Industrial Organization: A Survey of Laboratory Research

Charles A. Holt
University of Virginia
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CONTENTS

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Charles A. Holt*

1. OVERVIEW

Despite the contrast between the relative simplicity of the laboratory and the complexity of most naturally occurring markets, there is a well-established tradition of experimental research in the field of industrial organization (IO). Indeed, the first market experiment resulted from Edward Chamberlin's conjectures about the imperfect nature of competition. This chapter will survey the extensive experimental literature that is motivated by IO issues, beginning in sections 2 and 3 with the story of how economists initially became interested in experimentation, and with a discussion of the potential usefulness of laboratory techniques in this area. Section 4 contains a review of some procedural issues that arise in the conduct of market experiments. One pervasive theme is the importance of the rules and informational conditions of the laboratory *market institution*. Section 5 contains descriptions and comparisons of the trading institutions that are used in the study of industrial organization issues. The four substantive sections that follow are organized around traditional topics: monopoly regulation and potential entry, concentration and market power, conditions that facilitate cooperation, and product differentiation.

One set of issues to be considered is the extent to which a monopoly seller can exercise market power in the laboratory, whether this power can be protected with predatory pricing, and whether contestability and decentralized regulatory mechanisms mitigate this power. A second set of issues is based on the usefulness of simple concentration measures: do they predict supra-competitive pricing, or it is necessary to consider more subtle notions of market power? Contracts, trading rules, communications, and other factors that do and do not seem to facilitate cooperation in laboratory situations are discussed. In experiments with interrelated markets, the discussion covers failures (due to asymmetric quality information) and successes (where competition generates efficient coordination across markets).

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2. BEGINNINGS

Chamberlin, like many other economists, observed behavior in naturally occurring contexts and formulated theories to organize and explain these observations. *The Theory of Monopolistic Competition (A Re-orientation of the Theory of Value)*, which appeared in 1933, was inspired by the failure of markets to adjust to the shocks of the Depression. What differentiated Chamberlin from his predecessors is that he then set up an experiment to evaluate his theoretical work. He *induced* the structure of the laboratory market by handing out cards with value and cost information to students in his class.[1] For example, a student receiving a seller card with a cost of $1.00 would have the capacity to sell one unit, and the profit on this unit would be the difference between the sale price and the cost of $1.00. This seller would have an inelastic supply function with a "step" at $1.00. Similarly, a subject receiving a buyer card with a "value" of $2.00 would have the ability to purchase a unit, and the profit on the unit would be the difference between the value of $2.00 and the price paid for the unit. This buyer would have a perfectly inelastic demand for one unit of the commodity at any price below $2.00. If this seller and buyer were to arrange a contract for a price of $1.50, each would earn 50 cents from the trade. Other buyers and sellers can have different values and costs. The market demand and supply functions result from a horizontal summation of the individual buyers' and sellers' demand and supply functions. Students were allowed to circulate around the room and arrange trades in a decentralized manner. Chamberlin's (1948) experiment, to be discussed in more detail in the next section, provided some support for his conjecture that actual markets would not generate the efficient outcomes predicted by the intersection of market demand and supply.

Chamberlin's paper was initially ignored in the literature.[2] Vernon Smith, who was a student participant in Chamberlin's trading sessions, was also skeptical at first. But later, as an assistant professor at Purdue, Smith decided that the decentralized trading institution used in Chamberlin's sessions would not create an environment likely to be consistent with received theories of perfect competition. Smith (1962, 1964) developed a laboratory "double auction" institution in which all bids, offers, and transactions prices are publicly observed. In a double auction, buyers may start bidding at a low level and raise each other's bids as in a familiar auction for art or antiques. At the same time, sellers may start with high asking prices and begin a second, reversed auction process of price cutting. A contract occurs when the bid-ask spread narrows and a buyer accepts a seller's ask or a seller accepts a buyer's bid. A laboratory double auction can be a noisy process in which traders raise their hands frantically to get the attention of the auctioneer, who recognizes them one at a time and has their bid or ask recorded publicly on the blackboard, as only officially recorded bids and asks can be accepted by another trader.

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[1] Chamberlin's (1948) paper is also discussed in Roth (chapter 1).

[2] Chamberlin barely mentioned his own 1948 paper in a short footnote in the 8th edition of *The Theory of Monopolistic Competition*.

Smith was motivated by observations of efficient, centralized stock exchanges in which the best standing price quotes at any instant determine a bid-ask spread that is observed by all, unlike the Chamberlinian markets in which buyers' bids in one part of the room, for example, could be much higher than sellers' asking prices in another location. Smith demonstrated that double auctions could converge to efficient, competitive outcomes, even with a small number of traders who initially knew nothing about market conditions. Smith's early experimental work was also largely ignored, presumably because it was consistent with widely held beliefs. His intense interest in the mechanics of how markets function has led to a large number of subsequent papers, and many of his colleagues, students, and coauthors have become significant contributors.[3]

Charles Plott, who had been an assistant professor at Purdue, saw Smith's early work and realized that it could be applied to the study of public choice. Plott began doing voting and committee-choice experiments at Caltech in the early 1970s, and he taught a seminar with Vernon Smith during Smith's visit to Caltech in 1974. A particularly significant outcome of this collaboration was the Plott and Smith (1978) comparison of trading institutions, which reveals the inefficiencies that can result from a rule that limits the ability of traders to deviate from posted prices.

There is a separate and largely unrelated group of experimental studies done by psychologists, game-theorists, and business-school economists in the fifties and sixties.[4] Much of this work was stimulated by early interest in computerized business games with teaching objectives (Bellman, et al. 1957). The first oligopoly experiment to be reported is Hoggatt (1959), who used Berkeley faculty colleagues in a relatively uncontrolled setting with no financial incentives.[5] At about the same time, classic studies of cooperation and competition in oligopoly situations were conducted by Sauermann and Selten (1959), Siegel and Fouraker (1960), and Fouraker and Siegel (1963). The care with which Fouraker and Siegel (a psychologist) treated the laboratory environment and the financial incentives is particularly notable. These early researchers were intrigued by the structure of "prisoner's dilemma" duopoly games in which each of two matched participants would make a price or quantity decision and record it on a piece of paper, which would then be collected and used to calculate each person's earnings from a payoff matrix. The noncooperative equilibrium typically involves a low-profit outcome with low prices (or high quantities in a Cournot quantity-choice setting). In such an equilibrium, neither person has an incentive to raise price unilaterally, but both can increase their earnings considerably if they raise prices (cut quantities) at the same time. One effect of this work was to extend the psychologists' and economists' interest in prisoner's dilemma games (Rapoport and Chammah 1965, and Lave 1962, 1965) to the study of more complex bargaining and pricing interactions in market environments (e.g. Dolbear, Lave

[3] Smith is currently the director of the Economic Science Laboratory at the University of Arizona, where some of the most interesting experimental research in industrial organization is being done.

[4] See chapter 1 of this volume for more details.

[5] Friedman's (1969) somewhat critical review notes that Hoggatt (1959) is the first oligopoly experiment to be reported.

et al. 1968, and Friedman 1963, 1967, and 1969). The interdisciplinary approach at professional business schools such as Carnegie-Mellon's Graduate School of Industrial Administration led to a series of experimental papers, including an early survey paper (Cyert and Lave 1965) and an experimental thesis on behavior in oligopoly situations (Sherman 1966).[6]

Early laboratory results, however, were overshadowed by the outpouring of regression studies of "structure-performance" relationships that followed the advent of inexpensive computing. Indeed, the first edition of Scherer's (1970) textbook, which dominated the field for more than a decade, only contained a brief mention of prisoner's dilemma experiments and no mention of Vernon Smith's experimental research.[7, 8] Most of the econometric analysis of IO issues in the seventies was only loosely related to economic models, and the ensuing reaction stimulated an interest in theoretical foundations that is reflected in the heavy game-theoretic content of the Tirole (1988) book, which has replaced Scherer in graduate IO courses. It is only a slight exaggeration to say that all of the action in theoretical IO now involves applied game theory, and that very little of the new theory has been subjected to empirical testing.[9] Many of these new theories have subtle and important implications that are ideally suited for laboratory testing.

To summarize, most of the initial work in experimental economics was motivated by the study of issues central to industrial organization: competition, collusion, and market efficiency. Recent applications of game theory in industrial organization provide a rich agenda for laboratory research.

3. The Relevance of Experiments to the Study of IO

There is an important distinction between markets that occur naturally in society, i.e. natural markets, and laboratory markets in which the structure is determined by instructions and payment procedures specified by the experimenter. Natural markets are so complex that much of the empirical work in industrial organization is based on one or more convenient simplifications, e.g., perfect product homogeneity, which are violated in natural markets, often to an unknown extent. In contrast, laboratory markets are typically less complex; the procedures must be simple enough for subjects to understand and gain experience in the trading environment within the two-three hour time frame of most laboratory sessions.

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[6] Incidentally, much of this early work was done in Pittsburgh, the site of the 1990 conference for authors of this handbook.

[7] In the most recent edition, Scherer and Ross (1990), Smith is mentioned in a footnote, as is Charles Plott and several other experimentalists.

[8] When I started thinking about experiments, one of my dissertation advisors (Ed Prescott) warned me that "it was a dead end in the sixties and it will be a dead end in the eighties."

[9] In *Econometrica*, there were only two-three empirical papers on standard IO issues between 1980 and 1985, one of which was the Miller and Plott (1985) laboratory study of signaling.

Considering the complex workings of consumer and producer goods markets that have been the focus of antitrust cases, a skeptical reader must wonder whether effective simplification is possible, i.e. whether laboratory experiments will yield *any* useful insights for IO economists. Although this issue will be addressed in the context of specific examples in subsequent sections, it is instructive to begin here with a discussion of three basic purposes of laboratory experimentation in IO contexts.[10]

Experiments that Evaluate Behavioral Assumptions

It is difficult to falsify a theory with data from naturally occurring markets, since the simplifying assumptions of theories are rarely, if ever, satisfied in the field. Experiments do permit one to subject a theory to a minimal test, i.e. that it provide reasonably good predictions in special cases in which its basic assumptions are satisfied. A theorist may argue that this is the only appropriate test of a theory, since the theory does not predict anything if the assumptions are not satisfied. If this extreme position is accepted, then most theories in IO have no empirical implications for naturally occurring markets and can only be tested in the laboratory.

It is useful to highlight the distinction between the structural and behavioral assumptions of a theory to be tested. In game-theoretic terms, structural assumptions determine the extensive form, and behavioral assumptions pertain to the equilibrium concept. Experimentalists are usually not interested in trying to impose or induce key behavioral assumptions, e.g., a belief that one's purchases have no effect on the market price. But by controlling traders' incentives and information, the laboratory environment can be made to correspond quite closely to the structural assumptions of a specific theory. In this way, it is possible to evaluate the internal workings of a theory, e.g., behavioral assumptions such as noncooperative behavior and rational forecasting. This type of evaluation is important in oligopoly theory, where the word equilibrium frequently follows one or more juicy adjectives. Even if we restrict attention to noncooperative game theory, there are many equilibria, some of which are thought to be "unintuitive" and not "perfect," and others of which are termed "divine," "universally divine," or "strategically stable." Many of the theoretical issues here involve very subtle points, such as the nature of beliefs off the equilibrium path, and there is little hope that such issues can be evaluated with non-experimental data.

It is, however, more difficult to use experimentation to evaluate the usefulness of simplifying assumptions about the structure of the market environment. For example, consider a test of the contestable markets hypothesis in which the incumbent must make a binding, public price decision before the entrant. This timing assumption, which could be *imposed* as a part of the structure of the experiment, is precisely the main point of contention in some of the critical reviews of market contestability theory, and therefore,

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[10] The discussion of methodology that follows is strongly influenced by the work of others, as noted in the footnotes and references. Also see Davis and Holt (1993, chapter 9) for a consideration of the relationship between types of experiments, experimental designs, and nonparametric statistical tests.

the experiment would not resolve this particular controversy.[11] Even though it is possible to elicit some preference information from financially motivated subjects, experiments will never be very useful in settling important empirical disputes about the actual structure of the economy.

One argument against laboratory experimentation is summarized by Werden (1991, p.18): "Experimental conditions can never be very realistic. The subjects in the experiments are not experienced businessmen; they are not playing for serious sums of money; and they are not accountable to shareholders. The complex dynamics of real firms and markets, involving long-term investments and commitments also are not likely to be captured by an experiment." This comment raises an interesting question: which, if any, of the parameters and structural elements of the *formal theory* are not present in the laboratory? Most theories that pertain to industrial organization are cast at a level of generality that applies to laboratory settings. The best response to the argument that experiments are not realistic is given by Plott (1989, p.1165): "...laboratory markets are 'real' markets in the sense that principles of economics apply there as well as elsewhere....general theories and models should be expected to work in the special cases of laboratory markets."[12] Moreover, it is possible to use businessmen as subjects, and studies that have done this have not reported major differences in the rationality of decisions made by students and those made by professionals.[13] But the Werden critique should not be dismissed too casually. The possibility of subject-pool effects is more of a worry for industrial organization experiments than for other types of experiments that parallel natural situations in which students have experience (e.g., shopping, bargaining, and choices in risky situations).

In antitrust analysis, the effectiveness of a policy may hinge on behavioral assumptions, and it is risky to impose an antitrust or regulatory remedy that backfires under ideal laboratory conditions. For example, Hong and Plott (1982) conducted experiments with a proposed rate filing policy that would have required shippers on U.S. inland water routes to post prices with a regulatory agency. The effect of this proposal was to raise prices and reduce efficiency in the laboratory, as will be explained in section 8 below. If the behavioral assumptions fail under ideal conditions, the burden of explanation should be shifted to the advocates of a policy.

Tests for Sensitivity to Violations of Structural Assumptions

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[11] See Schwartz and Reynolds (1983) and Gilbert (1989) for discussions of timing assumptions in the contestable markets literature.

[12] Plott (1989) is an updated version of Plott (1982).

[13] DeJong, Forsythe, and Uecker (1988), for example, report that average performance was the same for businessmen and students, but that the market with businessmen subjects showed greater variance. Dyer, Kagel, and Levin (1989) and Burns (1985) find that businessmen sometimes attempt to transfer experience from naturally occurring markets by the use of rule-of-thumb decision procedures in the laboratory. These rules, which may be well adapted for dealing with uncertainties or sales quotas in the field, were sometime unprofitable in the laboratory environment. Ball and Cech (1991) survey the existing work on subject pool effects.

It is important to know whether the power of a theory (or the effectiveness of a policy) is sensitive to violations of "obviously unrealistic" structural assumptions.[14] For example, theories of perfect competition and perfect contestability would be of limited practical value if they were unable to accommodate finite numbers of agents or small, positive entry costs. By altering the treatment conditions of an experiment, these simplifying assumptions can be evaluated one at a time in a manner that is usually not possible with an analysis of data from naturally occurring markets. Another example involves information: most game theoretic models specify complete information or incomplete information in a carefully limited dimension. Game theory, which is the dominant approach to modeling in industrial organization at present,[15] is being applied too simplistically if the accuracy of its predictions is sensitive to small amounts of uncertainty, either about structural parameters or about the distributions that generate these parameters. There is some evidence that noncooperative equilibrium predictions are at least as accurate under conditions of incomplete information as they are under complete information.[16] This may be because subjects do not have to calculate the noncooperative equilibrium strategies in the way that a theorist would, all they have to do is to use the best response to the observed distribution of others' decisions. Moreover, with complete information, subjects may take other's earnings more seriously, which can generate the confounding effects of jealousy and altruism.

Searching for Empirical Regularities

It is often very difficult to evaluate theoretical propositions with firm-level or industry-level data, since the key cost and value parameters of most theories, e.g., marginal costs, are unobserved and must be estimated. Therefore nonexperimental tests of theories are really joint tests involving many auxiliary assumptions. In contrast, a particularly valuable type of empirical research in industrial organization has been the discovery of regularities in relationships between observable variables. For example, the effect of cumulative production experience on unit costs has led to a large theoretical and empirical literature on "learning curves."

Experimentation can also be used to discover and document such "stylized facts."[17] This search is facilitated in laboratory markets in which there are no measurement errors and in which the basic underlying demand, supply, and informational conditions are induced, and hence known. For example, it would be difficult to conclude that prices in a particular industry or trading institution are perfectly competitive if marginal costs or (discounted) transactions prices could not be measured very well, as is usually the case. Moreover, any student who has tried to make sense of the many inter-industry, concentration-profits studies can appreciate the attractiveness of learning something from market experiments, even if the conclusions must be interpreted in the

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[14] Coursey, Isaac, Luke, and Smith (1984) suggest that it is natural to test behavioral assumptions before exploring the sensitivity of the theory to violations of its structural assumptions.

[15] See, for example, just about any issue of the *Rand Journal of Economics*.

[16] This point of view is elaborated in Smith (1989, p.161).

[17] Roth (1986) presents a categorization of types of experiments that includes searching for stylized facts.

context of the specific parametric structure of the experimental markets. One potential problem with the search for stylized facts in the laboratory is that the choice of design parameters becomes more subjective when the work is not guided by a specific theory or a specific fact situation of an antitrust case. Porter (1991, p.566) is skeptical of the use of experiments to search for stylized facts: "In my view, experimental outcomes are of most interest when they are couched as tests of theories, rather than as data-generating exercises."

To summarize, experiments are usually not suited to address empirical issues about the underlying structure of industrial markets. An experiment can be used to test the behavioral assumptions of a theory that relates structure to performance, to stress-test a theory by introducing small violations of its structural assumptions, and to search for stylized facts or patterns in laboratory markets. The particular objective affects the degree of parallelism between the experimental design and the motivating theories or natural markets.

4. DESIGN AND PROCEDURAL ISSUES

My colleague Roger Sherman once remarked that the process of establishing the procedures for a laboratory market is a little like computer programming; a seemingly small error can render the data useless or difficult to interpret. This section deals with some preliminary procedural issues that come up in experiments motivated by IO issues; a more comprehensive discussion can be found in chapter 1 of Davis and Holt (1993).

Instructions

When I read an experimental paper, I often look at the instructions appendix first; this permits me to obtain a feel for the environment before reading the authors' interpretations. Instructions that are complete and clear will facilitate interpretation and replication of the data. The instructions and appended descriptions of procedures are inadequate if the author would not accept the validity of replication by a third party using these instructions.

Although simple tests of game-theoretic concepts can be (and usually should be) conducted without giving economic names to the decision variables, in other, more complicated trading institutions the use of market terminology is valuable in communicating the structure of the payoff functions effectively. In principle, it would have been possible to conduct Chamberlin's market experiments without ever using the words "buyer," "seller," "price," etc., but it would be very difficult to explain the structure to the subjects. The use of more complicated economic terminology, however, increases the risk that subjects' beliefs and decisions will be affected by the terminology and not by the underlying incentives.

The wording of instructions is very important; I generally begin with standard, commonly used instructions, and modify them as needed. For example, consider an excerpt of instructions, loosely adapted from Plott and Smith (1978, p. 150):

> *Instructions - General*
>
> This is an experiment in the economics of market decision making. Various foundations have provided funds for this research. The instructions are simple, and if you follow them carefully and make good decisions, you may earn money, which will be paid to you in cash, privately, immediately after the session ends today.
>
> In this experiment, we are going to set up a market in which some of you will be buyers and some of you will be sellers in a sequence of "trading periods." Attached to these instructions you will find a sheet, labeled Buyer or Seller, which describes the value to you of any decisions you might make. *You are not to reveal this information to any other participant.* It is your own private information.

Notice that there is no statement that can be interpreted as a suggestion of the type of behavior expected by the experimenter. In contrast, the instructions published in a recent issue of a major journal began: "This is an experiment funded by a government agency to study the operation of a competitive market....The objective will be for buyers and sellers to make a contract." The explicit statement of an objective introduces an unnecessary nuisance factor into the incentive structure. Pilot experiments and individual "debriefing" sessions are essential in spotting and correcting problems with the instructions.[18] For example, a student subject once told me that the word "oligopoly" on a receipt form "gave away" the purpose of the experiment, since he remembered from his introductory economics class that oligopolists should collude. This person was unusually successful at cooperating to earn higher profits in a duopoly market session, and therefore, I changed the wording and discarded the data that had already been collected.

Numerical examples in the instructions can be avoided in simple setups, but in complex institutions they are important. One approach is to use symbols such as "p" instead of actual numerical price examples. A computerized posted-price program, written by Doug Davis, solves this problem by having the computer program generate random numbers that are used for the values, costs, and prices that are used in the instructions. Subjects are told that the numbers are randomly generated and that they differ from subject to subject.[19] Perhaps the most common approach is to use obviously unrealistic, large dollar figures, as buyer's instructions that follow, again adapted loosely from Plott and Smith (1978):

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[18] The nature and extent of pilot sessions should be reported. The use of pilot sessions to debug instructions and procedures is less controversial than the use of pilots to refine a treatment structure. It is quite possible that a treatment effect is more apparent in some designs than others, but if one fiddles around until the treatment effect shows up clearly several times in a row, then the interpretation of statistical tests is misleading.

19. Instructions for this program are reprinted in Davis and Holt (1993, appendix A4.2).

Specific Instructions to Buyers

During each market period you are free to purchase from any seller or sellers as many units as you might want. For the first unit that you buy *during a trading period* you will receive the amount listed in row (1) of your decision sheet, marked *value of 1st unit*. If you buy a second unit you will receive the amount listed in row (4) marked *value of 2nd unit*, etc. (For illustrative purposes, we only consider the two-unit case.) The earnings on each purchase, which are yours to keep, are computed by taking the difference between the unit value and the purchase price of the unit bought.

Suppose, for example, that the value of your 1st unit is $200, as shown in row (1) on the right, and the value of your 2nd unit is $180, as shown in row (4). If you pay $150 for your 1st unit, you would enter this amount in row (2), and your earnings would be 200 - 150 = 50 on the 1st unit, as shown by the entry in row (3). Similarly, suppose that you buy a second unit and pay $160, which is recorded in row (5). Then your earnings for this unit would be 180 - 160 = 20, as shown by the entry in row (6). Your total earnings for the period would be 50 (on the first unit) + 20 (on the second unit), which equals 70, to be entered in row (7).

The blanks in the table will help you keep track of your earnings. Regardless of whether or not others have already purchased units during the period, the purchase price for the first unit that *you* purchase *in a trading period* should be entered in row (2) at the time of purchase. You should then record the earnings on this purchase, as directed in row (3). The purchase of your 2nd unit during the period would be recorded similarly in rows (4)-(6), of the column for the period. At the end of the period, record the total earnings on all units for the period in row (7). Subsequent periods will be recorded similarly, but at the beginning of each new period, you will start at the top of the column for that period and work downward. You cannot start purchasing units in the next column until that period begins. You may keep track of your cumulative earnings in the bottom row of the table.

row		period 0
1	value of 1st unit	200.00
2	- purchase price	-150.00
3	= earnings on 1st unit	= 50.00
4	value of 2nd unit	180.00
5	- purchase price	- 160.00
6	= earnings on 2nd unit	= 20.00
7	total earnings for period	70.00
8	cumulative earnings	0.00 (practice)

Figure 1. Decision Sheet for Buyer ___

In this modification of the Plott and Smith (1978) instructions, I removed 1) the prohibition against trades that generate a loss, and 2) the payment of a $.05 "omission" on each unit traded.[20] Specific instructions to sellers are similar, except that the sellers' costs are subtracted from the sale prices.[21]

Design Considerations

It is easy to lose ultimate research perspectives in the mechanical processes of generating and reporting data. Given the relative simplicity of laboratory markets, it is tempting to add complexity to an experiment, but this often results in situations that are difficult to analyze in theory and difficult for subjects to comprehend quickly. It is also tempting to err in the other direction; a researcher with a primary interest in theory may select a very sparse environment in which to consider policy issues that are more marketable with granting agencies. Another prisoner's dilemma experiment is not going to reveal much useful information about subtle issues in antitrust or macroeconomics, regardless of tantalizing interpretations and labels of players' decisions. One key to good experimental work on IO issues is to introduce the right simplifying conditions, without losing the essential features of the market environment.

Besides the choice of trading institution, discussed in the next section, the selection of a cost and demand structure is critical. The values and costs presented in the instructions determine the structure of the market. The example in figure 2 serves to introduce the simple mechanics of induced values. In the figure, the six buyers are indicated by the numbers B1..B6, and the six sellers are numbered S1..S6. Each step in the figure is a single unit. For example, B6 has a unit with a reservation value of $1.90

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[20] Such commissions, which were paid to induce the trade of marginal units, are no longer used (Plott 1989). Prohibitions against trading at a loss may help subjects avoid misunderstandings and keystroke errors, but warnings built into computerized market programs serve the same purpose, without a strict prohibition. Even warnings may be inappropriate in an experiment with the possibility of speculation or predatory pricing.

21. *Specific Instructions to Sellers:* During each market period you are free to sell to any buyer or buyers as many units as you might want. For the first unit that you sell *during a trading period* you will incur the cost listed in row (2) of your decision sheet, marked *cost of 1st unit*. If you sell a second unit, you will incur the cost listed in row (5) marked *cost of 2nd unit*, etc. (For illustrative purposes, we only consider the two-unit case.) The earnings on each sale, which are yours to keep, are computed by taking the difference between the selling price and the cost of the unit sold.

Suppose, for example, that the cost of your 1st unit is $140, as shown in row (2) of the first column on the decision sheet, and suppose that the cost of your 2nd unit is $160, as shown in row (5). If you sell your first unit for $200, you would enter this amount in row (1), and your earnings would be 200 - 140 = 60 on the 1st unit, as shown by the entry in row (3). Similarly, suppose that you sell a second unit at $190, which is recorded in row (4). Then your earnings for this unit would be 190 - 160 = 30, as shown by the entry in row (6). Your total earnings for the period would be 60 (on the first unit) + 30 (on the second unit), which equals 90, to be entered in row (7).

The blanks in the table will help you keep track of your earnings. Regardless of whether or not others have already sold units during the period, the selling price for the first unit that *you* sell *in a trading period* should be entered in row (1) at the time of sale. You should then record the earnings on this sale, as directed in row (3). The sale of your 2nd unit during the period would be recorded similarly in rows (4)-(6) of the column for the period. At the end of the period, record the total earnings on all units for the period in row (7). Subsequent periods will be recorded similarly, but at the beginning of each new period, you will start at the top of the column for that period and work downward. You cannot start selling units in the next column until that period begins. You may keep track of your cumulative earnings in the bottom row of the table.

and a second unit at $.90. An important detail is that the *first* unit purchased by a buyer is required to be the one with the higher reservation value, which implements an assumption that individual demand is downward sloping. Similarly, it is typically the case that a seller is required to sell the unit with the lowest cost first.[22]

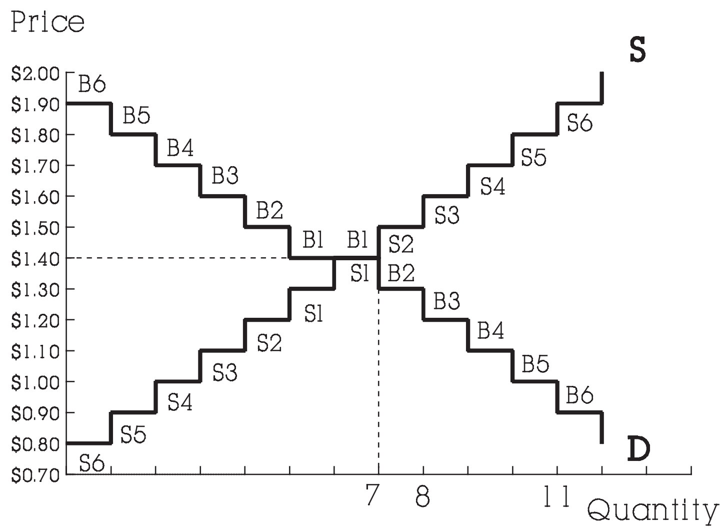

Figure 2. Induced Supply and Demand Structure for a Market Experiment

Figure 2 also illustrates the way in which the efficiency of a laboratory market outcome is usually measured. In the absence of externalities, the perfectly competitive outcome will maximize the total surplus, which equals the total combined earnings of all buyers and sellers in the market. Using this as the standard, one measures efficiency as the percentage of maximum earnings that is obtained. For example, the competitive outcome that results from matching B6 with S6, B5 with S5, etc. generates earnings of $1.10 on the trade between B6 and S6, $.90 on the next trade, etc., for a total of $3.60 on the six units traded. This allocation maximizes earnings and yields an efficiency of 100%. Efficiency is reduced by the failure to trade infra-marginal units or the trading of extra-marginal units. The design obviously affects the interpretation of the absolute levels of the efficiency measure. For example, a large increase in the value of the first unit for B6 will increase total earnings in a session, since this unit is very likely to be purchased. The simultaneous increase in actual and potential earnings will raise efficiency in a somewhat artificial manner.

