# Experimental Methods in Economics *

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## 1. Introduction

Today we celebrate the opening of a new laboratory of experimental economics at the Universitat Pompeu Fabra thirty-odd years after several widely separated scholars began almost simultaneous, but independent, economic studies using laboratory experimental methods. All of these fledgling investigations were conceived, and the research begun, in the 1950s: Sauermann and Selton in Germany, Hoggatt at Berkeley, Siegel, Fouraker and Harnett at Pennsylvania State, Shubik at Yale, Smith at Purdue. This led to a series of publications which in retrospect founded the field we know today as experimental economics (Sauermann and Selton, 1959; Hoggatt, 1959; Fouraker, Shubik and Siegel, 1961; Siegel and Fouraker, 1960, 1963; Siegel and Harnett, 1961; Smith, 1962) although, as with all new intellectual movements, there were precursors, most notably Chamberlin (1948), who certainly influenced me. Elsewhere, in an attempt to record the early history of experimental economic thought (Smith, 1992), I have called attention to the influence of the 1952 Santa Monica conference in, "Decision Processes" (Thrall, Coombs and Davis, 1954) oh some of the early writings of Simon (1955, 1956), which in turn stimulated some of the early work of Siegel (1959, 1961). This led to a growing, if modest, stream of experimental papers in the 1960's, that accelerated in the late 1970's, and the 1980's down to the present.

During this three-decade period experimentalists were repeatedly called upon by our external colleagues to explain what it was that we thought we were trying to accomplish in the laboratory. In the beginning this was difficult and illusive to articulate, but it became easier as we became more practiced, and after the emergence of a community of like-mined research scholars.

This has culminated in a diverse methodology of experiment for economic analysis. It is a natural and seductive methodology which is easily explained to anyone not trained in economics, (e.g. your brother-in-law, or even your 10 year old child), and this, I would suggest, is part of what accounts for its appeal and its growth.

Experimental economics deals operationally with the core of economic analysis -- the relation between observation and theory -- and from this core the extension to all areas of applied economics is natural and straightforward. It is this inseparability from all aspects and applications of economic analysis that accounts for the fact that as of 1992 we do not yet have a journal of experimental economics. Although our techniques are specialized, our research questions are general, fundamental, and cut across the range of economic, political and social discourse. Consequently, the-work of experimentalists is published in all the mainstream journals as well as the specialty journals. It is a tool -- a methodology -- not a field of economics: most significantly, it changes 'the way you think about economics in all its applications.

In what follows I propose to develop a view of what constitutes an economics experiment and why we do them, and then provide a range of examples that illustrate some of the principles that I discuss.

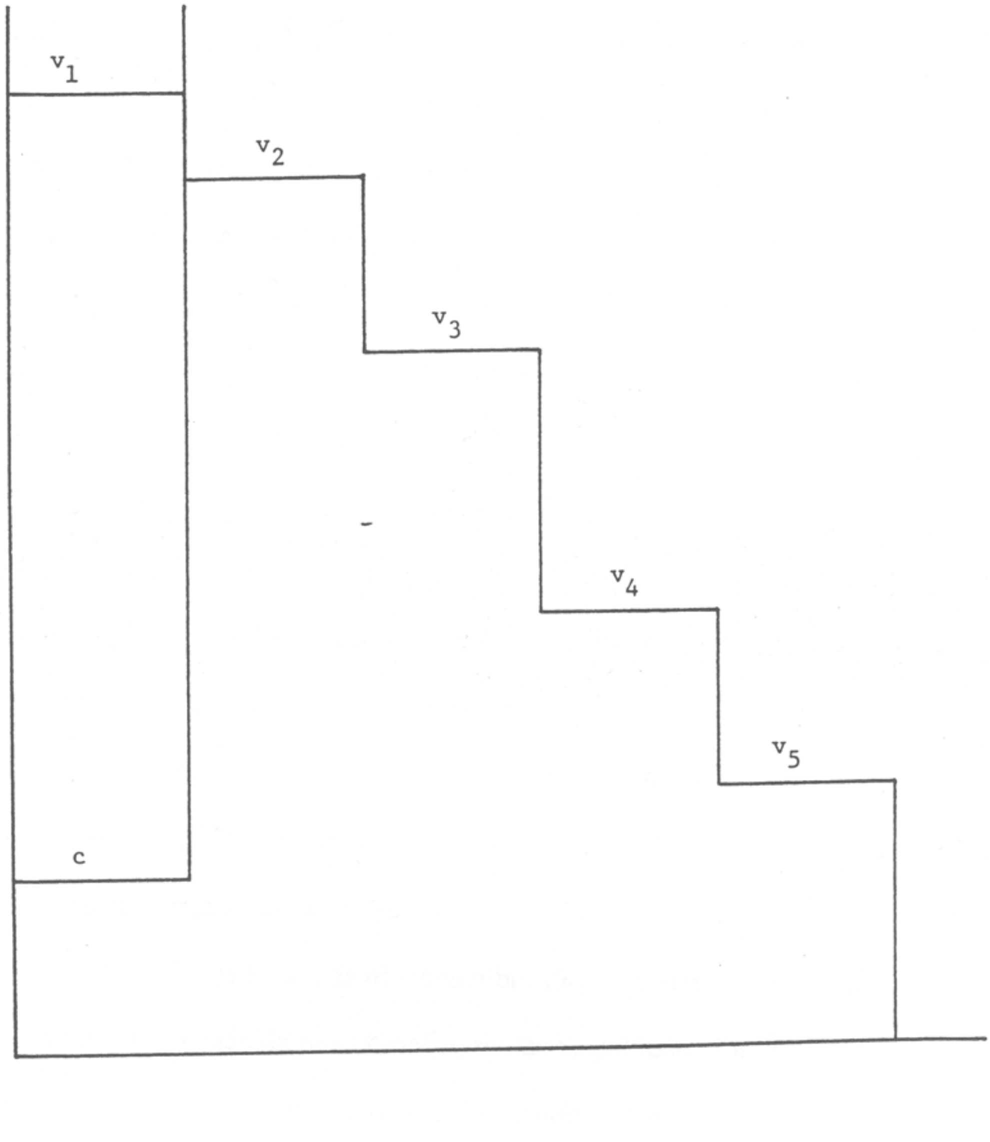
## 2. What is a Market Experiment?

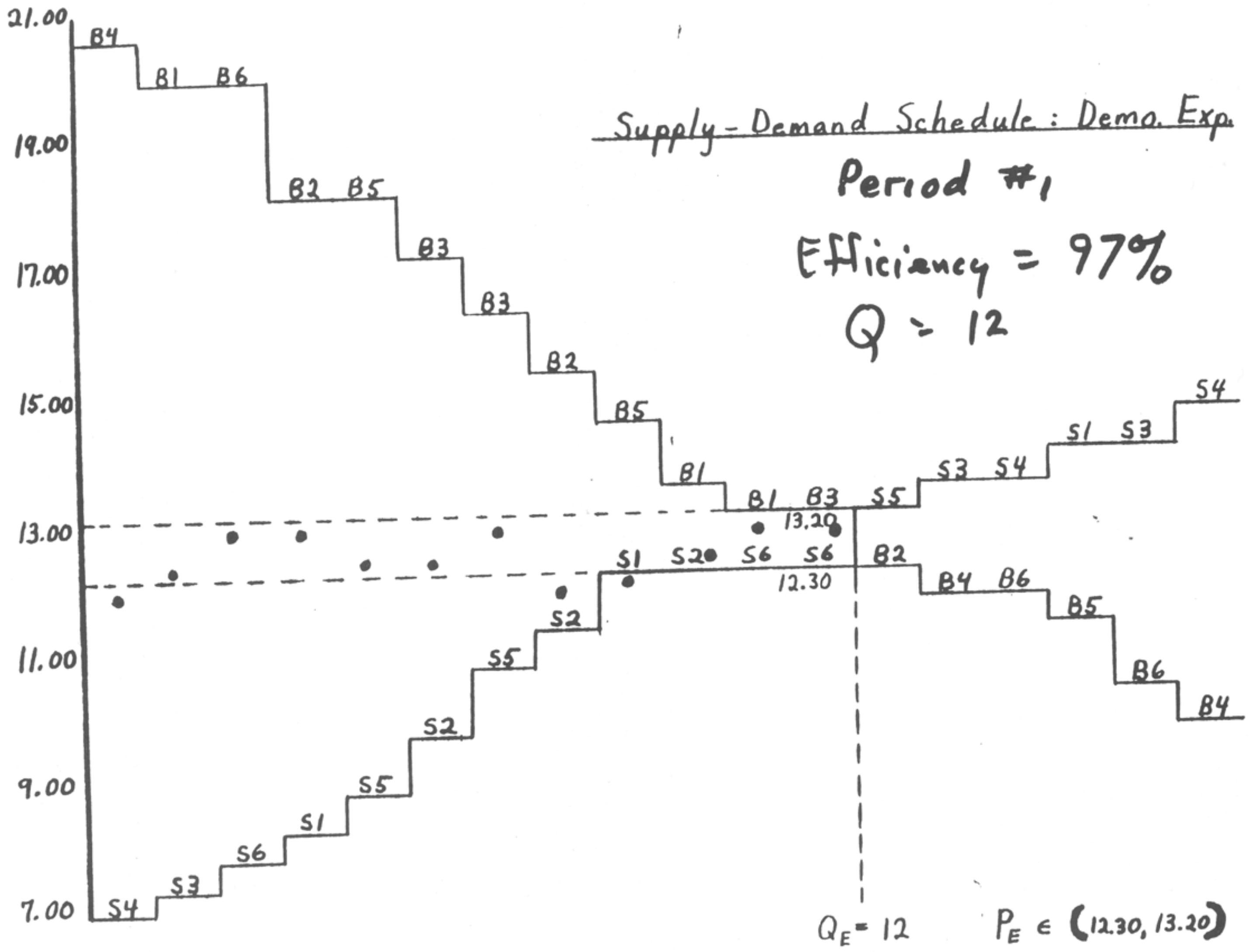
Every market experiment has just three elements (Smith, 1982).

2.1. The first is a value/cost environment, which specifies the underlying conditions that frame and motivate trade: number of agents, individual endowments and preferences, and their transformation or cost technology. A reduced form of the environment is represented by the number of buyers, number of sellers, and their individual demand and supply schedules for a particular market. A simple market example is shown in Figure 1. There are five buyers each with a maximum willingness-to-pay (WTP) value for a unique single item up for sale: $v_{1,}$ $v_{2,\ldots,}$ $v_5$. There is one seller whose minimum willingness-to-accept (WTA), or reservation price for the item, is c. A second example, in which multiple buyers and sellers each have more then one unit to buy or sell, is shown in Figure 2. Six buyers are each assigned, privately, a maximum WTP value for each of three units of an abstract commodity, right or service. For example buyer 1 (B1) has a WTP of $20 for a first unit, $13.50 for a second and $13 for a third. _Likewise, each seller is assigned a WTP cost for each of three units. In Figure 2 seller 4 (S4) is assigned unit costs of $7, $13.50 and $14.50. Each buyer understands that the experimenter will pay the difference between the value and price paid in the market for each unit purchased, while each seller is paid the difference between the selling price of a unit and the unit's assigned cost Thus, if B1 buys a first unit for $15 he can collect a $5 profit; if S4 sells a unit for $15, she collects $8 from the experimenter. These buyer induced values and seller induced costs represent the dispersed opportunity cost circumstances of all individuals in the market.

The array of individual buyer values ordered from highest to lowest defines the WTP inverse demand schedule in the market (Figures 1 and 2) At each price the schedule determines the maximum quantity that can be purchased profitably.

Figure 1





Supply - Demand Schedule : Demo. Exp.

Period #1

Efficiency = 97%

Q = 12

The array of individual seller costs from lowest to highest defines the WTA inverse supply schedule. At each price the schedule determines the maximum quantity that can be sold profitably. In Figure 1 the competitive equilibrium is any price between $v_1$ and slightly above $v_2$, with one unit being exchanged. Similarly, in Figure 2 this market clearing equilibrium is given by the set of prices in the open interval $P_E$ € ($12, $13) with the quantity exchanged $Q_E = 12$. Note that at this equilibrium the gains from exchange or surplus, given by the area between the supply and demand schedules to the left of the equilibrium quantity, is maximized.

These reward procedures permit the experimenter to project into an experiment a well-defined environment, known to the experimenter in advance of an experiment. The validity of this procedure requires only the assumption that subjects always strictly prefer any increase in the reward medium (Smith, 1976).

