree of substitutability by any of the other varieties in the market. Unit cost c is constant and equal for all varieties and no fixed costs exist. Despite systematic efforts by the subjects to tacitly coordinate setting prices above the non cooperative level, the Bertrand Nash equilibrium is found to be a strong attractor of individual strategies, especially towards the second half of the session. The 35-period horizon adopted proves to be sufficiently long for most subjects to converge surprisingly close to the Bertrand prediction, whereas in some sessions, observed and predicted behavior coincide. See Figure 1 for the evolution of prices in a typical session of this experiment. Abbink and Brandts (2004, 2005) also study experimental price setting markets whose results yield less clear cut conclusions on the predictive power of the Bertrand-Nash prediction, but their design is not directly aimed at testing any specific prediction of oligopoly theory.

García-Gallego and Georgantzís (2001a) implement the same demand and cost conditions as those adopted in García-Gallego (1998) to test the predictive power of Bertrand Nash equilibrium in the presence of multiproduct firms. Apart from increasing the complexity of a multiproduct firm's problem as compared with a single product one's, the existence of firms managing more products in the market yields asymmetric Bertrand equilibrium predictions despite the aforementioned symmetric demand system. It is found that multiproduct firms fail to realize the strategic benefits from their multiproduct market power emerging from the theoretical possibility of absorbing the horizontal externality between the jointly managed products. Thus, learning by trial-and-error in the basic treatment yields strategies which are closer to the single product Bertrand Nash equilibrium and, thus, do not confirm the corresponding multiproduct Bertrand Nash equilibrium prediction. This finding has been re-interpreted in the experiments by Davis and Wilson (2005) in terms of its implications for merger policy. That is, if firms fail to realize their market power, post merger equilibria may not look significantly less competitive than pre-merger ones. However, in an alternative treatment of the experiments by García-Gallego and Georgantzís (2001a), the imposition of an exogenous rule involving price parallelism among jointly produced varieties is shown to lead subjects' limit strategies close to the corresponding Bertrand Nash equilibrium. Figures 2 and 3 present examples of sessions with multiproduct oligopolies. The former is a typical session in which the adoption of price parallelism leads to the collusive equilibrium, whereas the latter depicts the case of a session in which multiproduct subjects do not adopt price parallelism and cannot escape from the single-product Bertrand-Nash equilibrium. The issue of price parallelism had been previously studied by Harstad, Martin and Norman (1998) in a context which was specifically designed to address this issue. It was found that the conscious adoption of price parallelism by competing sellers has the expected effect of raising prices towards the collusive prediction.

Summary: *Like in the case of a single-product monopoly, the symmetric Bertrand Nash equilibrium prediction is confirmed by limit strategies obtained from oligopolistic subjects who learn and decide using information acquired from the feedback received through a trial-and-error process. However, in the presence of some complexity and especially when the setup becomes asymmetric due to the existence of multiproduct firms in the market, the predictive power of the corresponding Bertrand Nash equilibrium is reduced and is not regained unless specific exogenous rules are imposed in order to help the learning process converge towards the 'right' attractor. Generally speaking, price parallelism facilitates sellers' coordination on prices which lie above the non cooperative prediction.*

II.3 Quantity-setting oligopoly

Unlike in the case of price-setting oligopolies in which the most appropriate experimental setup is that of imperfectly substitutable products, most experimental

Cournot markets have been studied under the assumption of product homogeneity. Thus, no direct comparison of the two setups has been attempted with the exception of the experiments reported by Altavilla, Luini and Sbriglia (2006), in which both quantity and price setting markets are studied in the framework of differentiated products.[6] Contrary to the moderately positive findings of this experiment concerning the predictive power of the corresponding oligopolistic equilibria, there seem to be fundamental differences in the degree to which Cournot and Bertrand equilibrium predictions organize the experimental data obtained in the corresponding experimental setups.

Rassenti, Reynolds, Smith, and Szidarovszky (2000) and Huck, Normann and Oechssler (2000, 2001) study experimental Cournot markets. A rather general finding in Cournot settings is that, while some learning occurs during the session, total output persistently oscillates around the Cournot prediction. Such persistent oscillations significantly decrease the predictive power of the corresponding equilibrium prediction. Furthermore, in many sessions total output is not significantly different from the collusive prediction, while in other sessions, total output oscillates between the collusive and the Cournot outcome.

Overall, the dynamics of experimental quantity-setting markets present much higher volatility than that observed in price-setting ones. Specifically, whereas volatility decreases and tends to disappear even from individual price data towards the end of a 35-period session, Cournot markets exhibit constantly volatile patterns which do not change over time. However, as said before, a formal comparison cannot be made here and all comments on the aforementioned differences are based exclusively on the observation of the temporal patterns presented by time series plots of the corresponding data. In fact, Huck, Normann and Oechssler (2000) implicitly

[6]Although, generally speaking, the experiment provides evidence supporting the Nash equilibrium prediction for both price and quantity setting markets, the role of information from past strategies and performance is shown to be crucial. Thus, it cannot be seen as a direct test of the two seminal oligopoly models. Therefore a more detailed comment is provided on this experiment in a section dedicated to information and learning from others' strategies.

propose inequality in earnings as an explanation of why subjects' strategies may fail to converge towards the theoretical predictions of asymmetric oligopolistic equilibria, although this explanation leaves unexplained the volatility of output observed in most experimental Cournot markets.