Value and cost parameters should be selected carefully, to simplify and separate the predictions of alternative theories. Since subjects expect to earn money, earnings should be adequate for all alternative outcomes under serious consideration. For example, Holt (1985) added $.45 to all entries in a payoff table so that the competitive outcome

[22] To induce decreasing marginal costs, the opposite convention could be imposed.

where price equals (constant) marginal cost would generate positive earnings. Subjects to make money during the experiment, and behavior may become erratic if earnings are zero or negative for several stages or market periods. Therefore it is important to have alternative equilibrium predictions provide a positive reinforcement at each stage. A related consideration is that earnings should be adequate for the session as a whole. The general feeling is that, for student subjects, payments should not fall below going alternative wage levels, say $7.00-10.00 per hour in the U.S. Game-theoretic equilibria can be difficult to calculate for the step-function structures that result from the trade of discrete units, and therefore, it is essential to work on applying the relevant theories, so that the design can be simplified as necessary before generating the data. Incredible as it may seem, authors sometimes overlook the most obvious alternative theories. For example, I know of at least five experiments in which sellers select quantities prior to market trading activity, but in no case did the authors calculate the noncooperative (Cournot) equilibrium for the quantity-choice game.

Obviously, the choice of treatments depends on which experimental objective is relevant. For example, a minimal test of the behavioral assumptions of an oligopoly or game theory should reproduce the informational environment that is assumed in the theory. Experiments in which traders do not know each others' costs and values, such as Smith's (1962) initial market experiments, can be appropriately viewed as both sensitivity tests and as efforts to discover stylized facts in realistic environments. Before proceeding, it will be useful to clarify some terminology used to describe information conditions. With *complete information*, participants know all features of the extensive-form game and, in particular, each participant knows the payoff functions of all others.[23] A common practice is to provide participants with only the relevant aspects of their own payoff functions. For example, Fouraker and Siegel (1963) gave subjects a table showing their own monetary earnings as a function of their decision and of the other seller's decision, but they were given no information about the other's payoff table. Fouraker and Siegel and others have called this "incomplete information," but I will refer to it as *private incomplete information* in order to distinguish it from a case in which subjects are given specific probabilistic information about others' payoff functions.[24] I will reserve the term *probabilistic incomplete information* for the approach, first taken by Vickrey (1961), in which the parameters of each subject's payoff function are drawn from a distribution that is known to all subjects.[25] For example, the unknown parameter could be the monetary value of a prize in an auction, and each subject knows his/her own value and knows the population distribution(s) from which others' values are drawn. The

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[23] In particular, complete information requires subjects to know the utility functions that others use to make choices between uncertain prospects.

[24] The reader should be alerted to the fact that some of the Fouraker and Siegel incomplete information treatments had the property that a seller was unable to observe the exact value of the other(s) decision(s) ex post. I will only use incomplete information with reference to payoffs.

[25] I was tempted to refer to the two cases more simply as "private information" and "incomplete information," but besides being inconsistent with Fouraker and Siegel, this would be inaccurate, since game theorists refer to *any* situation with less than complete information about the extensive form of the game as one of incomplete information.

advantage of using probabilistic incomplete information in the laboratory is that initial beliefs are directly induced, giving the experimenter greater control. Murphy (1966, p.298) notes that some subjects in incomplete-information duopoly sessions took it for granted that their partners had the same payoff table, and others expressed "wonder and surprise" when they realized that this was the case.

Finally, the order and nature of structural and institutional treatments can be important. In many market trading institutions, there may be large differences from one group of participants to another. If substantial "group effects" are anticipated, it is sometimes useful to apply different treatment conditions to the same group of participants, and alternate the treatment order in a "blocked" design.[26]

To summarize: attention to detail is critical; a procedural flaw can invalidate an extensive laboratory study. Instructions should be clear and complete enough to permit replication by a disinterested third party. There is no substitute for analysis of substantive theoretical and design issues before the data are generated.

5. TRADING INSTITUTIONS

Before conducting an experiment, many choices must be made about the exact nature and timing of subjects' decisions, e.g., who posts prices and in which order, whether and when discounts can be offered, and whether communications are allowed. Although the rules of trading institutions are rarely discussed in the IO literature, seemingly small variations in the market institution can have large effects, both on the relevant game-theoretic predictions and, as we shall see, on the observed behavior of subjects.[27] For this reason, issues of institutional design have been the focus of much experimental work. It is useful to begin with a description of some of the commonly used laboratory trading institutions before turning to more traditional IO topics. The emphasis in this section is on trading institutions that have direct applications in the study

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[26] Blocking is a term that was first used in agricultural experiments where there are many nuisance variables (moisture, exposure, soil) that differ from one plot of land to another. One solution is to divide each plot of land into two parts and apply one treatment (e.g. seed type) to each part, i.e. to each combination of nuisance variables. Besides sequence order, common nuisance variables in economics experiments are subject experience levels and the university location from which subjects are drawn. A complete, balanced block in this context would be to run each experimental treatment the same number of times for each possible configuration of nuisance variables, e.g., at each location, in each sequence order, and with each experience level. It is not feasible to block every possible nuisance variable. For example, it would be tedious to replicate sessions with every possible permutation of the relation between order of arrival to the experiment and role assignment (large buyer, monopolist, etc.) in a market. In such cases, the nuisance variable can be controlled with a randomized block, e.g. assigning experiment roles randomly. Blocking and other design issues are discussed in more detail in Davis and Holt (1993, chapter 9).

[27] The treatment of trading institutions in the first edition of Scherer's text, although limited, was more detailed than in most theoretical analysis that preceded. In the diagram of the Structure/Conduct/Performance paradigm, one of the "basic conditions" listed was institutional: "...the methods employed by buyers in purchasing (e.g., acceptance of list prices as given vs. solicitation of sealed bids vs. haggling)..." (Scherer 1970, p.4).

of IO issues; in each case the institution will be described, and representative results will usually be presented. One can think of institutions as spanning the range from highly structured two-person bargaining games (with a single price offer and a yes or no response) to large, complex double auctions (with no restrictions on the timing and order of price messages and responses). Most markets of interest to industrial organization economists have more structure than a double auction, and therefore, much of the discussion that follows can be thought of as a categorization of restrictions on the price posting process in different types of auction markets.

The primary differences between the initially bewildering array of laboratory market institutions to be considered in this section are presented in table 1, which will serve as a reference point. The institutions are listed in the first column on the left. The second column indicates the numbers of buyers and sellers, where a "-" indicates one or more, and the number of sellers (buyers) is listed to the left (right) of the "\" mark. For example, an auction institution with a single seller would be represented: "1 / -." The third column shows whether buyers or sellers send price messages: "bids" for buyers and "offers" or "asks" for sellers. The fourth column indicates whether the price messages are selected independently (and in this sense simultaneously) or sequentially. The final column on the right shows how trades are confirmed. The footnotes to the table describe special cases: "auctions" with a single prize and "bargaining games" with one buyer and one seller. These auction and bargaining games are treated in the Kagel and Roth chapters of this handbook.

Posted Prices

Publicly posted "list" prices are especially common in developed economies: sellers quote prices on a take-it-or-leave-it basis in many retail and mail-order situations, for example. Posted prices became common in the last century in large stores in which the owner/managers had to rely on numerous sales clerks.[28] In addition, government regulation in industries such as shipping and alcoholic beverages sometimes requires that prices be posted with the regulatory agency and that discounts not be granted.[29]

In theory, markets with independently selected, non-negotiable prices are analyzed as a Bertrand game. In the laboratory, this institution is called a *posted-offer* (PO) auction, but the laboratory implementation differs from the standard Bertrand model without capacity constraints, in that sellers are almost always given a limited number of "units" that can be sold. The posted-offer auction is summarized in row (1) of table 1. Each seller independently selects a price, and buyers are called on in a random order and

[28] This point is discussed in Smith (1982b), who provides relevant citations.
[29] Eckel and Goldberg (1984) describe such a regulation in the Canadian brewing industry.

Table 1. Laboratory Market Trading Institutions

		# Sellers/ # Buyers	Who Makes Price Proposals	Decisions Sequential or Simultaneous	How Contracts are Confirmed
(1)	Posted Offer Auction[a]	- / -	sellers	offers posted simultaneously	buyers shop in sequence
(2)	Posted Bid Auction[a]	- / -	buyers	bids posted simultaneously	sellers shop in sequence
(3)	Discriminative Auction[b]	1 / -	buyers	bids posted simultaneously	highest N bidders pay own bid prices
(4)	Competitive Auction[c]	1 / -	buyers	bids posted simultaneously	highest N bidders pay N+1st price
(5)	Clearinghouse Auction	- / -	buyers and sellers	bids and offers simultaneously	intersection of bid and offer arrays
(6)	Cournot quantity choice	- / -	price endogenous	seller quantities simultaneously	intersection of total quantity and demand
(7)	Walrasian Auction	- / -	auctioneer	price adjusted sequentially	confirmation when excess demand is 0
(8)	Dutch Auction	1 / -	seller clock	price lowered sequentially	buyer confirmation stops clock
(9)	English Auction	1 / -	buyers	price raised sequentially	sale to highest bidder
(10)	Bid Auction	- / -	buyers	prices raised sequentially	sellers
(11)	Offer Auction	- / -	sellers	prices lowered sequentially	buyers
(12)	Double Auction	- / -	both types	bids raised and offers lowered sequentially	both types
(13)	Decentralized Negotiation[d]	- / -	both types	sequential but decentralized	both types
(14)	List/Discount	- / -	sellers	simultaneous (list), sequential (discounts)	buyers

Key: "-" indicates no restriction on the number of traders.
[a] With 1 buyer and 1 seller, this is an ultimatum bargaining game.
[b] With 1 prize, this is a "1st-price auction," since the winning bidder pays the highest (1st) price.
[c] With 1 prize, this is a "2nd-price auction," since the winning bidder pays the 2nd highest price.
[d] With 1 buyer and 1 seller, this is a bilateral bargaining game.

allowed to make purchase decisions. Buyers can be simulated.[30] The trading rules of a posted-offer market are described in the excerpt reproduced below, which is adapted from Plott and Smith (1978, p.152).[31] This excerpt can be combined with the instructions components given above (general and specific for buyers and sellers) to obtain a complete set of instructions for a posted offer.

> *Market Organization (posted offer):*
>
> The market for this commodity is organized as follows: we open the market for each trading period. Each seller decides on a price offer, which he or she will write on one of the cards provided. The sellers will be given two minutes to submit their prices. After all sellers have chosen prices, the cards will be collected and the prices written on the blackboard.
>
> Buyers will then be free to make bids to purchase whatever quantities they desire and to specify the seller from whom they wish to buy. Bids will be made as follows: a buyer will be chosen using random numbers, and will indicate the seller and a desired purchase quantity. The designated seller will then accept any part of the buyer's bid by stating the quantity he or she wishes to sell. However, a seller who posts a price must be prepared to sell at least one unit at that price. If the first seller selected will not sell all units the buyer wants to purchase, the buyer is free to choose a second seller, and so on.
>
> When the first buyer has made all desired purchases, another buyer will be selected at random and will make bids in the same manner. The process will be continued until all buyers have had a chance to make purchases. This completes the trading period. We will reopen the market for a new trading period by having sellers submit new prices, and the process will be repeated. Except for the bids and their acceptance, you are not to speak to any other subject. Are there any questions?

When I used to conduct posted-offer markets orally, I would assign a color to each buyer, and I would draw colored marbles out of an urn to determine the shopping sequence. There can be a lot of interest and anxiety at this point, since buyers are looking at the sellers' prices on the blackboard, and they will want to be able to go to low-priced sellers before these sellers run out of stock.

When posted offers are run by computer programs, the seller typically is prompted to choose both a price and a maximum quantity to be sold at the price selected, perhaps subject to some restrictions, e.g., on not selling below cost. After prices and quantity limits have been selected independently, the prices (but not quantity limits) are displayed on all traders' computer screens. Then buyers (simulated or human) are chosen randomly from a waiting mode. The quantity limits preclude the necessity of asking the seller about a sale each time that a buyer wishes to make a purchase.

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[30] With simulated buyers, one way to present the payoffs for a duopoly price-choice experiment is to provide a payoff matrix, where the two sellers' prices determine a row and column, and the matrix entry consists of a payoff for each seller. One problem with matrix-payoff experiments is the matrices become large and cumbersome in markets with asymmetries and multiple agents or multi-dimensional decisions. As a consequence, most posted-offer experiments are implemented by explaining payoffs in terms of cost and revenue functions, not matrices.

[31] The Plott and Smith (1978) instructions are for a posted bid institution (described below), and the change to a posted offer required the obvious changes. I also made some minor modifications, mostly to avoid the exclusive use of the male pronoun. This is a Plott and Smith product that has been tampered with; I am to blame for any errors.

In order to understand the effects of the posted-offer institution, consider the simplest bilateral monopoly, with one seller, one buyer, and a single unit. Suppose that the seller has a cost of $1.00 for one unit and the buyer has a value of $2.00 for one unit. With unstructured bilateral bargaining, one would expect the traders to reach a price agreement somewhere in the middle. But if the trading institution enables the seller to post a take-it-or-leave-it price offer, then this institutional asymmetry would benefit the seller. In theory, the seller could sell one unit at a price of $1.99, but such extreme price demands often result in refusal to purchase and a zero efficiency.[32]

[32] A posted offer with one seller and one buyer, each with a single unit, is an example of an "ultimatum bargaining game" in the sense that the seller's non-negotiable price offer is essentially a proposed split of the surplus that equals the difference between the buyer's value and the seller's cost. The buyer must either accept the proposed split or reject, in which case both earn nothing. A posted-bid auction with a single seller and buyer also implements an ultimatum game. This type of bilateral bargaining game is discussed in detail in Roth (chapter ** of this handbook).

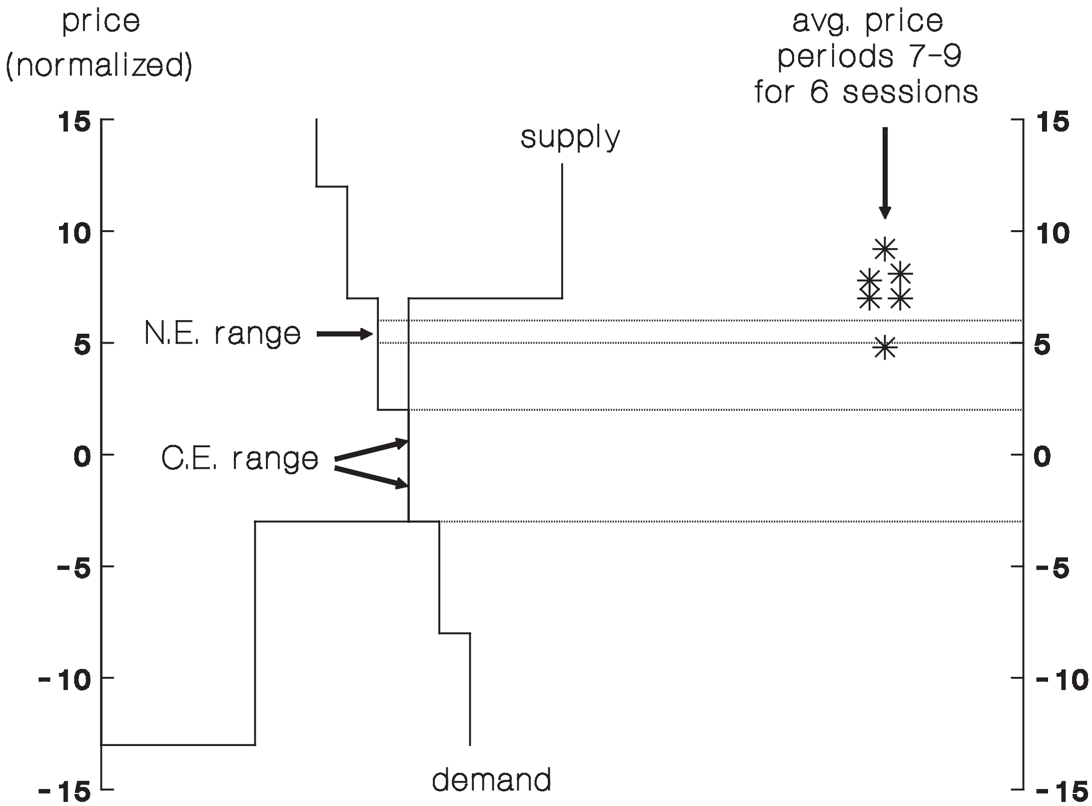

Figure 3. Average Prices for 6 Posted-Offer Sessions
Source: Ketcham, Smith, and Williams (1984), data for Design 2

If the intuition provided by the bilateral monopoly case carries over somewhat to oligopoly cases, then one would expect posted-offer auctions to result in prices that are higher than those observed in more symmetric trading institutions. Although the theory and observed behavior in posted-offer markets will be discussed in the next sections, it can be said here that the overall effect of requiring the sellers to post prices is to raise prices and reduce market efficiency, especially when limitations on sellers' capacities create market power. The price-increasing effect of this institution is illustrated by data from Ketcham, Smith, and Williams (1984), summarized in figure 3. Each of three sellers in this design has five units of capacity; seller one has the units on the lowest supply step on the left side of the figure, seller 2 has the units in the middle step, and seller 3 has the extra-marginal units to the right of the C.E. price, on the upper step. In a competitive equilibrium, the ten units of sellers 1 and 2 sell at a price in the range of (normalized) prices from -3 cents to 2 cents. The price of seven cents is a limit price in the sense that it precludes the third seller, but demand is only nine units here, and sellers 1 and 2 have an incentive to cut price to try to sell their 5th units. Seller 1, with the lowest costs, has the strongest incentive to cut price, and the authors show that a noncooperative Nash equilibrium for the market period game is for sellers 1, 2, and 3, to post prices of 5, 6, and 8 respectively.[33] In equilibrium, all units are sold at prices of 5 or 6, so these prices delimit the "N.E. range" on the left side of the figure. Six sessions are reported, and the average price for periods 7-9 of each session is represented as an asterisk next to the vertical price scale on the right side of the figure. Average prices are at or above the Nash range in the posted-offer markets. In contrast, all but one of the six parallel double auction sessions (not shown) were in the competitive range. This paper is notable in that, unlike other posted offer studies before (and many since), the noncooperative equilibrium price is calculated explicitly, which makes the deviation from competitive prices easier to interpret.

Since the posted-price institution is similar to the rate-posting procedures that have been imposed by government regulators in several industries, the relative inefficiency of the posted price institution has important policy implications (e.g., see Hong and Plott 1982, discussed in section 8 below). The inefficiency that can result from high posted prices may be mitigated by the fact that the posted offer institution reduces negotiation costs. In particular, haggling over price is not allowed, and search is simplified by the public nature of pricing. Indeed, I would not be surprised if the public, centralized nature of the posted-offer institution even enhances efficiency in some environments, as compared with a case in which buyers must incur a cost to travel to each seller to find out about that seller's price. Notice that the comparison here is not with a centralized double auction, but with costly decentralized negotiation. The point is that it is important to be specific about the standard of comparison when discussing the efficiency of a trading institution.

There are many variations and special cases of posted-offer auctions. When the roles of buyers and sellers are reversed, i.e. when buyers post bids and sellers are selected in a random order to make sales decisions, the institution is called a *posted-bid auction* (second row of table 1). The posted bid auction is most commonly encountered in the special case of a single seller. With multiple buyers submitting posted bids to a seller with N units or "prizes," the result is essentially a *discriminative auction* in which the highest N bidders obtain the prizes at their own bid prices (third row of table 1).[34] A variant of the discriminative auction is used in the weekly sale of U.S. Treasury bills to major buyers.

Uniform Prices

Uniform-price Auctions. The price discrimination that occurs in a discriminative auction can cause a sense of regret among buyers, and the sale of all prizes at a uniform price, in contrast, can create an appearance of fairness. A *competitive auction* (row 4) is a uniform price auction in which all *N* prizes are sold at the market-clearing price

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[33] The calculation of this equilibrium is a little more complicated than the discussion here would indicate, since the arrival patterns of buyers must be considered.

[34] The single seller in a discriminative auction has a passive role and is usually simulated in auction experiments, which are discussed in Kagel (chapter ** of this handbook).

determined by the highest rejected bid, the *N*+1st price.[35] Grether, Isaac, and Plott (1981) and (forthcoming) proposed a variation of a competitive auction as a way of allocating landing time "slots" at congested airports in the U.S. The auction allocation procedure was compared with a committee-consensus allocation process in a parallel series of laboratory sessions. The auction was much more efficient at reallocating slots from low-value owners to high-value users.[36]

A *call market* or *clearinghouse auction* is another uniform-price auction, but it differs in that both buyers and sellers submit price bids, offers, and quantity limits in a symmetric manner. The market-clearing price is determined by the intersection of the demand and supply functions obtained by arraying the bids and offers in order, as summarized in the fifth row of table 1. A call market procedure is used to provide the daily opening price on the New York Stock Exchange. Call markets are also used in some of the new electronic trading exchanges in the U.S. and abroad, and therefore, this institution is a candidate for computerized implementations of asset trading. The strong competitive tendencies of call markets are discussed in Smith, Williams, Bratton, and Vannoni (1982), who find that this institution, which they call "P(Q)," is not quite as efficient as the double auction but is more efficient than the other uniform-price auctions considered.[37, 38]

Cournot Games. The Cournot model is probably the most commonly used theoretical apparatus among IO economists; this model is tractable even in general settings, and the results are often (but not always) intuitive. In a Cournot market game, the sellers select output quantities simultaneously, which determine the market price at which all units are sold. It is sometimes useful to think of a Cournot game as a variation of a clearinghouse auction, with simulated buyers and with sellers being forced to offer a price minimum of zero for each unit of output that they decide to offer. Then the aggregate output of all sellers determines the uniform price at which there is no excess demand for the simulated buyers. This institution is summarized in row (6) of table 1.

In a quantity-choice duopoly experiment, the earnings for each seller can be determined by a payoff matrix, where the sellers' decisions determine a row and column. With matrix payoffs, the buyer side of the market is simulated and is built into the payoff matrix, which typically has a prisoner's dilemma structure that arises from the incentives

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[35] In a competitive auction with a single prize, the winner pays the second-highest price, and this is called a "second-price auction," to distinguish it from a "first-price auction," i.e. a discriminative auction with a single prize that is sold at the highest bid price.

[36] One feature of the Grether, Isaac, and Plott proposal was for the primary uniform-price auction to be followed by a secondary aftermarket in which airlines could adjust their portfolios of slots, e.g. to match takeoffs and landings, etc. Rassenti, Smith, and Bulfin (1982) developed and tested a "smart" computer-assisted auction program that was designed to optimize allocations without an aftermarket. Their program yielded higher efficiencies than a comparison set of sessions with the uniform price auction followed by a double auction aftermarket.

[37] Friedman and Ostroy (1989) also report surprisingly competitive results for the clearinghouse auctions in environments in which agents have unilateral incentives to try to manipulate the price outcome.

[38] See Davis and Holt (1993, chapter 5) for a discussion of recent experimental work on variations of call market procedures.

sellers have to defect unilaterally from a joint-profit-maximizing outcome. Some of the first Cournot quantity-choice sessions were reported in a classic study by Fouraker and Siegel (1963), which will be discussed in section 8 below.

A Cournot quantity-choice market can be explained without the use of a payoff matrix by providing subjects with the demand and cost functions, perhaps in tabular form. Subjects choose quantities simultaneously at the start of each period, and the aggregate quantity determines price according to a simulated-buyer inverse demand schedule. Subjects are always given their own marginal cost information, and they may or may not have complete information about demand and others' costs. The key feature is that quantity decisions are simultaneous, and all sales are at the uniform price at which the aggregate quantity intersects the simulated demand. This institution is sometimes called a "posted price" institution, which is very misleading terminology, especially for theorists who are unfamiliar with the experimental literature.[39]

Various applications of simultaneous-quantity-choice institution include: the Carlson (1967) and Johnson and Plott (1989) studies of adjustment and stability, the Wellford (1990) study of horizontal mergers, the Mason and Phillips (1991) study of vertical integration, the Binger, Hoffman, and Libecap (1988) study of cartel quotas, the Binger et al. (1990) study of communication , and the Beil (1988) study of factors, such as monitoring and punishments, that facilitate collusion. The main results from some of these papers will be reviewed in section 8, but one significant pattern can be summarized here: The outcome in multi-period, quantity-choice experiments with more than two sellers is usually *more competitive* than the Cournot prediction. In multi-period Cournot duopolies, the outcomes fall on both sides of the Cournot prediction and may range from perfectly collusive to relatively competitive.

Tatonnement Processes. Perhaps the most familiar uniform price auction for economists is the *Walrasian mechanism* in which the auctioneer calls out a price and agents submit proposed purchase or sales quantities. As indicated in the right-hand column of row (7) in table 1, the price is adjusted systematically until the reported excess demand is zero, at which time all trades are finalized. Notice that this is the first mechanism encountered in the table with a sequential timing element. A full description of a Walrasian trading institution requires a specification of the (real-time) rule that the auctioneer uses to adjust the called price, whether or not this rule is known by the traders. The Walrasian institution was first used in the laboratory by Joyce (1984).

One-Sided Sequential Auctions

Consider a special case of a Walrasian auction with a single seller of a single unit. If the auctioneer starts with a relatively high price, excess supply is positive. As the price is lowered, the first buyer who indicates a willingness to purchase will cause excess demand to be zero, which stops the process. When the lowering of the price is done

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[39] For example, Johnson and Plott (1989) use the terms "posted price" and "passive one price," which is not so bad, to describe markets in which sellers chose quantities simultaneously. I suppose the rationale is that sellers make simultaneous decisions in both quantity-choice and price-choice institutions, and that the main difference is in the slopes of the reaction functions.

mechanically, e.g. with a pointer that falls over a price scale on a "lock" visible to all bidders, this is known as a *Dutch auction* (row 8), which derives its name from its long use in the sale of flowers in Holland. On the other hand, suppose that the Walrasian auctioneer starts with a low price, i.e. with excess demand for the seller's single unit, and raises the price until only one interested bidder remains. This is called an *English auction* (row 9). As Ashenfelter (1989) notes, the seller often uses a reserve price; if the bidding does not reach the reserve price level the auctioneer will "knock down" the item as if a sale occurred, but only later will bidders realize that it was "bought in" by the current owner.

Two other one-sided, sequential auctions are listed in rows 10 and 11 of table 1. A (one-sided) *offer auction* is an institution in which sellers can make price offers at any time, and buyers are able to accept any offer, but not to make counter-offers (bids). This process is similar to what happens as airlines post fares sequentially in real time through a computerized reservation service, and travel agents and their customers make purchases at the best current rates.[40] Conversely, a (one-sided) *bid auction* refers to the opposite case in which buyers can make bids, but sellers can only indicate that a bid is accepted.[41]

Double Auctions

Smith's (1962, 1964) *double auction* (DA) is symmetric in that both buyers and sellers can actively post and accept prices in a public manner, as summarized in row (12) of table 1.[42, 43] A market period usually lasts from three to ten minutes, depending on the numbers of traders and units being traded. The following instructions component, again loosely adapted from Plott and Smith (1978), describes the trading process.[44]

> *Market Organization (double auction):*
>
> The market for this commodity is organized as follows: we open the market for each trading period, which lasts for _____ minutes. Any buyer is free at any time during the period to raise his or her hand, and when recognized by the auctioneer, to make a verbal bid to buy one unit of the commodity at a specified price. Always state your buyer ID number first, and then the price: "Buyer ____ bids $___." Any seller is free at any time to raise his

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[40] One difference, however, is that all traders in a laboratory offer auction observe each trade that is made.

[41] Note that a one-sided bid auction with a single seller of a single unit is similar to an English auction, but it is the bidders, not the auctioneer, who raise the price until excess demand falls to zero. The same comparison can be made between a Dutch auction and an offer auction with a single seller of a single unit who lowers the offer sequentially until one of the buyers indicates an acceptance.

[42] Hess (1972) uses a somewhat different procedure in an early experiment in which buyers were seated on one side of the room and sellers on the other. Negotiations were public because traders had to speak loudly enough to be heard on the other side of the room.

[43] Subjects in a double auction typically make bids and offers for a single unit. Competitive outcomes have also been observed with multiple-unit trading, e.g., Plott and Gray (1989). Friedman and Ostroy (1989) implement a double auction in which subjects make bids and offers for continuously divisible units.