2.2 Every market experiment also specifies an institution. The institution defines the language (consisting of messages) of the market, and the rules that govern (a) the exchange of messages, and (b) how it is that such messages determine binding contracts for trade. Simple auction markets for the sale of a single unique item provide four standard examples of auction institutions.

(1) The English or progressive auction. The rules of the institution operate approximately as follows. The auctioneer calls for bids from the buyers. If there is a minimum seller specified price, c, then the first bid must be at least as high as c. Any new bid can displace the standing bid if it is at a higher price. The price rises as long as there are new bids. When no new bid is forthcoming the item is awarded to the last bidder at a price equal to the amount bid.

(2) The Dutch descending price auction. The price starts very high and declines using a clock device indicating the price at each instant. The bidders each have a control button which, when first pressed by someone, stops the

clock at the price prevailing at the time. The item is awarded to the first bidder who stops the clock; the purchase cost is the indicated price.

(3) The high, or first, price sealed bid auction. In this institution each bidder submits a written bid to the auctioneer. The person who enters the highest of these bids is awarded the item at a price equal to the amount bid.

(4) The second price sealed bid auction. In this auction the procedure is as in (3) except that the item is awarded to the highest bidder at a price equal to the second highest bid.

2.3 Finally, there is the behavior manifest in the market by the participants, given their environment, who interact under the rules of the institution. This behavior is recorded in the messages they send, and in the contract outcomes that result. Sometimes the subjects are asked to respond to questions related to their participation, and their responses become part of the experimental record of behavior.

I want to emphasize that normally in an experiment the experimenter controls the environment using the above reward procedures, and controls the institution by means of the experimental instructions describing the rules of interaction of the participants. Within these confines the experimental subjects are free to make whatever choices they wish; these choices constitute the behavior observed by the experimenter.

## 3. Why Do We Do Experiments?

There are at least seven interdependent reasons why we conduct laboratory experiments: (1) Test, or select between, theories; (2) compare institutions; (3) compare environments; (4) explore the cause(s) of a theory's failure; (5) establish empirical regularities as a basis for new theory; (6) evaluate policy proposals; (7) use the lab as a testbed for institutional design.

### 3.1 Testing or Selecting Between Theories; Comparing Institutions

#### Methodology

Every well-specified theory defines a mapping that carries assumptions about the environment, the institution and individual behavior into a prediction about observable outcomes. We test a theory by comparing its predictions with the observations from experiments. But what is it about the theory that we test when we run an experiment? We test the theory's behavioral assumptions conditional on the environment and the institution. That is, in the design of the experiment we consciously reproduce the theory's assumptions about the institution and choose some particular instance of the environment postulated by the theory. If we don't do this we cannot meaningfully argue that we have tested the theory. We then observe behavior and ask if the observations correspond to the predictions of the theory, where "correspondence" is usually interpreted statistically; i.e. we ask if the observations are distributed around the point or in the set prediction of the theory. If the experiment has been designed with precision many outcomes besides those predicted will be possible (Selten, 1989); i.e. predictive success depends on a high hit rate when hits are unlikely. We give the theory some leeway so to speak by supposing that subject decisions, even if motivated as assumed by the theory, are subject to random error.

Using such an appropriate measure of predictive success (Selten, 1989), if the predictions of the theory are confirmed by experiment does this mean that the theory is "correct?" This is the case only in a conditional sense, since the theory's assumptions about the environment and/or the institution may be oversimplified, unreal or irrelevant to corresponding situations in the field. Consequently, we are not necessarily finished; we have merely shown that the particular form of the theory tested makes good predictions, and that the theory accurately captures behavior in the context that it models. It doesn't follow that it is a good theory for understanding the aspect of the economy that motivated it. Furthermore, we have only tested the theory for a particular set of initial conditions (parameters) defining the environment, and we must ask if the results are robust with respect to changes in the environment.

Suppose the opposite prevails -- the observations fail to support the predictions of the theory. Do we reject the theory? Not necessarily. When you test a theory you also test all the laboratory procedures, assumptions and conditions you used to implement the theory together with the initial conditions (parameters) you chose for the particular environment. There may be shortcomings in your procedures that fail to result in an appropriate, adequate, or convincing test of the theory. Also, your test is for a particular environment, and theories may sometimes work well for some environments but not for others. Thus common value auction theory performs poorly for 6-8 bidders, but much better for 3-4 bidders (Kagel and Levin, 1986), and still better when the theory is modified to allow for costly entry and exit (Cox and Smith, 1992).

Scientists do not accept theories because all tests have failed to refute them; neither do they reject theories because there exists experiments that falsify them. This follows from observing their practices not their rhetoric of scientific methodology, As noted by Lakatos (1978, p. 6) "there is no refutation without a better theory." Until a new theory resolves the empirical anomalies contained in an existing theory, scientists cling to the previous theory; they have little choice since the existing theory is consistent with many known facts, and to abandon it is to reject a questionable, perhaps cracked, foundation to build on the void. New theory, to be acceptable, must embrace the verified predictions of the old theory, explain at least some of the recalcitrant data, and offer testable implications on which the old theory is mute. This is why the methodological commitment to falsification is a false goal: in order to modify theory properly one needs to know both what is right and what is wrong with the existing theory.

## Auction Theory

We will illustrate some of the above principles by comparing the theory with experimental behavior in the four standard auction institutions under the assumption that bidder values are independent and strictly private.

The theory of the English auction is the simplest to understand based on the roles outlined in 2.2. Initially, the bidding can be expected to start at a low price, since all bidders are motivated to buy low. Given the first standing bid, say $b_{o,}$ it is a dominant strategy for bidder i to raise $b_o$ if it's value is greater than $b_o$; except that no one should be motivated to raise his own bid, or bid above his own value. Hence, the bids will continue to increase as long as there is at least one bidder's value that is above a standing bid made by someone else. Eventually, in Figure 1, bidder 1 with value $v_1$ will stop out bidder 2 with a bid above $v_2$. If the bid increment is small the stop out bid will be only slightly above $v_2$. Consequently, English auction theory predicts a final bid by bidder 1 at a price approximately equal to $v_2$' the value of the second highest value among those of all bidders.

The Dutch roles define a strategic auction in the sense that the price and award depends upon each bidder's assessment of the behavior of the other bidders. This is not the case for the English auction because its open outcry information properties imply that each bidder will learn what is the bidding behavior of others by direct observation. In Figure 1 once the Dutch price falls below $V_{1,}$ bidder 1's decision as to when to stop the dock depends upon where she thinks the first of the other bidders will act, and what she knows about the other bidder's valuations. If bidder 1 is not very risk averse she may let the dock fall below $v_2$. If $v_2$ is very risk averse he might stop the dock just below $V_2$ to avoid the risk of failing to win the auction. Thus, the price may be below $v_2$, and the award to bidder 2 or 3, depending upon bidder disparate attitudes toward risk and information on each other's values. In the special case where all values are equally likely on the interval [O, 1], and all bidders are risk neutral, Vickrey (1961) showed that for a bidder with value $v_{1,}$ a noncooperative equilibrium strategy is to stop the dock at a bid price of $b_i = (N-1)v_i/N$, when there are known to be N bidders. If all bidders do this bidder 1 will win with bid $b_1 = (N-1) v_1/N_1$.

The first price sealed bid auction is also a strategic auction, and as shown by Vickrey (1961) leads to the same analysis and predicted bidding behavior as the Dutch auction. As in the latter each bidder must select a strategy not knowing with certainty the behavior of others. Under the Vickrey conditions above, each i would submit the written bid, $b_i = (N-l) v_i/N$.

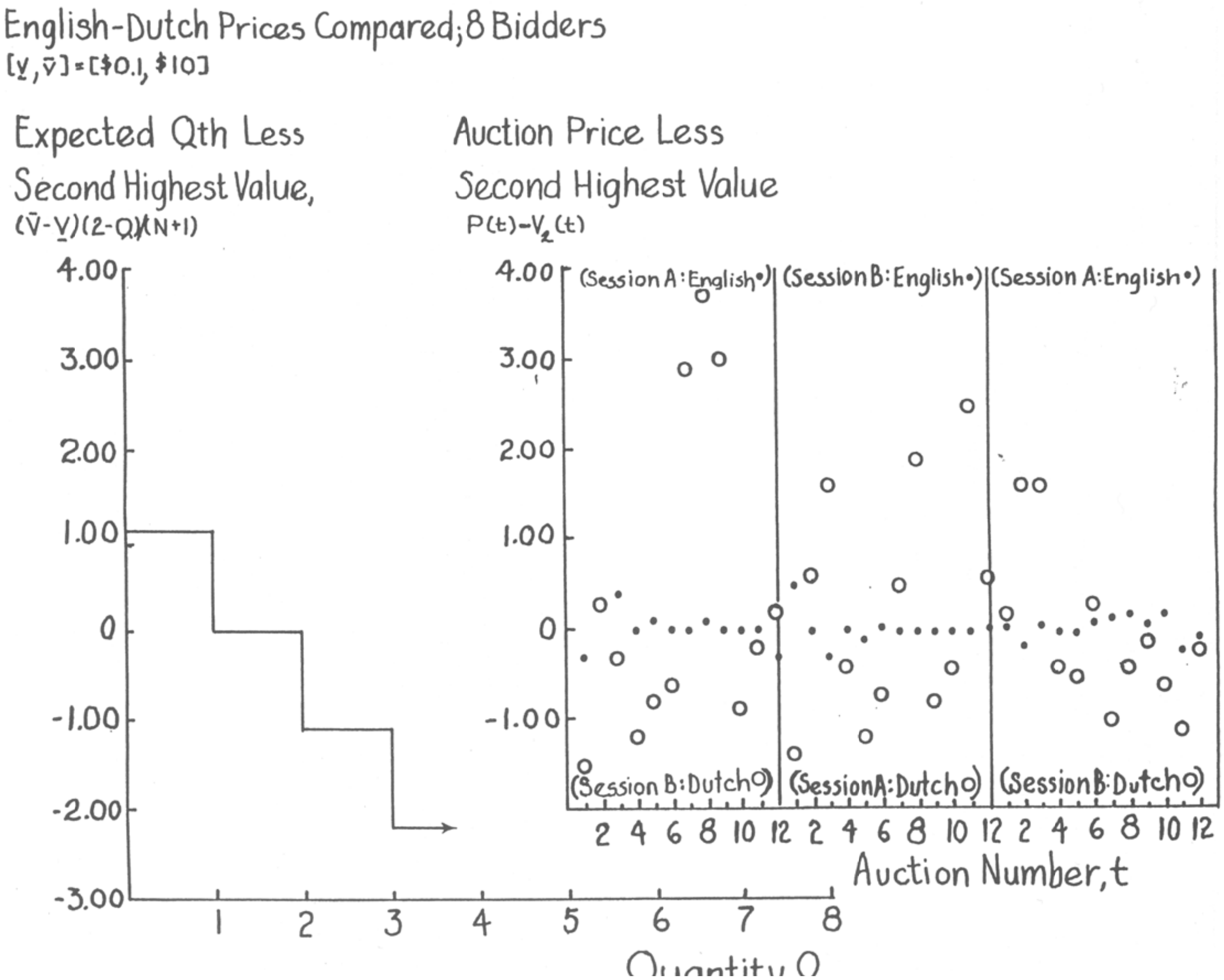
The second price sealed bid auction is the written bid equivalent of the English oral auction. This may seem surprising since you pay what you bid in the latter, but not in the former. It is because each bidder in the second price auction, conditional on winning, is in the position of being a price-taker. A winning bidder pays a price that is independent of the amount bid. The optimal strategy is therefore to bid your value to maximize the probability that your bid wins. To bid less is to risk not being the high bidder, while leaving unchanged the amount paid. To bid higher is to risk winning at a price greater than your value. Consequently, if all bidders reason in this way, each i will bid $v_i$, and, in Figure 1, the item will go to bidder 1 at price $v_2$, which is (approximately) the prediction in the English auction. Although the two institutions are equivalent in terms of their static outcome predictions they are much different processes. In the second price auction each bidder must understand through a reasoning process, or somehow see intuitively, that bidding value is optimal. In the English auction one need not have any subtle insights into the logic of uncertain choice; it is only necessary to be able to recognize when the standing bid is below your value, and that in the private values environment it is never in your interest to raise your own bid or to bid more than your value. As a consequence, all but the highest value bidder will bid up to their value, while the high bidder will discover that she does not have to bid more than enough to stop out the penultimate bidder.