Summary: *The theoretical predictions of quantity-setting models perform worse than their price-setting counterparts in organizing data obtained under the corresponding experimental market conditions. Specifically, total output in experimental Cournot markets is persistently volatile and often significantly differs from the corresponding theoretical predictions. Similar to what was observed in asymmetric price-setting experiments, asymmetric quantity-setting setups pose a further difficulty for the corresponding theoretical prediction to successfully organize behavior observed in the laboratory.*

II.4 The Hotelling model of product differentiation

In the basic economic model of product differentiation, firms choose first locations representing varieties on a continuous and closed product space and then compete in prices. This is the well-known model by Hotelling (1929). Several aspects of the model which have an important impact on human subjects' behavior are not addressed or are treated as trivial in the theoretical model and its numerous extensions. For example, the assumption of full market coverage cannot be guaranteed by the design of the experimental setup. Once incomplete coverage is allowed a proper experimental test of the theoretical predictions of the model becomes difficult or impossible. To tackle this problem, the vast majority of authors have opted for treating prices as given in order to study the first stage of the model alone. The experiments reviewed in this section are divided under two different headings depending on whether exogenous or endogenous prices were implemented in them.

II.4.1 Location with exogenous prices

Like in the case of many other phenomena for which real world data leave little space for empirically testing economic theories, product differentiation models have been tested in the laboratory. Brown-Kruse and Schenk (2000), Collins and Sherstyuk (2000), and Huck, Müller and Vriend (2002), study experimental spatial markets with 2, 3 and 4 firms, respectively. All three articles report experiments with individual subjects whose only decision variable is location. That is, like in earlier work by Brown-Kruse, Cronshaw and Schenk (1993), prices were taken to be exogenously given.

Minimal product differentiation predicted by theory as the non-cooperative equilibrium for the framework used in Brown-Kruse, Cronshaw and Schenk (1993) and Brown-Kruse and Schenk (2000), as well as 'intermediate' differentiation predicted as the collusive outcome of the framework when communication among subjects is allowed were given support by their experimental results.

II.4.2 Endogenous locations and prices

The assumption of exogenous prices present in the previous subsection leads to a framework which fails to address the standard intuition that a firm may want to differentiate its product from those sold by rival firms in order to relax price competition. Recently, Barreda, García-Gallego, Georgantzís, Andaluz and Gil (2006) report results from experimental spatial markets with endogenous pricing. The expected positive relationship between differentiation and price levels is largely confirmed. Regarding the location stage of the game, minimum differentiation receives stronger support than any of the alternative hypotheses. Figure 4 presents aggregate results from the location stage of the game. These results are robust to variations of the experimental conditions regarding the sharing rule implemented (automated versus human consumers) to resolve ties.

Finally, Camacho-Cuena, García-Gallego, Georgantzís and Sabater-Grande (2005) report experimental results from spatial markets with endogenous prices, but their setup significantly deviates from the standard location-then-pricing game in that they consider an extended game in which consumer locations are endogenous too. They find that subjects representing individual consumers fail to realize the benefits from locating in the middle between sellers in order to induce more competitive outcomes. Their learning is not only insufficient to teach them how to adopt this collectively profitable behavior, but on the contrary opportunistic behavior by other buyers locating where sellers are, increases the adoption of transportation cost minimizing locations and leads to less competitive outcomes than predicted.

In both location experiments reported here, coordination between sellers trying to avoid central locations in order to increase differentiation is proposed as the cause of significantly lower differentiation than predicted by the corresponding equilibrium prediction.

Summary: *The principle of minimum differentiation receives far more support than other theoretical predictions for the Hotelling model, even in settings in which some differentiation is predicted in equilibrium. The only exception seems to be found in location experiments allowing communication among rival firms. However, the interpretation of this finding as a result of collusion may underestimate the role of coordination problems faced by rival subjects when trying to simultaneously choose more differentiated locations. Endogenous pricing settings confirm the predicted positive relation between product differentiation and prices.*

II.5 Extensions of basic oligopoly models

This is the most incomplete part of the present review. In this subsection should appear all the research lines that are omitted because they do not immediately fall within the central theme of this article. We focus on oligopoly experiments which, rather than testing specific theoretical models, are inspired by real world phenomena on which the theory has not provided yet a clear cut prediction, often because theorists have not agreed on the right theoretical framework within which the corresponding questions should be answered. We are also interested in experiments which have identified regularities in human behavior which were not initially intended by the experimental design. However, we must admit that the issues reviewed here represent a small part of all experiments which have adopted theory-free designs or have discovered unpredicted regularities. Obviously, among a plethora of such experiments, I have chosen the research lines with which I am most familiar, in an effort to produce an indicative list of questions that have been addressed so far as an example of what else can be achieved by oligopoly experiments apart from testing the predictive power of oligopolistic equilibrium predictions.

II.5.1 Stackelberg competition and endogenous timing

Huck, Müller and Normann (2001) compare Cournot and Stackelberg quantity-setting experimental markets. Their results confirm the volatility of output data obtained from quantity-setting experiments. Furthermore, they report some evidence confirming the prediction that Stackelberg markets are more efficient than Cournot markets. However, the asymmetric nature of leader-follower interaction seems to be an obstacle in the convergence of observed behavior towards the theoretical prediction of the Stackelberg model. Kübler and Müller (2002) report results from price-setting markets designed to compare simultaneous and sequential decisions. An interesting behavioral finding is the difference between genuine sequential games and sequential strategies elicited through the strategy method.

The experiments reported by Huck, Müller and Normann (2002)[7], Fonseca, Huck and Normann (2005), Fonseca, Müller and Normann (2006) and Müller (2006) allow for endogenous timing of strategic decisions. Thus, Cournot or Stackelberg temporal structures may endogenously emerge in the lab. Finally, Huck, Müller and Knoblauch (2006) study an experimental spatial market with endogenous timing. In

[7]See also the analysis by Normann (2002).

all these settings the typically asymmetric results corresponding to leader-follower structures receive less support than expected. In fact, symmetric outcomes are supported by the evidence, even when leader-follower structures are predicted by the corresponding equilibria.