[44] I have changed the Plott and Smith oral bid institution to an oral double auction. I have also added some warnings that avoid common errors that subjects make in recording contracts. As before, I am to blame for any problems that are due to the modifications.

or her hand to state an asking price for one unit of the commodity at a specified price: "Seller ____ asks $___." Any bid or asking price will remain on the blackboard until it is either accepted or improved (replaced by a higher bid or a lower asking price). Any buyer is free at any time to accept or not accept the asking price of any seller, and any seller is free at any time to accept or not accept the bid of any buyer. If a bid or ask is accepted, a binding contract has been closed for a single unit, and the buyer and seller should record the contract price to be used in their earnings calculations. An acceptance cancels all outstanding bids and asks. Any ties in bids, asks, or their acceptance will be resolved by random choice of buyer or seller. Except for bids, asks, and their acceptance, you are not to speak to any other participant. There are likely to be many bids and asks that are not accepted, but you are free to keep trying. Are there any questions?...The market is now open for bids and asks; please raise your hands and do not speak until recognized by the auctioneer.

(to be read after the first contract in the first period):

The contract is: Buyer ___, Seller ___, at a price of $____. This buyer and seller should record their earnings for their 1st unit at this time. Then this buyer and seller will be considering a second unit. All other traders' bids and asks still pertain to their first unit until it is bought or sold.

Traders are typically given no information about the values and costs of other traders (private incomplete information). Smith (1976) recalls that he "...did not seriously expect competitive price theory to be supported....," but that the double auction would give the theory its best chance. Smith's sessions produced prices and quantities that were surprisingly near the competitive levels, although some marginally profitable units did not always trade, e.g., the units of traders B1 and S1 in figure 2.[45]

Due to its impressively robust performance, the double auction is probably the most commonly used laboratory trading mechanism. Such auctions are often conducted on a computer network, either a mainframe network or a network of personal computers.[46] In particular, there is typically an "improvement rule," which specifies that bids (offers) must be successively higher (lower), and a "rank queue," which stores ranked bids that are below the highest outstanding bid (or inversely ranked offers that are above the lowest outstanding offer).[47] Computerization greatly facilitates the bookkeeping associated with queues, but outrageous errors are more common in computerized markets, e.g. entering a price of $10.30 instead of a price of $1.30.

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[45] For more discussion of the competitive tendencies of the double auction, see Smith (1982a).

[46] Williams (1980) and Smith and Williams (1981, 1983) describe the details of a popular mainframe implementation of the double auction on a PLATO (now "NovaNet") network. A double-auction program for networked personal computers is documented in Johnson, Lee, and Plott (1988), and their program is available from the authors on request. The latter program permits subjects to trade in up to twenty double-auction markets simultaneously. There are a number of other PC-based programs for double auctions; these differ in the amount of graphical feedback that traders receive during and between periods. This diversity is good since there is some benefit from being able to check results with different implementations.

[47] Smith and Williams (1983) studied the effects of these institutional features. The simplest baseline is a temporal queue in which the last bid and offer submitted are displayed to the market for a minimum period of time, and bids and offers that arrive are queued by time of arrival. The variability of prices is reduced and the speed of convergence is increased if this temporal queue is changed to a rank-order queue. Although only the best standing bid and offer are displayed under a rank-order queue, the ranking of non-displayed bids and offers induces a type of competitive jockeying for position that seems to enhance the competitiveness of a double auction. The rank-ordered queue is an electronic version of a "specialist's book."

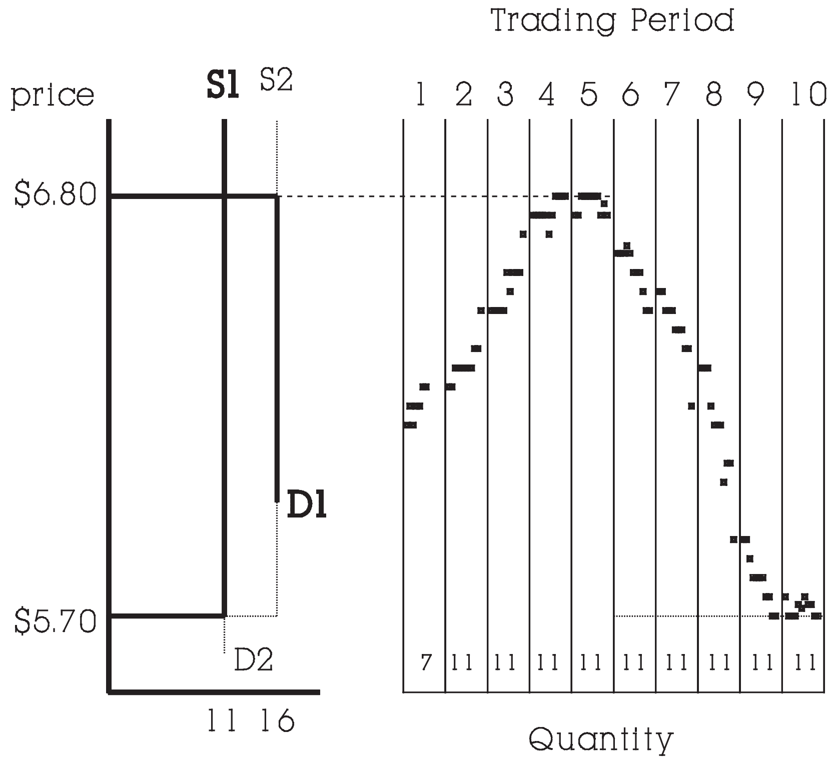

Figure 4. A Rectangular Design
Source: Holt, Langan, and Villamil (1986)

Figure 4 presents the structure and data for a simple double-auction market from Holt, Langan, and Villamil (1986), which replicates a session reported in an earlier version of Smith and Williams (1989).[48] There are four buyers and four sellers in this market. In each of the first five periods, each buyer has four units with values of $6.80, so the market demand, represented by the dark line labeled D_1 in figure 4, is perfectly inelastic at a quantity of 16 for all prices below $6.80. Three of the sellers have three units and one seller has two units, all with costs at $5.70, so market supply at higher prices is vertical at a quantity of 11, as shown by dark line labeled S_1 in the figure. These functions intersect at a quantity of 11 and a price of $6.80, in each of the first five

[48] See Holt, Langan, and Villamil (1986) for a discussion of the slight procedural differences between their session and that of Smith and Williams.

periods.[49] No trader knew the costs or values of any of the other traders. The transactions prices for each period are plotted sequentially as a series of dots between the two vertical lines that fall on each side of the period number. The initial prices in period 1 were about midway between the sellers' costs and buyers' values, and prices rose slightly during the period, with seven units being traded, as indicated by the number above the horizontal axis. There is an excess demand of five units at prices in this range, and therefore, the upward trend in prices continued until prices reached the level of buyers' values in period four. Even though buyers were earning very little in period 5, trading efficiency was 100% at the competitive equilibrium.

At the beginning of period 6, all sellers' capacities were increased to four units at the same cost level as before, and buyers' units were reduced, so that the new demand curve, D_2, intersected the supply S_2 at a price of $5.70 and a quantity of 11. Since subjects received new decision sheets with their own costs or values at the start of each period, no subject had any way of knowing whether others' unit allocations had changed. But surely the sellers, who were earning about a dollar per unit in period five, would have been delighted with additional unit(s), and conversely, the buyers would have been frustrated. These emotions were short-lived, since prices began an immediate decline in period 6, and fell to the competitive level in period 10. Although trading eleven units at any price between $5.70 and $6.80 would yield 100% efficiency, the actual prices converge to the competitive levels, despite the resulting inequality in earnings.

The striking competitive tendency of the double auction institution, which has been confirmed by at least a thousand market sessions in a variety of designs, indicates that neither complete information nor large numbers of traders is a *necessary* condition for convergence to competitive equilibrium outcomes. Gode and Sunder (1989, 1991) have also observed very high efficiencies in double auctions involving simulated traders with "zero intelligence," i.e. traders who use pre-programmed trading rules.[50] Smith (1976, p.57) concludes:

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[49] Following Smith and Williams, a five cent "commission" was paid to each trader for each unit transacted. Since sellers (buyers) were prohibited from selling at a price below cost (buying at a price above value), the effect of the commissions was not precisely equivalent to raising buyers' values and reducing sellers' costs by five cents. Until recently, such commissions were commonly used in double-auction experiments; the effect of small commissions is to induce the trading of marginal units. The incentive effect of the commission, together with the no-loss trading rule, is not exactly analogous to that of commissions paid in actual auction markets, and therefore, the commissions are now used less frequently.

[50] See Kagel (chapter ** of this handbook) for a discussion of auction experiments with zero intelligence traders.

> There are no experimental results more important or more significant than that the information specifications of traditional competitive price theory are grossly overstated. The experimental facts are that no double auction trader needs to know *anything* about the valuation conditions of other traders, or have *any* understanding or knowledge of market supply and demand conditions, or have *any* trading experience (although experience may speed convergence) or satisfy the quaint and irrelevant requirement of being a price "taker" (every trader is a price *maker* in the double auction).

Whether or not these conditions are sufficient for convergence is an issue to be considered in section 6.

The double auction yields higher market efficiencies than institutions with which it has been compared. Some representative comparisons are summarized in table 2.[51] Row (1) shows the Davis and Williams (1986) comparison of their posted offer sessions (82% efficiency) and the parallel series of double auction sessions (96% efficiency) done earlier by Smith and Williams (1982). Both studies used the same pair of designs in which 2/3 of the trading surplus goes to either the buyers or sellers and in which supply and demand schedules that did not shift between trading periods. Ketcham, Smith, and Williams (1984) made a similar comparison of double auctions and posted-offer auctions using the PLATO computer network. Davis, Harrison, and Williams (1993) compare the institutions under conditions of shifting and cycling supply and demand. The PO efficiency is only 66% on average, because there is less information transmitted during posted-offer trading, and as a result, the posted prices do not track the changes in competitive equilibrium prices very well.[52] Finally, note that the double auction has also performed better than the clearinghouse mechanism in the two studies listed in rows (5) and (6) of the table.

The superior performance of the double auction probably has a lot to do with its sequential nature, which provides a strong temptation to make price concessions at the end of the period in order to make sales or purchases of marginal units. The importance

[51] The efficiencies for Davis and Williams (1986) and (1991) are as reported by the authors. In the other cases, the overall efficiencies in table 2 had to be calculated from numbers given in the papers. For each session, I averaged the efficiencies for all periods, and for each treatment, I averaged the efficiencies for all sessions. Exceptions, noted in the footnotes in the table, were motivated by a desire to make a balanced comparison.

[52] Mestelman and Welland (1988) compare the outcomes of double auctions and posted offer auctions when production decisions are made in advance of the trading activity, with no inventory. For their design, the double auction is more efficient, but the prices in the posted offer institution are not significantly higher than in the double auction (unlike the usual case). This is because prices in an oral double auction with advance production are no higher than with production to demand, but prices in the posted offer institution are reduced by the requirement to produce in advance. See Mestelman and Welland (1987) for a description of the market structure for which these conclusions apply. The possibility of inventory carryover with advance production is introduced in Mestelman and Welland (1991). Subjects have trouble keeping inventory costs down, as was also the case in Friedman and Hoggatt (1980).

Table 2. Comparisons of Market Efficiency across Trading Institutions[a]

		Trading Institution				
		DA	PO	CH	NP	PPN
(1)	Davis and Williams (1986)[b]	96%	82%			
(2)	Ketcham, Smith, and Williams (1984)[c]	97%	94%			
(3)	Davis, Harrison, and Williams (1993)[d]	97%	66%[e]			
(4)	Davis and Williams (1991)	98%	92%[f]			
(5)	Smith, Williams, Bratton, and Vannoni (1982)	95%		89%		
(6)	Friedman and Ostroy (1989)[g]	96%		90%		
(7)	Hong and Plott (1982)		87%		92%	
(8)	Davis and Holt (1994a)		94%			83%

Key:
DA - double auction
PO - posted offer
CH - clearinghouse
NP - negotiated prices
PPN - posted price with subsequent negotiations

[a] Efficiencies are average of the overall (all-periods) efficiencies for all sessions in a treatment, except as noted below.
[b] Efficiencies are an average for periods 1-8 for both designs 1 and 2. The double auctions used for comparison were originally reported in Smith and Williams (1982).
[c] Efficiencies are for periods 7-9.
[d] The efficiency listed is an average of the efficiency for "cyclical" and "trend" treatments.
[e] Buyers in the posted offer sessions were simulated.
[f] Buyers were simulated in half of the PO sessions.
[g] The comparison involves the sessions: "ODD1," "ODD2," "CH2," and "CH3." Under each institution, fractional units could be traded.

of this sequential property is also suggested by the classic Plott and Smith (1978) comparison of sequential, one-sided bid auctions (99% efficiency) and a parallel series of non-sequential, posted-bid auctions (95% efficiency). The importance of sequential price reductions is also indicated by the effect of the possibility of a "clearance sale" in a posted-offer market with advance production (Mestelman and Welland 1992). The sale is a second simultaneous price posting at the end of the period that allows sellers to unload unsold units and avoid inventory carryover charges. There is no additional production at the time of this second sale, but this chance to offer a nonselective, public discount increases the efficiencies of posted offer markets. For the advance-production setup used by Mestelman and Welland (1992), there is very little difference between efficiencies in double auctions and those in posted offer markets with the clearance sale. Finally, it should be noted that double auction efficiencies can be degraded by the introduction of seller fixed costs that preclude the existence of a competitive equilibrium (Van Boening and Wilcox 1992).

A second stylized fact that emerged from double auction experiments (Smith 1962) is that the price tends to converge to the competitive level from below if producer surplus exceeds consumer surplus at the competitive price, and from above in the reverse situation.[53] This convergence pattern is necessarily observed in the design in figure 4, but it also shows up with other, less extreme imbalances in trading surplus. Holt and Villamil (1990) argue that the direction of convergence in double auctions can also be affected by an extreme asymmetry of market power, as is the case in figure 5. (Market power is discussed in section 7 below.) Moreover, the initial prices in early trading periods seem to be pulled away from the competitive equilibrium towards the average of the lowest costs and highest values, i.e. the costs and values of the first several units on the left sides of the supply and demand functions. Finally, the division of the surplus at the competitive price does not affect the direction of convergence in posted offer markets, where prices tend to exceed competitive levels in most designs.[54]

Note that table 2 contains no comparisons between double and one-sided sequential auctions. Smith (1964) initially observed a consistent ranking: bid-auction prices > double-auction prices > offer-auction prices. Roth (1986) noted that there is no theoretical basis for expecting such a ranking, and therefore, in the absence of additional studies, the ranking should not be regarded as an established pattern. Interestingly, the pattern observed by Smith did not appear in another series of experiments with a different parameterization (Walker and Williams 1988). This episode is important because it illustrates the importance of 1) evaluating results in the context of theory, and 2) verifying results through a series of related experiments.

Decentralized Negotiations

The simplest, symmetric two-sided institution with a sequential dimension involves unstructured, decentralized negotiations. Recall that Chamberlin's (1948) subjects were allowed to roam freely around the room and negotiate contracts, which were reported to the front desk. The most striking departure from the competitive outcome predicted by the intersection of the induced (step-function) supply and demand curves was the tendency for quantity exchanged to be too high.

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[53] Chamberlin (1948) conjectured that asymmetries in the valuations and costs of infra-marginal units would have a stronger effect on price than asymmetries for extra-marginal units.

[54] Davis and Williams (1986) use the Smith and Williams (1982) design in a series of posted offer sessions, and report that the distribution of the surplus has no significant effect on the direction of convergence in these PO markets.

Chamberlin attributed the high sales quantity to the decentralized nature of the bargaining process, and he supported this conjecture with a *simulation* in which he first constructed a series of submarkets by randomly drawing three buyer cards and three seller cards from a deck of cost and value cards, and enacting all trades that would occur in a competitive equilibrium for the submarket.[55] Un-traded cards were returned to the deck, and the process was repeated many times. This simulation generated transactions quantities that exceeded the competitive level, and the excess quantity declined as the size of the submarkets was increased.

To understand how decentralized negotiations can generate high trading volume, the reader may wish to calculate the maximum number of units that can be traded (at a positive profit from each agent) for the market depicted in figure 2. In determining the trade pattern that maximizes the number of (individually profitable) transactions, the reader should specify the exact order in which all trades occur and the total earnings that result from the allocation. Notice that the number of units traded can exceed the competitive quantity of six or seven, but that price has to be quite variable to generate (inefficient) trades of extra-marginal units with high costs or low values. This is the way that price variability, which goes with decentralized trade, can generate the inefficient trade of extra-marginal units. If eleven units trade, for example, total earnings are reduced by $2.00 to a level of $1.60, for an efficiency of 44%. This excess-quantity result is discussed in more detail in section 8.

Discounting

Both in a Bertrand game and in the corresponding posted-offer auction, sellers are not able to discount from the posted list price. But buyers are in fact able to solicit and obtain price concessions in many markets for producer goods and consumer durables. Note that sellers in a double auction are able to reduce price at any time during a market period in response to the reductions of rivals, but such reductions are public and nonselective in the sense that the price reduction is offered to all buyers. Price reductions are also public and nonselective in the interesting "clearance sale" structure of the Mestelman and Welland (1992) posted offer markets, described above. One striking regularity about many producer-goods markets is the prevalence of discounts that are selective and private. Indeed, the apparent absence of secret discounts from list prices was one of the factors that triggered the Federal Trade Commission investigation of contractual practices of lead-based gasoline additive producers (the *Ethyl* case).[56]

Experiments with discounts from posted list prices are relatively rare. Grether and Plott (1984), motivated by the *Ethyl* case, conducted sessions in which one of the treatments involved the electronic communication of sellers' list prices to buyers and sellers in individual rooms. Then buyers could contact sellers by telephone to seek

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[55] Note the difference between an experiment with human traders and a simulation with artificial agents that use exogenously specified trading rules.

[56] *Ethyl Corporation, E.I. du Pont de Nemours and Company, PPG Corporation and Nalco Chemical Corporation*, Docket no. 9128. Federal Trade Commission. This case will be discussed in more detail in section 8.

discounts, subject to contractual constraints that were the target of the FTC litigation. More recently, Davis and Holt (1994a) used a "list/discount" institution in which sellers post prices at their computer terminals, and buyers are selected from a waiting queue in a random sequence as in a posted-offer auction (see row 14 of table 1). Once selected, a buyer can request a private discount, and the seller may or may not respond with a price reduction for that particular buyer.[57] One significant result is that sellers will offer discounts if given the opportunity, at least in the market structure used by Davis and Holt (1994a). This propensity to discount highlights the importance of the restriction to a non-negotiable price in the commonly-used posted-offer institution. In particular, the results of posted offer experiments should not be invoked casually when considering policies in markets where discounts are common. When discounts are permitted, it may not be as unfortunate for a seller to post the highest price, since buyers may come anyway in search of large discounts. This observation may help explain the high list prices reported by Davis and Holt (1994a) for some of the sessions with discount possibilities, which in turn reduced efficiencies (see the bottom row of table 2).[58] In other sessions, sellers seemed to compete on the basis of list prices, which generated very competitive outcomes. The inefficiencies in sessions with high list prices is interesting. When list prices are high and deep discounts are common, there can be a considerable variation in transaction prices. The extent of this variability depends on the costs that buyers face in their price search process. When inflated list prices lose their informational value, market efficiency suffers.

Other Institutions

There are many ways to alter the posted offer and double auction institutions described in this section. These alternatives deserve serious consideration for several reasons. Discounts from posted prices are pervasive in many markets of interest to industrial organization economists, e.g. producer goods markets; indeed the absence of discounts (in combination with other factors) can raise antitrust scrutiny. And while the double auction approximates the structure of many asset markets, there are few (if any) producer and consumer goods markets in which bids and offers are displayed publicly in continuous time. Given the documented importance of the rules of the trading institution, it is important to use institutions carefully, with an eye to parallel naturally occurring markets. Hong and Plott (1982) and Grether and Plott (1984) are particularly good examples of studies in which the alternative trading institutions were carefully designed to address relevant antitrust and regulatory issues. One interesting variation is the introduction of continuous trading in a continuous-time context. Millner, Pratt, and Reilly (1990a and 1990b) have developed a flow-market version of the posted-offer institution.

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[57] The computer program that controls the experiments was written by Doug Davis of Virginia Commonwealth University.

[58] In some sense, it is surprising that nonbinding list prices would have any effect, since, for example, buyers seem to ignore nonbinding, false advertising in other contexts (Lynch, et al. 1986, conclusion 14). One relevant difference may be that Davis and Holt use a restriction that buyers cannot visit a seller twice in the same period, which introduces a type of search cost.

Sellers can alter prices at any instant, and the simulated demand determines sales flows per unit of time as a function of the prices. Although flow markets have not been analyzed theoretically, they introduce an element of realism that, as we shall see, is useful in the analysis of "hit-and-run" entry.

Disadvantages of the Cournot Quantity-Choice Institution

After reviewing the differences between diverse pricing mechanisms, the market-clearing assumption of the Cournot model appears to be quite mechanical. The Cournot model is much more commonly used in theory than it is in experiments, and in this case, it is the experimentalists who are right, in my opinion. One disadvantage of this quantity-choice institution is that behavioral assumptions are built into the market institution; the implicit assumption is that, after having produced their output quantities, competition will drive price down to the level at which there is no excess demand. One defense of the Cournot assumption is that it is thought to be a reasonable predictor of the result of *price competition* with small numbers of sellers. For example, Spence (1976, p.235) notes that "...the quantity version captures a part of the tacit coordination to avoid all-out price competition, that I believe characterizes most industries." Hart (1979, p.28) makes a similar argument: "We reject the Bertrand approach because it has the implausible implication that perfect competition is established even under duopoly." These arguments cannot be used to justify the exogenous imposition of the Cournot institution in laboratory markets. Indeed the arguments suggest the opposite approach: i.e. the use of a price-choice institution to see whether the prices that result approximate the level determined by a Cournot equilibrium.

A second, more persuasive defense of the Cournot assumption has been provided by Kreps and Scheinkman (1983), who analyzed theoretical models in which firms simultaneously choose capacity in the first stage, and after capacity decisions are observed, choose prices in the second stage. Noncooperative behavior in the Kreps and Scheinkman two-stage game generates the Cournot price and quantity outcome. But for most purposes, it is a large leap to "hard-wire" the price determination into the mechanics of the experimental institution exogenously, especially since the Kreps and Scheinkman result is sensitive to the rationing rule used to allocate excess demand.[59]

From a game-theoretic point of view, the relevant issue to be decided is: what is it that firms choose independently? If firms make key input purchases that limit their quantity decisions before learning others' decisions, then it would be appropriate to implement some variant of the Kreps and Scheinkman model with second-stage price competition. But if firms set prices independently, with sales quantities being determined jointly by buyers' responses to all prices, then a price-choice model is appropriate. In either case, there are many possible institutional arrangements under which actual transactions prices can be negotiated.

[59] See Davidson and Deneckere (1986).

Many results in the theoretical IO literature are reversed when one switches between Bertrand price-choice and Cournot quantity-choice assumptions.[60] The same issue arises in antitrust policy, where one would take a much more tolerant view of horizontal mergers if the industry is characterized by price rather than quantity competition. Experiments cannot settle the issue of whether firms do or do not make key, independent input decisions that pre-commit them to quantity decisions. In contrast, experiments can indicate whether the Cournot outcomes are observed if the trading rules impose quantity pre-commitment prior to the market trading that determines prices. I know of no study that directly addresses this issue.[61] Mestelman and Welland (1987, 1988), Mestelman, Welland, and Welland (1987), and Johnson and Plott (1989) report prices that converge to competitive levels when quantity pre-commitment decisions are followed by auctions (double or posted offer) that determine prices. These experiments, however, involve four-6 sellers, so the Cournot prediction (which is not provided) may be close to competitive levels. For the design used by Mestelman and Welland (1987, 1988) and by Mestelman, Welland, and Welland (1987), I calculate that the Cournot equilibrium involves a 1-unit restriction of output by the seller with the marginal units (#2), which would raise price about six cents and raise this seller's profit by about four cents.[62] Therefore, the design does not distinguish between the Cournot and competitive outcomes very well, but the clearly competitive outcomes for this design do not provide support for the Cournot model.

The sections that follow describe how these laboratory trading institutions have been used in the reexamination of traditional IO issues, beginning with the exercise of monopoly power. Before proceeding, it is useful to summarize.

Trading institutions are characterized in table 1, with posted price auctions in rows (1)-(3), uniform-price institutions in rows (4)-(7), one-sided sequential auctions in rows (6)-(11), and double, sequential institutions in (12)-(14). The more structured, simultaneous-choice institutions at the top of the table are generally those for which it is easiest to derive the implications of relevant theories. More complicated institutions, especially those that allow discounting and active buyer shopping for discounts, are difficult to analyze but provide rich environments that are appropriate for the study of markets with large buyers, such as producer-goods markets.

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[60] This reversal may seem curious, since both Cournot and Bertrand games can be represented in matrix form as prisoner's dilemmas, with a Nash equilibrium that is Pareto dominated by a collusive outcome. The reversal of comparative statics effects is caused by the fact that the reaction functions have positive slopes in price choice models (one should raise price if competitors do so) and negative slopes in quantity choice models (one should expand quantity if others restrict their quantities, and thereby shift your residual demand outward).

[61] The first experimental and theoretical analysis of capacity choice decisions can be found in several papers, including Sherman (1969) and (1971), which are collected in Sherman (1972, part II). The emphasis is on risk attitudes and psychological factors that affect the propensity to cooperate when capacity decisions precede price competition.

[62] I assumed that price is determined by the midpoint of the vertical overlap of demand and supply functions.

Double auctions, which mimic markets with organized exchanges, e.g., securities, do not implement the message structure of markets of most interest to IO economists. The double auction tends to yield efficient outcomes, as indicated by the comparisons in table 3. Prices can be higher, and efficiencies lower, in the posted-offer institution, however. This institution seems to be a good approximation of the pricing process in retail situations in which sellers price on a take-it-or-leave-it basis, perhaps because buyers are small and relatively insignificant. But sellers in typical posted-offer designs will offer private, selective discounts to human buyers if such discounts are permitted, so the results of PO markets with a single-price restriction should be interpreted with caution. The simultaneous nature of PO price competition implements a situation in which sellers make price decisions at discrete intervals. In contrast, the newly-developed flow-market version of the posted-offer institution may prove to be useful in the analysis of markets with more-or-less continuous opportunities to monitor and adjust price and quantity decisions.

Despite its prominence in the theoretical literature, the Cournot model is deficient for the experimental study of many IO issues because the essential mechanics of price determination are simulated. One open question, taken from Kreps and Scheinkman (1983), is whether quantity pre-commitment and Bertrand competition yield Cournot outcomes (in the laboratory).

6. MONOPOLY REGULATION AND POTENTIAL ENTRY

Two aspects of monopoly performance that receive the most attention are: the welfare loss due to prices that exceed marginal cost, and the presence of supra-competitive profits.[63] Most economists, however are more worried about the traditional cure, regulation, than the monopoly problem itself, especially since many monopoly positions are obtained and protected by regulation. The standard, decreasing-cost rationale for regulation has been questioned by the proponents of the "contestable markets hypothesis," who argue that potential competition, under some conditions, is as effective as actual competition in constraining market power. The first part of this section is a review of monopoly experiments, which is necessary to evaluate the extent of the monopoly problem in laboratory markets, for purposes of later comparison with decentralized regulatory schemes that are discussed in the second part. The third part of the section summarizes experiments in which one seller's monopoly position can be contested by equally efficient potential competitors. Experiments discussed in the final part pertain to an incumbent seller's ability to price in a predatory manner in an effort to secure a monopoly position.

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[63] These two aspects of the monopoly problem are related, but not perfectly. For example, monopoly pricing in the box design of figure 5 yields high profits, but no welfare loss. Other aspects of monopoly performance, such as the possibility of a reduced incentive to innovate, are more controversial and have been generally ignored in the experimental economics literature, with the exception of Isaac and Reynolds (1988, 1992).

Before proceeding, it will be useful to clarify the terminology that will be used to describe subject experience. By common usage, "experienced" means that all subjects in a session have participated in at least one previous session using the same trading institution, but possibly with different market parameters and role assignments, e.g., as buyers or sellers. The terminology to be used here is: *inexperienced*: have not participated with the same institution; *experienced*: have participated at least once with the same institution; *design experience*: have participated with the same institution and parameters; *role experience*: have participated with the same institution and role.