Vickrey's assumptions and analysis leads to the result that expected selling prices in English and second price auctions are equal, independently of bidder risk attitude. Expected prices in the Dutch and first price auction are equal to each other and are above (equal) those in the English and Second price auction if bidders are risk averse (neutral). If bidders are risk neutral or all are equally risk averse then allocations are efficient in all four institutions; i.e. the award is to the highest value bidder.

## Auction Behavior

We report the results of four experiments using data from Coppinger, Smith and Titus, (1980). (The charts are from Smith, 1987, pp. 142-143).

Figure 3 provides a chart comparing Dutch and English prices in two experiments. In session A using 8 subjects there were 12 auctions using English roles, followed by 12 using Dutch rules, then ending with 12 auctions again using English rules. Session B used 8 new subjects who participated in 12 Dutch, followed by 12 English and, finally, 12 Dutch auctions. Values were drawn from a rectangular distribution with $v_i$ € [\$0.10, \$10.00]. On the left is shown the expected highest of 8 random values from this distribution, the expected second highest, etc., in order, measured relative to the second highest value. On the right, the ruling auction price less the second highest value is plotted for each auction.


English-Dutch Prices Compared; 8 Bidders
$[\underline{v}, \bar{v}] = [\$0.1, \$10]$
Expected Qth Less
Second Highest Value,
$(\bar{V}-\underline{V})(2-Q)/(N+1)$
Auction Price Less
Second Highest Value
$P(t)-V_2(t)$
4.00
3.00
2.00
1.00
0
-1.00
-2.00
-3.00
1
2
3
4
5
6
7
8
Quantity Q
(Session A: English•)
(Session B: English•)
(Session A: English•)
(Session B: Dutch○)
(Session A: Dutch○)
(Session B: Dutch○)
2 4 6 8 10 12 2 4 6 8 10 12 2 4 6 8 10 12
Auction Number, t

Any idea that auction institutions do not matter is clearly falsified by this data and many similar experiments. The switchover English and Dutch treatments clearly affect behavior with the same group regardless of treatment order; Dutch and English prices are quite different, with English prices much closer to the second highest value than are Dutch prices.

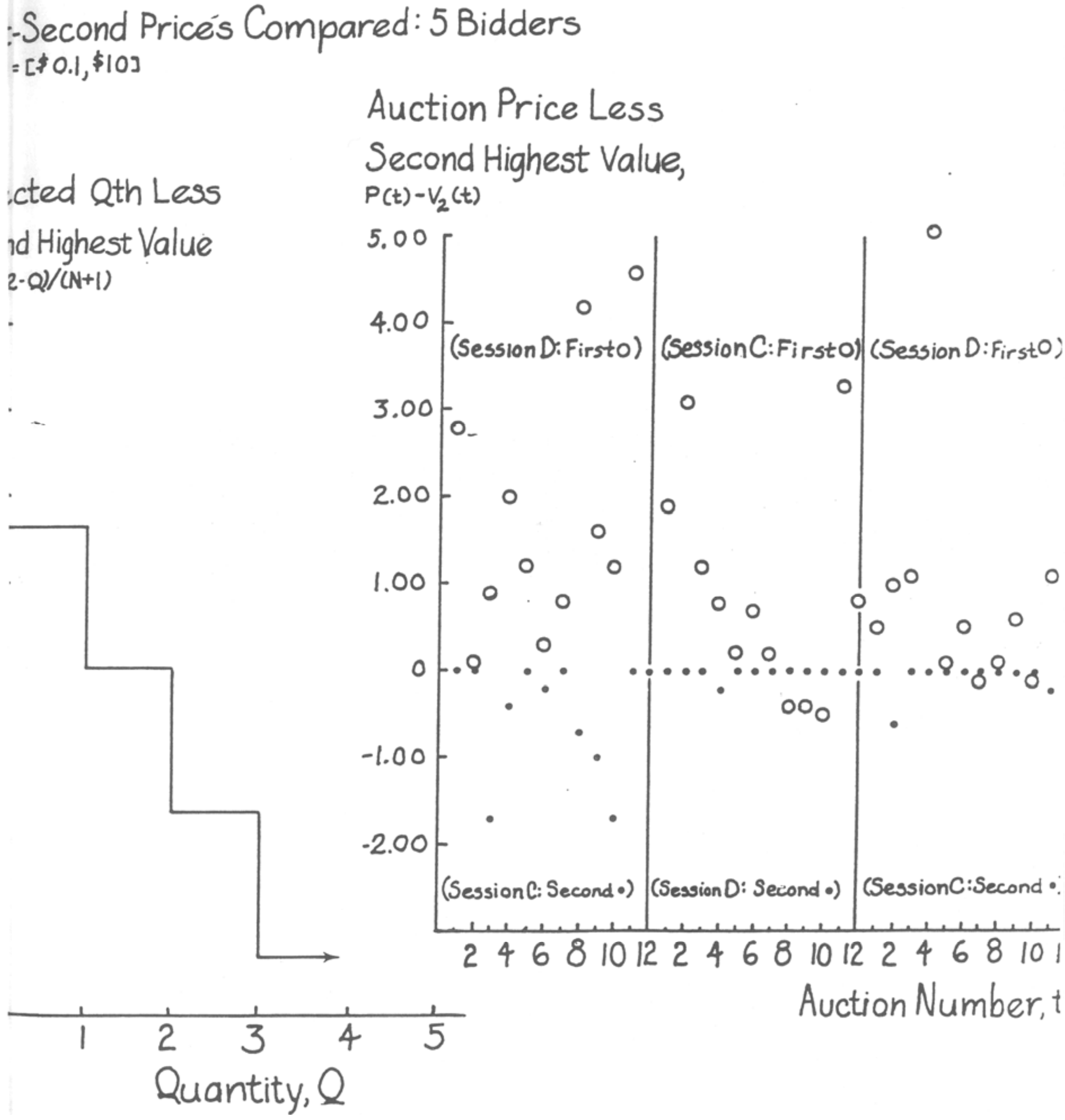
The results of a comparison between the first and second price auctions in shown in Figure 4, for N = 5 bidders, with values drawn from the rectangular distribution on [$0.10, $10.00]. Awards are at substantially higher prices in the first than in the second price auction with the latter approaching (with learning) the second highest value.

Summarizing the results of a large number of experiments in Coppinger, Smith and Tutus (1980) and Cox, Roberson and Smith (1982), English and second price auctions converge to about the same mean prices near the second highest value; Dutch mean prices are higher than the risk neutral prediction, while mean first auction prices are substantially above mean Dutch prices. Although the risk neutral model is rejected in both the Dutch and first price auctions, the hypothesis that they are equivalent is also rejected. Efficiency, as measured by the percentage of awards that are made to the highest value bidder is as follows: English, 97 percent; second, 94 percent; first, 88 percent; Dutch, 80 percent.

### 3.2. Exploring the Causes of a Theory's Failure, Comparing Environments

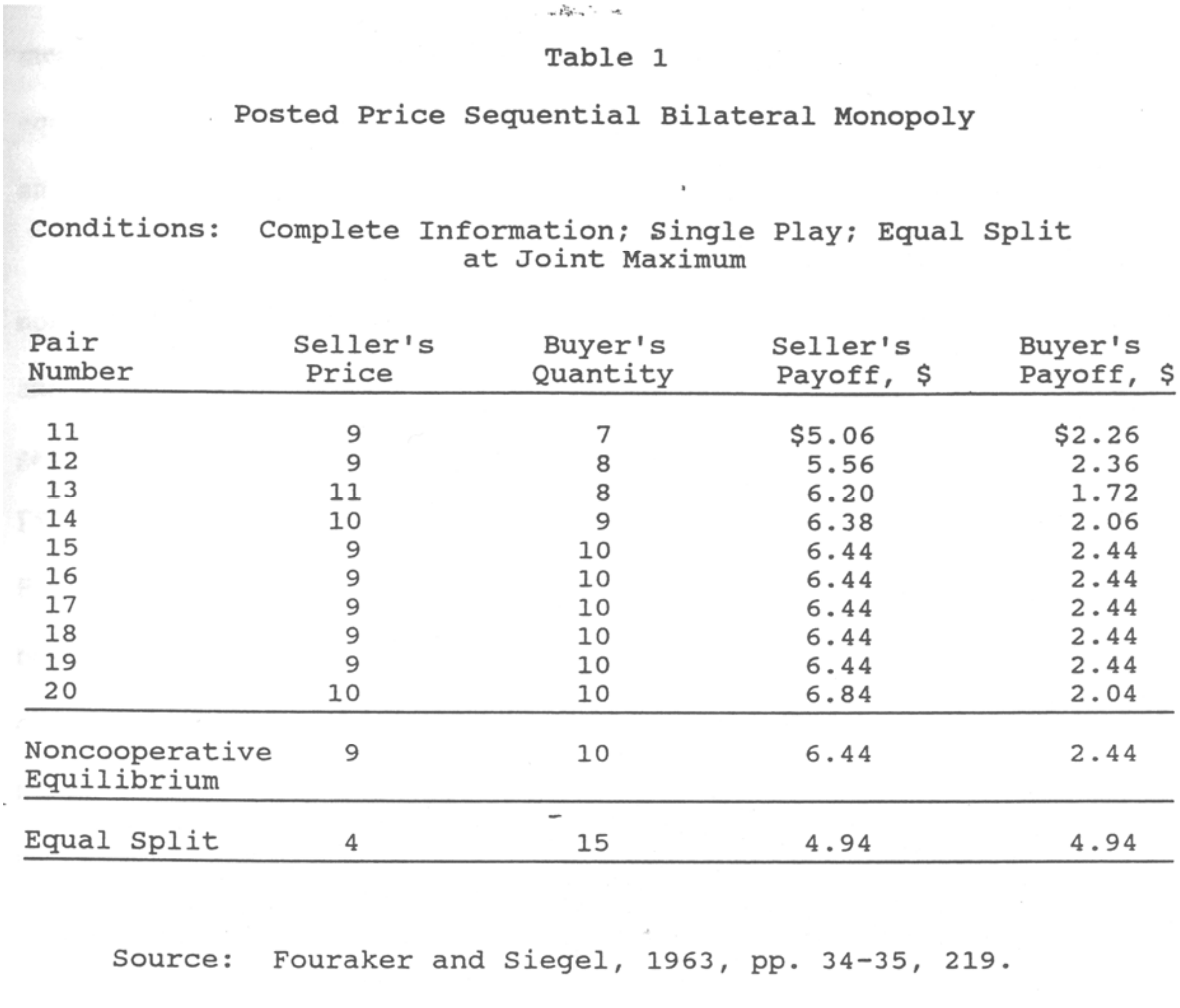
Sometimes we compare environments 10 see if a theory's predictive ability is robust with respect to changes in the environment. Sequential bargaining theory provides one example.

Figure 4


-Second Price's Compared: 5 Bidders
= [$0.1, $10]
Auction Price Less
Second Highest Value,
P(t) - V₂(t)
cted Qth Less
nd Highest Value
2-Q)/(N+1)
5.00
4.00
3.00
2.00
1.00
0
-1.00
-2.00
(Session D: First o)
(Session C: First o)
(Session D: First o)
(Session C: Second •)
(Session D: Second •)
(Session C: Second •
2 4 6 8 10 12 2 4 6 8 10 12 2 4 6 8 10 1
Auction Number, t
1 2 3 4 5
Quantity, Q

The institution is "posted offer" in which the seller moves first by naming a price, $P \geq 0$. The buyer then chooses a nonnegative quantity, $Q \geq 0$. This results in a binding contract in which Q units are sold by the seller to the buyer at the price P, and the game ends. The game is analyzed by backward induction: given the price posted by the seller, we ask what is the best response for the buyer. Given the best response of the buyer as a function of the seller's price, we can then ask what is the best price for the seller to post. The equilibrium of this noncooperative game is a pair (P*, Q*) in which P* maximizes the profit of the seller given that Q* maximizes the profit of the buyer. Thus, for any P, let Q*(P) maximize the buyers profit, where Q* is such that $P = WTP = D(Q^*)$, where $D(\cdot)$ is the inverse of the buyer's demand schedule. Given $D(Q^*)$ the seller maximizes profit by choosing P* so that incremental revenue equals supply (incremental cost), $P^*\Lambda D(Q^*) + D(Q^*) = S(Q^*)$. P* is the monopoly price because of the seller's first mover advantage of the seller in the posted price institution. Note that this noncooperative equilibrium differs from the competitive equilibrium where $WTP = D(Q_E) = WTA = S(Q_E) = P_E$ (the market clearing price as in Figure 2), which also maximizes the surplus or total joint profit of the buyer and seller.