II.5.2 Vertical relations and delegation contracts

Oligopoly models of vertical relations have received less attention by experimentalists than models of horizontal relations. Durham (2000) confirms the existence of the double marginalization phenomenon predicted by the theory, whereas Martin, Normann and Snyder (2001) test and partially confirm the theoretical predictions on vertical foreclosure. However, Hück, Müller and Normann (2004) is the only experiment on the influential theory by Vickers (1985), Sklivas (1987) and Fershtman and Judd (1987), concerning the strategic role of delegation in oligopoly through the design of managerial incentives. In fact, among all the incentive schemes proposed in the vast literature inspired by the aforementioned seminal papers, the experiment exogenously imposes schemes which compensate managers by linear combinations of profit and revenue-related performance of their firms. The remaining types of contracts have not been studied in the laboratory so far. This lack of systematic experimental research on strategic delegation in oligopoly contrasts with a plethora of experiments on the role of bargaining and incentives on economic agents' actions. This is certainly an unexplored area in which experimental research could yield very fruitful results and strategy-relevant insights.

II.5.3 Equilibrium price dispersion and price dynamics

So far, we have reviewed experiments which were aimed at testing oligopoly theories whose equilibria involve a single price. Contrary to this prediction, but not surprisingly, experimental price-setting markets produce dispersed price data. Little has been written on this systematic divergence between theoretical predictions and observed behavior. A different strand in the experimental literature has focused on the issue of price dispersion inspired by oligopoly models whose equilibria are expressed in terms of price distributions. There are basically two theoretical settings that have inspired experiments aimed at studying price dispersion. The first setting is Bretrand-Edgeworth competition and the second are models with informed and uninformed consumers like Varian's (1980) model of sales.

Firms competing according to the Edgeworth-Bertrand model, set prices under the restriction imposed to them by their capacity constraints. Framed as a test of Bertrand-Edgeworth competition models, the experimental price dynamics reported by Brown-Kruse, Rassenti, Reynolds and Smith (1994) offer some evidence for the theory of Edgeworth cycles. In fact, this is the first confirmation of this theory's prediction concerning time dependence and cycles observed with respect to the subjects' pricing strategies.

A more recent wave of experimental studies focuses on price dispersion, implementing setups which are inspired by Varian's (1980) model and the model by Burdett and Judd (1983) focusing on the role of price sampling by informed buyers. Experiments reported by Morgan, Orzen, and Sefton (2006) and García-Gallego, Georgantzís, Pereira, and Pernías (2004) confirm the basic comparative statics prediction of the Varian (1980) model according to which prices are higher in the presence of more sellers in the market, despite the fact that observed price distributions significantly differ from theoretical ones. This can be seen on Figure 5. However, the results obtained in the latter experimental paper offer little, if any support for the Burdett and Judd (1983) model and for an extension of it accounting for biased sampling of prices by the Internet-based search engine. Finally, Orzen (2005) offers some evidence for the conjecture by Janssen and Moraga-González (2004) concerning the collusive-pricing attractor which tends to reverse Varian's (1980) comparative statics prediction regarding the size of an industry. The rotation of price distributions reported in García-Gallego, Georgantzís, Pereira, and Pernías (2004) may also be due to these coexisting equilibria, although that paper only implicitly and briefly refers to the issue of equilibrium multiplicity.

A small number of theoretical papers study the dynamic properties of price distributions in markets with consumer search. Hopkins and Seymour (2002) have shown that a broad family of learning dynamics may be stable under a relatively demanding condition on the proportion of uninformed consumers in the market (*sufficient ignorance*). While several experimental studies have addressed the comparative statics of price dispersion in markets with buyer search, a smaller number of papers by Cason and co-authors[8] focus on the dynamics of price dispersion in laboratory data. Especially, the Edgeworth cycles reported by Cason, Friedman and Wagener (2005) can be seen as evidence for the instability of price dispersion predicted by Hopkins and Seymour (2002). Also, the serial correlation of individual strategies detected by Cason and Friedman (2003) can be interpreted as evidence against the hypothesis of mixed strategy play. Finally, García-Gallego, Georgantzís, Pereira, and Pernías (2005) focus on the dynamic implications of the coexisting dispersed and monopoly pricing equilibria in markets with informed and uniformed consumers. Contrary to the majority of previous experimental studies, the subjects were faced with the same history of rival prices, given that each subject is faced with a number of simulated rivals whose behavior is extracted from mixed strategy equilibrium distributions. Two coexisting dynamic patterns are identified occurring parallel to each other. The two patterns concern two alternative peaks of typically bimodal price distributions. The first peak is labeled as the interior pricing mode and is shown to exhibit a decreasing trend over time, whereas the second is referred to as the monopoly pricing one and is found to attract an increasing number of observations. Surprisingly, these dynamic patterns concern behavior by individual subjects learning from trial-and-error strategies when faced with a stationary series of rival prices extracted from equilibrium price distributions.

[8] Cason and Datta (2004), Cason and Friedman (2003), Cason, Friedman, and Wagener (2005).

II.5.4 Price guarantees

One of the most controversial practices in oligopolistic markets is the adoption of guarantees by oligopolists ensuring the consumers a reimbursement in case the latter encounter a lower price for the same product at a rival's shop. In fact, price matching guarantees promise that the rival's lower price will be eventually matched after the reimbursement is paid, whereas price beating guarantees promise reimbursements which exceed the price difference reported by the claimant. The theory has provided several explanations for the adoption of such guarantees. They may have an informative role for consumers to easier identify low-price sellers, they may be used as incentives for consumers to report a deviation by a firm's cartel partner from the agreed cartel price or alternatively they may be a way of increasing the consumer's valuation of the firm as a whole. Obviously, the policy prescriptions for guarantees inspired by each type of motive are different.