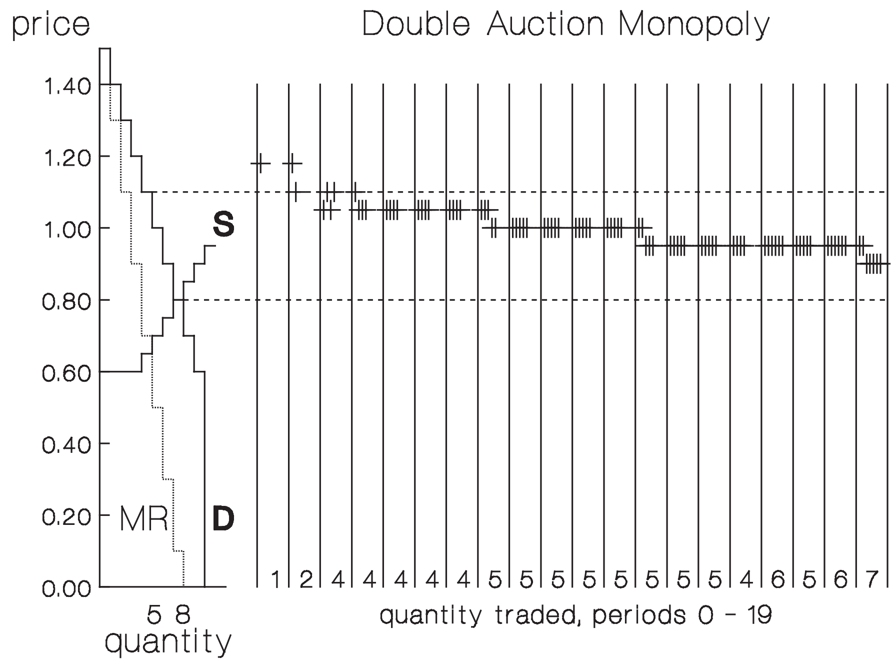
Monopoly

Smith (1981a) reports the results of several posted offer sessions that illustrate the effect of the type of trading institution on a monopolist's ability to exercise market power. Figure 5 shows two sessions with identical cost and demand conditions; in each case the monopolist has increasing marginal costs for twelve units, and the five buyers have two units each at varying valuation levels. The solid marginal cost line (labeled *S*) and the dotted marginal revenue line (labeled *MR*) cross at a quantity of five units, yielding a monopoly price of $1.10. The "competitive" price at which marginal cost and demand intersect, is $.80. These sessions were conducted under conditions of private, incomplete information. The top chart shows the sequence of transactions prices for twenty four-minute periods of double auction trading; notice that there is a downward trend and that the prices are about midway between the competitive and monopoly levels in the last half of the session. The index of monopoly effectiveness, defined in equation (1) below, is approximately .6 in the final periods of the session.

$$(1) \qquad M = \frac{(\textit{actual profit} - \textit{competitive profit})}{(\textit{monopoly profit} - \textit{competitive profit})} .$$

Other double auction monopolies that fail to yield monopoly prices are reported in Smith and Williams (1989). In contrast, the monopolist in the *posted-offer* session shown in the bottom chart of figure 5 achieves a monopoly outcome with five units sold and $M = 1$.

Plott (1989, p. 1144) notes that the monopolist has trouble exercising power in a double auction because buyers are not behaving as passive price takers, but rather are withholding purchases. This buyer resistance caused *M* to be negative in one of Smith's other replications of this design. Porter (1991) has questioned this interpretation by noting that, in a static, single-period context, the monopolist has an incentive to lower price at the end of the period in order to sell marginal units. Porter conjectures that the noncooperative equilibrium in this context may involve pricing in the range between competitive and monopoly levels.



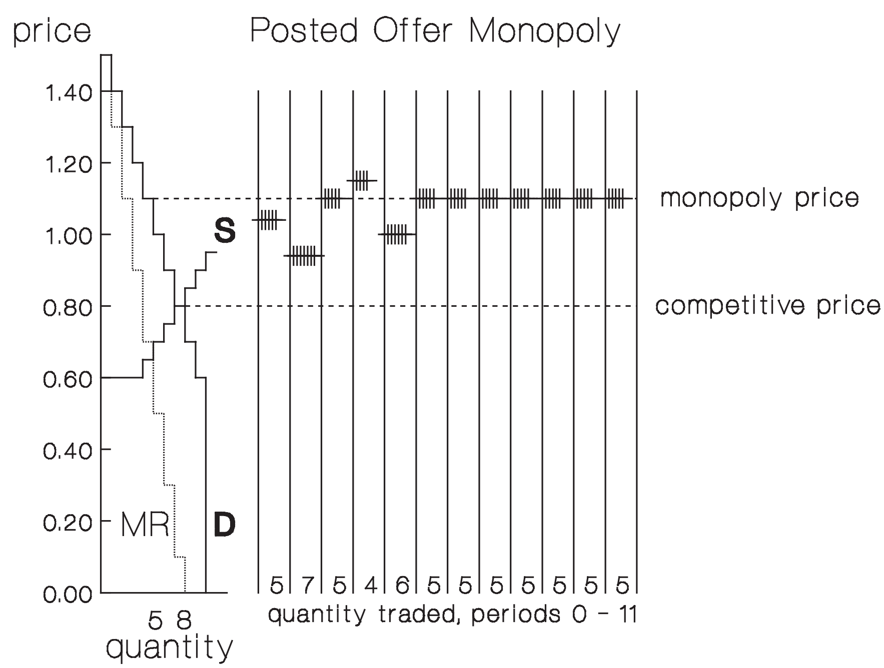


Figure 5. Two Monopoly sessions: A Comparison of DA and PO Outcomes
Source: constructed with data from Smith (1981a)

One key to the monopolist's success in the posted-offer market can be seen by considering buyers' incentives. Once a buyer is given an option to shop and decides not to purchase all profitable units, there is no chance to recover the lost profits later in the period. In a posted-offer auction, when viewed as a static, single-stage game, it is always a dominant strategy for each buyer to purchase all profitable units; it would only make sense to withhold purchases in a multi-period posted offer auction, where such behavior may affect price posting in subsequent periods. This is different from the double auction case in which buyers can hold out in the early part of a period, knowing that if the price is not lowered as a result, they have a chance to make a purchase later in the same period (Harrison, McKee, and Rutstrom 1989, p. 68).

When the tables are turned and the buyers post bids for the product of a single seller, the monopolist is in a much weaker position. Prices were quite competitive in these sessions, which were also conducted with private incomplete information and the parameters of figure 5 (Smith 1981a). The monopoly effectiveness index, averaged over the final period for all periods for all sessions in each treatment cell revealed this pattern:

double auction monopoly	$M = .36$,
posted offer monopoly	$M = 1.00$,
posted bid monopoly	$M = .15$.

Smith's (1981a) posted-offer auction is perhaps unusual in that each buyer only has one unit to purchase profitably at the monopoly price, so under-revelation of demand means accepting a profit of zero. This may discourage under-revelation.[64] In PO monopoly sessions with a similar demand structure and with increasing costs, Isaac, Ramey, and Williams (1984) also observed one monopolist who fully exploited the market power, but two of the other three were unsuccessful at maintaining supra-competitive prices. The index of monopoly effectiveness for the final period, averaged across sessions, was only .45, about halfway between the theoretical values for competitive and monopoly outcomes.

Coursey, Isaac, and Smith (1984) also report the results of four monopoly PO sessions, but with decreasing costs up to capacity. The structure is that of a natural monopoly in the sense that, when one seller is producing at minimum average cost (which is also the capacity in this design), demand would be insufficient to enable another with the same cost function to sell any output at a profit. Significant demand withholding by experienced buyers prevented two of the monopolists from sustaining monopoly prices. Again, the index of monopoly effectiveness ended up being rather low: .56, as compared with a theoretical value of 1.0. (In this decreasing-cost, natural-monopoly design, the authors define the competitive quantity to be the largest that can be sold without a loss by at least one seller, and the corresponding "competitive price" is equal to the firm's average cost. This is the price used as the baseline for calculating monopoly *M* values.)

[64] This observation does not affect the validity of the comparisons of the DA and PO trading institutions, it merely suggests that prices may be unusually high in all of the sessions with this design.

Table 3. The Effects of Restraint Mechanisms on Monopoly Effectiveness in Posted-Offer Auctions

	subject experience	buyer type	cost function	monopoly *M* value	Loeb-Magat *M*-value	contested market *M* value
Smith (1981a) (1 session)	?	human	increasing	1.00		
Isaac, Ramey, Williams (1984)[a]	inexperienced	human	increasing	.45		
Coursey, Isaac, and Smith (1984)	experienced	human	decreasing	.56[b]		.02[b]
Harrison & McKee (1985)[c]	design experience	simulated	decreasing	.72	-.36	.09
Harrison, McKee, Rutstrom (1989)[d]	inexperienced	simulated	decreasing	.44	-.22	.00
Harrison, McKee, Rutstrom (1989)[d]	design, role experience	simulated	decreasing	.78	-.24	.06

Key: *M* = [trading profit - CE profit]/[monopoly profit - CE profit], calculated as an average of M values for the final period common to all sessions in a treatment cell. The trading profit does not include regulatory subsidies.

[a] The final-period value of *M* for was estimated from a figure in their paper.
[b] The CE profit used to calculate the M value is determined by a price-equals-average-cost condition.
[c] Data from experiments C2 (with complete demand information) and C4 (with an opportunity for conspiracy) were omitted. The subjects in some sessions were preselected on the basis of a test for risk neutrality. Some of the contested markets involved two sellers, and others involved three sellers.
[d] All subjects were preselected on the basis of a test for risk neutrality, and some of the contested market sessions involved three sellers.

A number of other papers report monopoly PO experiments under a variety of information and cost conditions.[65] Table 3 provides a comparison of final-period monopoly *M* values (but recall that Coursey, Isaac, and Smith 1984, is not strictly comparable since they based their *M* value calculations on a condition that price equals average, not marginal cost). The papers just discussed are listed in the first three rows; the three studies listed at the bottom, in contrast, involved simulated buyers, as can be seen from the "buyer type" column. One reason for using simulated buyers is that

[65] In addition, see Palfrey (1983, 1985) for an experimental analysis of pricing when a multi-product monopolist can sell products jointly in a "bundle."

Coursey, Isaac, and Smith had noted the effect of buyer under-revelation on the relatively low values of *M* in their monopoly sessions. Harrison and McKee (1985) argued that the use of simulated buyers is an interesting treatment because it is difficult to take the possibility of buyer under-revelation very seriously in many natural monopoly markets (e.g., telephones) in which the buyers are small and dispersed.[66] Harrison and McKee (1985) observed higher values of monopoly effectiveness in their simulated-buyer, monopoly markets, but the participants had design experience with the decreasing-cost design, subject to an additive parametric shift, as indicated in the experience column of the table.[67]

Another interesting issue is the effect of experience. As shown in table 3, Harrison, McKee, and Rutstrom (1989) subsequently found that subjects with design and role experience were much more effective monopolists (*M* = .78) as compared with inexperienced monopolists (*M* = .44), even when buyers were simulated in both experience conditions. They conclude that experience makes subjects into better monopolists, especially experience in a separate, earlier experiment: "Experience in the form of more periods in the initial session is not equivalent to coming back and participating a second time despite having to face new cost and demand conditions in the latter situation." (p. 89) They also observed that the data with experienced subjects are less variable: "This suggests that small sample observations with inexperienced subjects be viewed with some skepticism." (Harrison, McKee, and Rutstrom (1989, p. 90). The effects of experience in other contexts will be discussed in detail in section 8 below.

Harrison, McKee, and Rutstrom also evaluate the effects of altering the shape of the cost function. They find that subjects are: 1) better monopolists with constant costs than with decreasing costs, and 2) better monopolists with decreasing costs than with increasing costs (Mann-Whitney probabilities 1.00 and .90 respectively). But the indices of monopoly effectiveness for period four, the final period common to cost treatments with experienced subjects, are: .77 with constant costs, .76 with decreasing costs, and .09 with increasing costs.[68]

To summarize, pricing in posted-offer monopolies is higher than in double-auction monopolies. Posted-offer monopolists are generally able to hold prices well above competitive levels, but on average, profits are significantly below theoretical monopoly levels. Monopoly pricing in posted offer markets is facilitated by experience and by

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[66] Vernon Smith has told me that this conjecture has never been tested formally. The use of human buyers may make a difference even in a large-numbers situation, since buyers may withhold demand out of a dislike for monopolies. And the monopolist may fear that human buyers will resist a price increase after a decrease has occurred. Smith (1981b) speculates on the importance of using human buyers, as opposed to simulated buyers.

[67] The observation that posted prices are higher with simulated buyers is consistent with the results of Brown-Kruse (1991) in non-monopolized, contested markets; she reports that pricing is more competitive with human buyers.

[68] The effect of demand characteristics on monopoly posted offer pricing has not been explored systematically, with the exception of the Reynolds (1991) ongoing experimental study of the effects of durability. This experiment is designed to evaluate the "Coase conjecture" that the power of a monopoly producer will be diminished or eliminated if the good is durable and can be resold. Preliminary results provide some support for the Coase conjecture under private-information conditions.

constant or decreasing costs. The effect of using simulated buyers, as compared with a small number of human buyers, is probably to facilitate monopoly pricing a little. I would conjecture that, under posted-offer rules, natural markets with large numbers of small buyers are best approximated by simulated buyers in the laboratory.

Decentralized Regulatory Proposals

Despite the fact that rate-of-return-regulation is the most commonly used procedure in natural-monopoly situations, it is known to create incentives for inflating both costs and the rate base. Even if an astute regulator can avoid these abuses, this system does not allow for subsidies, so rate-of-return regulation would, at best, result in average-cost pricing. Given the heavy informational requirements of rate-of-return regulation, there is considerable interest in alternatives, especially alternatives with subsidies that may generate efficient marginal-cost pricing outcomes.

Loeb and Magat (1979) proposed a mechanism in which the regulator promises to pay a subsidy that equals the Marshallian consumer surplus at the price selected by the monopolist. Since the regulated monopolists' profit would then include all surplus, the efficient, marginal-cost price would result if the regulator knows the demand curve and the monopolist knows the cost curve. When these information conditions are implemented in the laboratory, the Loeb-Magat mechanism works nicely; prices are driven down to competitive (marginal-cost) levels, as indicated by the low numbers in the "Loeb-Magat *M*-value column of table 3.[69] Harrison and McKee (1985) found that the large subsidies generated by this mechanism could be eliminated by having prospective monopolists bid for the right to be a monopolist. They used a second-price auction designed to induce demand revelation with risk-neutral subjects, and they preselected their subjects on the basis of a test for risk neutrality.

The most significant drawbacks of the Loeb-Magat mechanism are the magnitudes of the subsidies and the requirement that the regulatory agency be able to calculate surplus-based subsidies accurately. Finsinger and Vogelsang (1981) proposed a modification in which the subsidy is an approximation of Marshallian surplus that is calculated on the basis of observed prices and quantities. Let p_0 and q_0 denote the initial (supra-competitive) price and quantity before the regulation is implemented, and let p_t and q_t denote the prices and quantities demanded in period $t = 1,2,....$ Then the subsidy in the first period is: $q_0[p_0 - p_1]$, which generates a penalty if price is increased. The subsidy in each subsequent period is the previous period's subsidy plus a term that represents the quantity-weighted value of the price reduction, so in period two the subsidy is: $q_0[p_0 - p_1] + q_1[p_1 - p_2]$, and so forth. With a uniformly decreasing price sequence, these subsidies generate a step-function approximation of the gain in consumer surplus, which provides the intuition for the theoretical attractiveness of the mechanism. This mechanism

[69] The negative Loeb-Magat *M*-values are due to the fact that the marginal cost curve overlaps demand on a 25 cent vertical region for the designs being reported, and the highest competitive price was used to calculate the C.E. profit, so $M = 0$ at this highest competitive price. The *M* value becomes negative as the monopolist lowers price below the highest competitive price, but the reduced trading profit is exactly matched by increased subsidy payments.

does not require knowledge of the demand curve, and the subsidies can be much lower than those of the Loeb-Magat mechanism.

One problem is that a price increase results in a penalty that must be paid in all future periods. Since the penalty is calculated on last-period's high demand at the lower price, a price increase followed by an equal decrease will result in a negative increment to surplus forever after.[70] This unforgiving aspect of the mechanism caused bankruptcies in three of the four sessions in which it was used in Cox and Isaac (1986). Bankruptcies occurred whether or not the monopolist was given complete information about the demand curve. Cox and Isaac (1987) developed a modification of the Finsinger-Vogelsang subsidy calculation for the case of a price increase. This modification avoids the penalties that are generated by price cycles; there is a permanent penalty for permanent price increases, but not for price increases that are reversed. All ten sessions using this new mechanism converged to the optimal (marginal-cost) price outcome.

In summary, although there is a monopoly-pricing problem in laboratory PO experiments, it can be alleviated with decentralized regulation. With demand information, the Loeb-Magat mechanism works very well, and an auction can be used to reduce subsidy payments. In the absence of demand information, the Cox-Smith modification of the Finsinger-Vogelsang mechanism has yielded good results, at least in one decreasing-cost environment.

Potential Competition as a Regulator: Market Contestability

It has been about a hundred years since Clark (1887) emphasized the role of latent competition and raised the question of whether it would be as effective as actual competition in restraining monopoly pricing. More recently, the theory of contestable markets has formalized the effects of potential entry in a way that highlights the importance of the absence of sunk costs. In order to evaluate the design conditions of alternative experimental studies of contestability theory, it is necessary to review the requirements of the theory for the special case of homogenous-product markets used in the laboratory tests to date.

Baumol, Panzar, and Willig (1982, p. 6) characterize a *contestable market* as one in which: 1) there is at least one potential rival with the same cost structure, 2) "...potential entrants evaluate the profitability of entry at the incumbent firm's prices...," and 3) there are no barriers to entry or exit, and in particular, there is a possibility of hit-and-run entry: "Such entrants need not fear changes in prices by the incumbent firms for, if and when such reactions do occur, ...that firm need only exit." Therefore, there can be no sunk costs. The fundamental result is that a contestable market can only be in equilibrium if the prices and quantities of the incumbent firm are *sustainable*, which in turn requires that no new firm with the same cost function as the incumbent can earn a profit by charging a lower price and earning a profit by selling all or part of the demand at that lower price. For the decreasing cost, natural monopoly environment found in

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[70] Suppose that price is raised in period 1 and reduced again in period two, so that $p_2 = p_0$, and therefore $p_1 - p_0 = p_1 - p_2 > 0$. Then the usual formula for the subsidy in period two, $q_0[p_0 - p_1] + q_1[p_1 - p_2]$, will be negative since demand in period 0 is higher at the lower price: $q_0 > q_1$.

laboratory tests, any equilibrium must involve the incumbent choosing the price and quantity for which demand equals average cost.

The formal statement of the contestable markets theory does not predict that the average-cost pricing outcome will be always observed, but this seems to be the position taken by the theory's proponents: "Even if it is run by a monopoly, a contestable market will yield only zero profits and offer inducements for the adoption of Ramsey-optimal prices...." (Baumol, Panzar, and Willig 1982, p. 292). In particular, the assertion is that potential competition in the absence of sunk costs is as good as actual competition, and that even horizontal mergers among potential entrants that do not alter contestability will not have harmful effects.

Coursey, Isaac, and Smith (1984) conducted an experiment designed to evaluate the effects of contestability under the same decreasing-cost, natural monopoly conditions described above for their posted-offer monopoly markets, which were used as a basis of comparison. Sellers chose prices independently in a standard posted-offer environment. In this context, a "competitive price" is the Ramsey-optimal price, the lowest price that yields non-negative earnings for the incumbent, i.e. this is an average-cost price for the incumbent. In the contested experimental markets, four of the duopolies yielded competitive price outcomes, and the other two exhibited downward trends in price, with price deviations from the CE level being less than 50% of the monopoly price deviation. Average final-period market efficiency increased from 49% in the monopoly experiments to 86% in the contested markets. The final-period value of the monopoly effectiveness parameter, averaged across experiments, was .02, which is significantly lower than the *M* value of .56 for the baseline monopoly sessions.[71] Harrison and McKee (1985) and Harrison, McKee, and Rutstrom (1989) observed similar, low values of the monopoly effectiveness parameter in contested markets, even though the buyers in their experiments were simulated; see the right-hand column of table 3 to make comparisons with monopoly *M* values.

One interesting feature of summary data in table 3 is that monopoly effectiveness is lower in the Loeb-Magat regulated markets than is the case in contested markets. This observation is consistent with the theory: price is supposed to fall to average cost (the Ramsey-optimal level) in contested markets, but the Loeb-Magat mechanism should drive price down to marginal cost, which is below average cost under decreasing cost conditions.[72] Contestability does not demand that a regulator have demand information, however, nor does it involve subsidies.

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[71] Brown-Kruse (1991) modified the Coursey, Isaac, and Smith (1984) design by introducing an "alternate market" that was selected by choosing a 0 quantity limit in the contested posted-offer market. The purpose was to find out whether previous competitive outcomes were the result of competition that was forced artificially by not providing an alternative activity. The price patterns for sessions with the alternate market were not noticeably different from price paths in control sessions without the safe haven. The sessions with human buyers yielded prices that appeared to be heading for a level that equates profits in the two markets, which is roughly consistent with the Coursey, Isaac, and Smith results for a case of a zero profit for a seller who makes no sales in the contested market.

[72] As indicated above, under the Loeb-Magat mechanism, prices were driven below the highest competitive price, which generated negative *M* values.

Contestable market theory would have little practical value for policy makers if the theory were sensitive to "small" sunk cost imperfections. Coursey, Isaac, Luke, and Smith (1984) take the same decreasing-cost structure from the Coursey, Isaac, and Smith paper and introduce a sunk cost in the nature of a five-period operating license. This license had a price of $2.00, which is less than the theoretical monopoly profit. The "incumbent" was required to purchase this license once for periods 1-5 and again for periods 6-10. The other seller stayed out and earned a "normal rate of return" for the first five periods, but could enter by purchasing a license after period five. Beginning in period 10, both sellers made license purchase decisions independently. The prices supported the "weak contestable markets hypothesis," in the sense that prices were closer to the competitive (Ramsey-optimal) level than to the natural monopoly level, in all twelve sessions, six with simulated buyers and six with human buyers. But prices actually converged to the competitive level in only about half of the sessions, as compared with the two-thirds that had converged without sunk costs in Coursey, Isaac, and Smith (1984). Moreover, no single-seller, competitive natural monopoly was observed; the entrant entered in all twelve sessions in period 6, and all sellers who exited later reentered the market if given the chance, i.e. if the market did not terminate.

Gilbert (1989) has argued the Coursey, Isaac, Luke, and Smith (1984) results with sunk costs do not justify a claim that contestable markets theory can be extended to cover situations with sunk costs. In particular, the entry observed in laboratory markets generates inefficient duplication if the license fee represents a real cost.

It is important to distinguish between the predictions of contestable markets theory and the predictions of the relevant noncooperative game theory. I would expect that an increase in the number of price-setting competitors from one to two would improve market performance in a noncooperative equilibrium in most market structures, although it is possible to construct Cournot examples with inefficiently high levels of entry. It would be nice to see an experiment that could distinguish the implications of contestability from those of the noncooperative theories that IO economists commonly use.[73] Certainly, it is easier to check the necessary conditions for contestability than it is to calculate noncooperative equilibria in all but the simplest environments, and in this sense, contestability would be a convenient crutch if it works.

A key behavioral assumption of the contestable-markets theory is that the entrant evaluate the profitability of entry given the incumbent's current prices. Harrison (1986) reports an experiment in which this restriction is "hard-wired" into the institution by forcing the incumbent to post a price first, which the entrant can observe before deciding on a price for that period. As Gilbert (1989) notes, Harrison thereby provides a test of the theory under the most favorable condition, in which a critical behavioral assumption is satisfied. But the timing assumptions in Harrison's design do not correspond to the setup in most unregulated markets, where the incumbent can respond quickly to an entrant's price cut. In contrast, a regulated monopoly, such as AT&T in the seventies,

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[73] I would guess that the equilibria involve randomization for the step-function environments used in the experiments discussed here, and such equilibria are difficult to calculate.

may have operated with the first-mover disadvantage that is hard-wired into the Harrison setup.

Using a continuous-time flow market described in section 5 above, Millner, Pratt, and Reilly (1990a) were able to implement a condition that, in my view, implements the possibility of "hit-and-run entry" in an interesting and relevant manner, thereby providing a useful "stress test" for contestable-markets theory. At any instant, the seller with the lowest price in their design generally makes all sales, and in this sense, is the incumbent. The other seller can observe the price and decide whether to under-cut it at any moment. Since the probability of an incumbent's price change is essentially zero on a sufficiently short time interval, the entrant can be very sure that a price cut will initially capture the market. In addition, exit can be almost instantaneous. The flow-market experiments involved decreasing costs, up to capacity, and simulated, continuous-time buyers. Market efficiencies were quite low, and efficiencies with experienced subjects were not much different from the theoretical efficiency in a monopoly, which is a direct contradiction of contestable markets theory.[74] See table 4 for comparisons. What Millner, Pratt, and Reilly do not observe is any stable pricing behavior; when the prices fall too low, one seller will often exit, at which time the other will raise price dramatically. I suspect that the unstable price cycles could eventually lead to some continuous-time analogue of noncooperative randomization in the presence of small adjustment costs or perceptual delays.[75] In one of their sessions, however, the price cycle switched to a very slow and disciplined decline as each seller undercut the other by pennies every several seconds in a successful attempt to share the market at near-monopoly prices.[76]

Future experimental work should make more effort to distinguish the predictions of noncooperative game theory from those of contestable markets theory. In addition, experimenters should provide an alternative for the potential entrants that is more interesting than simply earning nothing or a deterministic normal rate of return in a dummy alternate market. Subjects probably feel a desire to be "in" rather than "out," and the construction of an interesting, market-like alternative to entry into the incumbent's market would make the results more convincing. Since contestable markets theory seems to work well in some environments and not in others (e.g., flow markets), experiments that deal directly with the policy implications of contestable markets theory would be most valuable. For example, is it really irrelevant that a horizontal merger wave among potential entrants will have no effect on performance in a contestable market?

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[74] As is usually the case in reporting the results of a contestable market experiment with decreasing costs, the competitive equilibrium baseline used in efficiency calculations is the allocation that maximizes total surplus, *subject to the constraint that no firm earn a loss*. Therefore, the competitive equilibrium in this context involves a price-equals-average-cost condition for the incumbent.

[75] In a very narrow and uninteresting sense, this unstable behavior is consistent with the formal "fundamental result" of contestability theory, i.e. that any equilibrium must be sustainable, at least as long as the concept of equilibrium precludes unstable behavior.

[76] This type of tight, almost disciplined price decline was also observed by Davis and Holt (1994b) in some of their relatively long (60-period) posted-offer sessions with five sellers.

Table 4. Effects of Monopoly Restraint Mechanisms on Market Efficiency in Posted-Offer Auctions

	design			efficiency (E)		
	exper-ience	buyer type	cost	theoretical monopoly	observed monopoly	contested market
Isaac, Ramey, & Williams (1984)[a]	inexp.	human	increasing	85	85	-
Coursey, Isaac, & Smith (1984)	role exp.	human	decreasing	60	49	86
Millner, Pratt, & Reilly (1990a)	inexp.	simulated	decreasing	50-60	55	67
"	design, role exp.	simulated	decreasing	50-60	-	62

Key: E = [actual surplus / CE surplus]*100, calculated as an average of the E values for the final period (or time interval) common to all sessions in a treatment. For the sessions with decreasing costs, the CE surplus is determined by a price-equals-average-cost condition.

[a] The final-period efficiency value was estimated from the authors' figure 16.

To summarize; the simultaneous-choice, discrete-time PO experiments show that the addition of an equally efficient potential competitor can reduce monopoly effectiveness to competitive levels. The discipline of potential competition is not as effective when the no-sunk-cost assumption of contestable markets theory is violated. More damaging to contestable markets theory is the poor performance of contested flow markets with no sunk costs and a continuous-time structure that, in my opinion, provides the best implementation of the hit-and-run entry condition assumed by the theory.

Predatory Pricing and Antitrust Remedies

The existence of predatory pricing is one of the more controversial issues in industrial organization. Most, but not all, would agree that companies such as Standard Oil of New Jersey engaged in predatory pricing, a pattern of behavior that reduces the predator's current profits in a manner that can only be justified by the prospect of subsequent monopoly profits. Predatory behavior is thought to be less common today; my colleague Kenneth Elzinga once characterized the issue as being whether it is rare like an old stamp or rare like a unicorn. Since it is usually difficult to document predatory intent, and since even a perfectly competitive firm would never price below marginal cost, antitrust scholars have proposed the use of cost-based tests, and the arguments in predation cases often center on cost and profit/loss measurements. In contrast, there is no problem with the measurement of costs in the laboratory, so it is possible for the experimenter to spot behavior that cannot be optimal except as an attempt to exclude competitors.

Recall that the contestable-markets experiments involved sellers with identical technologies, and even though profits were driven down to low levels, market dominance by one seller was not observed. Isaac and Smith (1985) conducted a series of posted offer sessions in which they modified earlier contestable-markets designs by introducing asymmetries to provide the incumbent, seller *A*, with an advantage over the other, seller *B*. The incumbent had a higher capacity, lower costs, and a larger initial cash endowment to cover losses. Importantly, the PLATO posted-offer program was altered to permit price and quantity choices that yielded losses.