Fouraker and Siegel (1963, p. 35; hereafter FS) report the first experiment testing the equilibrium predictions of this noncooperative bargaining model. The data they report, for 11 bargaining pairs (anonymously and randomly paired in private cubicles), is shown in Table 1. The modal outcome (5 of 10 observations) is the predicted equilibrium and the mean and median of the price-quantity outcome pairs do not differ significantly from this equilibrium. None of the observations support the joint maximum at (4, 15) which is also an equal-slit ‘fair’ outcome.



## Table 1

### Posted Price Sequential Bilateral Monopoly

Conditions: Complete Information; Single Play; Equal Split at Joint Maximum

| Pair Number | Seller's Price | Buyer's Quantity | Seller's Payoff, $ | Buyer's Payoff, $ |
|---|---|---|---|---|
| 11 | 9 | 7 | $5.06 | $2.26 |
| 12 | 9 | 8 | 5.56 | 2.36 |
| 13 | 11 | 8 | 6.20 | 1.72 |
| 14 | 10 | 9 | 6.38 | 2.06 |
| 15 | 9 | 10 | 6.44 | 2.44 |
| 16 | 9 | 10 | 6.44 | 2.44 |
| 17 | 9 | 10 | 6.44 | 2.44 |
| 18 | 9 | 10 | 6.44 | 2.44 |
| 19 | 9 | 10 | 6.44 | 2.44 |
| 20 | 10 | 10 | 6.84 | 2.04 |
| Noncooperative Equilibrium | 9 | 10 | 6.44 | 2.44 |
| Equal Split | 4 | 15 | 4.94 | 4.94 |

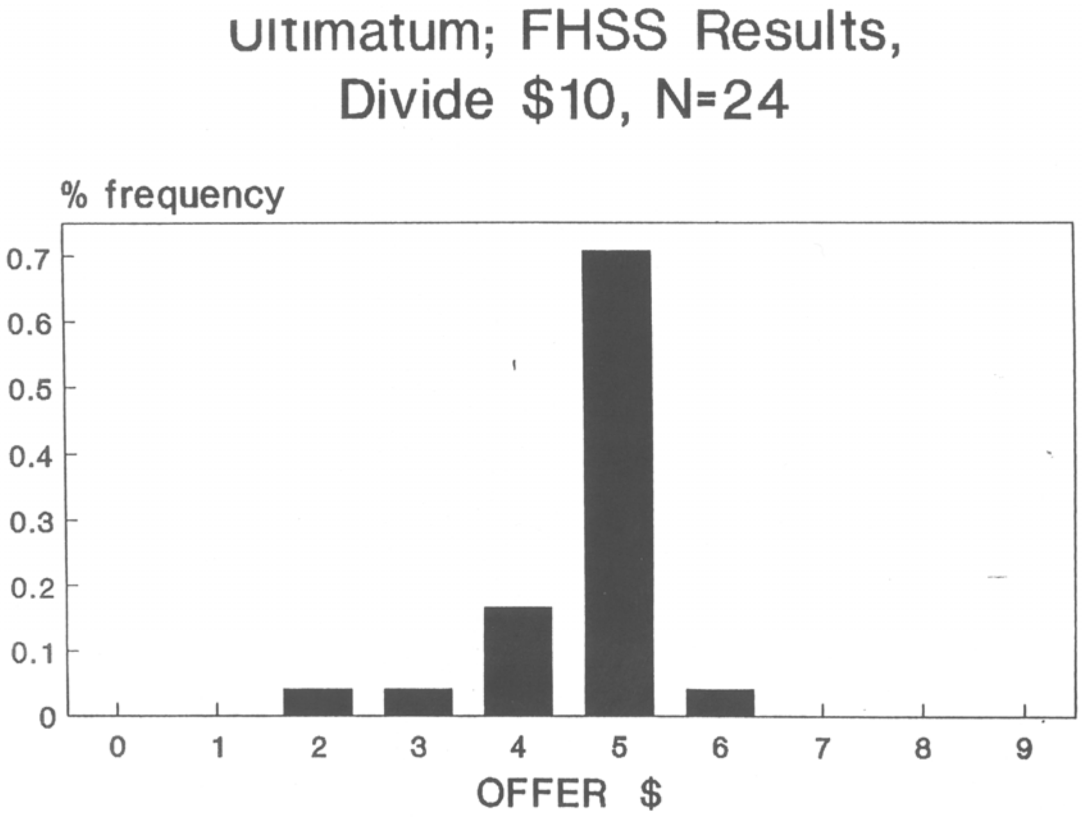
Source: Fouraker and Siegel, 1963, pp. 34-35, 219.

The FS results were widely interpreted as tending to confirm the predictions of noncooperative bargaining theory until the challenging contribution of Guth, Schmittberger and Schwarze (1982) (hereafter GSS) who first studied subject behavior in the ultimatum game. The ultimatum game is a special case of the sequential bargaining game studied by FS. Two people, who are matched anonymously must divide a sum of money, say $10. Person one moves first and offers person two any nonnegative portion of the $10. Person two responds by accepting the offer, in which case the $10 is so divided, or by rejecting the offer, in which case both get zero. This is the same game as that studied by FS except that the environment is different: the amount of surplus 10 be divided is fixed. Think of the ultimatum game as an exchange of $Q = 1$ unit, or $Q = 0$, with a total exchange surplus of $10; for one unit seller WTA = O, and buyer WTP = $10. The equilibrium of this game is for the first mover to offer the minimum unit of account, say $1, where the sum to be divided consists of ten $1 bills, and for the second mover to accept this offer since it is better than nothing.

Since the original work of GSS, this game has been replicated hundreds of times by many experimentalists. Some typical recent results are shown in Figure 5 (Forsythe, Horowitz, Savin and Sefton, 1988) (hereafter FHSS). The modal offer is $5; none give $1 as predicted by noncooperative equilibrium theory. Research has centered on why the results are so different from those of FS. One view is that first movers want to be 'fair,' but this doesn't explain why non e of the FS subjects chose equal-split. A partial answer has been provided by FHSS who study the dictator game' in which the second mover must accept (cannot reject) the first mover's offer. The 'equilibrium' is to offer zero. The FHSS results for the dictator game are shown in Figure 6. Now the modal offer is $3, there are several offers of $0, $1, and $2, and the offers of $5 are greatly reduced compared with Figure 5. This shows that high offers in the ultimatum game cannot be due only to a concern for 'fairness'; it is in part a <u>strategic</u>

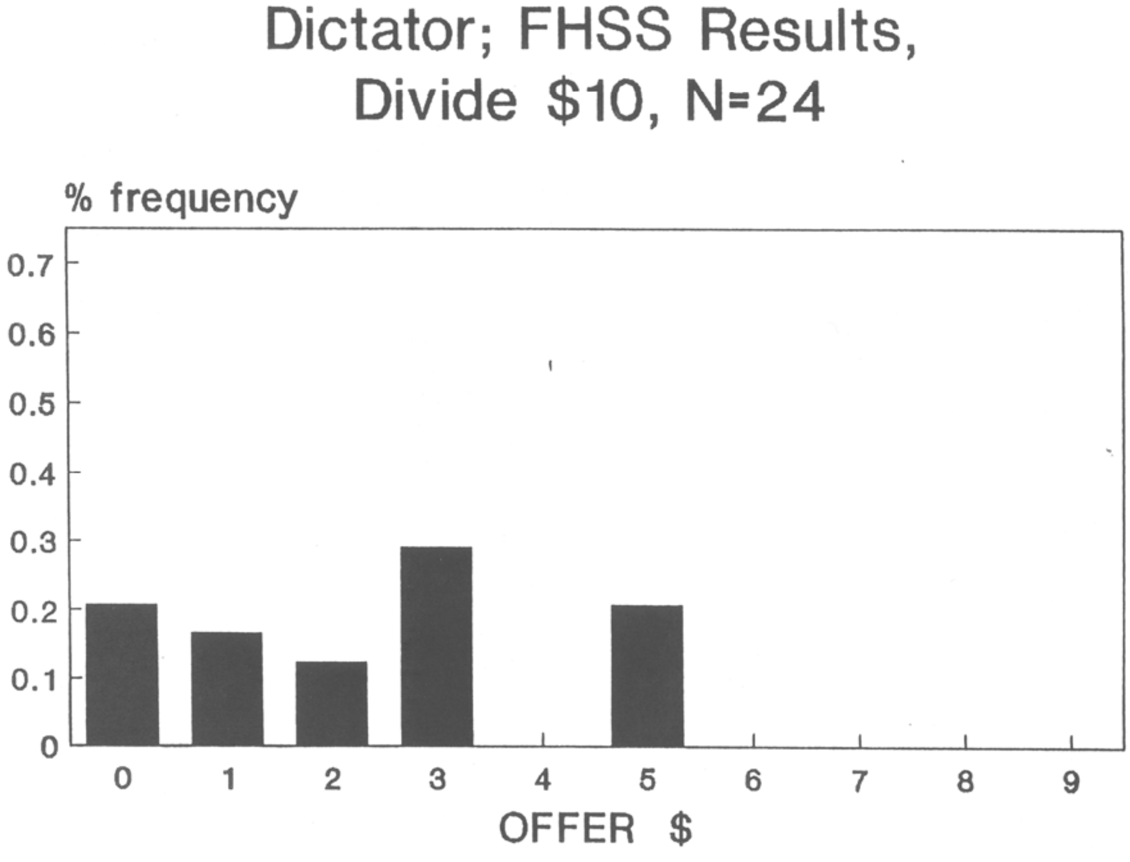
concern by the first mover that his offer might be rejected if it is too low.

Figure 5



But what accounts for the presence of so many positive offers in the Dictator game? 'Fairness' is not a theory nor an explanation with any predictive power: it is a word for describing the tendency toward equal-split or to be other-regarding. Such outcomes could of course be the result of social norms, as suggested by GSS and others, but why do such norms persist when people are paired anonymously? Game theory postulates that bargainers are strictly self-regarding strangers who will interact only once. Repeated games are analyzed differently because the bargainers can develop their own history and future. Hoffman, McCabe, Shachat and Smith (1992) (hereafter HMSS) have conjectured that the problem might be that although the subjects are anonymous with respect to each other, this is not so with respect to the experimenter and anyone who might see the data from an experiment. The subject might be concerned that the experimenter will be judgmatical and consider that the data reflect who is greedy and who is not; or even that the experimenter will use the data to decide which subjects will be recruited to the laboratory for later experiments. To examine this hypothesis HMSS conducted 36 'double blind' experiments in which a carefully structured procedure made it transparent to all subjects that <u>no one</u> including the experimenter could possible know who made what decision. The results of the HMSS double blind experiments are dramatic. They find two-thirds (24/36) of the subjects give nothing; thirty-three give $3 or less; only two give $5 and one enigmatic subject gave $9. Total anonymity produces by far the largest incidence of self-regarding behavior. The small residue of 'fair'

Figure 6



outcomes, we would argue, is truly an indicator of other-regarding preferences since the conditions of the experiment control fully for behavior influenced by strategic and social exchange considerations. HMSS also show that offers are more self-regarding in both dictator and ultimatum games when the task is represented as an exchange between a buyer and seller; and offers are still more self-regarding when a general knowledge contest is used to determine who earns the right to be the seller (first mover) in each pair. These treatments serve to legitimate the first mover advantage to both parties: offers are smaller, and buyers (second movers) are willing to accept these lower offers.

The HMSS dictator game results suggest that 'fairness' is a form of equal treatment that represents social exchange. You treat me fairly because you expect me to think well of you and reciprocate the treatment. Friends and neighbors in small communities find it easy to 'keep score' on these exchanges; anyone violating the unspoken rules is subject to retaliation. When this social bonding is removed, as with 'double blind' anonymity, we observe an increase incidence of narrowly or instantaneously self-interested behavior.