Starting from this lack of agreement, experimental markets with price guarantees have been studied in a rather theory-free way, given that none of the experiments reported here is explicitly designed as a test of a specific theoretical model. The majority of experiments on price guarantees focuses on price matching alone[9], whereas Fatás, Georgantzís, Máñez and Sabater-Grande (2005) study price beating in isolation of other types of guarantees. Price matching and price beating guarantees were compared by Fatás, Georgantzís, Máñez and Sabater-Grande (2006), who distinguish between aggressive and soft price beating, depending on the degree to which the price difference is exceeded by the reimbursement. It is found that price matching and soft price beating have a positive effect on final prices, whereas aggressive price beating tends to put downward pressure on prices. Thus, whereas the effect of soft price beating and price matching is similar to that of price parallelism, aggressive price beating is, as one would have thought, pro-competitive. This result is

[9] See Datta and Offenberg (2005), Dugar (2005) and Fatás and Máñez (2006).

graphically presented on Figure 6.

II.5.5 Other (ir)regularities

In this subsection I briefly refer to a series of other regularities observed in oligopoly experiments which should definitely receive more attention in future research.

An issue which has been recurring in all oligopoly experiments without being a central theme of the majority of them is learning.[10] In fact, I will argue here that the learning process determines, to a large extent, the outcome reached in an oligopolistic market. In fact, Cyert and DeGroot (1973) had made a seminal contribution in this direction, by relating learning in oligopolistic markets with the duopolists' ability to reach the collusive outcome.

Several studies have aimed at identifying possible systematic patterns in subjects' learning strategies. Adaptive learning has been addressed in many of them.[11] Thus, it has been implicitly admitted that subjects do not try to learn more on the market than is necessary for them to support their decision making. Furthermore, human agents do not seem to learn from sophisticated or formal processes leading to an understanding that allows them to calculate optimal or equilibrium strategies. To my knowledge, García-Gallego (1998) and García-Gallego and Georgantzís (2001a) were the only experiments offering subjects the opportunity to learn from more sophisticated ways of processing feedback on past strategies. A whole range of tools were available to the subjects, like OLS estimates of the underlying demand model based on past data and several options concerning the desired graphs (quantity-price, profit-price, etc.) of past periods. The conclusion of both studies is clear cut: no subject made any effort to systematically infer information on the demand conditions in order to calculate the optimal strategy by the use of explicit

[10] A necessary large omission is made here, given that I focus on learning in oligopoly experiments alone, without reviewing the extensive theoretical and experimental literature on the more general issue of learning in games.

[11] See, for example, Nagel and Vriend (1999).

optimization, despite the fact that subjects were students of relatively advanced and even postgraduate courses in Economics. Yet, learning significantly affects the observed behavior, as strategies in most oligopoly experiments seem to start from almost random, dispersed strategies which evolve over time towards the zone of candidate benchmark solutions like are the collusive and the non-cooperative outcomes. Thus, although subjects do not seem to use explicit learning tools like those offered to them in the aforementioned studies, they adopt strategies which serve at the same time for earning profits from current actions and improving future actions using the feedback received on past performance.

Using the data from the two aforementioned studies, García-Gallego and Georgantzís (2001b) estimate linear adaptive learning models of the type: $p_{it} = A_i + B_i E_{j \neq it} + \Sigma_{k \neq i} G_{ik} p_{kt}$, where p_{it} is product i's price in period t. A_i, B_i are product-specific parameters. E_{jt} is the producer's expectation of rival firms' prices for the same product. The last term refers to the degree of price parallelism followed by a firm with respect to its other products ($k \neq i$). The expectation for rival firms' prices in a period is a weighted sum of a pre-established expectation and a term referring to rival past prices as expressed in: $E_{jt} = \omega E_{jt-1} + (1-\omega)\Sigma p_{j \neq it-1}$. The estimates obtained confirm that most subjects' actions can be classified according to different values of the *adaptive* parameter ω, as defined in this model. As mentioned in the section on price-setting experiments, this has lead the participants of this experiment to successfully converge close to the theoretical prediction for single product price-setting oligopolies. In the case of multiproduct oligopolies, a further condition is required for convergence close to the corresponding multiproduct oligopoly equilibrium prediction. The condition concerns the significance of the *parallelism* terms G. Although these results are specific to the design adopted in those papers, a general conclusion can be reached: The model describing the learning strategy adopted by the subjects of an experiment determines to a large extent the degree to which the observed behavior is compatible with the corresponding theoretical prediction.

A natural conjecture stemming from this observation is that the more complex an oligopoly setting is, the more restrictive are the requirements concerning the learning process adopted by subjects in order for their limit strategies to confirm the corresponding equilibrium predictions. If we would like to make the term *complexity* more specific, we could mention asymmetries and multiproduct activity as two of the numerous sources of it. However, the existing results are far from exhaustive and different sources of complexity should be studied both in isolation and in combination with each other in order to gain new insights on the interplay between the oligopolistic environment and the learning process as causes of the observed behavior.

This brings us to an important determinant of whether non-cooperative or collusive outcomes are observed in oligopoly experiments. There is no doubt that information affects the observed behavior. For example, Mason and Phillips (1997) confirm the importance of information in a duopoly with cost asymmetries. It must be stressed however, that a difference should be made on whether the treatment of information in oligopoly experiments concerns *ex ante* information given to the subjects by instruction or *ex post* information available to the subjects as feedback available from past actions. Contrary to what is often asked by theorists in conferences, ex ante informational treatments have little if any effect on observed behavior because, as reported in García-Gallego (1998), subjects do not use information which is not readily interpretable in terms of their decision making process. And of course, this is true for both *ex ante* and *ex post* information. Therefore, informing the subjects on the exact demand and supply conditions, when these are not easy to interpret in a linear way in terms of proportional reactions of feedback to their strategies, has little if any effect on observed behavior. On the contrary, informing subjects on their rivals' strategies in past periods and even more importantly on others' performance has a significant effect.