The relevant parts of the Isaac and Smith cost and demand structure are shown in figure 6. In order to construct the market supply function, consider the average costs for sellers *A* and *B*, shown on the right side of the figure. Since the minimum of seller *A*'s average variable cost function, AVC_A, is at $2.50, the low-cost seller *A* would supply 0 units at lower prices, and the (thick) market supply function follows the vertical axis up to $2.50. At this price, seller *A* would supply the seven units that are arrayed with decreasing costs on the left side of the figure (each unit cost for seller *A* has an "A" underneath the corresponding step on the left). Seller *B* would not supply any units until the price rises to $2.66, the minimum of its average cost, so the thick market supply curve is vertical at seven units between $2.50 and $2.66, a price at which seller *B* provides the three units with decreasing costs shown on the left side of the figure. The supply overlaps the market demand function in the vertical range from $2.66 to $2.76, which is labeled the "C.E. price range." Seller *A* has three extra-marginal units shown at costs of $2.80, just above the competitive price range, and seller *B* has other units with even higher costs (not shown).

Now consider the ability of seller *A* to engage in predatory pricing. There are various types of predatory behavior, but one possibility is for seller *A* to choose a price below the minimum of AVC_B (to keep *B* out), and therefore, below the marginal cost of meeting demand at that price. Pricing below marginal cost in this predatory manner need not result in a loss for seller *A* if the price is above AVC_A, as would be the case for a price in the "predatory range" of the demand curve, shown on the right side of the figure, with a quantity limit of ten.[77] This action will leave no room for profitable entry by seller *B*, and seller *A* will earn a small profit since price exceeds average cost at ten units. This action is predatory in the sense that prices in the predatory range are below the $2.80 marginal cost of the 10th unit for seller *A*. An outcome in which *A* sells all ten units is inefficient, since this seller's 3 extra-marginal units are more costly than the three infra-marginal units of seller *B*. Therefore, this design permits an inefficient predatory outcome that does not require the predator to sustain losses, although profits during the predation phase are lower than would be the case in a competitive equilibrium. A predatory action that drives the other seller out *may* allow seller *A* to earn much higher, monopoly profits.

[77] Recall that each seller in a posted offer market chooses a price and a quantity limit, which is the maximum number of units offered for sale at the posted price.

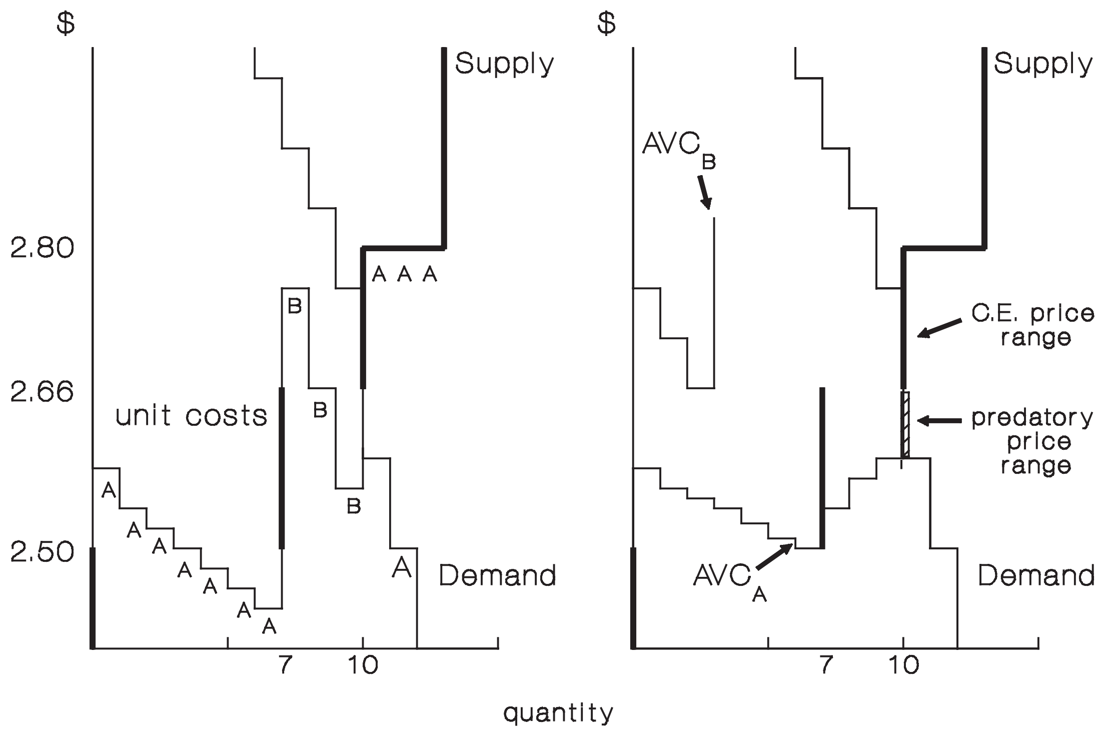

Figure 6. The Isaac and Smith Design for Predatory Pricing

Predatory pricing was not observed in any session, even after introducing several other design variations (e.g., sunk costs) intended to be progressively more favorable to such pricing, and hence the provocative title "In Search of Predatory Pricing." Anyone who has witnessed subjects' enthusiasm for being in the market trading process will wonder if the lack of predation is due to the absence of a reasonable alternative activity for the "prey." In particular, will a low-cost seller forego predation because of common knowledge that even a high-cost seller would suffer some loses rather than stay out of the market? Rutstrom (1985) modified the Isaac and Smith design by introducing an "alternate market" with fixed earnings of twenty-five cents per period, but this modification did not produce predatory pricing either.

Harrison (1988) modified the Isaac and Smith design in a clever manner; he conducted a posted-offer session with five markets and eleven sellers, each of whom could only enter one market at a time. Seven of the sellers were given the Isaac and Smith "seller *B*" cost function, shown in figure 6, regardless of which market they entered. Each of the other four sellers had a preferred market in the sense that they could be a low-cost "seller *A*" in that market, but they would have seller-*B* costs if they entered any other market. There was only one potential seller *A* in each of four markets; in this sense, each potential low-cost seller had its own market. The efficient entry pattern required each of the four potential low-cost sellers to go to their "own" market and share it with a high-cost seller, and for the remaining high-cost sellers to congregate in the only market for which no seller can have low costs. Demand in each market was simulated and corresponded to the demand in Isaac and Smith.

Table 5. Market I of Harrison's (1988) Multi-market Predatory Pricing Session

period	seller ID	posted price	quantity limit	quantity sold	characterization of outcome
1	1	$2.90	3	2	
	4*	2.51	7	7	
	7	3.49	3	0	
2	1	2.85	4	0	
	4*	2.69	10	10	
3	1	2.60	3	3	efficient
	4*	2.69	10	7	
4	1	2.70	3	3	efficient,
	4*	2.69	7	7	competitive
5	1	2.70	3	0	predatory
	4*	2.64	10	10	
6	1	2.66	3	0	predatory
	4*	2.60	10	10	
7	4*	2.65	7	7	
8	4*	2.85	7	7	supra-competitive
9	4*	3.15	7	7	supra-competitive
10	4*	2.60	10	10	predatory
11	4*	3.10	7	7	fortunate
	7	3.14	3	0	
12	4*	3.15	7	3	
	10	2.99	3	3	

Harrison reports one session with this multi-market version of the Isaac and Smith design. There are instances of predatory pricing. The outcomes for one of these markets, market I, are reproduced in table 5. In period 1, three sellers enter, sellers 1 and 7 with high costs and seller 4, marked with an asterisk in the table, with a seller-*A* cost function for this market. As can be seen from the table, seller 7 posts the highest price, sells no units, and leaves for one of the other four markets in period 2. Sellers 1 and 4 remain, and this market reaches an efficient outcome in period 3, with seven units for the low-cost seller and three units for the other, as was seen from the earlier analysis of figure 6. The outcome is efficient again in period 4, and both prices are in the competitive range. In period five, seller 4 offers ten units at a price of $2.64, which is below seller 1's lowest average cost, in a clear instance of predatory pricing. This behavior is intensified in the next period, after which seller 1 switches to another market. Seller 4 takes advantage of the resulting monopoly position by raising price in the following periods, which were quite profitable. Prices for all markets were posted on the blackboard after each period, and seller 4 offers a predatory price/quantity combination in period 10, perhaps in an attempt to counter or deter entry, which occurs anyway in the next period. There were cases of predatory pricing in several of the other markets; there was even one instance of a small seller pricing below the average cost of the larger, more efficient seller.[78]

Jung, Kagel, and Levin (1990) followed a different approach in their search for predatory pricing; they structured an experiment on the basis of a simple signaling game in which predatory pricing is an equilibrium outcome. Each session involves a subject monopolist who encounters a different potential entrant in a series of eight periods. In each period, the potential entrant for that period decides to enter or stay out, and the monopolist decides to fight or accommodate, which is observed by the prospective entrants. An entrant's preferences are such that entry is only worthwhile if the monopolist accommodates. The monopolist is one of two "types"; a strong monopolist prefers to fight and a weak monopolist would prefer to accommodate in a single period. The monopolist knows his/her own type, which was determined randomly at the start of the eight-period sequence, but the entrant can only try to infer the monopolist's type on the basis of observed responses to previous entrants. There is a sequential equilibrium in which a weak monopolist will fight entry in early periods in order to deter subsequent entry. This "predatory" fight response by weak monopolists was commonly observed. The sessions were conducted in an abstract setting, e.g. the monopolist was called a "type-*B* player," and there was no mention of prices, quantities, entry, etc.[79]

Since predation is so difficult to diagnose in legal proceedings, a number of more-or-less mechanical rules have been proposed to prevent predation. Isaac and Smith (1985) ran several sessions that implemented two restrictions on predatory pricing that had been proposed in the antitrust literature: a prohibition of quantity expansion by the incumbent for two periods after entry, and a prohibition of temporary price cuts, i.e. price cuts by the incumbent after entry had to be maintained for five periods. The effect of this policy

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[78] Although it is unusual to report only one session, the purpose of the paper was to demonstrate the possibility of predatory pricing. One other unusual aspect of this session is that all subjects had experience in three somewhat related PO experiments, and all subjects were also students in Harrison's class. It would be worthwhile to replicate these important results in a more standard environment.

[79] Garvin and Kagel (1989) work with a design that has somewhat more of a market-like appearance. Here the monopolist is either a high-cost or low-cost type, determined randomly. The monopolist begins by choosing an integer, which can be interpreted as an output. This decision (but not the monopolist's type) is observed by the other player, who then chooses between two decisions that can be interpreted as entry or no entry. This is a matrix game, with post-entry profits that equal those in the theoretical Cournot duopoly equilibrium. For some parameter variations of this game, experienced subjects settle into a pooling equilibrium in which monopolists who draw a high cost expand output and deter entry. In this sense, there is limit pricing on the part of the high-cost monopolists.

was to raise prices and to reduce efficiency.[80] These experimental results are important since the implementation of anti-predation policies with perverse effects would be unfortunate if predatory pricing is rare. One might object that anti-predation policies should be evaluated in a context where predation occurs, but remember that these policies would restrict an incumbent's price and/or production responses to entry in any market, not just those where predation is thought to occur. Therefore, we should be careful about advocating a policy that has unwanted side effects in otherwise healthy markets.

To summarize, predatory pricing is not observed in simple posted-offer market environments that, in some respects, are quite favorable to predatory behavior. Moreover, some prominent anti-predation proposals for limiting the price and quantity responses of an incumbent can have perverse effects in laboratory markets that were relatively efficient before the implementation of the anti-predation policy. But the provision of an interesting alternative market to serve as the home base for the prey can yield predatory outcomes. In abstract experimental games with asymmetric information, subjects make decisions that correspond to the predation interpretation of the game. The interesting policy issue is not whether predatory pricing can be observed in the laboratory, but rather, it is whether and under what conditions predatory pricing is likely to occur in natural markets. The issue then is to what extent laboratory results will carry over into markets of antitrust concern. I believe that the home-market cost advantage in the Harrison design and the signaling opportunities in the Jung, Kagel, and Levin design are present in a variety of naturally occurring markets. But the observations of predatory pricing in the laboratory would be more convincing if there were more replication in multi-market design, and if the signaling design had more market-like details.

7. MARKET STRUCTURE AND MARKET POWER

Market power exists when a seller has the ability to raise price above competitive levels, and to do so profitably. One of the central issues in industrial organization is the manner in which market power can be created, exercised, and extended. In laboratory experiments, even a monopolist may have considerable difficulties if the demand function is unknown and if human buyers can resist price increases, as indicated by the wide range of observed values of the monopoly effectiveness index in table 3.

The addition of competitors may mitigate the market power of a monopolist. But observation of prices that converge to competitive levels in an experiment cannot be interpreted as the failure to exercise market power if this power does not exist for the multi-seller environment being considered. The degree of market power is usually not considered explicitly in discussions of the competitive tendencies of non-monopolized PO and DA experiments. Despite the fact that supra-competitive pricing usually involves quantity reductions, such reductions are typically discussed in the context of the efforts

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[80] Holt and Solis-Soberon (1990) analyze the theoretical effects of quantity and price-based anti-predation policies in posted-offer environments. The anti-predation policies alter the equilibrium mixed distribution of prices in a very simple, finite-horizon model.

of buyers to under-reveal demand in an effort to "counter-speculate" against an explicit or implicit seller conspiracy.[81]

Definitions of Market Power

As was the case with simple monopolies, it is necessary to distinguish between the existence of market power as a theoretical matter and the exercise of such power in a multi-seller situation. Market power can exist on either side of the market, but the discussion that follows will pertain to sellers' market power.

Holt (1989) suggests two alternative definitions. *Equilibrium market power* exists if there is a noncooperative equilibrium that results in supra-competitive prices. When buyers are major players in the market, such an equilibrium must include their behavior. Since it is difficult to calculate noncooperative equilibria in many trading institutions, e.g. double auctions, it is useful to have an alternative, non-game-theoretic definition.[82] This second definition is based on the 1984 Department of Justice horizontal merger guidelines. A seller is said to have *unilateral market power* if a unilateral deviation from a competitive equilibrium is profitable for that seller, given that all other traders continue to use the strategies that generated the competitive equilibrium. The class of deviations that can be considered in this test depends on the nature of the decision variables in the laboratory market institution, e.g., quantity in a Cournot quantity-choice experiment.[83] One drawback of this definition is that a seller with unilateral market power may not be able to exercise it if one or more buyers also have unilateral market power. Both definitions of market power are sensitive to the nature of the feasible messages and

[81] Of course, experimentalists are aware of the possible effects of market power, as is apparent from a comment made by Smith (1976, p.44): "None of the experiments to be summarized in this report have systematically varied market structure except insofar as changes in the conditions of supply and demand have been affected by changes in the number of sellers and buyers. But in each case reported here numbers are large enough and economic power sufficiently dispersed to yield competitive price behavior."

[82] The existing analyses of noncooperative equilibria in continuous-time double auctions are dependent on restrictive structural and/or behavioral assumptions. In a recent survey of auction theory, Wilson (1990, p.36) notes the strong tendency of double auctions to converge to the perfectly competitive outcome, but he adds that this "...striking finding is quite robust, but its conformity to the predictions of game theory is mute due to the dearth of theoretical results." See Gode and Sunder (1991) for a non-game-theoretic analysis of adjustment in double auctions. Easley and Ledyard (1988) and Friedman (1991) have also made progress in modeling behavior in double auctions. Cason and Friedman (1991) discuss the degree to which some of these models are able to explain observed patterns in bids, asks, and transactions in double auctions. This latter paper is reviewed in Kagel (chapter ** of this handbook).

[83] Although easier to use in practice, the unilateral market power test is not as straightforward as it may seem. First it is necessary to specify a configuration of traders' strategies that generated a competitive outcome (and some ambiguity is present if there are many such configurations). The resulting strategy vector is typically not a noncooperative equilibrium, and it is only necessary to evaluate the profitability of unilateral deviations from this vector; it is not necessary to calculate such an equilibrium. Moreover, the deviation that turns out to be profitable when unilateral market power exists does not have to be an element in a noncooperative equilibrium strategy vector. For example, consider a Bertrand price-choice duopoly game with common, constant average costs of zero. Capacity constraints may make it profitable for a seller to raise price above the competitive level of zero, and yet this increase is typically not an element in an equilibrium price vector; and it may not even be in the range of prices selected in a mixed-strategy equilibrium.

decisions for traders in a particular laboratory trading institution. This sensitivity is desirable, given the documented effects of institutional variations on prices in experiments.

Since experiments typically consist of a series of repeated market periods, it is natural to distinguish between static market power, obtained by applying one of the definitions to the single-period market game, and dynamic market power that may exist in the supergame. With an infinite horizon, it is well known that, in theory, collusive outcomes can be supported by noncooperative behavior with appropriate threats to revert to the noncooperative outcome in stage games that follow deviations. Cooperation can be an equilibrium strategy if the expected gain from defecting in the current period is outweighed by the reduction in expected future profits when both players defect in all subsequent periods until the randomly determined termination.[84] In this manner, equilibrium market power can exist in a dynamic sense, even when it does not exist in a static sense.

When subjects are not permitted to communicate directly, I will use the term *tacit collusion* to refer to outcomes in which prices exceed the levels determined by static noncooperative equilibria in the market-period stage games. Tacit collusion of this type can result from the fear of punishments in a dynamic, noncooperative equilibrium, as noted above. Tacit collusion can also result from the altruism and mutual respect that can develop in multi-period interactions.

Market Power in Double Auctions

One reason that the double auction is widely used in experimental research is that it is reliable; competitive outcomes are almost always obtained in non-monopolized DA markets with private incomplete information and stationary supply and demand conditions. But this convergence to the competitive price would not be surprising if traders did not have the power to manipulate price in their favor. Consider, for example, the DA design used for the last five periods in figure 5. Recall that each of the four sellers has a capacity of four units at a cost of \$5.70 and that the quantity demanded is eleven. If all sellers offer to sell at \$5.70 and buyers divide their purchases randomly, the sellers will obtain five cent commissions on the units sold. A unilateral increase in a seller's offer will result in no sales, since the others' residual supply exceeds the market demand quantity. In other words, excess supply at supra-competitive prices exceeds each seller's capacity.[85]

Although the lack of market power in the figure 4 design (periods 6-10) is extreme, it is not common in experimental designs for sellers to have enough low-profit

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[84] In practice, Roth and Murnighan (1978) seem to have been the first economists to attempt to induce an infinite horizon by using a random mechanism to terminate the session. Murnighan and Roth (1983) observed that an increase in the probability of continued interaction resulted in greater cooperation in prisoner's dilemma games (in which subjects were, unknowingly, playing against simulated opponents).

[85] A relatively minor variant of this box design (with five units of excess supply) was used by Kachelmeier and Shehata (1990) in a comparison of double-auction trading in the U.S., Canada, and the People's Republic of China. Subject-pool differences, if they exist, may be easier to spot in a design with more latitude for efforts to manipulate price.

marginal units to make it worthwhile to attempt to manipulate price. In contrast, there is no market power when sellers have only a single unit that is traded in a competitive equilibrium, since it is not profitable to refuse to sell this unit in order to alter price, unless the seller anticipates that the effect would endure until a subsequent period.[86]

When I first started to think about double auctions about ten years ago, I was surprised that the conventional wisdom then (and now) seemed to be that prices in a non-monopolized double auction are not affected by most of the structural market characteristics that are the focus of a standard course in industrial organization: demand elasticity, concentration, capacity constraints, entry barriers, etc. So I decided to try to design a double auction treatment that would not yield competitive prices, even with multiple sellers. The resulting design, developed in collaboration with Anne Villamil and Loren Langan, involves five buyers and five sellers, with values and costs that generate the supply and demand structure shown at the left side of figure 7. Three of the sellers have one to three infra-marginal units that could be traded in a competitive equilibrium, but the other two sellers (S1 and S2) have five inframarginal units, most of which are located on the horizontal step at the competitive price of $2.60. If one of these large sellers were to refuse to sell two units, and if all other traders behaved competitively, then the price would rise by 25 cents to $2.85. Since the two marginal units withheld were at a cost of $2.60 and would be traded at $2.60 in a competitive equilibrium, the only loss is the five cent commission on each. The price increase yields a gain of twenty-five cents on each of the other units, so the unilateral refusal to sell is profitable.[87] The buyers in this design were given three high-value units at $3.35 in an attempt to make any effort to counter-speculate unprofitable, since each unit is so profitable that the loss from under-revealing demand is not justified by the possibility of driving the price back toward the competitive level.

This design was used in our very first double auction (Holt, Langan, and Villamil, hereafter HLV 1986), with inexperienced subjects and inexperienced experimenters! The prices did not converge to the competitive level. The sequence of transactions data for one of these markets is shown on the right side of figure 7. The prices start low, probably as a result of the very low costs on the first five units, but afterwards prices pass through the CE price and do not return. The transactions quantity was at fifteen after the fourth period, so the price/quantity combinations can be thought of as falling on the vertical region of the demand curve between $2.60 and $2.85.[88] As long as the price does not reach the $2.85 level, there is no substitution of a high-cost extra-marginal unit,

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[86] Interestingly, some theoretical proofs of the convergence of DA prices to competitive levels involve assumptions that precluded the exercise of market power. For example, Friedman (1984) and Wilson (1987) assume that each trader has only one unit to buy or sell.

[87] Recall that the deviation need not be an element of a noncooperative equilibrium. As noted by Porter (1991), noncooperative equilibrium behavior in the single market period could not involve quantity withholding, since it is always optimal to sell inframarginal units at the last instant if there is an outstanding offer that is no lower than the CE price.

[88] The absence of quantity withholding is consistent with Porter's (1991) observation in the previous note.

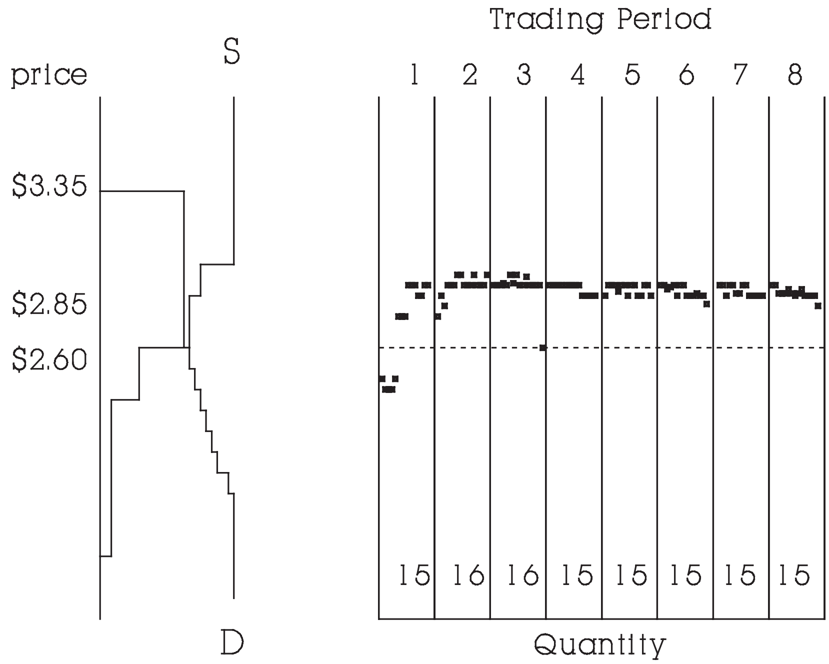

Figure 7. DA with Seller Market Power
Source: Holt, Langan, and Villamil (1986)

and hence, no efficiency loss. Prices in about half of the other sessions stayed above the CE level in this manner, but surprisingly, price converged to within pennies of the CE level in the other sessions. This indicates just how competitive the DA institution is.

Davis and Williams (1991) replicated this experiment with the PLATO network, and they also found supra-competitive pricing, but with less bimodality in the data. In figure eight, the vertical axis measures penny deviations from the competitive price, so 0 and 25 correspond to the competitive price of $2.60 and the supply step at $2.85, respectively. For the double auction results in the lower part of the figure, the eight asterisks show the average prices (across four sessions) in each of eight periods. The bands of dotted lines show the range in which 95% of the prices lie. Davis and Williams ran a parallel series of four posted-offer sessions with this HLV seller-market-power design using simulated buyers, and the shaded band with 95% of the data is much higher, with average prices ending up at a level of about $0.35 above the competitive price. The double auction is still more efficient in this environment, as can be seen from row (4) of table 2. The passive role of simulated buyers in a posted offer auction is probably a factor in the less competitive nature of this institution, as the analysis of the next subsection indicates.

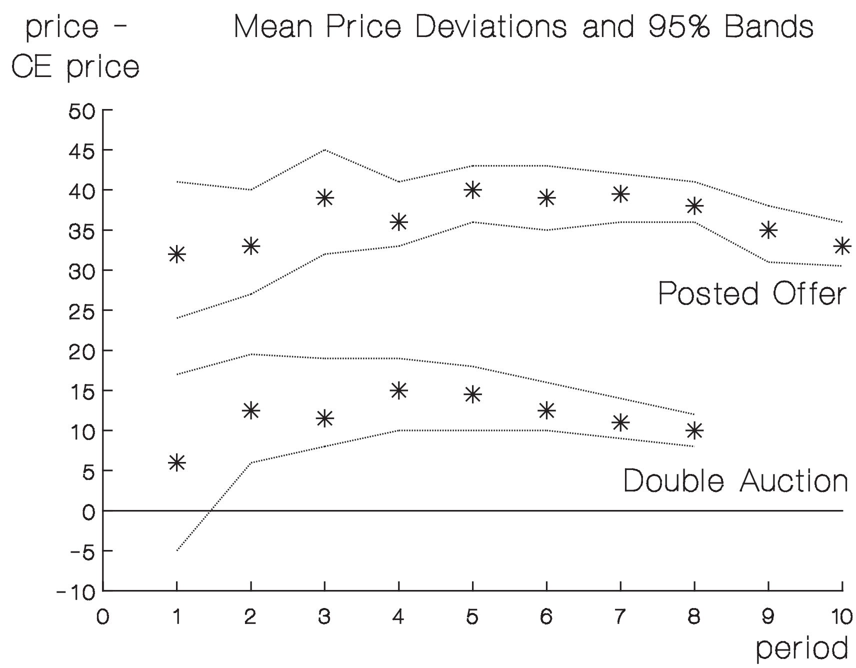

Figure 8. DA and PO Prices for the HLV Seller Market Power Design
Source: constructed with data from Davis and Williams (1991)

How significant is the exercise of market power with the HLV design? Davis and Williams stress that they see little evidence of quantity withholding by sellers with market power in double auctions, and that the outcomes are very efficient. These results are consistent with Porter's (1991) observation that a seller would never want to leave profitable units unsold in the final moments of trading in a Nash equilibrium for that period. Plott (1989, p.1125) argues that results with the HLV design should be interpreted with caution. Plott notes that excess supply is only one unit at prices just above the competitive equilibrium in this design, and that the Easley and Ledyard (1988) (non-game-theoretic) model of double-auction pricing, which predicts convergence to the C.E. price in other cases, does not necessarily predict convergence in the special case of one unit of excess supply. In a different design, Friedman and Ostroy (1989) do not observe the exercise of market power in either double auctions or clearinghouse auctions. The question is whether the exercise of market power in double auctions is a "boundary" result for a particular parameter choice, without much general significance; this is Vernon Smith's view, as expressed in private correspondence. A related issue is whether market power will ever have any efficiency effects in non-monopolized double auctions.[89]

[89] Van Boening and Wilcox (1992) have shown that double auctions may not produce high efficiencies when sellers face fixed costs that preclude the existence of a competitive equilibrium.

Market Power in Posted-Offer Auctions

Plott (1986, p.735) comments that "The posted-price institution induces an upward pressure on prices....The relative effect of the posted prices was first demonstrated by Plott and Smith in comparison experiments....Even now no theory about the relative influence of the posted-price institution has been published to my knowledge, but the effect has persisted under a variety of parametric situations...." (footnotes omitted).

In posted-offer auctions, capacity constraints arise naturally from the finite numbers of units provided to sellers. In such contexts, the competitive equilibrium may not be a noncooperative equilibrium if excess supply at supra-competitive prices is so small that sellers have a unilateral incentive to raise price above competitive levels, i.e. if a lower quantity at a higher price is more profitable than a higher quantity at the competitive price. The critical factor is not the absolute amount of excess supply, but rather, the residual demand that remains after other sellers make all sales at the lower price.