### 3.3 Establishing Empirical Regularities as a Basis for New Theory

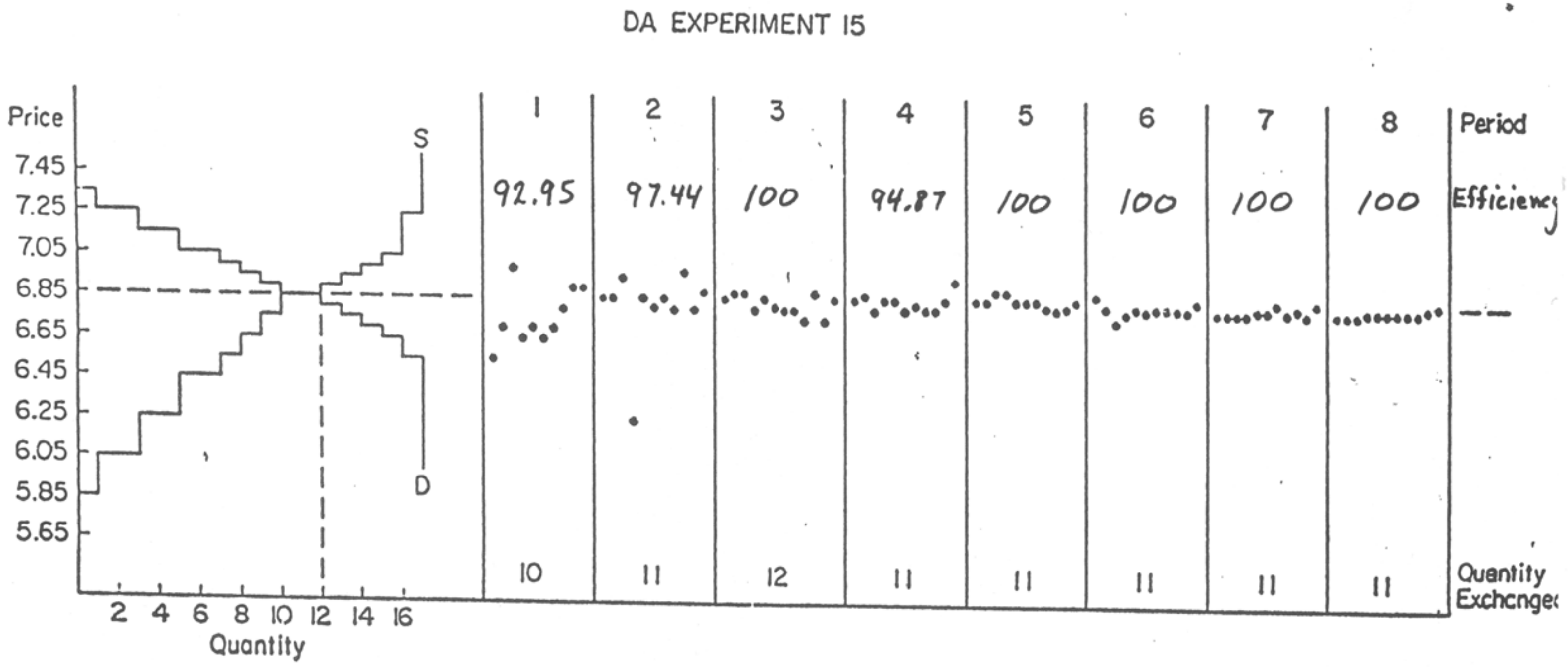
An example of extensive experimentation which has provided a basis for motivating new theory is represented by the study of the double continuous auction (DA) mechanism used extensively in financial markets in the United States. Originally (Smith, 1962), these were conducted using the oral DA institution, but beginning in 1976 when Williams (1980) developed the software for the first computerized DA, this form of the' institution has gradually come to dominate experimental work.

Under standard computerized DA rules any buyer (seller) can enter a public buying price (offer selling price). Once a standing bid (offer) has been established, a new bid (offer) must provide better terms for the other side: new bids must increase, while new offers must decrease in price (rules 71 and 72;

New York Stock Exchange, 1987, p. 2044) (hereafter NYSE). In Williams' version a bid (offer) is for a single unit or lot, but in more recent versions the volume bid or offered at the quoted price is also specified. Contracts occur by a buyer accepting the offer of a seller, or a seller accepting the bid of a buyer. Under New York stock exchange rule 72 an auction ends with a contract, and the process waits for a new bid and offer; i.e. "a sale shall remove all bids … (and) after bids have been removed … priority shall be determined … by subsequent bids." (NYSE, p. 7) The same holds for offers.

The results of an oral DA are shown in Figure 2. The dots are contracts (accepted bids or offers in the order in which they were executed. It is unusual to observe such complete convergence to the competitive equilibrium in the first trading period. A more typical case is shown in Figure 7.

Figure 7


DA EXPERIMENT 15
Price
7.45
7.25
7.05
6.85
6.65
6.45
6.25
6.05
5.85
5.65
S
D
2
4
6
8
10
12
14
16
Quantity
Period
1
2
3
4
5
6
7
8
Efficiency
92.95
97.44
100
94.87
100
100
100
100
Quantity Exchanged
10
11
12
11
11
11
11
11

The reliable and highly replicable convergence properties of DA has stimulated attempts to articulate theories of the DA process which imply or predict these convergence results (Wilson, 1987; Friedman, Geanakopolis, Lane and Rust, 1992). These efforts have not been successful, however, in computing or characterizing convergence in the double auction game because of the inherent complexity of continuous time games of incomplete information. This led to an alternative approach: a tournament, sponsored by the Santa Fe Institute, in which the contestants entered computer programmed strategies for decision making under DA roles. It was hoped that this would provide a deeper understanding of DA. "The winning strategy can be described quite simply: wait in the background and let others do the negotiating. but when bid and ask get sufficiently close. jump in and 'steal the deal'." (Rust, Palmer and Miller, 1992). Needless to say, these very interesting results suggest that a satisfactory modeling of DA as a process continues to elude some of the best scientific minds in the profession. This is, or should be, very humbling, for the DA was invented by practitioners over the course of centuries, without formal methods or understanding of the ends that were achieved. The result]t is a remarkable institution which allows untrained users, with private information, to walk into a room, interact under DA roles, and converge to welfare maximizing equilibrium states.

### 3.3. Evaluating Policy Proposals

We illustrate the very large number of cases where the laboratory has been used to examine policy questions (Plott, 1987), by discussing two examples: The Ethyl case and the efficacy of a price limit change role for reducing stock market volatility.

## The Ethyl Case

In 1991 the Federal Trade Commission (FTC) filed a complaint against the manufacturers of tetraethyl lead, an antiknock compound used as an additive for decades in the gasoline industry. Four common contracting practices in the industry were mentioned in the complaint: (1) customers were assured of a thirty-day advance notice of price increases; (2) prices were quoted as delivered prices at the same level regardless of differing transportation cost in the quotation; contracts guaranteed that (3) the seller will sail to no other at a price less than that quoted the buyer, and (4) the seller will match any lower price in the market or release the buyer from the contract.

The product is sold by four firms, two of about equal size with 70 percent of sales, and two of about equal size that satisfy the remaining 30 percent. Sixty percent of sales are to eight large buyers, and the rest to a proliferation of small companies.

Advance notice of price increases, (1), and no secret price discounts, (3) and (4), in the FTC complaint, were the key elements (among others) studied experimentally as treatments by Grether and Plott (1984). The hypothesis was that these factors enable de facto collusion to occur by contractual arrangements justified on the basis of competition and good customer relations. The benign interpretation of the thirty-day advance notice to customers by public announcement was to enable customers to prepare for cost increases. The strategic interpretation is that it allows a seller to, signal an increase, without committing 10 an increase if it is not matched by the other three sellers. This blunts a strategic response in which other sellers would undersell the price leader to increase market share, since all sellers know that the leader can rescind the announced intention if other sellers do not also raise prices before the deadline. If a uniform industry price increases profit for each firm at the higher price, it is in their interest to match it. Decreases in price will similarly be matched in the unlikely case that industry demand is increased enough for it to be profitable.

Condition (3), offering to sell to no other buyer at a lower price, sounds like a guarantee of 'fair,' nondiscriminatory, treatment. Furthermore, it is contractual proof that the firm does not, and cannot be in violation of Robinson-Patman strictures on price discrimination -- differences that are not warranted by cost differentials. In fact it is a good hypothesis that these strictures are the origin of this contractual practice. But, strategically, what does it mean? It means that all firms using this clause are credibly precommitting not to lower prices to anyone since the cost of any such move is that the price must be lowered to all customers. Consequently, the incentive is to lower the price to no one, unless it happens to be optimal to lower it to everyone. Finally, (4), standing ready to match any lower price offered by another seller, sounds like an attractive deal to a prospective buyer, but the effect is to remove all incentive for a competing seller to make such an offer to any buyer. Although taken together these conditions provide a grid-lock form of non price discrimination which, superficially, may look 'desirable' from the perspective of the Robinson-Patman act, they also compromise the core of the competitive process. That process involves price discrimination in the out-of-equilibrium dynamics of market adjustment, as first one firm, then another undercut existing prices. At least this is what is implied by the theory of unrestrained competition.

Grether and Plott (1984) ask if the collusive hypothesis is supported and their experiments show that it is. One of their more dramatic examples demonstrating the effect of these contracting practices is shown in Figure 8. Trading was organized as a negotiated contract market with subject’s located in different rooms and communicating by telephone. Under the treatment conditions the practices listed in (1), (3) and (4), were in force. Using the supply and demand conditions shown on the left of Figure 8, trading started under the control condition, in which contracting was unconstrained, and proceeded for eleven periods. This allowed the market to stabilize, which it did by period five, as indicated by the plot of mean contract prices on the right of Figure 8. In period twelve the contracting provisions were introduced into the trading rules and continued through period 15; then the provisions were removed for the final two periods. As the data show, the effect of advance notice of price increases combined with no secret price discounting was to raise the mean contract price from about 60 to around 90.

Grether and Plott (1984, Table 5) report that the increase in prices when these features are present is statistically significant relative to unconstrained negotiated pricing. Furthermore the conjunction of all the practices was essential in this result. Experiments which used only advanced notice of price increases, or used only the disallowance of secret price discounting, in neither case led to a significant increase in prices.

Finally, although the conjunction of these practices raised prices significantly above competitive levels, the Grether and Plott data clearly reject the joint profit maximizing model. Prices, though higher, were significantly below the monopoly level.