Feedback from own past actions is a plausible but not a unique source of learning in oligopoly settings. A series of experiments have focused on other types of learning.[12]. However, several experiments have identified a number of learning processes which significantly differ from what has been assumed to happen in the stylized abstract settings adopted by theorists. For example, information on the strategies adopted by other players is studied by Huck, Normann, and Oechssler (2000) and is found to play a significant role in the emergence of collusive outcomes. Furthermore, imitation of successful rivals is supported by the experimental evidence reported by Offerman and Sonnemans (1998), Offerman, Potters and Sonnemans (2002) and Bosch-Doménech and Vriend (2003). Recently, Altavilla, Luini and Sbriglia (2006), find that informing oligopolists on rival past prices leads quantities closer to the Cournot-Nash equilibrium prediction, whereas information on industry-wide profit averages yield higher levels of cooperation due to less profitable subjects' efforts to improve their performance.

Finally, pre-play communication is certainly more likely to induce collusive outcomes as has been established in various experimental studies[13] even in dynamic and complex oligopolistic environments[14].

Another important behavioral issue which systematically affects behavior in oligopolistic settings is inequity aversion. Although the result reported by Huck, Normann and Oechssler (2001) is the only one which explicitly relates inequality of earnings with the lack of stability in Cournot settings, we have seen above that asymmetric settings are more likely to yield significant divergence between theoretical predictions and observed behavior in different contexts (quantity-setting, price-setting, leader-follower models, *etc.*). Thus, inequity aversion is an important

[12]Theorists have offered a number of different alternatives on how learning occurs in strategic settings. Although a review of the theoretical papers on learning is beyond the scope of this article, it is worth mentioning Hopkins (2002) and Hopkins and Seymour (2002) as two of the most representative examples of theoretical approaches to strategic contexts similar to the ones studied here.

[13]See for example the experiments in Brown-Kruse and Schenk (2000).

[14]See the dynamic duopolistic market implemented in García-Gallego, Georgantzís and Kujal (2006b) as a water management setting with tacit pre-play confirmation of strategies.

determinant of the degree to which theoretical predictions can organize behavior in experimental oligopolies.

The oligopolists' aspiration levels are also an important factor when analyzing the relation between experimental and theoretical results. Huck, Müller, Konrad and Normann (2006) find that aspiration levels can be used to explain why the merger paradox may or may not fail in the laboratory. Davis and Wilson (2005) have tested the Antitrust Logit Model in the laboratory. Several shortcomings are identified which may also be attributed to the fact that merging firms have been in the market place before the merger and that their past affects their current strategies in a way which deviates from the post merger equilibrium prediction. Combining this conjecture with the fact that asymmetric settings make it difficult for subjects to learn their way towards an equilibrium which accounts for their increased market power,[15] we conclude that antitrust and merger policy must be redesigned to account for the reduced predictive power of certain oligopolistic equilibria in a broad range of situations.

The role of risk aversion on behavior in strategic environments is established by Sabater-Grande and Georgantzís (2002), who report that more risk averse subjects are less likely to cooperate in a prisoners' dilemma. Strangely, despite the claim that some unexpected results in oligopoly experiments may be due to subjects' uncontrolled risk attitudes, there is only one precedent of oligopoly experiments designed to jointly address risky decision making and price competition. More in line with the result in Sabater-Grande and Georgantzís (2002) than with the theoretical prediction on pricing in search markets, García-Gallego, Georgantzís, Pereira and Pernías (2004) find that risk averse subjects tend to price their products more competitively. Therefore, despite the theoretical prediction that in search markets the safe strategy is to set the monopoly price in order to guarantee the maximum safest profit, the

[15] Due, for example, to the finding by García-Gallego and Georgantzís (2001a) for multiproduct oligopolists managing differentiated products.

link between competitiveness and risk aversion seems to be an empirically confirmed fact.

These last findings concern factors which are traditionally related with individual decision making. The example of Huck, Müller, Konrad and Normann (2006) on the merger paradox is central in replying to critiques on whether experimental results should be used to guide policy making in real world markets. A usual critique is that while experimental subjects may be risk averse, firms are risk neutral. This means that, presumably, not all factors affecting the convergence of observed behavior towards the corresponding theoretical predictions are relevant for real-world markets. However, this critique is used too often without considering, for example, the fact that most strategic decisions are made by individuals who possess similar characteristics with those reported above. The managerial literature is full of case studies in which a manager's excessively risky or intelligent decision is recognized. Furthermore, expected utility maximization, the central economic hypothesis on individual risky decision making is not a psychological theory, but a theory on non linear utility from monetary earnings. If we recognize that managers make the decision on behalf of firms, and considering the fact that managers may have aspiration levels due to personal, psychological reasons or due to their managerial incentive contracts, why is it still a plausible critique that experiments run with individual subjects have little to teach us on real-world companies?