By reassigning units of capacity from one seller to another, there is no change in either market supply or excess supply at supra-competitive prices, yet market power can change. I attended a conference two years in a row in which a researcher reported that this type of unit reallocation had an unanticipated and unexplained effect on average prices. As a consequence, Davis and I decided to design a reallocation that would have a clear and easily calculated effect on market power. Consider the design shown on the left side of figure 9, where the identity number of one of the five sellers is listed below each unit on the supply curve. Sellers 1, 2, and three each have three units, and sellers 4 and 5 each have a single unit. Notice that all units for all sellers can be sold at a common price of $3.09, which is the highest competitive price. At this price, any seller who raised price unilaterally would make no sales, since the excess supply is three units at supra-competitive prices. Conversely, a unilateral price cut from a common price of $3.09 would not increase a seller's sales quantity, and hence, would be unprofitable. The highest competitive price is, therefore, a Nash equilibrium in the market stage game, and there is no market power by either definition given at the beginning of this section.

Next suppose that the two (boldfaced) high-cost units for seller 3 are given to sellers 1 and 2. This does not alter supply, demand, or the excess supply, but it does increase the residual demand should either of these sellers raise price unilaterally. Sellers 1 and 2 now have four units, and a unilateral price increase from $3.09 to the limit, $5.39, will increase the seller's profit (since the $2.30 increase in the price obtained for the 1st unit exceeds the loss of $0.50 on each of the three marginal units). After obtaining the additional unit, sellers 1 and 2 have market power, and the Nash equilibrium for the market stage-game involves randomization on the range from $3.29 to $5.39.[90]

Davis and Holt (1994b) report the results of six PO sessions, each with 30 periods under the no-power treatment and 30 periods under the power treatment that results from the reallocation of seller 3's marginal units. The order of treatments was reversed in

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[90] Holt and Solis-Soberon (1992) discuss the various methods of calculating mixed-strategy equilibria in posted-offer markets with step-function structures that arise naturally in the laboratory from the provision of discrete units.

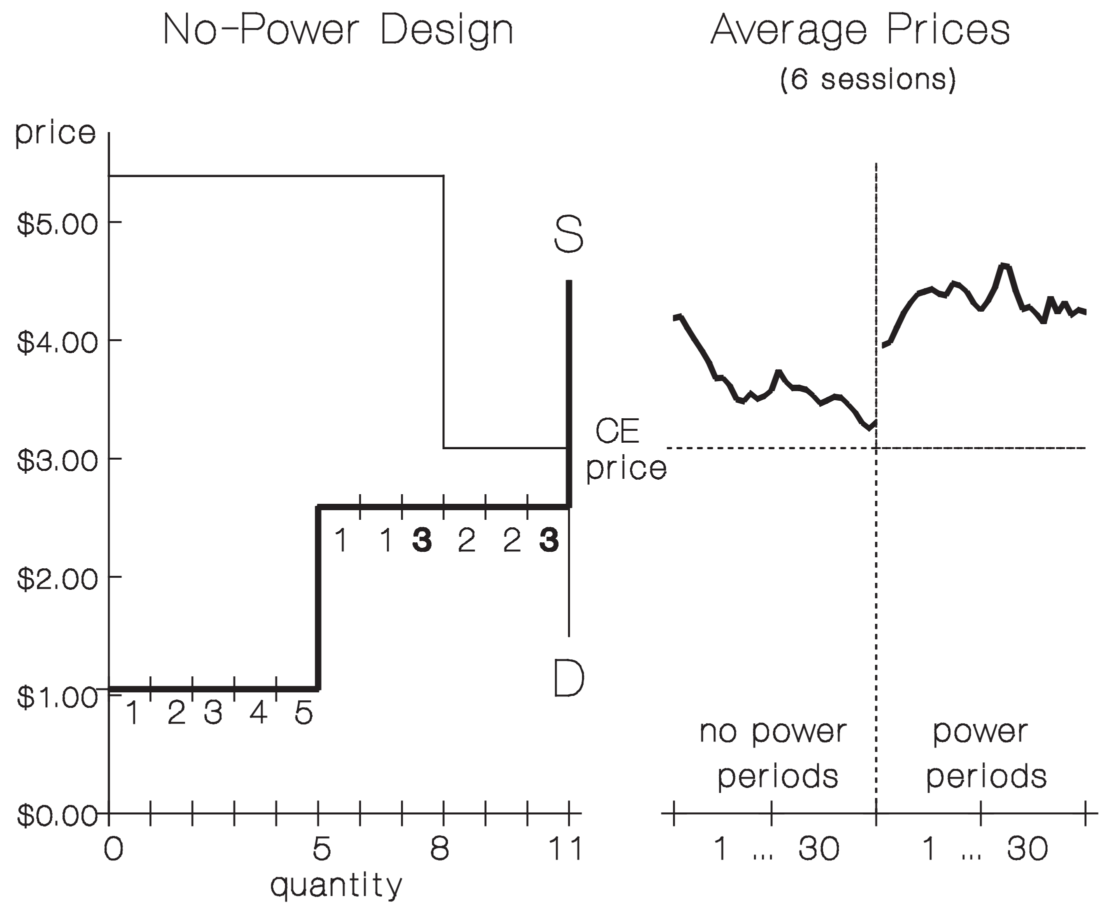

Figure 9. The Effects of Market Power in Posted-Offer Auctions
Source: constructed with data from Davis and Holt (1994b)

every other sequence. Subjects were experienced, and buyers were simulated. In the no-power periods, prices begin high and fall to near-competitive levels, as shown in figure 9 to the left of the dotted vertical line. In the periods with the power treatment, prices initially rose and then stayed high and variable, as shown to the right of the dotted vertical line in the figure. Prices were higher under the power treatment in all six sessions. Prices in the power design are well up into the range of randomization that is applicable for this design. In both designs, there is some evidence of tacit collusion in the sense that prices are above the levels predicted by static, noncooperative theory. This type of tacit collusion in posted-offer markets with seller market power is also reported by Davis, Holt, and Villamil (1990) for a different design in which the stage-game equilibrium also involves randomization. Besides the fact that prices are too high relative to the mixed-strategy equilibrium, there is considerable autocorrelation in the price series for most subjects, which is inconsistent with randomization. This autocorrelation is also reported by Kruse, Rassenti, Reynolds, and Smith (1994), who nevertheless conclude that the theoretical mixed-strategy equilibrium tracks some of the qualitative features of the equilibrium price patterns as excess capacity is altered.

Grether, Schwartz, and Wilde (1988) review several equilibrium shopping models in which seller market power could result from the presence of a shopping cost or an exogenous limitation on buyers' information about posted prices. Pricing behavior in posted-offer sessions tended to conform to the (Nash equilibrium) prediction for the informational and structural conditions used in the session. When the prediction involved supra-competitive pricing, it was always observed. One of the treatments involved a setup in which the prediction is the monopoly price. In this treatment, sellers' posted prices were written on the blackboard, but without their identification numbers. Buyers, who each had a single unit with a reservation value of L, were able to observe the exact price distribution before shopping. Each buyer could either pick a single seller at random from this distribution or pay for a sample of two prices and buy a unit from the seller with the lowest price in the sample. No buyer would wish to purchase the sample if its cost is greater than the spread between high and low prices. Therefore, the equilibrium cannot involve sellers choosing a common price below L, since a small unilateral price increase by one seller will not cause any buyer to purchase a sample. Consequently, a small price increase will not reduce the number of buyers who randomly arrive to make purchases. It follows that each seller has a unilateral incentive to raise price at any common price below L, and model parameters were selected so that the noncooperative equilibrium is the monopoly price of L.[91] Prices converged to L in three of the four times that this treatment was implemented.

It would be very misleading to conclude that laboratory evidence largely supports the notion that competitive, Walrasian outcomes are resilient to changes in institutional and structural conditions. Market power that results from capacity constraints or shopping costs can produce supra-competitive prices reliably in posted-offer auctions. Changes in market power that leave the shapes of supply and demand unchanged can also affect prices significantly. Sellers are sometimes able to exercise market power in double auctions, but the influence of seller market power is much weaker because of the incentives to offer last-minute price concessions and the more active role that buyers have in this institution. I have yet to see a design in which efficiency is significantly reduced by market power in a non-monopolized double auction.[92]

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[91] Buyers were not permitted to pay a price above L, and they were paid a ten cent "commission" on each unit purchased in order to induce purchases at the price of L.

[92] I suspect that, if efficiency is to be reduced in stationary double auction trading, one would need a large number of buyers, each with only one infra-marginal unit. This single infra-marginal unit would give the buyers a strong incentive to make purchases and no incentive to behave strategically (within a period). The number of sellers would have to be low enough so that sellers have numerous units that are inframarginal and marginally profitable at the competitive price. Excess capacity at supra-competitive prices would have to be small enough so that a small minority of sellers could not expand production and negate other sellers' efforts to restrain production and force prices up. The inefficiency might arise when some sellers give in to the temptation to sell

8. "PLUS FACTORS" THAT FACILITATE COLLUSION

After measuring concentration and the changes that would be caused by a proposed horizontal merger, a standard procedure in antitrust analysis is to consider "plus factors" or market conditions that may make collusion (either tacit or explicit) more likely. Some of the most important plus factors, such as the absence of potential entry, have been covered in earlier sections. This section covers repetition, communication, numbers, and contracts. Many other interesting factors that come up in antitrust cases have not been evaluated in the laboratory, and this is an important area for further work.[93]

Output of Row Player	Output of Column Player: 5	6	7	8	9	10	11	12
5	80, 80	77, 84	75, 87	72, 89	70, 90	67, 90	65, 89	62, 87
6	84, 77	81, 81	78, 83	75, 85	72, 85	69, 85	66, 83	63, 81
7	87, 75	83, 78	80, 80	76, 81	73, 81	69, 80	66, 78	62, 75
8	89, 72	85, 75	81, 76	77, 77	73, 76	69, 75	65, 72	61, 69
9	90, 70	85, 72	81, 73	76, 73	72, 72	67, 70	63, 67	58, 63
10	90, 67	85, 69	80, 69	75, 69	70, 67	65, 65	60, 61	55, 57
11	89, 65	83, 66	78, 66	72, 65	67, 63	61, 60	56, 56	50, 51
12	87, 62	81, 63	75, 62	69, 61	63, 58	57, 55	51, 50	45, 45

Figure 10. A Bimatrix Cournot Duopoly Game (payoff for row, payoff for column)
(Source: from Holt 1985)

Very simple laboratory environments are especially useful for isolating the effects of communication, repetition, payoff symmetry, and other factors that may enhance or retard cooperation. Therefore, much of the work to be surveyed in this section involves situations in which the payoffs are presented in a simple matrix form, e.g. prisoner's dilemma and matrix oligopoly games. To understand better the strategic situation that subjects face in this type of game, consider the payoff matrix in figure 10, which is a

high-cost extra-marginal units to the market as the price rises.

[93] Scherer and Ross (1990) contains a broad discussion of factors that are thought to facilitate or to limit oligopolistic coordination. See Jacquemin and Slade (1989) for a more theoretical treatment of this topic.

truncated version of the Cournot duopoly payoff table used in Holt (1985).[94] Subjects could choose any output quantity between 4 and 22, but the part of the table reproduced here only shows the penny payoffs for outputs from five to twelve, with the payoff of the row player listed first. Looking down the diagonal from the upper left to the lower right, it is apparent that the symmetric perfectly collusive output is 6, which yields profits of 81 for each. Looking down the "8" column, it is apparent that row's best response to an output of 8 for column is to choose an output of 8, and vice versa, so (8,8) is a symmetric Cournot-Nash equilibrium.[95] These payoffs were generated with a linear demand, constant marginal cost, and a normal profit (negative fixed cost) to ensure that profits were 45 cents at the competitive outcome. For the demand and cost functions used, the competitive outcome, where price equals marginal cost, occurs with outputs of 12 for each person.

The competitive output of 12 is also the output predicted by the "consistent conjectures equilibrium" (CCE) proposed by Bresnahan (1981). Early oligopoly theory was long plagued by the indeterminacy of "conjectural variations," and the CCE is a method of determining which of many possible conjectural variations is consistent with actual responses. Mechanically, the consistent conjecture is found by taking the total differentials of sellers' first-order conditions (when they contain conjectured responses), and then imposing a consistency requirement that the actual response to others' decisions be equal to the conjectured responses. I was initially interested in a new equilibrium concept with an intriguing title, and with the ability to explain most of the tacit price collusion observed by Dolbear et al. (1968) in simultaneous-price-choice matrix games.[96] But I was skeptical of the CCE prediction that a duopoly market with a homogenous product, linear demand, and constant cost would yield a competitive price. These structural assumptions were satisfied in the Fouraker and Siegel (1963) experiment to be discussed below; and to my surprise, they had observed very competitive outcomes, especially in triopoly sessions.

The Fouraker and Siegel experiment did not clearly distinguish the Cournot and CCE (in this context competitive) outcomes, in part because the profits at the CCE/competitive outcome were zero in the Fouraker and Siegel design. Subjects are always led to believe that they may earn a significant amount of money in a laboratory session, so behavior is less likely to stabilize around the predictions of an equilibrium that yields zero earnings. To give the CCE a reasonable chance, I added 45 cents to all earnings amounts to obtain the payoffs shown in figure 10, and the payoff of (45,45) for outputs of 12 was thought to be sufficient to keep subjects motivated.

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[94] The layout of the payoff table used in Holt (1985) has been altered so that the basic features will be more easily recognized by the reader who is familiar with the prisoner's dilemma game. The game in the table is not, strictly speaking, a prisoner's dilemma, since the decision to "cooperate" with an output of 6 is not a dominated strategy.

[95] Because payoffs were rounded off to the nearest penny amount, there are asymmetric joint-profit-maximizing outcomes, but always with a market output of 12. There are also asymmetric Cournot\Nash equilibria, but the outputs sum to 16 in each case.

[96] See the discussion in Holt (1985, section II).

Several series of complete-information duopoly markets were conducted with this design. In one session, twelve subjects were successively rematched with different partners in a series of ten single-period games (Holt 1985, section IV). Subjects were separated into two groups of six and were seated in two adjoining rooms at a distance that made it impossible to see others' decision sheets. Participants were given ID number that were written on their decision sheets, and they were shown the sequence of numbers of the other subjects with whom they would be matched. Subjects could see that they were matched with a different person in each period. At the start of a period, they were given several minutes to choose and record a quantity decision. Then the decision sheets were collected and matched. The "other seller's quantity" and the subject's own earnings were recorded on each decision sheet, which was then returned.

The data for every third matching (matchings 1, 4, 7, and 10) are plotted as frequency distributions in figure 11. Initially, the output choices were fairly uniformly distributed from five to eleven, as indicated by the flatness of the "ribbon" for the first matching or period ("pd.1") at the front of the figure. In the fourth matching, two of the twelve subjects were still trying to cooperate, but there is a prominent hump around the outputs of 8 and 9. The modal output choice in the seventh matching is 9, and some of the subjects making this choice were writing rivalistic comments about relative earnings on their "Comment Sheets" for this period.[97] For example, one subject who chose an output of 9 in the sixth period remarked: "only a 1 cent 'loss' occurs producing at 9 instead of 8. This keeps the other firm's profits down." This seller chose 8 in the final matching, and most other output decisions shifted back to the Cournot level, as shown by the ribbon at the back of the figure. This session has not been replicated with other groups of subjects, and given what I now know about group effects, I am hesitant to conclude that Cournot behavior will result from sequences of one-period matchings in quantity-choice games.[98] The session does provide a counterexample to the predictions of the CCE concept. In separate sessions with the same payoff matrix, subjects were matched with the same duopolist partner for a sequence of periods, with a random stopping rule, and about one fourth of the pairs were able to reach the collusive outcome (see below). There was no support for the CCE concept under either treatment; this is an example of an experiment that is used for theory rejection.

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[97] The use of comment sheets is not common, and for good reason. First, the comments are generally worthless remarks, at least in terms of their economic content. Second, as economists, we mostly care about what people do, not what they say, although the rivalistic comments in the bimatrix experiment did help me understand how subjects could be moving in the "wrong" direction away from tacit collusion. Finally, there is some concern that behavior may be affected if subjects are put in a situation in which they may feel like they have to rationalize their actions. This potential bias can be avoided by asking for comments at the end of the session, and not using the same subjects in a later session.

[98] Notice that each subject has been matched with each other subject by the final matching, so the six duopoly choices in the final period will not be independent observations if behavior is affected by outcomes of previous matchings. In other words, the behavior of a subset of participants in early matchings may affect the behavior of others in later matchings. Clearly, more independent observations with different cohorts are needed to make any statistical claims.

Figure 11. Frequency of Quantity Choices for the 1st, 4th, 7th, and 10th Matchings in a Sequence of 10 Single-Period Cournot Duopoly Games (Source: Holt 1985, section IV)

Repetition with Different Cohorts: Experience

There are two issues that arise with repetition: the effects of repetition with the same cohort, and the effects of previous experience with other cohorts. Repetition with the same cohort in a series of market periods could increase cooperation if it takes time to establish trust and\or a reputation for punishing defections. Repetition with different cohorts may increase cooperation, for example, if it is hard to repair a breakdown of trust, and the switch to a new cohort allows people to start over in their attempts to cooperate. These are intuitive, non-game-theoretic observations; in theory, the effects of repetition depend on the stopping rule and the structure of the payoffs.

First consider experience with different cohorts. In the *single-period*, quantity-choice duopolies discussed above, Holt (1985, section IV) found that initial attempts to cooperate vanished after successive re-matchings with different partners in a deterministic rotation pattern. Cooper, DeJong, Forsythe, and Ross (1991) observed that players made cooperative decisions about 30% of the time in single-period prisoner's dilemma games with re-matching.[99] The incidence of cooperation was higher in initial matchings (43%)

[99] There are many related papers that report results of public goods experiments, which typically have a structure that is similar to a prisoner's dilemma; there is a joint-payoff-maximizing outcome that is not a noncooperative equilibrium. The rate of cooperative contributions to the public good is relatively high (50-60%)

than in later matchings (20%). Therefore, repetition of single-period encounters has been observed to reduce cooperation, which in theory should not exist in these single-period encounters.

Repetition with previous cohorts has been observed to increase cooperation in multi-stage games. Stoecker (1980) matched subjects in a sequence of ten-period price-choice duopoly games with a tabular payoff function that simulated demand. The ability to switch partners every ten periods probably allows subjects to break out of deadlocks, and the ten-periods of repetition provides some inducement to cooperate, even though the unique subgame-perfect outcome in this finite-horizon structure is to defect and price competitively in all periods. After a number of rematchings of this type, Stoecker found that the rates of cooperative behavior were very high until the last several periods of the ten-period sequences. In a later paper with sequences of ten-period prisoner's dilemma games, Selten and Stoecker (1986) observe some decay in cooperation rates ("unraveling") in later matchings.

Davis and Holt (1989) also observed that subjects with previous experience in two-stage matrix games were more cooperative and were more likely to use decisions in the second stage that punish defection and reward cooperation in the first stage. This was a relatively complicated game in which cooperation in the first stage can be an equilibrium outcome, which may explain the importance of experience. Benson and Faminow (1988) report an experiment that was designed explicitly to compare the behavior of experienced and inexperienced subjects (in duopoly price-choice markets with product differentiation and incomplete information). The experienced subjects had participated in similar, but not identical sessions. They observe significantly more tacit cooperation among subjects with such experience. The authors do not consider the alternative hypothesis that people who cooperated more successfully in earlier sessions were more likely to sign up again for the experienced sessions. It is a possibility that the effect of experience would be overstated as a result. Nevertheless, it is reasonably safe to conclude that experience with previous cohorts in multi-period encounters can increase cooperation, whether or not such cooperation is an equilibrium outcome for the multi-period game.

One relevant distinction may be whether or not the change in cohort occurred in the same session or between sessions on different days. In the multi-period duopoly markets in Holt (1985), subjects were rematched after the random termination of the first pairing, and the levels of cooperation for the second pairing were no higher than for the first. In contrast, the increased cooperation observed by Davis and Holt (1989) and Benson and Faminow (1988) was for changes in cohorts on different days. If this difference is relevant, then it provides support for the standard practice of using "experience" to mean participation in the same type of game or institution in a previous session.

Multi-period Repetition with the Same Cohort

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in a single-period public-goods game, but cooperation declines with repetition, whether or not the repetition involves being re-matched with different groups of potential contributors. These results are discussed in Ledyard (chapter ** of this handbook).

Fouraker and Siegel (1963) matched subjects in groups of two or three for a sequence of identical market periods. The number of periods was unknown to subjects until the end. Subjects chose quantity levels simultaneously, and each person's payoff was calculated with a table that was determined by a linear demand function for a homogeneous product, with constant costs of production. Fouraker and Siegel report outputs for the 21st period. In the complete-information duopoly markets, outputs were approximately uniformly distributed in the range from the collusive industry output of 30 to the competitive (price-equals-common-marginal-cost) industry output of 60.[100] Industry outputs were often below the static Cournot level of 40-44 for a duopoly, which indicates that some tacit collusion developed in these repeated Cournot games.[101] In the complete-information three-seller markets, about two-thirds of the industry outputs were *above* the Cournot triopoly output of 45-48, i.e. most of the triopoly participants exhibited rivalistic rather than tacitly collusive behavior. About half of the complete-information, triopoly outcomes were very close to the competitive output prediction of 60, despite the fact that this yielded zero profits.[102] With incomplete information about others' payoffs (and only information about the sum of others' quantity decisions), triopoly outcomes were closer to the Cournot outcomes that correspond to the static noncooperative equilibrium for the stage game.

Carlson (1967) used a variant of this non-matrix setup, with incomplete demand information.[103] In two sessions, he used a steep demand function that should yield explosive price oscillations under the cobweb theory in which sellers base current production decisions on the assumption that price will be the same as it was in the previous period. In two other sessions, the demand was flatter, and the market should converge under static cobweb expectations. The observed price patterns for the sessions with the explosive design were no more unstable than for the other sessions.[104] In Carlson's sessions, the output quantities converged to near competitive levels in all

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[100] In one sense, there was never complete information, since subjects were not told the number of periods in advance.

[101] For 16 complete information duopoly markets, the industry outputs for period 21 were 25, 30, 30, 32, 33, 38, 39, <u>40</u>, <u>40</u>, <u>44</u>, 45, 49, 50, 55, 59, and 60, where outputs in the Cournot range have been underlined.

[102] The period 21 outputs for eleven complete-information triopoly markets were: 40, 44, <u>46</u>, <u>47</u>, 51, 58, 59, 59, 62, 63, and 70, where outputs in the Cournot triopoly range are underlined.

[103] Subjects were told that price is a decreasing function of the market quantity. In two of the sessions. But some demand information was provided by suggestive examples in the instructions. For example, subjects were all instructed to choose a common quantity in a no-pay practice period, which revealed a single point on the demand curve, but in a manner that was highly suggestive since the resulting market quantity was lower than the competitive quantity. Even worse, the suggested output decisions yielded different market prices for the two demand-slope treatments. In the other two sessions, subjects were told that the price in the previous period had been .12, which is also suggestive since this price is .05 below the competitive price.

[104] Wellford (1989) and Johnson and Plott (1989) also report stable results for parameterizations that would be explosive in a cobweb model. A partial exception to this pattern is a 4-seller session described in Holt and Villamil (1986) in which the market price and quantity followed a nearly square, counterclockwise cobweb path for about seven periods. Even here, the elicited pre-period price expectations indicate that only one seller was basing quantity choice on a static expectation that price would not change. Johnson and Plott (1989) observed several damped cobweb-like cycles in their Cournot, quantity-choice sessions.

sessions, but this result must be interpreted with caution since the sessions involved twenty-twenty-five sellers and the author does not calculate the Cournot equilibria. Subjects in the Holt and Villamil (1986) four-seller session were given no demand information, and the mean and median price was near the competitive level, and nowhere near the Cournot level. Binger et al. (1990) report the results of 40-period Cournot markets with complete demand information. Averaging across sessions and periods, the market quantities approximate the Cournot levels for the two-seller no-communication sessions, and quantities are about midway between competitive and Cournot levels for the 5-seller, no-communication sessions. Wellford (1990) reports outcomes in the range between the Cournot and competitive predictions for multi-period sessions, with either five or eleven sellers and complete demand information. Beil (1988), who used a payoff matrix to simulate demand, also finds that the quantity decisions typically exceed the static Cournot levels in four-seller markets. There is more tacit collusion with only two sellers, Holt (1985) and Mason, Phillips, and Redington (1991) report that quantities in multi-period duopoly games are between the Cournot and collusive levels.

The overall pattern of results in multiple-period, Cournot quantity-choice experiments is summarized: 1) with Cournot duopolies, outcomes fall on both sides of the Cournot prediction, and some cases of near perfect collusion occur, and two) with more than two sellers, outcomes are often more competitive than the Cournot prediction.

Next consider the effects of repetition in price-choice experiments. Fouraker and Siegel observed a downward price trend in price choice experiments with a very competitive setup: a homogeneous product and no capacity constraint (the seller with the lowest price sells all).[105] The price decline was more abrupt for triopolists than for duopolists. Murphy (1966) used a modification of the basic Fouraker and Siegel (1963) incomplete-information design for price-setting duopolists, and he ran the sessions for more periods. He found that an initial downward trend was reversed later.[106] Very extensive repetition has sometimes resulted in high levels of cooperation. Alger (1986, 1987) also reports significant amounts of cooperative pricing behavior in duopoly posted-offer markets (with no-power designs) that sometimes lasted for more than 100 periods. The stopping rule for these markets was not announced to the subjects. Harrison, McKee, and Rutstrom (1989, p. 89) note one potential problem with Alger's markets: "...one would want to ensure that the rewards to subjects after so many periods dominated the subjective costs of participating in a meaningful way (one of us observed some of these experiments in progress, and was struck by the widespread boredom of the subjects as well as their relief at the end of the session). It is not obvious that statistically-significant differences of prices of a few pennies implies statistically-significant differences of expected income to subjects." This raises an important methodological issue; for most purposes, incentives should not be diluted to keep earnings constant when the number of market periods is increased.

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[105] The payoffs were presented as a column of earnings numbers that correspond to each possible of the lowest posted price.

[106] The reader should be warned that the figure in Murphy's paper that summarizes his data is incorrectly labeled as Fouraker and Siegel data, and vice versa.

The way in which cooperation can change over time is critical for many applications. Experimentalists usually do not want to truncate treatment sequences before behavior stabilizes, but unnecessarily long sequences can limit the ability of the experimenter to switch treatment conditions. My own experience in current work with Doug Davis is that prices in the first ten-twenty periods of a posted-offer auction can be misleading. Some of our (to date, unreported) posted offer sessions involve five sellers in a "no-power" design with simulated demand and a preannounced stopping point of 60 periods. Prices can rise significantly above competitive levels between periods 10 and 20, and there is no predominant pattern after that point in most sessions. In a bimatrix quantity-choice setting with four sellers and no information about the stopping point, Beil (1988) reports two 70-period markets in which the outcomes reached the approximate Cournot level by period 5 and did not change significantly thereafter.[107] Mason, Phillips, and Nowell (1991) report that the adjustment is slower in Cournot duopoly matrix games when the payoffs are asymmetric than is the case with symmetric payoffs. Moreover, subjects in the asymmetric games were less cooperative.

Although the studies just discussed involved repetition for a sequence of periods with the same cohort, none provided a specific control, i.e. a matched treatment with no repetition. Using the same payoff table that generated the noncooperative outcomes by period 10 in the single-period games reported in figure 11, Holt (1985) conducted multi-period sessions with a random stopping rule. In particular, subjects were told that they would continue to be matched with the same partner until the throw of a die yielded a six, so the probability of continuation was 1/6.[108] As is well known, this introduces a type of discounting that gives more weight to current earnings. By the end of the multi-period markets (determined by the throw of a die), about 40% of the subjects were selecting output decisions below the static Cournot level, i.e. more cooperative than Cournot behavior. Overall, about one-fourth of the duopoly pairs were able to reach the symmetric, joint-payoff-maximizing outputs. This is reassuring, since the joint-maximizing outcome can, in this infinite-horizon context, be supported by the threat of reversion to the static Cournot decisions in all periods following a defection.[109] But perhaps more important than the threat of this "trigger" punishment is the opportunity to establish trust in duopoly situations with repetitions; a number of pairs were able to coordinate joint incremental movements toward the joint-maximizing levels by

[107] In this design, the quantity-choice behavior in these relatively long sessions did differ from behavior in shorter, twenty-period treatment sequences, but the small number of independent observations makes it difficult to infer much from this difference.

[108] The die was not thrown in the presence of the subjects, which is unfortunate since the credibility of the stopping rule is enhanced if subjects can monitor procedure.

[109] From figure 10, we see that subjects earn 81 each in the cooperative (6,6) outcome and only 77 in the Cournot (8,8) outcome. Starting in a cooperative outcome, a subject can raise earnings from 81 to 85 by expanding output from six to eight, for a 1-period gain of four cents. But if the other seller expands output to the Cournot level of eight in subsequent periods, each seller will earn 77. Thus the sure 1-period gain of four cents from defection in the current period must be compared with the 5/6 probability of having earnings reduced by four cents in the next period, and in every subsequent period until the experiment is terminated. It is straightforward to show that the four cent gain from the initial defection is less than the expected value of the reduction in earnings that occurs in the punishment phase.

simultaneously choosing outputs of (8,8), followed by (7,7) and (6,6). In several cases, large, seemingly punitive output expansions were used by subjects who had been choosing outputs below the Cournot level while their partners had been earning higher payoffs by using higher outputs.