Figure 8

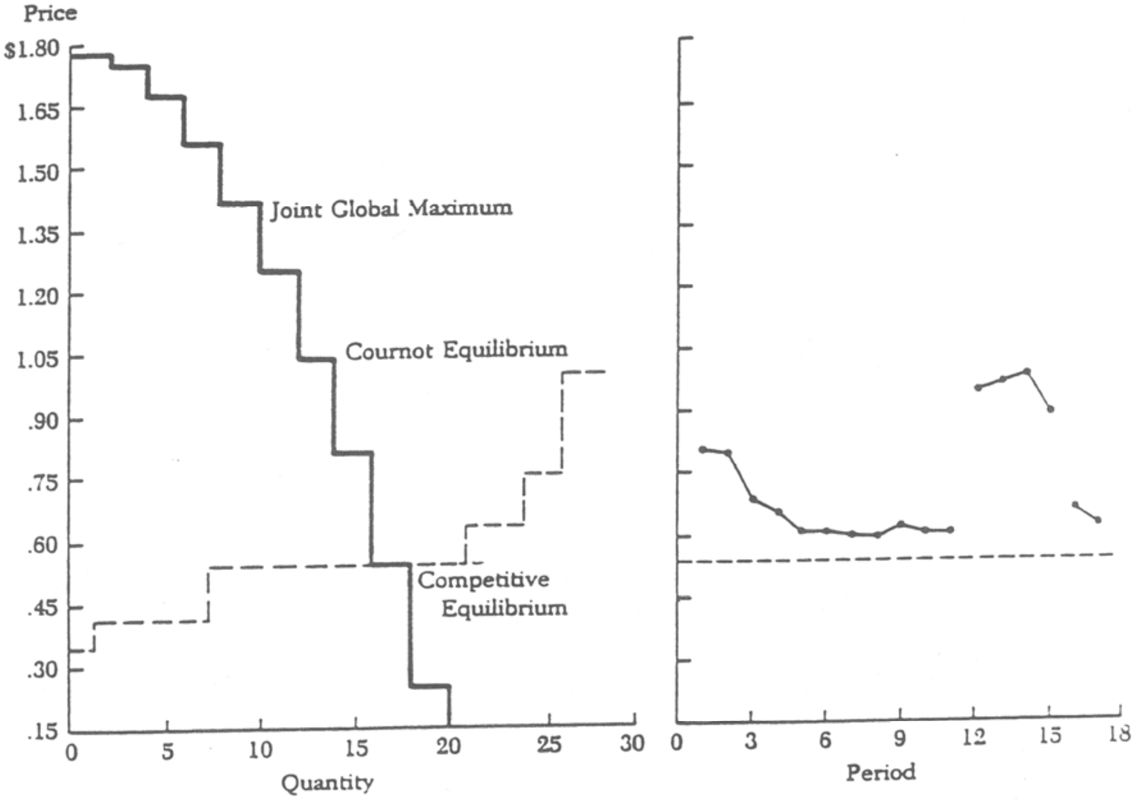
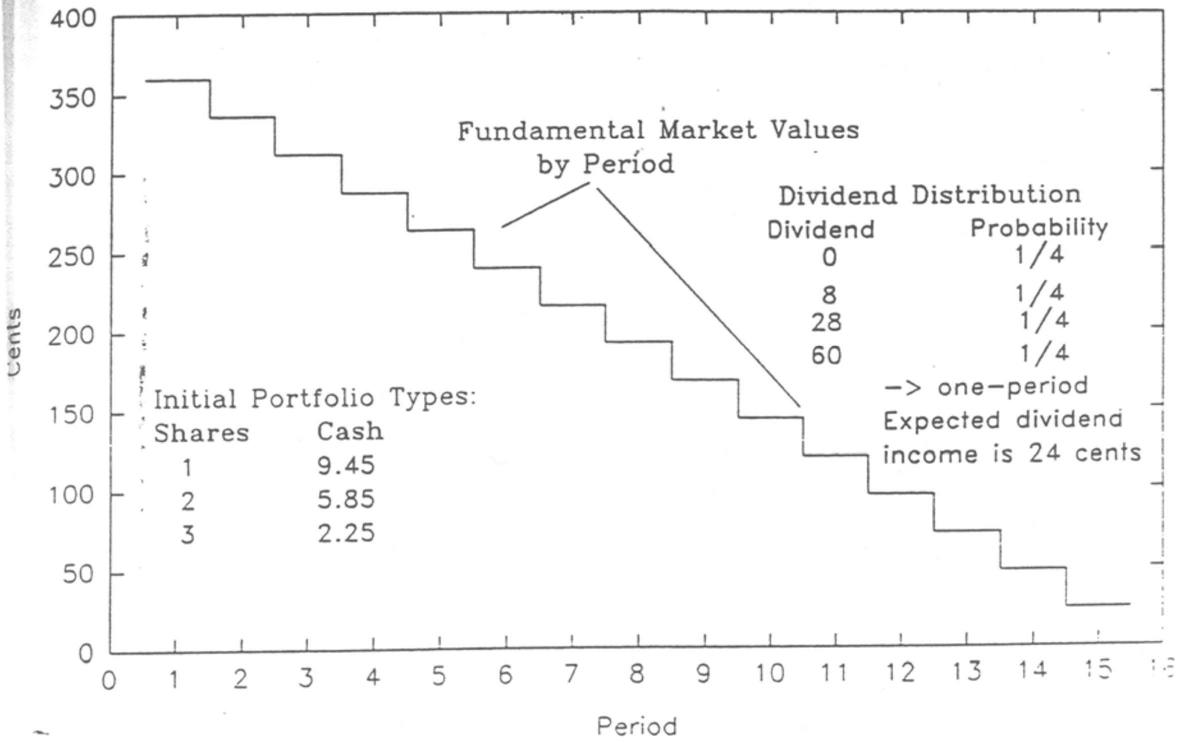


*Figure* 14. Parameters and Average Price Per Period

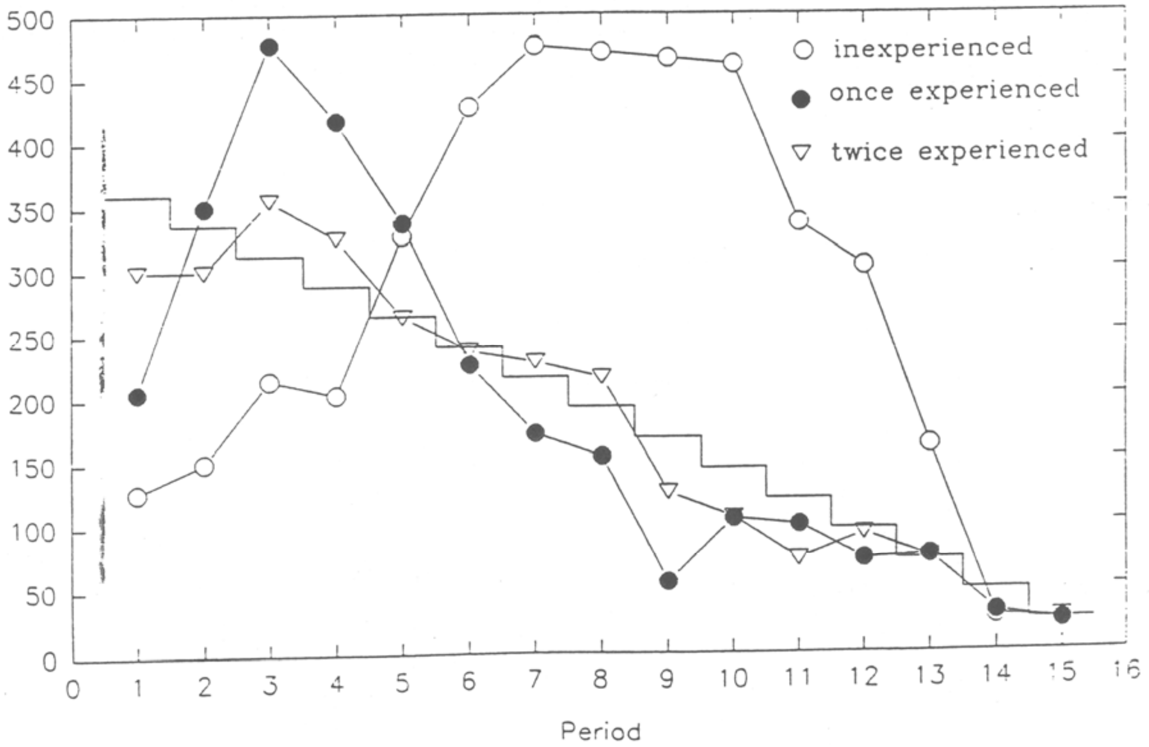
## Price Limit Change Rule and Stock Market Volatility

Smith, Suchanek and Williams (1988) (hereafter SSW) study the following asset trading environment. Each of 9 (or 12) subjects is endowed with cash and shares ($m_i$, $x_i$). Shares held at the end of each trading period receive a common dividend paid each share he Id in inventory. The dividend is drawn from a common information probability distribution, with announced expected value, for example E( d ) = \$0.24. All participants are informed that trading will be conducted (under double auction rules) for 15 trading periods. Consequently, the fundamental (dividend) value of a share during period t (prior to the dividend declaration at the end) is (15 - t + 1)(\$0.24) or \$3.60 in period 1, \$3.36 in period 2, and so on down to \$0.24 in period 15 (see top panel in Figure 10 for all design parameters).

The experiments reported by SSW, replicated and extended in several subsequent studies (see Porter and Smith, 1991, for a summary), find that when subjects are previously inexperienced these laboratory stock markets uniformly produce price bubbles followed by crashes measured relative to the controlled linear declining fundamental value schedule over the trading horizon. This is the case for undergraduate (and graduate) students (even finance majors), small business persons, corporate middle level managers and over-the- counter stock traders. However, these bubbles are less pronounced, and trading volume is reduced when a subject group returns for a second 15-period session. Bubbles essentially disappear and volume shrinks to very low levels when groups return for a third session. The performance of one group through three levels of experience is shown by the plot of mean prices by period in the bottom panel of Figure 9.



Baseline Asset Market Experiment Parameters



Asset Market with Short Sales 9 Subjects--Arizona

These experiments demonstrate that common information on fundamental value is not sufficient to induce common expectations of market value. There is still uncertainty about how others will react to the common information. The latter is resolved through experience, a process that creates common expectations.

Following the world-wide stock market crash in October, 1987, it was widely recommended by various study commissions that price change limit rules be implemented in some U.S. markets, particularly in stock futures indexes: The results of six laboratory experiments illustrate a principle which experimentalists have discovered over and over again in different contexts: The law of unintended effects. Figure 10, 11, 12 chart the price behavior of three stock markets with the same group of subjects operating under a rule that constrains the amount that prices can deviate from the previous period's closing price: 12 inexperienced subjects with a price change limit at ± $0.32 (2 x $0.16, the one-period expected dividend); 9 experienced subjects (out of the previous 12), with price change limit ± $0.48 (2 x $0.24, the one-period expected dividend); the same 9, now twice experienced, subjects with price change limit ± $0.48. In Figure 10 we see that, far from dampening the price bubble, the price change limit rule causes the bubble to last longer. When the market finally crashed in periods, 14 and 15, there are no buyers. With experience (Figure 11) the bubble bursts earlier (period 6) and crashes with zero volume until period 15 when we have 5 trades at a mea n price near intrinsic value. Upon retuning for a third session (Figure 12) the market follows intrinsic value after a mini bubble in the first three periods. But die convergence pattern across Figures 10-12 is qualitatively the same for groups that are not subject to price change limits.