Summary: *The learning process affects and is affected by the context in which decisions are made. A broadly confirmed intuition is that subjects in oligopolistic environments learn from trial-and-error processes. Such processes can be reasonably organized by models of adaptive learning in which subjects adapt their expectations of others' strategies based on past information and then react to this expectations. However, more complex environments, like for example multiproduct oligopolies yield more complex learning rules and are more demanding on the conditions that have to be satisfied by the learning process in order for observed behavior to converge close* *to equilibrium predictions. Other types of learning like imitation of successful others have also received support by the experimental evidence, but their role in determining the speed and the limits of the convergence process is still an under-investigated research area. Information on other's past strategies has ambiguous effects with different results reported for Cournot and Bertrand markets, whereas information on industry-wide performance increases oligopolists' ability to reach and maintain collusive outcomes. The role of other behavioral factors like risk and inequity aversion or decision making intelligence on behavior in oligopoly settings is largely unknown.*

III Conclusions and Methodological Remarks

Extremely simple, symmetric settings offer the perfect ground for a harmonic coexistence between experimental and theoretical results. However, the presence of either asymmetries or a minimum degree of complexity alone is sufficient for a significant divergence between theoretical and experimental results. As either of these factors or both increase, deviations become larger. Some other factors may mitigate or enhance these deviations. The list of such factors presented in this paper is incomplete. However, even if such a complete list existed it would fall short of the list of factors which remain unexplored or under-investigated. Some of the experiments reviewed here have introduced a number of interesting and policy-relevant research questions which remain largely unexplored by theorists and unknown by policy makers. For example, which is the reason for the systematic failure of asymmetric quantity-setting experimental markets to converge towards the equilibrium prediction in a precise and smooth way? Why do differentiated price-setting oligopolies suffer less from this volatility and lack of clear convergence towards the equilibrium prediction? But most importantly, which are the implications of this finding for policy making in real-world markets or even for empirical research?

Many other questions are equally or even more under-investigated than the aforementioned differences in the performance of the Cournot (1838) and Bertrand (1883) predictions when contrasted with behavior by human agents in the lab. For example, two-stage games like the Hotelling (1929) model of product differentiation or oligopoly models of strategic R&D investments and a huge number of *theoretical facts* have received attention in few (a single paper, in most cases), if any, papers.[16] And this is a major shortcoming of the way economists have used the experimental methodology so far. Experimentalists from other disciplines usually find it difficult to believe and rely on the results obtained from an experiment which was run once, by a single research group in a single research institution. In that sense, experimental economists suffer the consequences of employing an extremely 'young' methodology. An economist will, with probability close to 1, receive a rejection by most journals if the submitted manuscript reports results from a replication of an existing experiment. The critique that a certain experiment was already run 10 years ago sounds like a reasonably good reason for not publishing a paper, which is invalidated by its unique precedent. Rather than being surprised by the long time it took for this experiment to be replicated, even the author usually agrees that this critique is a good reason for never publishing a manuscript. Contrary to this negative attitude towards replication, *Experimental Economics*[17] explicitly encourages authors to submit papers replicating previous experimental results. This and the increasing tendency of experimental economists to interact with researchers from other disciplines will gradually make us understand the value of replication and, sooner or later, this will hopefully affect oligopoly experiments.

Future research should focus more on the most important although yet under-exploited ground for cooperation between oligopoly theory and experimental eco-

[16] Just to mention three examples of important but under-investigated issues involving interesting behavioral aspects which have been studied in few occasions —often only once— in the laboratory, *predatory pricing* was studied by Isaac and Smith (1985), *contestability* by Brown-Kruse (1991) and *limit pricing* by Müller, Spiegel and Yehezkel (2006). Finally, dynamic oligopoly theory is probably the most promising but under-investigated area of research for experimentalists.

[17] The official journal of the Economic Science Association.

nomics, which is the link between *individual decision making* and *strategic market interaction*. Risk and inequity aversion, imitation, aspiration levels, envy, learning shortcomings and even gender or decision making intelligence cannot be considered policy or strategy-irrelevant any more.

IV Appendix: Figures

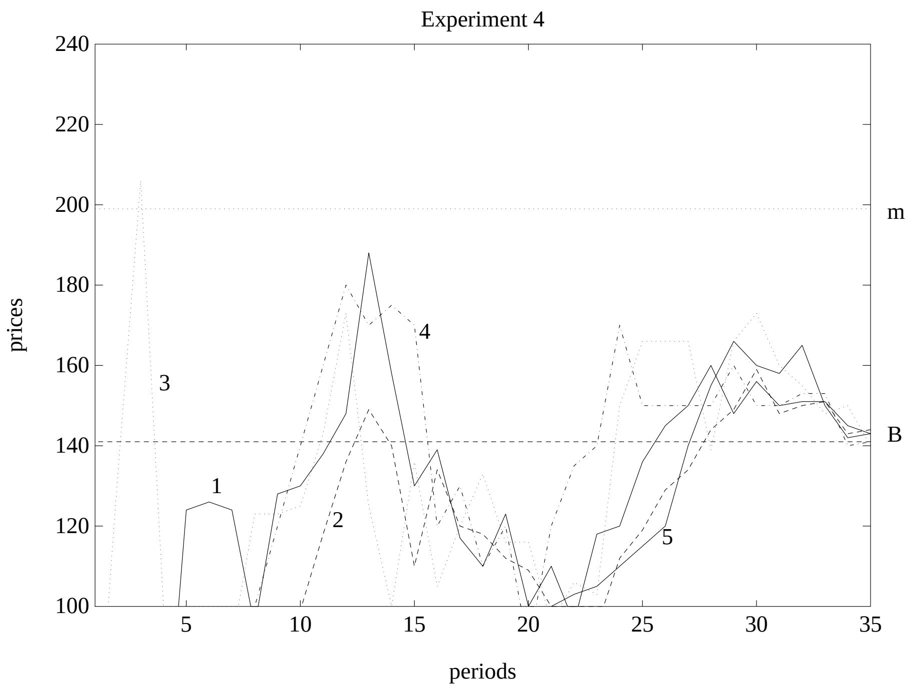


Figure 1: Experimentally testing the Bertrand-Nash prediction in a differentiated oligopoly with 5 varieties. 'B': Bertrand-Nash, 'm': Monopoly (collusive) pricing. *After the initial periods of price volatility, strategies clearly converge to the Bertrand-Nash prediction.*
Source: García-Gallego and Georgantzís, (2001b).