Feinberg and Husted (1993) investigate the effects of the rate of discount on collusion in quantity-choice games by 1) having a random termination probability of 1/6, and 2) by having payoffs decline over time at either a fast rate or a slow rate. They find that collusive duopoly outcomes are less likely with high discount rates.

Palfrey and Rosenthal (1992) provide another direct study of the effects of repetition. Their experiment involves a comparison of 1) repeated one-shot games with different cohorts, and 2) non-repeated multi-stage games with the same cohort, where a random device was used to determine the final period. Although this is a public goods game with a complicated private information structure, the basic incentive structure similar to that of a prisoner's dilemma, with a noncooperative equilibrium for the stage game that yields earnings that are far below earnings that would result from cooperative decisions. In the repeated treatment, the authors show that a cooperative outcome with rotation of contributions could be supported by "trigger strategy" threats to revert to the noncooperative equilibrium for the stage game. In the experiments, repetition raises contributions rates, by an amount that is statistically significant but not particularly large relative to the cooperative outcome. Palfrey and Rosenthal (1992, p.4) conclude that these results are "...not encouraging news for those who might wish to interpret as gospel the oftspoken suggestion that repeated play with discount rates close to one leads to more cooperative behavior." Sell and Wilson (1991) also find little support for the use of trigger strategies to support cooperation in repeated, four-person public goods games with a random termination device. Of course, the effects of repetition may be more pronounced in simpler games. In particular, punishments are more likely to be effective when there are only two players, so that a punishment can be targeted to the defector without harming third parties (see the discussion of numbers effects below). Non-binding communications can also increase the likelihood of observing the more efficient outcomes supported by trigger strategies (see the discussion of Brown-Kruse, Cronshaw, and Schenk 1990, in the next section).

To summarize, repetition has been observed to decrease cooperation in single-period market games. In multi-period games, repetition with the same cohort and with previous cohorts has been observed to increase cooperation. The amount of experience needed before behavior stabilizes is an open and important question, and the answer may be design and institution specific. Posted-offer markets probably ought to be run for at least fifteen periods, unless pilot sessions indicate otherwise. Very long sequences of market periods, however, do not necessarily generate perfect collusion. Moreover there is no direct evidence to support the view that trigger strategies will result in cooperative outcomes in multi-stage games with random termination rules and no communications.

Pure-Numbers Effects and the Ability to Punish

The possibility of direct punishment is a factor that facilitates cooperation. In a duopoly market, either seller can send a direct message by reducing price or expanding quantity. Davis, Holt, and Villamil (1990) found a fair amount of tacitly collusive pricing in posted-offer duopolies, even in their "no-power design." But there was much less supra-competitive pricing in triopoly markets with the no-power design. The authors conjectured that this difference was due to the inability of triopolists to punish one noncooperative rival without harming the other. The subjects in Stoecker's (1980) sequence of ten-period duopoly experiments were unable to maintain collusive prices when they were subsequently matched as triopolists. Fouraker and Siegel (1963) also found more competitive behavior with three sellers than with two. Binger et al. (1990) observe 1) high levels of cooperation in quantity-setting duopolies, and 2) near-competitive behavior with five quantity-setting subjects (in the later periods of parallel sessions). Isaac and Reynolds (1989) survey the state of general opinion and advice about workable competition in antitrust settings and find considerable support for the notion that two firms are too few and four may be sufficient for good performance. A change in the number of sellers may alter the price predictions of standard oligopoly models, but it was Chamberlin (1962) who first suggested that the underlying nature of the equilibrium concept may differ between "small group" and "large group" situations.[110] Nevertheless, I am skeptical that there will be a magic number of sellers that ensures competitive outcomes; institutional and structural details cannot be ignored. For example, posted prices are way above competitive levels in the five-seller power design of Davis and Holt (1994b) that is reproduced in figure 9.

It is useful to distinguish between two possible effects of increasing the number of sellers beyond two: it is harder to monitor the specific decisions of the others, and it is harder to punish a specific rival. On rereading Fouraker and Siegel (1963) for this survey, I noticed that their incomplete information treatments were altering both payoff and monitoring information. In the quantity-choice sessions with incomplete information, each seller was only told the sum of others' quantity choices, so a duopolist could monitor the other's output, and a triopolist could not do so with the same precision. Was the more competitive behavior in the Cournot triopolies due to the increase in the number of sellers or to the change in the ability to monitor?

Beil (1988) reports some preliminary research designed to address the importance of firm-specific monitoring and punishment. In four-seller Cournot sessions, the ability to monitor the previous periods' outputs of each of the other three sellers did not increase observed cooperation beyond that observed in sessions without monitoring. A second treatment involved the ability to punish a specific rival; this was implemented by giving each seller the ability to direct a payoff penalty toward one specific rival in each period. The penalty was fixed and ranged from ten to 50 cents. Observed cooperation increased dramatically in periods with the targeted-penalty option, and joint-maximizing outcomes

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[110] There is at least one well-documented case of the absence of a numbers effect in laboratory markets. In a constant cost, repeated Cournot game, Wellford (1990) found no statistically significant price effect of a merger that reduced the number of sellers from five to four or from eleven to ten. Recall from the earlier discussion that quantity-choice markets with more than two sellers tend to be more competitive than the Cournot prediction, and this fact would dilute the price effect of a merger in a constant-cost environment. Moreover, the data in these Cournot markets was quite variable from period to period, which may mask any treatment effect.

were often observed. Although this penalty was costless to the sender and perhaps unrealistically precise, its dramatic effect can help us understand why there is less tacit collusion with more sellers in markets with no specific penalty.[111] If two sellers are showing a lot of restraint and a third is cutting price (or expanding output), then neither of the two cooperative sellers can punish the deviant with a price cut without also affecting the earnings of the other cooperative seller, which may trigger a price war.

One feature of all of these analyses is that an increase in the number of sellers typically changes the incentive structure of the game in a variety of ways. For example, increasing the number of price-setting sellers of a homogeneous product from two to three will reduce the profit for each if they share the demand at a common price, but correcting this by increasing demand will increase the incentive that each has to under-cut the others' common price. One interesting issue is whether the numbers effect on prices is only due to the change in the individual's own incentive structure and has nothing to do with the number of sellers. A "pure-numbers" effect could be investigated by altering the number of sellers, holding the incentive structure constant. Such a pure-numbers effect could be due to a number of factors, including the reduced ability to punish a deviant competitor in a large-numbers situation.

Dolbear et al. (1968) used a clever design that isolated a pure-numbers effect, holding constant the incentives to collude tacitly. This was done by using a bimatrix-game payoff table with the row determined by the subject's own price decision and the column determined by the "average price of competitors.,[112]" [113] In the duopoly sessions, the column was determined by the other seller's price, but using the same table in the four-seller and 16-seller designs was the way in which the authors were able to change the number of competitors without altering the incentives to raise prices above static noncooperative equilibrium common to all treatments. Subjects always knew the number of other sellers, and that the stage game would be repeated an indeterminate number of times with the same group of competitors. Some sessions were conducted with complete information about payoffs but incomplete information about the termination point, which was undisclosed but which turned out to be at the end of period 15. Prices in the twelve duopoly markets with complete payoff information ranged from being lower than the noncooperative level up to the collusive level. But four out of six of the four-seller markets with complete information yielded noncooperative prices.[114] The same

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[111] One simple way in which a punishment can be very direct is the ability of a buyer to switch to another seller. This type of punishment is implemented in Wiggins, Hackett, and Battalio (1990) and Davis and Holt (1994c), both of which will be discussed in section 9.

[112] The use of words such as "competitors" is undesirable, since such words may induce rivalistic behavior. It is not clear from the description of the procedures whether the table used in the experiments was labeled in the same manner as the table that was published in the article.

[113] This payoff structure was generated from a demand function that involved some product differentiation, i.e., the seller with the highest price did not necessarily have zero sales. The underlying demand function was linearly increasing in the average of others' prices, and linearly decreasing in the seller's own price.

[114] The authors state that the noncooperative equilibrium price is 18, which is true, but the restriction on the use of integer prices in the payoff table results in a second symmetric equilibrium at 17. My summary of their data reflects this fact.

pattern was observed in a parallel series of markets with private incomplete information; all four-seller markets and a 16-seller market converged to the noncooperative price level, but prices in five of six incomplete-information duopolies were above the noncooperative levels.[115] Therefore, an increase in the number of sellers produces a reduction in prices that cannot be attributed to changes in the incentive structure.

A surprisingly small pure-numbers effect is reported by Davis and Holt (1994b) in a design in which a merger reduces the number of sellers from five to three. The authors use as a baseline a "power design," which is the design in figure 9 after reallocating the boldfaced units from seller 3 to sellers 1 and 2. This power-design baseline is then altered by merging sellers 3, 4, and 5, a merger that reduces the number of sellers, but as they show, does not alter the noncooperative equilibrium mixed price distribution. The merger increases prices in five of six sessions with paired pre-merger and post-merger treatments; the effect is small but statistically significant. Similarly, Isaac and Reynolds (1989) find a "marginally significant" increase in efficiency when a fixed industry capacity is equally divided among four sellers instead of two sellers, in posted offer sessions with identical simulated demand functions. The plots of average prices, however, reveal a clear pure-numbers effect on price.

In contrast, Isaac and Walker (1988) find no clear pure-numbers effect in a public goods experiment in which the size of the group is changed from four to ten without altering the marginal per capita return of a contribution to the public good. They discuss two other studies of pure-numbers effects in the literature on prisoner's dilemma games, with group sizes ranging from three to nine; in one study, the effect was not significant, and in the other the effect was for larger groups to cooperate more (when the payoffs were altered with group size to hold constant the marginal incentive to cooperate).[116] The primary difference that I detect between studies that find no pure-numbers effects and those that do not is whether duopoly is the basis of comparison. For example, there would be no clear numbers effect in the Dolbear, et al. data if one were only to compare their four-seller sessions with the single 16-seller session.

To summarize, increases in the numbers of sellers result in more competitive behavior, both in absolute terms and (with two sellers as a baseline) in relation to the static, noncooperative equilibrium (which itself typically changes with the number of sellers). But with more than three participants, there seems to be little or no evidence for a "pure-numbers effect" that is measured by changing the number of sellers in a way that does not alter the incentive structure. With two sellers, a defector can be punished directly without harming a cooperative third party, and there is some evidence that the possibility of direct punishment enhances cooperation.

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[115] In fact, average prices for each treatment were essentially the same (within two-tenths of a penny) in the two information conditions. This is interesting and perhaps surprising, since the good performance of the noncooperative equilibrium in the four-seller case is not negated by incomplete information. Conversely, the average tendency to cooperate tacitly in duopoly markets is not facilitated by complete information.

[116] See Ledyard (chapter ** of this handbook) for more discussion of the Isaac and Walker results.

Communication

The simplest form of communication is indirect; it involves sending "signals" with price and quantity decisions. Fouraker and Siegel (1963) limited this type of signaling in their "incomplete-information," price-choice sessions; the subjects were only told whether their price was low, tied, or high. The others' prices were observed in the complete-information sessions, which generated more tacit cooperation, especially with two sellers. Is the more competitive behavior in their incomplete information treatment due to the inability of a high-price seller to communicate a signal by going all of the way up to the joint-maximizing price, instead of inching up timidly? Signaling of this nature precedes collusive phases of the Davis and Holt (1994b) sessions with publicly posted prices. My guess is that the Fouraker and Siegel data present a biased impression of the likelihood of obtaining noncooperative outcomes under incomplete *payoff* information.

Most of the experimental work on communication pertains to explicit, verbal discussions. Non-binding communications generally improve cooperation in prisoners' dilemma games (Dawes, MacTavish, and Shaklee 1977) and in sealed bid auctions (Isaac and Walker 1985).[117] Daughety and Forsythe (1987a, 1987b) and Binger et al. (1990) report that face-to-face non-binding group discussions are effective in raising price in repeated Cournot games in which the quantity decisions are made privately after the pre-period discussion. Moreover, Daughety and Forsythe (1987a) report that the opportunity to collude in initial periods of a session had a carry-over effect in subsequent periods in which discussion was not permitted. Similarly, Isaac, Ramey, and Williams (1984) find that posted-offer prices are increased when sellers are given a chance to meet face to face and discuss collusion in a non-binding manner prior to each trading period. Indeed, PO conspiracies generate high prices as reliably as PO monopolies, but the index of monopoly effectiveness is lower for PO conspiracies, as is apparent from table 6.

In contrast, non-binding group communications did not appear to increase the incidence of cooperation in a parallel series of double auctions conducted by Isaac, Ramey, and Williams (1984). This observation is consistent with the results of attempts to conspire in double-auctions reported earlier by Isaac and Plott (1981). The failures of conspiracies are probably due to the strong temptation that sellers have to cut price during double auction trading.[118,119] Another case of ineffective (non-binding group) collusion is reported by Harrison and McKee (1985, p.64) for decreasing-cost, posted-

[117] Dawes et al. (1977) point out that communication is a complex variable, and they attempt to isolate the element of communication that increases cooperation in prisoner's dilemma situations. Discussion of an unrelated problem (humanization) does not increase cooperation, but discussion of the dilemma at hand (humanization + relevant discussion) does raise cooperation rates from 31% to 72%. Allowing participants to make a non-binding commitment after the discussion has no additional effect beyond discussion with no commitment.

[118] Kirkwood (1981) suggested that the failure of explicit conspiracies in double-auction markets may be either due to the lack of seller market power or to the tendency for buyer market power to neutralize any power that sellers possess. I would be curious to see what happens with a seller conspiracy in a double auction using the HLV seller market-power design that was discussed in the previous section.

[119] The results reported in Clauser and Plott (1991) also highlight the importance of the temptation to offer sequential price reductions in a double auction that follows a conversation among sellers.

Table 6. The Effects of Conspiracies

	price (deviation from C.E.)	efficiency	monopoly effectiveness
theoretical C.E.	.00	100	0
DA with conspiracy	.15	92	38
PO without conspiracy	.03	90	-15
PO with conspiracy	.27	85	17
PO monopoly	.28	85	45
theoretical monopoly	.60	85	100

Source: Isaac, Ramey, and Williams (1984). The data are for the final period of treatment, averaged across all sessions in each treatment cell. The data were obtained by interpolation from figure 16.

offer experiments with simulated buyers. I would conjecture that the breakdown of collusion here is due to the strong incentive to expand sales in a decreasing cost environment (recall that Isaac, Ramey, and Williams observed effective collusion in PO markets with increasing costs).

Cooper et al. (1991) implement a tightly controlled amount of communication that involves a written suggested decision in a prisoner's dilemma game. There is one-way communication when only one person can send such a message, and there is two-way communication when both players can send such messages simultaneously. In both cases, the communication is just the label of a decision, and there is no opportunity for response. Neither form of communication increases cooperation in their single-period prisoner's dilemma games, with rematchings.[120]

Holt and Davis (1990) introduced a similar type of controlled communication into posted-offer triopoly markets with simulated demand, but with an opportunity for response. Prior to posting prices, a randomly determined seller could fill in the blank in the following sentence: "_______ is an appropriate price for the market in this period." The other sellers could indicate a general response: "*A*" for agreement, "*L*" for too low, or "*H*" for too high. We began by adding a couple of periods of this treatment onto the end of some sessions being run for a different purpose, and the results were immediate jumps of prices to near-collusive levels. We thought that we knew what to expect when we later started to run sessions that began with an initial fifteen periods of ordinary posted-offer trading, and with ten subsequent periods of posted offer trading preceded by the non-binding announcements. The general pattern without announcements was for

[120] The effects of cheap talk in games is reviewed in Ochs (chapter ** of this handbook).

prices to start high and decline gradually over the initial fifteen periods. The first several price announcements were at the joint-maximizing level, but the seller making the announcement would often price a little below the suggested price, and others sellers would tend to do the same. The incentive to reduce price slightly is large in these posted-offer markets with a homogeneous product. As a result, prices declined again, with a level and slope that almost matched the initial decline without announcements. The non-binding announcements had a transitory effect in both designs used (with market power and without it). This episode illustrates the importance of letting a treatment condition run more than several periods.

Friedman's (1967) classic study of collusion also involved a message from one duopolist and a response by the other. These communications were written in prose on pieces of paper. The trading institution was a simultaneous-price-choice matrix game, with essentially complete information, which was repeated between five and twenty-five times. The payoff matrix incorporated a significant amount of product differentiation, which reduced the incentive to make small price reductions from a common, collusive price. In over three-fourths of the periods, the proposal transmitted was accepted in the response, and these agreements were honored in nine-tenths of the periods in which they were reached. In another paper with product differentiation (along a spatial dimension), Brown-Kruse, Cronshaw, and Schenk (1990) find that the introduction of non-binding communication changes the predominant outcome from an inefficient Nash equilibrium for the stage game to an efficient, joint-maximizing pattern of locations. I would conjecture that the effectiveness of the communication activity in these differentiated-product environments is due to the reduced incentive to make small price cuts, as compared with the Holt and Davis (1990) markets with a homogeneous product.

To summarize, the effectiveness of non-binding communication in inducing cooperation seems to be sensitive to the trading institution and the incentives to defect at the margin; the effect is greatest with posted prices and differentiated products, and the effect is less in double auctions. Other factors, such as decreasing costs and the nature and timing of messages, are probably important. Therefore, future work on communication could be usefully focused on designs that parallel specific environments that may come up in antitrust cases, e.g., the trade press announcements of price changes, posting of future prices in computerized listings, and sellers' ability to confirm buyer-specific price quotes with each other.

Contractual Provisions

Market institutions and contractual practices are like organisms that compete for survival in an environment in which efficiency is rewarded. In evaluating the effects of institutions and contractual practices, I generally take a position of "innocent until proven guilty," unless the practice is being imposed by government agencies or industry trade associations. Even in the latter case, it is essential to keep in mind what the alternative would be in the absence of the proposed practice. The focus in this subsection is on contractual provisions that may facilitate supra-competitive pricing; contracts that have other, efficiency-enhancing effects are discussed in section 9.

An important type of contractual restriction is one in which sellers are forced to post prices and to sell at the posted price, as opposed to a situation in which negotiations are decentralized and bilateral. Recall that Chamberlin (1948) observed a tendency for the transactions quantity to be inefficiently high under decentralized trading. In contrast, Joyce (1983) did not observe much difference between symmetric double auction markets of the type that Smith (1962) had used and markets with decentralized trading among subjects walking around a room ("Chamberlin markets").[121] But a closer examination of the Joyce structure suggests to me that, if anything, his experiment provides *support* for the excess-quantity hypothesis described above. This is because the supply and demand functions used are such that there is only one extra-marginal unit that could have traded, i.e. the competitive equilibrium quantity is just one unit less than the total number of units that sellers have to sell and buyers have to buy. The Joyce design would be quite similar to the design in figure 2 if one were to truncate the supply and demand curves to the right of a vertical line at a quantity of 8 (by removing the second, high-cost units for sellers S3-S6 and the second, low-value units for buyers B3-B6). Then, at most, the excess quantity could be one unit, and the resulting efficiency loss would be small if the difference between cost and value of the extra-marginal units were small, as was the case in his design.

Hong and Plott (1982) also consider the effects of decentralized trading. This paper represents an innovative laboratory study of a proposal to require shippers on U.S. inland water routes to file rates with the ICC, with changes to be filed in advance (a fifteen-day period was discussed). This proposal really involves at least two aspects: centralized price posting ("announcements") and advance notice of price increases. Hong and Plott consider the announcement aspect by comparing two telephone-negotiation sessions with two parallel posted-offer sessions. The decentralized nature of telephone trading corresponded to the *status quo* in which contracts were negotiated bilaterally, with the terms only being known to the participants. The posted offer was implemented in a parallel manner by letting buyers call sellers in any order (no restrictions other than those resulting from busy phone lines) to make purchases at the posted prices; discounts were not permitted. To prevent collusion, sellers were not given the phone numbers of other sellers.

All four sessions involved the same group of 33 subjects, which makes the notion of independent observations a little fuzzy, and therefore I will only discuss the first sessions under each treatment. The demand and supply configurations, shown on the left side of figure 12, were carefully motivated by a study of the structure of the U.S. barge industry, and demand shifted to the right in period 5. As can be seen from the diamond symbols that mark the mean prices in the PO markets, prices are a little above the competitive equilibrium in the first four periods, as would be expected from previous PO results. The mean negotiated prices, represented by asterisks, are approximately competitive. Recall that posted prices do not respond quickly to demand shifts (Davis, Harrison, and Williams 1989). In figure 12, the posted prices that are above the

[121] Unlike Chamberlin, Joyce allowed the same group of subjects to interact in a series of market periods.

competitive level before the demand shift are approximately competitive after the shift. Negotiated prices respond immediately to the shift.

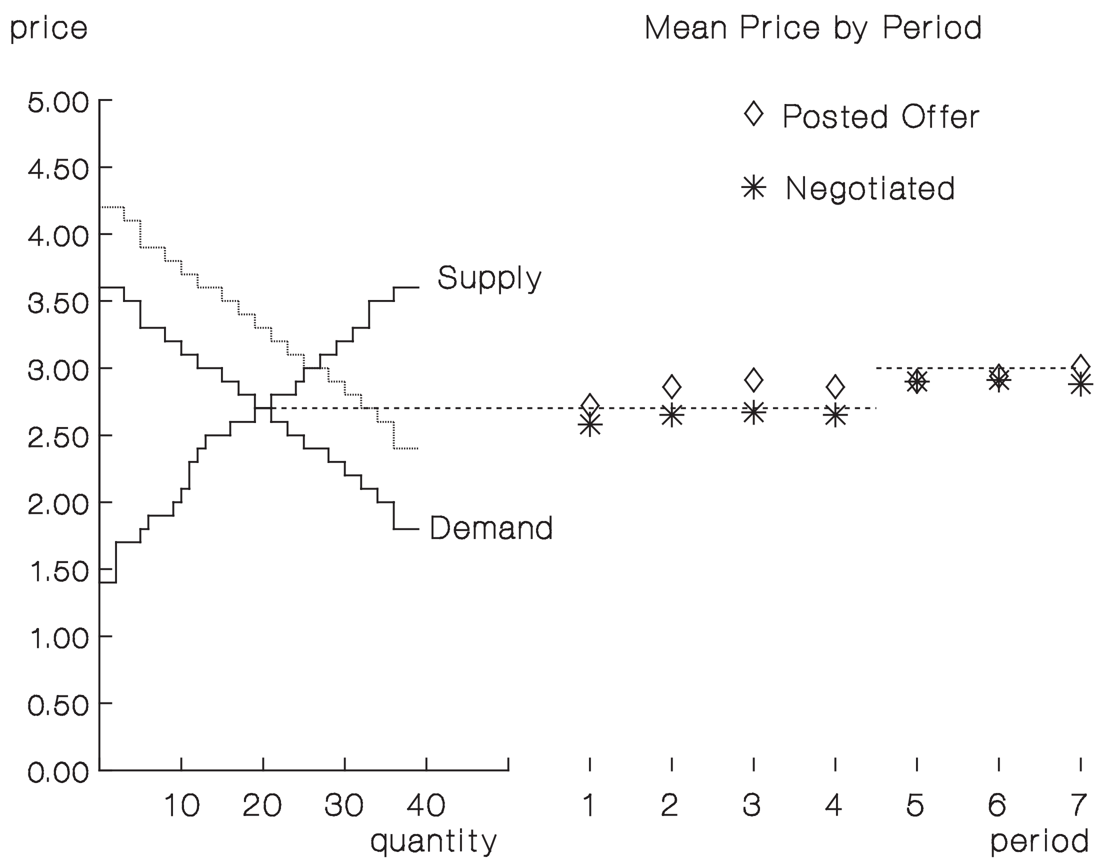

Figure 12. A Comparison of Mean Negotiated Prices and Posted Prices
Source: constructed with data from Hong and Plott (1982), sessions 1 and 2

The supply and demand functions have been redrawn in figure 13 with quantity on the vertical axis, and here we see the Chamberlinian tendency for trading volume to be a little too high under decentralized trading, as the asterisks are above the dashed lines that track the competitive quantity predictions. Interestingly, the PO volume, which is "too low" before the demand shift is approximately competitive after the posted prices are slow to adjust to the shift. In sessions 3 and 4, not shown, demand shifts back to its original position in period 8, and negotiated prices adjust downward more quickly. Over all four sessions, the efficiency is 92% under negotiations and 87% under posted pricing (see table 2 for comparisons with other studies). The reduced trading volume in the PO treatment falls most heavily on small sellers. Projecting the results back to the structure of the U.S. barge industry, Hong and Plott conclude that the rate-filing proposals would reduce efficiency and force many small operators out of business.

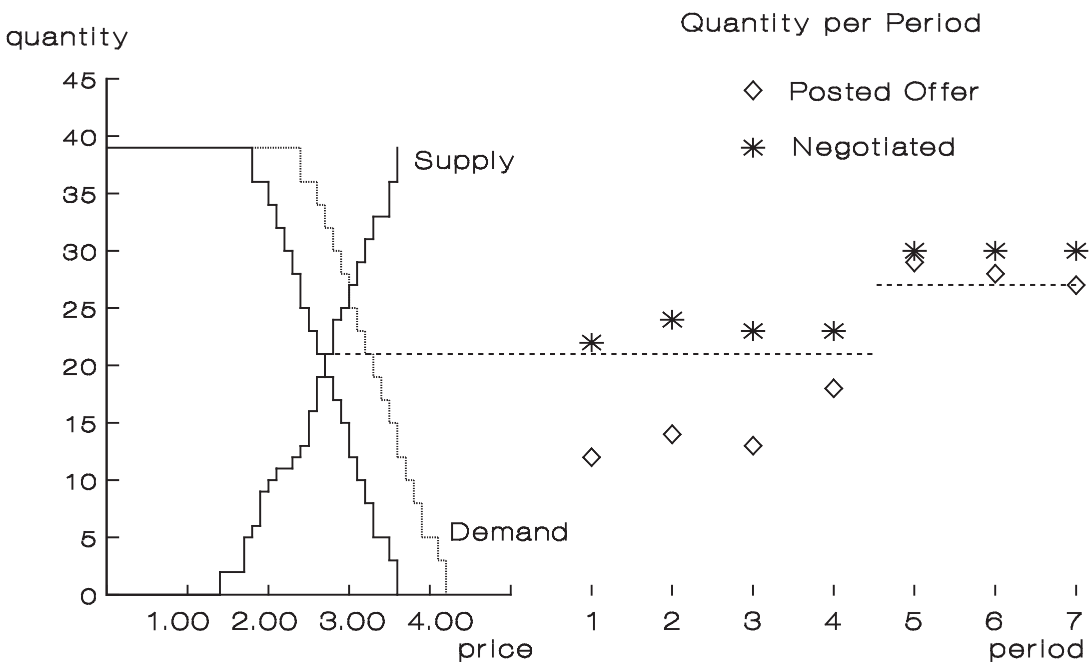

Figure 13. Transactions Quantities for Negotiated-Price and Posted-Price Sessions
Source: constructed with data from Hong and Plott (1982), sessions 1 and 2

Although the excess-quantity results in Hong and Plott (1982) are consistent with earlier experiments and with Chamberlin's simulations, I am a little uneasy about classifying the excess-quantity outcome with negotiated prices as a confirmed empirical pattern. Chamberlin's subjects had no financial motivation, and Hong and Plott (1982) only report two sessions, done in the same week with the same group of subjects. In addition, Grether and Plott (1984), to be discussed next, also contains results for markets with decentralized telephone communications (their N-NN treatment). They report that prices are somewhat above the competitive level, and that efficiencies are near 100%, which leads me to doubt that trading volume exceeded competitive levels.