Figure 10
Mean Price, Volume, and
Price Change Limits
Experiment 304; 12

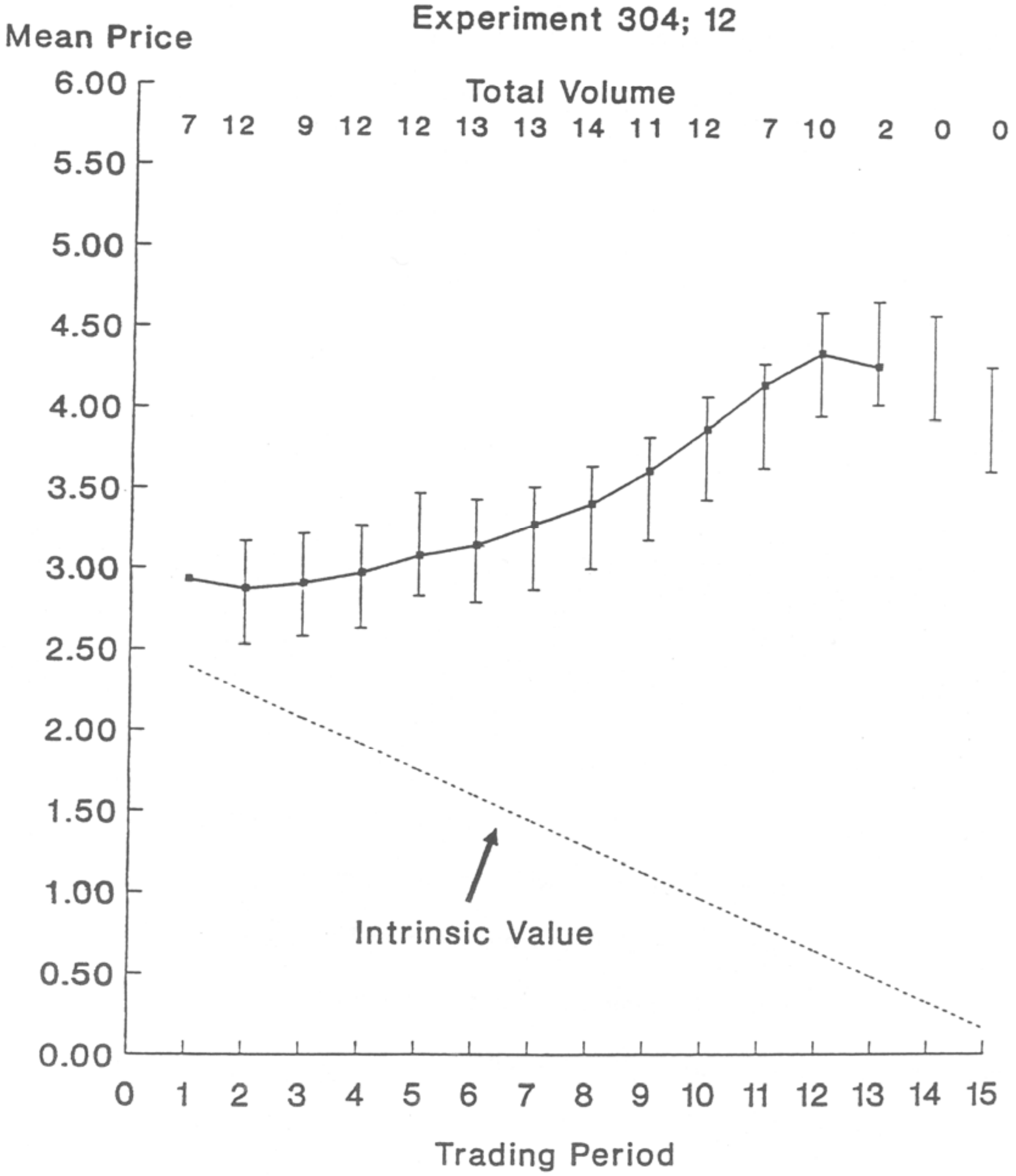


Figure 11
Mean Price, Volume, and
Price Change Limits
Experiment 305; 9x

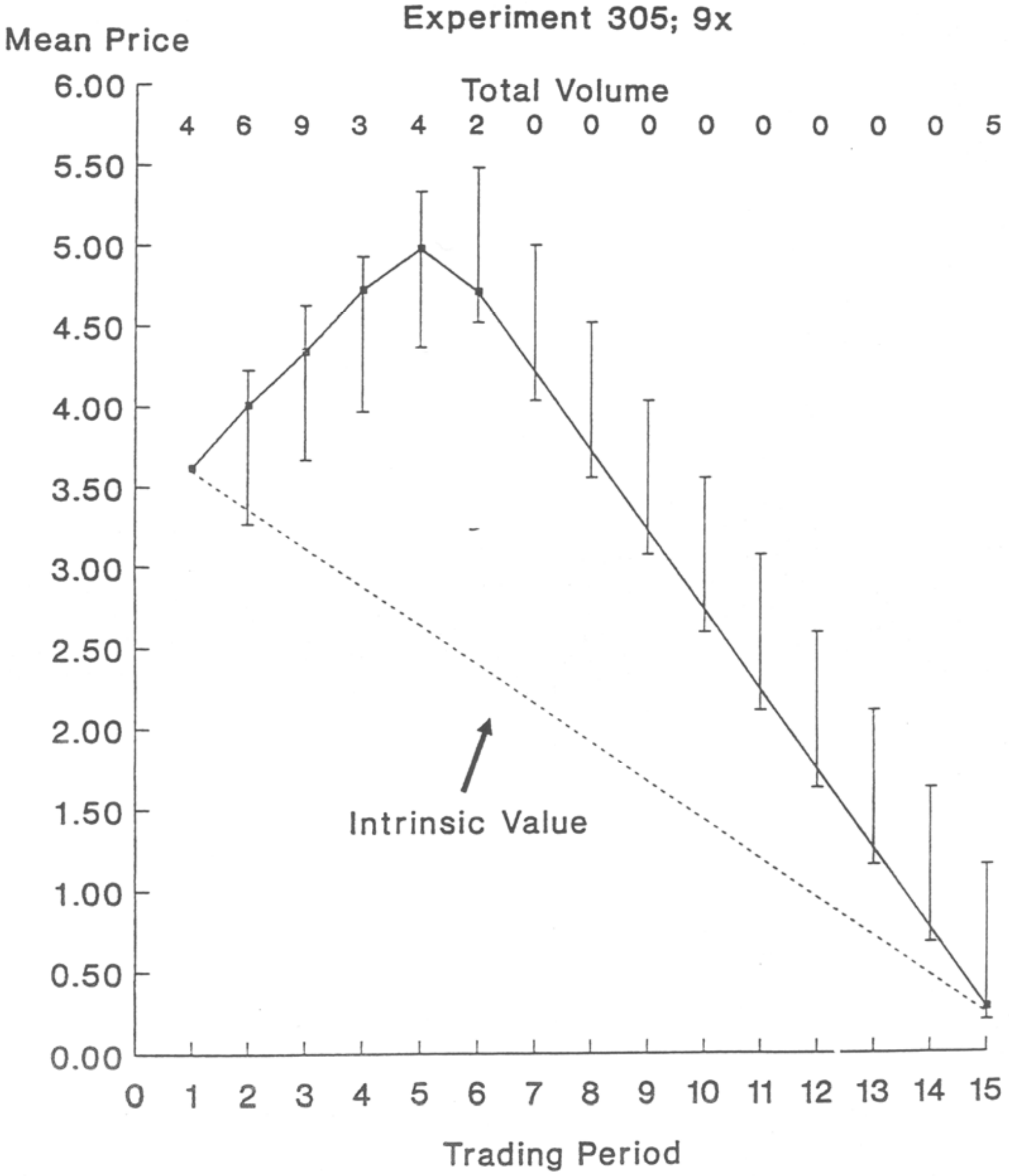
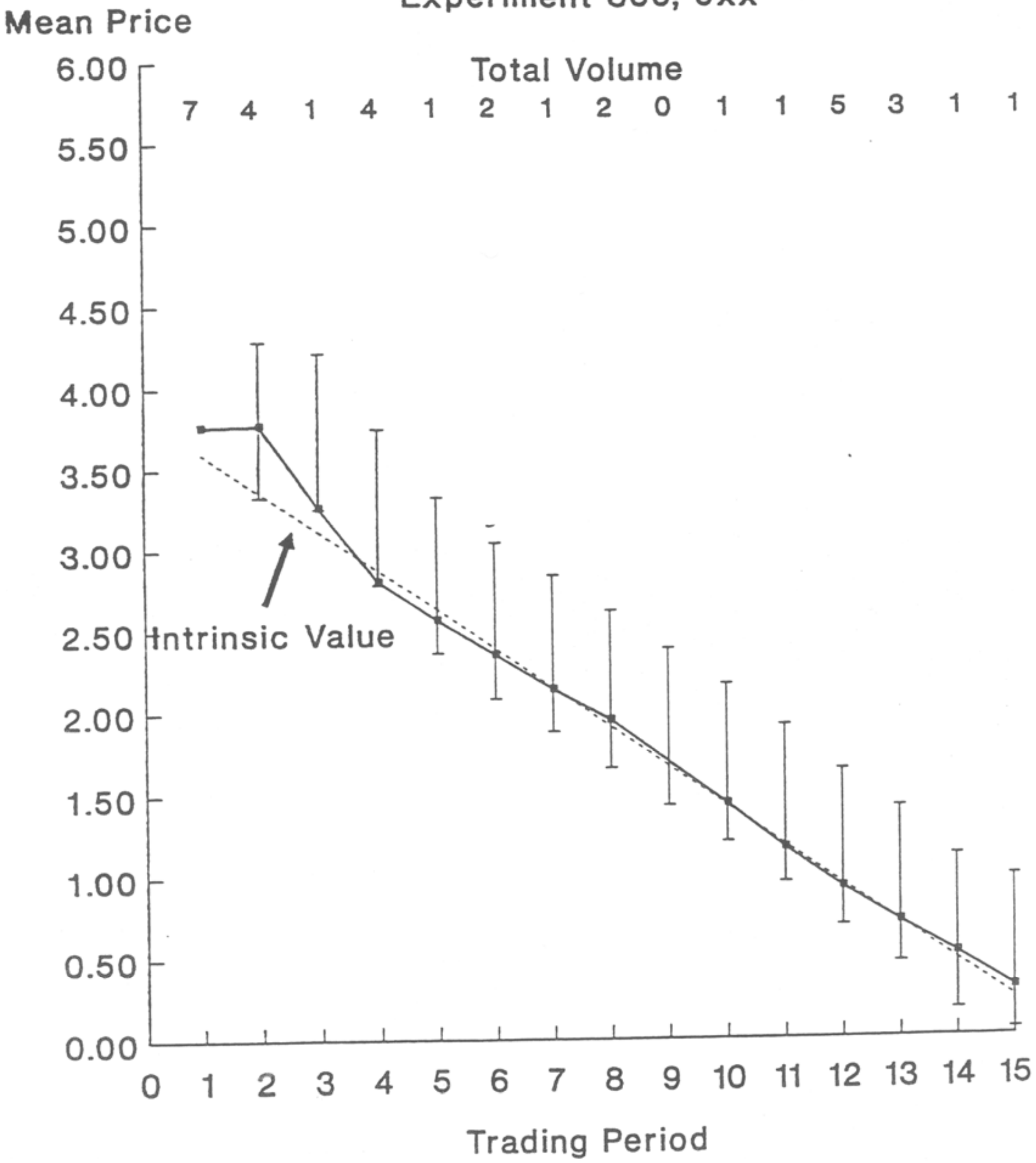


Figure 12
Mean Price, Volume, and
Price Change Limits
Experiment 306; 9xx



The tendency of bubbles to be worse, initially, under price change limits can explained as follows: all market participants perceive that the floor on the amount that prices can fall reduces the downside risk from riding the bubble higher and longer. The new element to be learned is the fact that when the market turns, no one is willing to buy at the limit price decline. Through experience the participants come to have common intrinsic value expectations, but this is exactly what happens in markets without the limit price change constraint.

To the extent that such constraints exacerbate bullish expectations, bubbles may be stimulated, not dampened, and such constraints should be avoided.

### 3.4. A Testbed for Institutional Design: Smart Computer Assisted Markets

Over a decade ago the concept of the smart computer assisted market was developed and illustrated in terms of two potential applications: the problem of allocating airport runway time-slot rights (Rassenti, 1981; Rassenti, Smith and Bulfin, 1982) and the problem of choosing and financing television programs to be broadcast over the network of Public Broadcasting System (PBS) stations (Rassenti, 1981). The latter problem had begun as a field experiment, called the Station Program Cooperative, first conducted by the PBS in the 1974-75 season, and has continued thereafter (Ferejohn and Noll, 1976). In these two examples Rassenti (1981) developed discrete optimization algorithms to provide allocations given the resource restrictions and the decentralized bids of individual users. The first of these examples – the combinatorial auction – will be developed in brief detail, and then subsequent applications of the concept of smart computer assisted markets will be described including work in progress.

## The Combinatorial Auction

Commodities and rights often have the property that they are desired and the user in particular individualized combinations. In fact individual elements contained, these combinations may have much less value to the user if they are not part of a desired combination: in private evaluation the whole may be much more than the sum of the parts. An extreme example is airport runway rights which an airline must acquire in even-multiple combinations of takeoffs and landings that are compatible with the airline's flight schedules. Thus an aircraft might take off in Baltimore, land in Chicago, take off from Chicago and land in Tucson, requiring a package of four elementary runway time slots. In this case individual elements are worthless in use; only the combinations compatible with viable flight schedules have value. But there are other less extreme examples: (1) in auctions far microwave spectrum licenses, as in New Zealand (Mueller, 1991), bidders may desire chains of stations in the major cities, and be willing to pay more for certain combinations of licenses than would be forthcoming if the licenses were sold singly; and (2) timber rights on contiguous tracts of land might be more valuable than on an equivalent set of separated tracts.

The environment for one of the experimental designs in an abstract combinatorial auction reported by Rassenti, Smith and Bulfin (1982) is shown in Table 2. There are six elemental resources, A through F. Agent 1 desires one unit each of A and B with a maximum WTP of \$6.27. Among the six bidders there is a demand for 30 packages which yields demands varying from 9 to 14 units for the elementary resources. Only 7 units of each resource are available.

Two different institutions are compared using inexperienced and experienced subjects.

1. The independent auction with after market. In this institution (studied along with committee and price discriminatory auctions by Grether, Isaac and Plott, 1989) each elemental resource is offered in inelastic supply. Each bidder submits a WTP bid for units of each resource. The bids for each resource are

ranked from highest to lowest, and the highest seven bids are accepted at the eighth highest bid price. An after-market, consisting of a billboard exchange is then used to allow auction awards to be transferred among participants who failed to acquire all the elements they needed through the primary auction. For example in Table 2 if agent 1 acquired three units of A but none of B or E that agent must then attempt to buy a unit of B and E in the aftermarket to fill out two packages, or sell one or two surplus units of A in which case not all demand is satisfied.