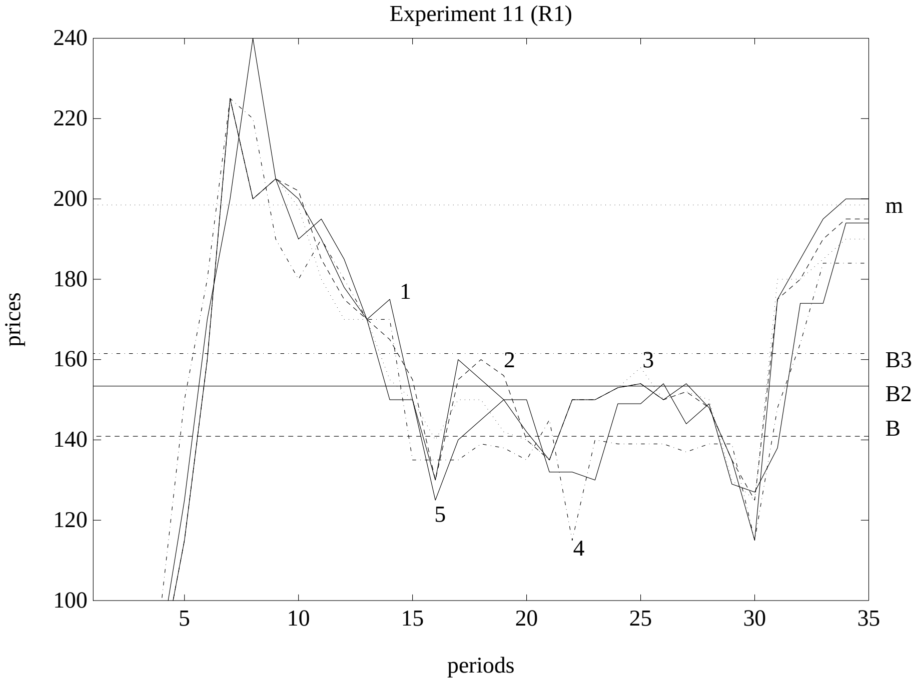


Figure 2: Convergence to the collusive outcome in a differentiated price-setting oligopoly with 5 varieties and multiproduct firms. 'B3': Multiproduct Bertrand-Nash equilibrium prediction for a firm jointly setting prices for 3 varieties. 'B2': Multiproduct Bertrand-Nash equilibrium prediction for a firm jointly setting prices for 2 varieties. 'B': Bertrand-Nash, 'm': Monopoly (collusive) pricing.
After the initial periods of price volatility, strategies clearly converge to the collusive outcome in a session in which multiproduct subjects adopt price parallelism among products managed by the same firm throughout the experiment and tacitly coordinate on price parallelism with rival firms.
Source: García-Gallego and Georgantzís, (2001b).

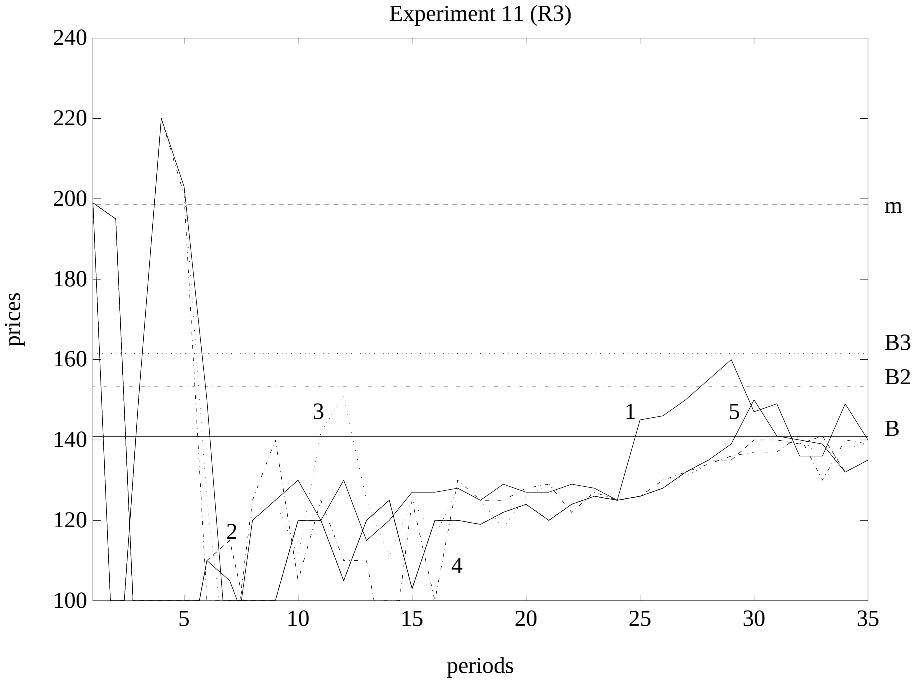


Figure 3: Testing the predictive power of the Multiproduct Bertrand-Nash equilibrium in a differentiated oligopoly with 5 varieties. 'B3': Multiproduct Bertrand-Nash equilibrium prediction for a firm jointly setting prices for 3 varieties. 'B2': Multiproduct Bertrand-Nash equilibrium prediction for a firm jointly setting prices for 2 varieties. 'B': Single-Product Bertrand-Nash equilibrium, 'm': Monopoly (collusive) pricing.
After the initial periods of price volatility, strategies fail to confirm the corresponding Multiproduct Bertrand-Nash equilibrium. Subjects fail to realize their market power and the Single-Product Bertrand-Nash equilibrium is supported by limit strategies.
Source: García-Gallego and Georgantzís, (2001b).