A second innovative analysis of facilitating practices is the Grether and Plott (1984) paper, which was motivated by the Federal Trade Commission litigation of the *Ethyl* case. The practices involved 1) uniform delivered pricing, 2) advance notice of price increases, and 3) "most-favored-customer" contracts, which specify that the buyer is entitled to a discount if the seller offers a discount to another buyer. Advance notice lets sellers post price increases on a trial basis and rescind them if others do not follow; this ability to communicate may facilitate coordinated price increases. But high posted prices may have little meaning if sellers engage in aggressive discounting, and the theory of the FTC case was that the most-favored-customer contracts deter discounting. To understand how the contract may affect discount decisions, imagine a seller saying to a buyer: "If I give you this discount, I'm required by contract to give a matching discount to all other buyers with whom I have sales contracts, and I cannot afford to do this."[122]

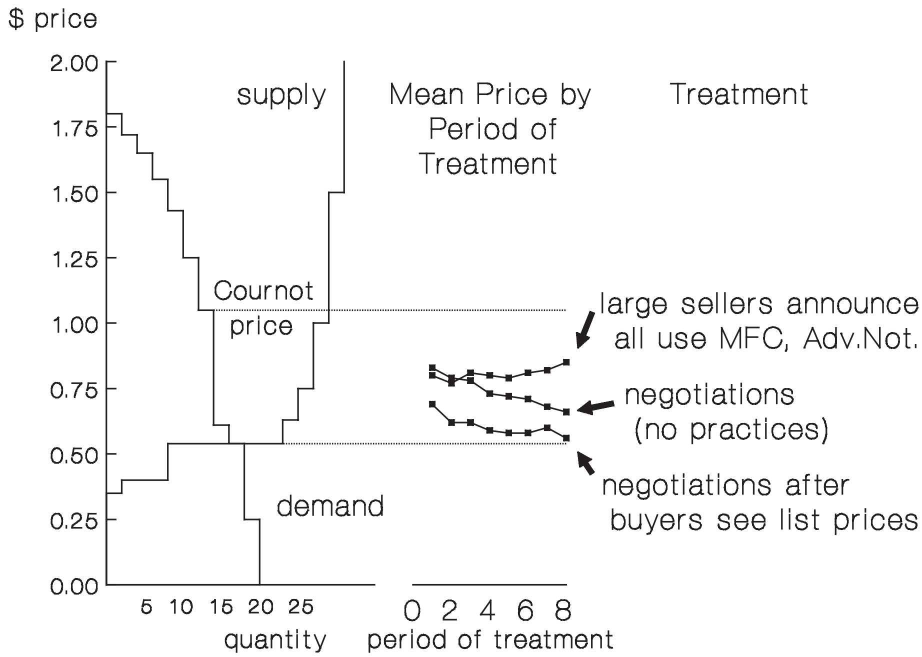

Figure 14. The Effects of Facilitating Practices Litigated in *Ethyl*
Source: calculated with data from Grether and Plott (1984)

Grether and Plott implement treatments that correspond to a number of variations of these practices, and two-three treatments were used in each of the eleven sessions. The treatments usually ran for 3-15 periods before being changed. Figure 14 shows the supply and demand structure, which was selected on the basis of industry-specific information that came out in the FTC investigation. In particular, there were nine buyers and four sellers, two of which were dominant and had most of the marginal units on the flat part of the supply curve as it crossed demand at a price of 54 cents. These sellers would have market power in a quantity-choice setting, and the price that would result from a Cournot equilibrium (in quantities) would be $1.05, as shown by the upper horizontal dotted line in the figure. The noncooperative equilibrium (in the actual price/discount decisions) was not provided; this equilibrium could, of course, be affected by the practices.

The connected dots on the right show the mean prices by period number after the start of a treatment condition. With telephone negotiations (with no restrictive practices),

[122] Also present in many contracts, but not explicitly litigated, were "meet-or-release" provisions that release a buyer from a purchase contract if a seller does not meet a lower price offered by a competitor.

prices start midway between competitive and Cournot levels and fall toward the competitive level. The failure of mean prices to reach competitive levels quickly may be due to the concentration of units in the hands of the two dominant sellers, which contrasts with the less concentrated structure used by Hong and Plott.

One other treatment seemed to be even more competitive than decentralized negotiations, this involved only large sellers making price announcements to buyers, with no restrictions on subsequent telephone negotiations, i.e. no MFC or advanced notice. In this treatment (ABNN), the prices fall to competitive levels, as shown by the line labeled "negotiations after buyers see list prices" in figure 14. The essential difference between this treatment and the posted-price treatment used by Hong and Plott is that discounts from list were not permitted in the latter case.

The least competitive treatment involved all practices, with large sellers announcing their prices to all buyers and sellers, with advance notice and MFC restrictions imposed. Under this treatment (LAYY), prices are about midway between Cournot and competitive levels. Grether and Plott consider other combinations of practices, but none of the other treatments was implemented enough times to isolate the effects of specific practices with precision. Nevertheless, the overall pattern is that the practices raise prices. This latter finding is consistent with the subsequent analysis of facilitating practices in Holt and Scheffman (1987), a theoretical paper that was largely stimulated by the earlier experimental results.

One methodological issue raised by the Grether and Plott study is the extent to which the laboratory market structure should mimic the structure of markets that motivated the study. It is impractical to incorporate the complexity of naturally occurring markets into a design that subjects will comprehend in a two-hour session. Moreover, it is usually preferable to use very simple designs, so that equilibria for competing theories can be explicitly calculated. The key is to simplify in a way that allows one to focus on the issue at hand. In this case, the defense in the *Ethyl* case conceded that prices were probably above competitive levels in the market for lead-based additives, but they argued that this was a result of the concentrated structure, not of the contractual practices being litigated. Consequently, Grether and Plott used a design that incorporated structural factors thought to facilitate supra-competitive prices: inelastic demand, two dominant sellers, and no entry.

There are many other ways in which contracts, regulations, and industry practices can alter firms' incentive structures. If the number of possible decisions that can be made is institutionally restricted, the effect may be to facilitate cooperation. For example, Dolbear et al. (1969) used a two-person price-choice matrix game that was repeated for 32 periods with the same pairings. One treatment involved a large 35x35 matrix, and the other involved a 2x2 prisoner's dilemma payoff matrix that results from extracting the noncooperative and joint-maximizing points embedded in the larger matrix. Cooperation was more difficult to coordinate and maintain with the larger matrix, and payoffs were lower. Brown-Kruse (1991) observes some cases of reasonably effective tacit cooperation in PO markets in which price is restricted to be in multiples of $0.25. Overall, the average price was not significantly different from the average price for markets with no such restriction. Since restrictions of this type are unlikely to arise in naturally occurring markets, these results are perhaps of most interest to experimentalists who must decide how many gradations to introduce in a laboratory setup. Finally, note that contractual practices in unregulated markets are endogenous, so the effects of exogenously imposed laboratory rules should be interpreted with care.[123]

To summarize, contractual provisions can have a price-increasing effect that cannot be attributed to concentration or other factors. As compared with unrestricted and decentralized telephone negotiations, prices are higher with publicly posted list prices, provided that either: 1) discounts are not permitted, or 2) discounts trigger MFC clauses that reduce the price for other buyers, and increases in list prices are restricted by an advance notice requirement. This is a useful area for experimentation, despite the fact that innovative facilitating-practice cases are not being pursued at present.

9. PRODUCT DIFFERENTIATION AND MULTIPLE MARKETS

A common reaction that non-experimentalists have to many of the results reviewed here is that the theories work remarkably well, but that this may not be the case in complex, multi-market situations. One case in which multiple markets may matter is the Harrison (1988) study in which predatory pricing, which had been the object of a search, appeared when sellers could choose between a number of markets in which to sell.[124] This section reviews some other applications involving related markets that are distinguished spatially, vertically, or in terms of product quality.

Product Quality, Asymmetric Information, and Market Failures

Lynch, Miller, Plott, and Porter (1986) conducted sessions in which sellers would first choose one of two quality levels. Quality could not be directly observed by buyers. Both sellers' costs and buyers' values depended on quality, and the high-quality "supers" yielded a greater surplus of value over cost than the lower-quality "regulars." The product was sold in a variation of a oral double auction, where each bid or offer had to specify the quality to which it allegedly pertained. When sellers were forced to advertise the true quality of the product, the result was an efficient provision of the high-quality product, the quality that provided the most surplus. Removing the identities of sellers and providing only post-purchase quality information led to inefficient "lemons" outcomes in which low-quality products were produced and sold at correspondingly low prices (96% of the units sold in sessions with unknown seller identities were of low quality). The

[123] Laboratory studies with endogenously determined contractual practices are rare. One exception is Berg, Coursey, and Dickhaut (1988). These authors conducted sessions in which traders could choose between two trading institutions, a stylized, auction-like mechanism and a bargaining mechanism. Efficiency was increased when a third-party "market provider," who earned a fixed percentage of the trading profits, was allowed to decide which institution(s) to offer.

[124] Another recent study of entry is that of Meyer et al. (1992), which can be interpreted as a 2-market Cournot competition in which each subject must choose only one of the markets in which to offer the subject's single unit of output.

overall proportion of efficient, high-quality units sold increased if sellers' identities were observed, thereby permitting some development of reputations. But lemons outcomes were frequently observed in sessions with known seller identities. Efficiency was increased dramatically by giving sellers the opportunity of offering a warranty that would force the seller to compensate a buyer if the advertised quality did not match the delivered quality.[125] Holt and Sherman (1990) also observed lemons outcomes in posted-offer auctions with a large number of quality "grades."

DeJong, Forsythe, and Lundholm (1985) investigate a similar multi-grade structure, with the clever twist that higher quality means a lower probability that the buyer will suffer a fixed monetary loss. But there is some chance that a loss will occur even with the higher grades, and therefore, the buyer is unable to distinguish a "rip off" from bad luck, ex post. Sellers propose a price and a quality level independently, and these decisions are posted as in a posted-offer auction. Then buyers select sellers. Finally, sellers decide on the actual quality level to deliver, which determines their costs. A lemons outcome (low quality, low price) is only observed in about half of the cases. Sellers' ID codes are observed by buyers, and there is some evidence of reputation building; sellers who deliver high quality are, on average, able to obtain higher prices. But it was common for sellers to "rip off" buyers who had trustingly paid a high price in anticipation of high quality.[126]

The importance of repeated interaction in establishing efficient outcomes is indicated by the results of three-person games reported in Davis and Holt (1994c). These games were presented in matrix form, where one person, who can be thought of as a buyer, decides which of the other two to "do business with." The person selected, who can be thought of as a seller, would then choose between two quality levels. The seller not selected would earn nothing, and the seller selected would earn more with the decision that can be interpreted as low quality. The decision to provide high quality maximizes joint payoffs. Sellers tended to provide low quality in single-stage games. Low quality was also prevalent in two-period matchings, despite the tendency for buyers to punish a low-quality decision by switching sellers after the first period. This switching by buyers in the final stage is not irrational, non-Nash behavior, since all sellers have the incentive to provide low quality in the final stage, whether or not the buyer switches. Therefore, the threat to switch (if low quality is delivered in the first stage) is credible, and this possibility can (at least in theory) support a subgame-perfect equilibrium in which the seller selected in the first stage provides high quality, the buyer does not switch, and the same seller provides low quality in the second and final stage.[127] Similarly, the buyer strategy of rewarding high quality by not switching and punishing

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[125] DeJong, Forsythe, Lundholm, and Uecker (1985) also find that a liability rule, which forces compensation for the delivery of a low-quality item, will eliminate the effects of moral hazard in their laboratory environment. Palfrey and Romer (1986) report an experiment in which sellers can choose between different types of warranties.

[126] DeJong, Forsythe, and Uecker (1988) report similar results when businessmen are used as subjects.

[127] This equilibrium is a weak Nash equilibrium, since the buyer is indifferent between sellers in the second stage, as both will provide low quality.

low quality by switching can support cooperative, high-quality outcomes in non-terminal periods of longer games. When the same buyer and sellers were matched for ten periods, such cooperative outcomes were much more common than was the case in the two-period matchings. Even though quality was not observed prior to purchase, the ability to switch provided a strong incentive to develop reputations in the ten-period treatment.

One way around problems of "moral hazard" that arise with asymmetric information is to allow sellers to invest in costly, observable signals. If the cost of signalling is lower for a high-quality product, then it is often the case that there is a separating equilibrium in which the buyers can infer the unobserved quality from equilibrium signals. Miller and Plott (1985) designed and conducted an experiment with these features. Sellers were endowed with units that were exogenously designated as having high or low quality (regulars or supers). The value of a unit for the buyer consisted of two parts; one part that depended on intrinsic quality and another that depended on the seller's signal, which added value in the same way that a warranty can both serve as a signal and make a product more valuable to buyers. Buyers could not observe the product's intrinsic quality prior to purchase, but they could observe the signal. Trades were made via oral double auctions, with simultaneous markets going for different signal levels. For example, a buyer could announce a bid price for a product with a signal of 30, and a seller could announce an asking price for a product with a signal of 20, etc. Although there was considerable variation across sessions, about half of the sessions were best characterized by significant signalling behavior. A typical pattern of adjustment was for signalling to occur in excessive amounts, i.e. in greater amounts than was needed for separation, and then for the amount of signalling with supers to be reduced downward toward the efficient level that just deters the sale of regulars with positive signals. Efficient signalling outcomes were more likely to occur when the difference in signalling costs for supers and regulars was large.[128]

One case of a reasonably efficient outcome, despite informational asymmetries, is provided by Plott and Wilde (1982) in a study of the operation of markets for expert advice. In these markets, buyers could either buy product *X* or product *Y*, and the product with the highest value was determined by the unobserved value of a random variable. In one state, the buyer was better off with product *X*, and in the other state, the buyer was better off with product *Y*. Each buyer was given a card with probabilistic information about the buyer's own state. Under the diagnosis treatment, only the sellers could observe this information and recommend a product. Sellers had an incentive to recommend product *Y* to all buyers, as it was more profitable at the near-competitive prices determined by double auction trading. Buyers could consult with different sellers, and the competition among sellers resulted in a common diagnosis pattern that did depend on the information on the buyer's card. The temptation to deviate and recommend the most profitable product in all cases was restrained by the apparent reluctance of buyers

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[128] Since nobody has been able to analyze the equilibrium of the double auction as a noncooperative game, the standard game-theoretic concepts cannot be applied to evaluate the Miller and Plott data. Other theories can be applied. For signalling experiments in simpler matrix-game situations, see Garvin and Kagel (1989), Brandts and Holt (1992), and Banks, Camerer, and Porter (1994).

to purchase from sellers who offered a diagnosis that differed from the norm. Pitchik and Schotter (1984) also report relatively high levels of honest diagnoses in an experiment in which consumers could search sequentially for expert advice, at a cost.

Another way in which sellers can differentiate their products is in the terms of the contracts that they offer. Wiggans, Hackett, and Battalio (1990) set up a variation of one-sided offer markets in which sellers compete in the dimension of the fixed payment components of contracts. One market involves fixed-price contracts, where the fixed payment is the only payment. The other market involves cost-plus contracts, where the cost "report" made by the seller is added to the fixed payment. For the structure used, the cost-plus contract provides the seller with the incentive to make an optimal "effort" decision, but it also provides the seller with an incentive to overstate cost, ex post. This paper is innovative in that simultaneous, one-sided offer markets endogenize the choice of contract. When buyers have enough ex post information to detect and switch from sellers who overstate costs, the (subgame perfect) equilibrium involves the use of efficient cost-plus contracts, which is what is uniformly observed in the high-information sessions after an initial adjustment phase. With less information, there is more over-reporting of cost, and consequently, a higher proportion of inefficient fixed-price contracts.

Spatial Competition

The most interesting implication of Hotelling's theory of spatial competition is that there will be too little product differentiation in terms of firms' locations. For example, suppose that consumers are located uniformly along a line of unit length, and that each consumer's demand is a decreasing function of the full price, i.e. monetary (F.O.B.) price plus the product of travel cost and distance traveled. If all firms have constant costs and are forced to charge a common price that exceeds this cost, then a consumer who makes a purchase will choose the closest seller. In this context, the efficient outcome is the one that minimizes the sum of consumer's travel costs, by having firms be equally spaced. But if two sellers are equally spaced at locations of .25 and .75 on the line, both have a unilateral incentive to increase sales by moving toward the center. The Nash equilibrium for the single-period game is for them to locate in the center, and in this sense there is too little differentiation.

Brown-Kruse, Cronshaw, and Schenk (1990) conducted a duopoly experiment with this structure. The random stopping rule was to terminate the market if a red ball was drawn (with replacement) from an urn for which 1/8 of the balls are red. The resulting probability of continuation (7/8) is high enough to support the efficient outcome (locations at .25 and .75) as a Nash equilibrium, with trigger strategies that specify a punishment location of .5 following any deviation. The overwhelming tendency was for subjects to locate at the center (.5), which is another example of the noncooperative stage-game equilibrium outperforming a trigger-strategy equilibrium. But there was a second series of sessions with non-binding communication via message boxes on the subjects' terminal displays, and in this case the predominant locations are at .25 and .75, which corresponds to the efficient outcome supported by trigger strategies.[129]

Besides generating a type of product differentiation, geographic distance can result in separate markets. One plus factor that is sometimes mentioned in antitrust cases is a situation in which two competitors face each other in a number of geographic or product markets. The argument is that this multi-market exposure gives each seller an incentive to exercise restraint or "mutual forbearance," since opportunistic behavior in one market may invoke a price war in other markets. It is also possible to tailor market-specific punishments for a rival's competitive behavior in that market. Feinberg and Sherman (1985, 1988) evaluate this conjecture in both quantity-choice and price-choice matrix-game experiments. Under one condition, subjects are paired with a different person in each of two or three duopoly markets for a sequence of periods with no announced endpoint. The other condition is identical except that each subject meets the same rival in all markets. More cooperation was observed under the multi-market condition in both studies, but the test statistics indicate that the effect is marginal, and in my opinion, too small to have antitrust implications. Phillips and Mason (1992) also find somewhat mixed results; when Cournot duopolists compete simultaneously in two markets with different payoff matrices, cooperation is higher on one market and lower in the other, as compared with control treatments in which subjects compete in a single market.

Vertically Related Markets

Another category of experiments with multiple markets involves vertical relationships. If a product can be purchased in one market and sold in a second, that is separated in space or time, then the product can be thought of as an input that is transformed into output in the second market on a one-to-one basis. Experiments with this general setup have been reported by Miller, Plott, and Smith (1977), Williams (1979), Plott and Uhl (1981), Hoffman and Plott (1981), and Williams and Smith (1984). With double auction trading, speculators generally increase efficiency and reduce inter-market or inter-temporal price fluctuations due to demand shifts. More recently, Goodfellow and Plott (1990) report the results of simultaneous double auction trading in a setup in which the production function for the output is nonlinear. There were six suppliers of the input who traded only in the input market, and six consumers who traded only in the output market. In addition, there were four producers who could buy input and transform it, at a cost, into output to be sold in the output market. The parametric structure is simple, but the simultaneous determination of two market prices and quantities would probably require a lot more calculation time for most of us than the fifteen-twenty minutes that it took most of the laboratory markets to adjust to the competitive equilibrium.

There is a series of experimental papers on vertical issues that arise in the transportation of natural gas through pipeline networks. In these applications, there are

[129] In a separate study with a qualitatively similar demand structure, Brown-Kruse (1989) fixed the locations of two sellers symmetrically around the midpoint of a line and let them choose prices simultaneously. Prices tended to be below the Nash equilibrium prices. In some location treatments, the price is close to the price that maximizes the minimum payoff.

two levels of input markets, the wellhead markets for gas and the space on interconnected pipelines. Markups over cost at each level ("double marginalization") can compound monopoly problems unless the system is vertically integrated. Each link in the pipeline network can be priced separately, and therefore, coordination problems are severe. Pipelines have traditionally been viewed as natural monopolies to be regulated, but there is recent interest in whether competition can improve performance. Plott (1988) shows that the network coordination problem cannot be solved with a multi-market version of a Walrasian tatonnement mechanism. McCabe, Rassenti, and Smith (1989) discuss an experiment in which a multi-market variation of a uniform-price clearinghouse auction was used to determine prices, and the resulting outcomes were substantially competitive. Rassenti, Reynolds, and Smith (1988) show that, in this uniform-price auction framework, the replacement of monopolized pipeline links with joint ownership (cotenancy) increases efficiency.

The relevant results from multi-market experiments can be summarized: When quality is not observed by buyers prior to purchase, the result is often a "lemons outcome" in which units of inefficiently low quality dominate the trading at low prices. Efficiency is improved by warranties, signals, and competition among sellers for the trust of buyers. When products differ in a linear, spatial dimension, differentiation can be excessive (locations at the center). Speculation tends to increase efficiency in double auction markets that are separated spatially or temporally. Competitive price theory has generally worked well in multi-market trading under double auction rules. I would like to see more work in vertical antitrust issues, e.g. vertical foreclosure, using trading institutions that are appropriate for producer goods markets.

10. CONCLUSION

This section does not contain a summary for skimmers or bewildered readers; the italicized summary paragraphs at the ends of subsections are written for this purpose. Instead, this conclusion consists of a number of comments and suggestions.

Beginning with Cournot's (1838) original theoretical analysis of structures ranging from monopoly to pure competition, there has been relatively little emphasis on the effects of market institutions and contractual practices. Perhaps the most interesting outcome of the experimental work on IO issues is the surprisingly large effect of institutional changes on trading outcomes. Indeed, a casual reader of the experimental economics literature may wonder what happened to all of those structural variables, (concentration, demand elasticity, etc.). But structural variables can have important effects. For example, potential competition can have a dramatic effect in contested markets, an effect that is mitigated by the introduction of sunk costs. Also, price levels can be sensitive to market power that is derived from monopoly, oligopoly with capacity constraints, and restrictions that contracts and trading institutions place on flexible price concessions. In particular, supra-competitive prices are regularly observed in laboratory institutions that approximate conditions found in many retail and producer-goods markets. It would be seriously misleading to sweep the literature on market experiments under the rug of competitive Walrasian outcomes for double auctions, and to ignore the prevalence of supracompetitive prices in many oligopoly experiments.

There is, however, a wide range of laboratory settings that seem to generate reasonably efficient, competitive outcomes. One of the ongoing embarrassments in this area is the lack of a convincing theory of why such competitive outcomes are observed in complex real-time markets such as double auctions. One research agenda would involve a series of interactive modifications of theory and experimental designs that span the gap between the rather rigid, no-discount structure of a posted-offer auction, the more interactive double auction, and the free-for-all nature of decentralized Chamberlinian bargaining markets.

One common pattern is for theorists and antitrust economists to begin an analysis by choosing an oligopoly model, such as Cournot or Bertrand. It is natural, therefore, to encounter curiosity about whether one's favorite model outperforms others in the laboratory. Werden (1991, p.18) recently concluded his review of the experimental evidence on structure and performance: "The experimental literature generally indicates that the competitive outcome does not occur with a small number of players. There is support for the Cournot model, but it is not overwhelming." Most experimentalists would probably disagree with this conclusion; competitive outcomes can occur with small numbers of sellers, even with monopolists, when they face human buyers in double auctions or decentralized negotiations. Werden (1991, p. 19) explicitly notes that double auctions do not match the trading institutions used in most industrial markets, a view that I share. But decentralized (e.g. telephone) negotiations are relevant to the study of producer-goods markets, and have been observed to generate reasonably competitive outcomes (Grether and Plott 1984; Hong and Plott 1982). In addition, the Cournot model doesn't even work particularly well when its controversial assumptions (quantity choice and market-clearing-price) are imposed by the experimenter; quantities are too high with three or more sellers interacting in a series of market periods (Binger et al. 1990; Wellford 1990; Beil 1988). Moreover, at this time there is very little support for the Cournot model if sellers make quantity decisions before price negotiations with human buyers (see section 5 above).

To a theorist, a behavioral assumption such as subgame perfectness should apply in all noncooperative games if it applies in one such game. In contrast, Chamberlin's (1962) distinction between large groups and small groups is based on the view that the appropriate equilibrium concept for one situation may not be appropriate for another. The experimental economics literature indicates that one should be cautious about arguments that extend behavioral assumptions to new environments. It is apparent from the literature on experimental bargaining (Roth, chapter ** of this handbook), that perceptions and notions of fairness and focalness can be important, especially in contexts in which the nature of the equilibria depend on beliefs off of the equilibrium path. Moreover, some principles of rationality such as backward induction are difficult for subjects to discover in the absence of experience in the subgames, which is a tall order in complicated dynamic situations. Just because a behavioral assumption, such as subgame perfectness, yields good predictions in a particular game does not mean that we should accept the implications of a theoretical model that relies on this assumption in another context. This is also an argument in favor of designing experimental environments to more closely approximate markets of interest in the study of industrial organization.

Plott (1989, p.1170) also discussed the issue of when a model applies:

> Three models do well in predicting market prices and quantity: the competitive equilibrium, the Cournot model, and the monopoly (joint maximization) model. Experiments help define the conditions under which each of these alternative models apply. Some tendency exists for the error of a model when applied to data to be sensitive to structural and institutional variables (e.g. posted prices tend to be higher than prices under oral double auctions) but, generally speaking, when a model applies, it does so with reasonable accuracy.

This point of view is disconcerting for theorists, who as Camerer has commented, search for the Holy Grail, a general principle that applies in all situations. The approach of experimentalists seems to be to try to find a theory that is good for a specific situation, or as John Ledyard remarked, "theory with a dummy variable," and only then look for unifying principles.[130]

My own opinion is that noncooperative game theory, which is the dominant paradigm in IO, should play a larger role as the unifying principle in the analysis of laboratory market data. Why was the competitive outcome observed in the no-power treatment and not in the power-treatment variation of figure 9? Because it is a noncooperative equilibrium for the market-period stage game in one case and not in the other. Why is a monopoly seller unable to establish monopoly prices in a double auction? Porter's (1991) answer is that the noncooperative equilibrium probably involves making price concessions late in the market period. There are many instances in which noncooperative equilibria in the market period stage games provide biased predictions, but I think that we should begin with these predictions and, as experimentalists, try to explain the direction of the bias. For example, if tacit collusion causes prices to be above noncooperative levels in price-choice environments, then why do quantities tend to be above noncooperative, Cournot levels, i.e. why do we often see the reverse of tacit collusion in quantity-choice environments with more than two or three sellers? The answers to questions such as these may aid in the refinement of dynamic theories.

Several warnings are appropriate at this point:

1) It is not true that a design is always better if it replicates more of the key assumptions of some theory, nor conversely is it always best to make experimental conditions as "realistic" as possible.

Recall that experiments can serve a variety of purposes, such as testing the behavioral assumptions of a theory, testing the sensitivity of the accuracy of the theory to violations of "unrealistic" structural assumptions, and searching for stylized facts in complex market processes. It is not always the case that a theory has more predictive power in the laboratory if all of its assumptions are strictly implemented; there is some evidence that static, noncooperative equilibria for complete information games may have just as much predictive power under conditions of private incomplete information. The

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[130] Camerer's and Ledyard's comments were made in the 1990 conference for handbook authors in Pittsburgh.

appropriate degree of conformity between the laboratory environment and related naturally occurring markets, or between the laboratory environment and relevant theoretical constructs, depends on the purpose of the experiment.

2) Sometimes it is appropriate to design with theory in mind.

It would be nice to know what are the stage-game noncooperative equilibria in market experiments, even if subjects are not given complete information. To do this may require using simpler market structures and running the risk that referees will criticize you, either for not fully implementing the conditions of the (in this case, noncooperative game) theory, or for not being able to find all of the dynamic equilibria that involve inter-period punishments and rewards. Noncooperative equilibrium predictions can be useful even under conditions of private incomplete information, just as competitive predictions can be useful with a finite number of sellers and as monopoly predictions can be useful when the seller initially has no demand information. For example, consider the observation that prices are lower and more variable in a contested PO market than in an uncontested monopoly PO market. Is the presence of contestability anything more than the game-theoretic addition of a second competitor? To answer this, we need to calculate the (possibly mixed) equilibrium for the contested market. And the monopoly outcome is a useful standard of comparison in such experiments, even under private incomplete information.

3) Generalize with caution.[131]

Researchers should be careful in comparing results with previous work when both experience conditions and market cost/demand conditions are different. The ground rule here is to replicate first and then compare. Trader experience with the same institution and market structure can reduce variability and increase the accuracy of theoretical predictions. Experience in a previous session with different subjects is especially important. Experiments with inexperienced subjects are often appropriate and interesting, but comparisons across experience levels can be risky, and more data may be needed to establish results with inexperienced subjects. The shapes of supply and demand curves can also matter. (The subjects in the Harrison, McKee, and Rutstrom (1989) sessions were better monopolists when costs were constant or decreasing than when costs were increasing.) It is especially risky to claim that a single experiment confirms a general theory or establishes a stylized fact, as the Walker and Williams (1988) reconsideration of the effects of one-sided bid or offer auctions indicates. A theory that is consistent with the data from a series of experiments can be used to project the results to other environments.

4) Choose research topics with care.

To focus on important IO issues requires keeping up with the theoretical and antitrust literatures, and maintaining a curiosity for understanding the mechanics of how markets function. Comparisons of trading institutions should be well motivated by questions of theory or policy. We must continue to refine and develop laboratory trading

[131] Vernon Smith suggested "Summarize, Don't Generalize" as an alternative title for this section.

institutions. New hardware and software technologies make it possible, when appropriate, to alter trading institutions (e.g., PO markets with discounting, PO flow markets).

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********* warning: some of the dates have been changed in the text, but not here:

CITATIONS INDEX