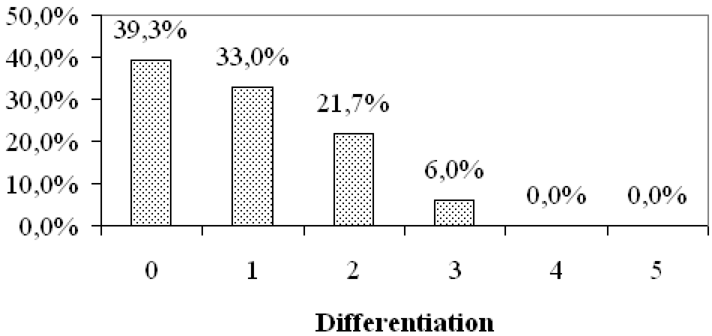
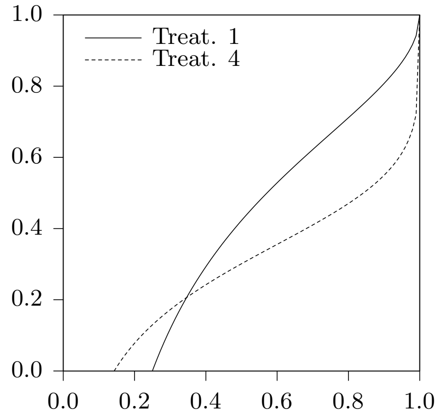
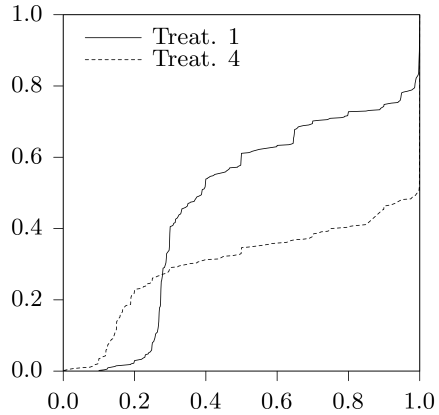


Figure 4: Experimentally testing the minimum differentiation principle.
Hotelling's (1929) prediction of minimum differentiation is confirmed as the modal choice in an experiment with endogenous prices.
Source: Barreda, García-Gallego and Georgantzís, Andaluz and Gil (2006).



(a) Theoretical distributions



(b) Empirical distributions

Figure 5: Experimentally testing the predictions of Varian's (1980) model of sales with 3 (Treatment 1) and 6 (Treatment 4) firms.
Empirical distributions are significantly different from theoretical ones, but the predicted effect of industry size on prices is confirmed.
Source: García-Gallego, Georgantzís, Pereira and Pernías (2004).

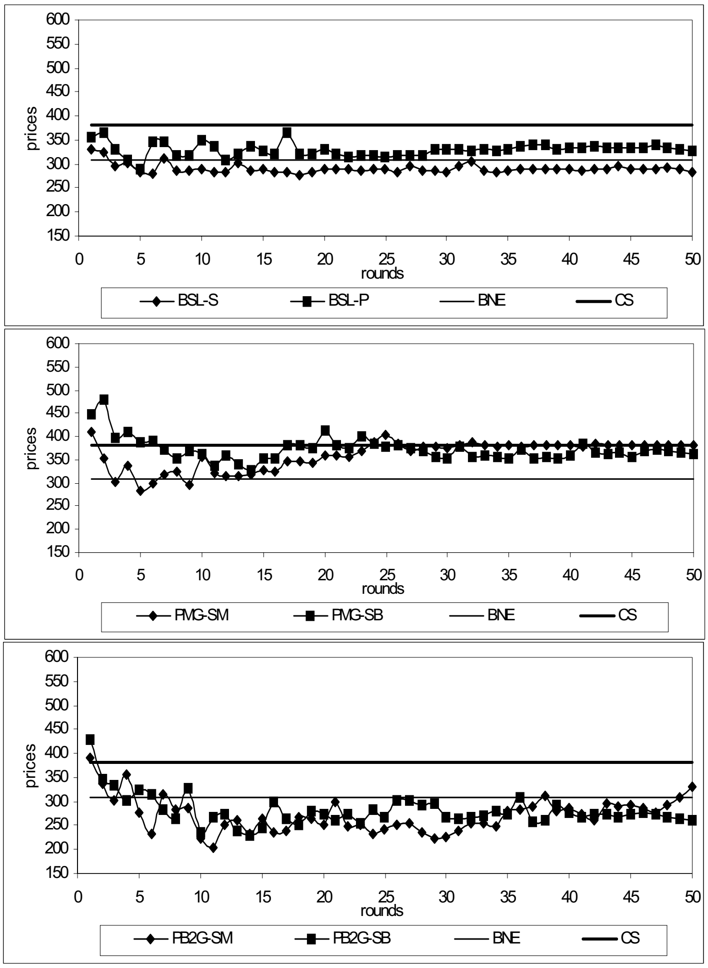


Figure 6: The effect of price guarantees in a symmetric differentiated duopoly. 'BSL': Baseline treatment (no guarantees), 'PMG': Price matching guarantees, 'PB2G': Aggressive price beating guarantees promising to reimburse double the price difference reported by the claimant. 'BNE': Bertrand-Nash equilibrium, 'CS': Cooperative solution.
Aggressive price beating guarantees yield prices which are lower than those observed in duopolies without guarantees, whereas price matching guarantees have a clearly anti-competitive effect. In all cases, partners *treatments (fixed matching of subjects forming a duopoly) yield higher prices than* strangers *(random matching of subjects forming duopolies in each period).*
Source: Fatás, Georgantzís, Máñez and Sabater-Grande (2006).

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