2. The combinatorial auction with after market. In this smart computer assisted procedure, agents submit bids for the combinations of the six elements needed to satisfy their package demands. Agent 1 might bid $6.00 for package 1 and $8.25 for package 4. Given the bids for all packages, and the elemental resource restrictions, the computer algorithm finds allocations and elemental resource prices that maximizes systems surplus as revealed in all agents' bids. Each package is then priced to the winning bidders at the sum

Table 2

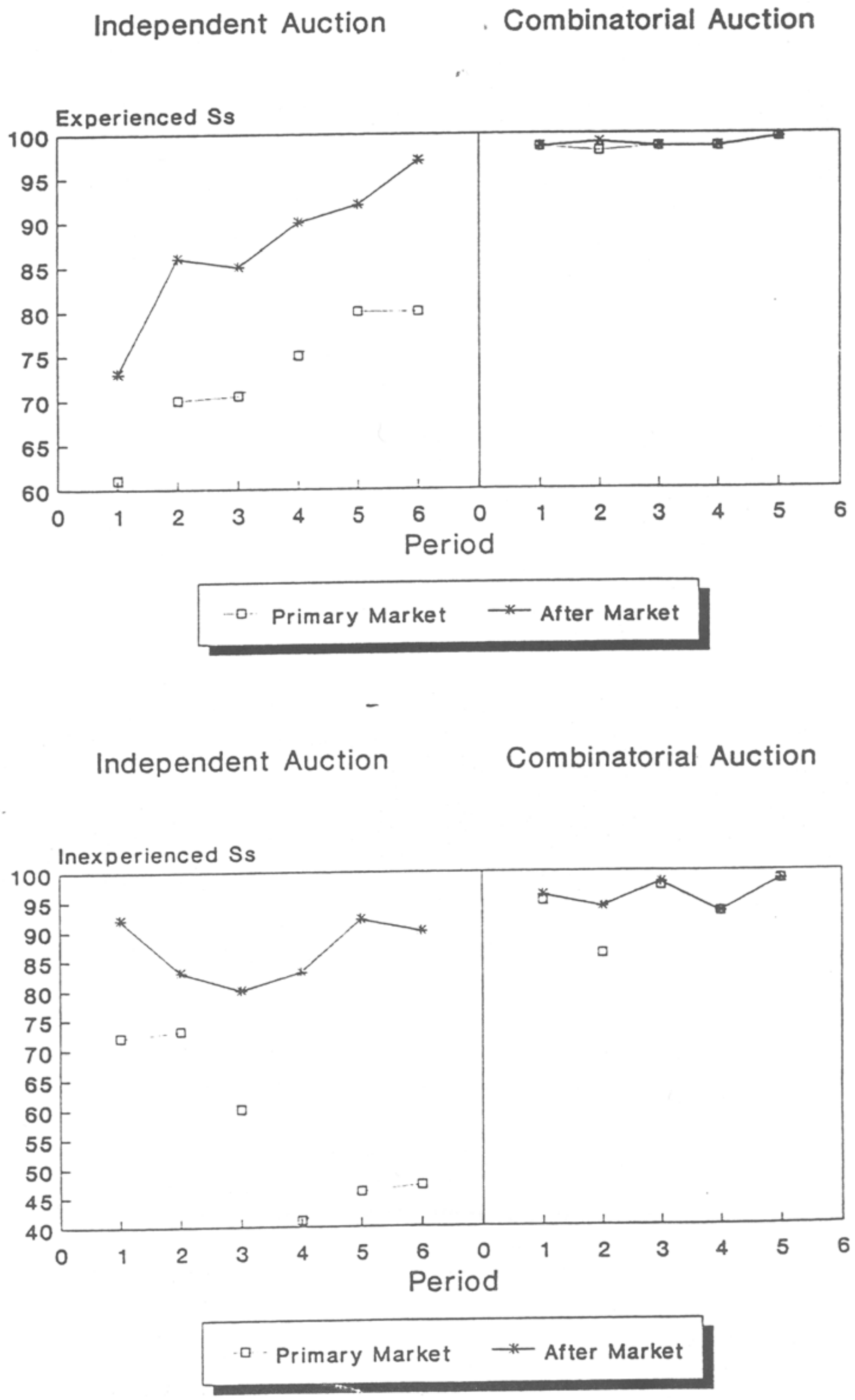
### ☐ Difficult resource utilization design.

| Agent | Package | Value | Item *A* | Item *B* | Item *C* | Item *D* | Item *E* | Item *F* |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 6.27 | 1 | 1 | | | | |
| 1 | 2 | 5.77 | | | 1 | 1 | | |
| 1 | 3 | 5.06 | 1 | | | | 1 | |
| 1 | 4 | 8.25 | 1 | | 1 | | | 1 |
| 1 | 5 | 8.34 | | 1 | 1 | | 1 | |
| 2 | 6 | 5.31 | 1 | 1 | | | | |
| 2 | 7 | 5.56 | | | 1 | 1 | | |
| 2 | 8 | 5.76 | 1 | | 1 | | | |
| 2 | 9 | 6.44 | | 1 | | | 1 | |
| 2 | 10 | 5.84 | | | 1 | | 1 | |
| 2 | 11 | 8.86 | 1 | | | | 1 | 1 |
| 3 | 12 | 5.17 | 1 | 1 | | | | |
| 3 | 13 | 5.76 | | | 1 | 1 | | |
| 3 | 14 | 8.87 | 1 | | 1 | | 1 | |
| 3 | 15 | 9.40 | | 1 | 1 | | | 1 |
| 4 | 16 | 5.98 | 1 | 1 | | | | |
| 4 | 17 | 6.27 | | | 1 | 1 | | |
| 4 | 18 | 5.78 | 1 | | | | | 1 |
| 4 | 19 | 5.78 | | 1 | | 1 | | |
| 4 | 20 | 5.56 | | | | 1 | | 1 |
| 4 | 21 | 8.61 | | 1 | | | 1 | 1 |
| 5 | 22 | 5.60 | 1 | 1 | | | | |
| 5 | 23 | 5.82 | | | 1 | 1 | | |
| 5 | 24 | 5.65 | | 1 | | | | 1 |
| 5 | 25 | 8.34 | | 1 | | 1 | 1 | |
| 5 | 26 | 7.82 | 1 | | | 1 | | 1 |
| 6 | 27 | 5.07 | 1 | 1 | | | | |
| 6 | 28 | 5.65 | | | 1 | 1 | | |
| 6 | 29 | 8.33 | | 1 | | 1 | | 1 |
| 6 | 30 | 9.59 | 1 | | | 1 | 1 | |
| # Units Demanded | | | 14 | 14 | 12 | 12 | 9 | 9 |
| # Units Available | | | 7 | 7 | 7 | 7 | 7 | 7 |

of its elemental 'shadow' price. For example, if the shadow prices of A and B are $\lambda_A$ = \$2.00 and $\lambda_b$ = \$2.75, then package s 1, 6, 12, etc., consisting of one each of A and B are priced at \$4.75. Thus, except in the case of a rare tie, agents do not pay the amount they bid for a package, but rather a fixed price practically independent of their bid for the package. This provides good incentives to bid one's true package value to maximize the chance of acceptance, much as in second price and uniform price auctions. But the existence of multiple interdependent units implies that the system is not theoretically strategy proof. Consequently, if there are behavioral attempts to manipulate the auction, this leads to inefficient allocations, and we still incorporate an aftermarket to allow such inefficiencies to be corrected. A primary objective of the experiments was to measure the extent of inefficiencies introduced by subject under revelation of the WTP demand for packages.

The results of four experiments in a 2 x 2 design comparing two levels of experience and the two auction institutions is shown in Figure 13. Each auction was run in a sequence of five or six periods. For both levels of experience the combinatorial auction all but eliminates the need for an aftermarket. For experienced subjects the combinatorial auction was 98-99 percent efficient indicating that the consequences of under revealing package WTP were negligible. But for the independent auction, an aftermarket is essential, and, with experienced subjects, achieved over 95 percent efficiency in period six. Inexperienced subjects perform very poorly in the independent auction. This was because of repeated attempts to acquire unneeded surplus resource units in a misguided effort to resell them at a profit in the aftermarket. This strategy failed massively, resulting in many cases of negative profits, and low allocative efficiency.

Figure 13


Independent Auction
Combinatorial Auction
Experienced Ss
100
95
90
85
80
75
70
65
60
0
1
2
3
4
5
6
0
1
2
3
4
5
6
Period
Primary Market
After Market
Independent Auction
Combinatorial Auction
Inexperienced Ss
100
95
90
85
80
75
70
65
60
55
50
45
40
0
1
2
3
4
5
6
0
1
2
3
4
5
6
Period
Primary Market
After Market

## Network and Other Examples

Beginning in 1987 the Department of Energy (DO E) funded two projects with the Economic Science Laboratory to study the feasibility, efficiency and pricing properties of a smart computer assisted auction for natural gas pipeline networks. We proposed an auction market (Gas Auction Network) supported by linear programming optimization algorithms applied to the decentralized location-specific WTP bid schedules of wholesale buyers, the location-specific WTA offer schedules of well-head producers, and the leg-specific offer schedules of transportation capacity by pipeline owners whose network connects producers with wholesale buyers (Rassenti, Reynolds and Smith, 1992).

One of the networks we used as a testbed for the auction mechanism consisted of six wholesale buyers, and six producers, connected via a network of pipelines with three owners. This simple network, suggested by the DOE, has several features that are important in the field: the case of buyers served by only one pipeline; a pipeline interconnect junction; a mix of independent and pipeline-owned producers. Consequently, we chose a pipeline network with quite limited constestability as a worst-case situation for testing Gas Auction Network.

We also parameterized the network for fairly severe pipeline capacity constraints (winter conditions). Each agent was assigned a two-step ($P_i$, $Q_i$) marginal cost or marginal value schedule. Since all agents submitted two-piece step function bid (offer) schedules, this information defined a linear programming problem for maximizing revealed surplus subject to the constraints defined by the step lengths in each schedule. By running the algorithm for bid (offer) schedules equal to induced value' (cost) we could compute a bench-mark competitive equilibrium. Since the subjects were free to inefficiently under reveal their induced values and costs, the experimental results report calculated realized efficiency (percent of total surplus) for each trading period, as well as the buyer/seller/pipeline profit shares for comparison with the competitive equilibrium shares.

The primary purpose of the experiments to be reported here was to test the hypothesis that efficiency and competitiveness can be improved by requiring bottle neck (monopoly) pipelines in the system to be owned by at least two (in this case three) cotenants. In the network this meant that we compared seven experiments with single holders of transportation rights on all segments of each of the three pipelines shown, with seven experiments in which rights to the monopoly segments are shared among three cotenants. In the cotenant experiments with rights to capacity shared equally among the coowners, each agent independently submits an offer schedule of transportation for his/her segment share.

The experimental results showed that cotenancy increases network competition leading to higher overall efficiency, but the greater impact is to increase the buyers' and producers' profit shares at the expense of the profit share of pipelines. Also, buyer prices are reduced by cotenancy while producer's prices tend to increase.

Since efficiency tended to rise asymptotically across time (up to 25 periods in sequence) toward the 100 percent level the data were pool to yield the following regression equation:

$$Y_i = [85.58 + 3.20D_i][1 - \exp(-1.03t_i)];$$

(0.84) (1.21) (0.06)

$R^2 = 0.42$, N = 238 observations, where $Y_i$ is efficiency for observation i, Di is one if i is a cotenancy observation, zero, otherwise, $t_i$ is the time period for i, and standard errors are shown in parentheses. The effect of cotenancy and of time in improving efficiency are statistically significant.

Currently, work is underway to improve the Gas Auction network pricing mechanism with the objective of improving its efficiency. The new price mechanism will be a continuous real time double auction with all contracts binding at the close of a fixed 'call auction' period. The first experiments with this new system suggest that it yields higher efficiency by providing better incentives to reveal marginal values and costs.

Research on many other important applications of the concept of smart computer assisted markets has been reported in the literature. The National Aeronautics and Space Administration funded research at the Jet Propulsion Laboratory to develop an auction process to price resource utilization by commercial users of space stations. The results was the development of a combinatorial auction procedure specialized to this application. Other applications have been developed for matching buyers and sellers in labor market settings (students to corporate interviewers; medical students to hospital internships, etc.), for decentralized pricing of electric power in privatized transmission networks, scheduling computer time for multiple users, and many more. In fact any mathematical optimization problem whose implementation requires measures of incremental cost and value, is a candidate for automation in an integrated person-computed market decision making system.

## The Future

We have discussed the beginnings and a small sample of the immense literature that characterize the current state of experimental literature. Where will it be in the future? There seems little double, now, that experimental economics is here to stay, and that it will continue to grow in importance if not always so rapidly, in the decades to come. As its professional view becomes better known it is likely to change mainstream economic thinking, much as it has changed the way experimentalist think about economics. It is inevitable that, like other sciences, economic theory will depend for its survival more upon evidence from direct tests, and less upon its association with authority a logical novelty. As the interest of game theorists turn today to equilibrium models of learning and evolution, so tomorrow must they become more dependent upon the constraining guidelines implied by experimental data, and new developments in theory will inspire deeper more challenging experimental designs. What particular forms all of these developments will have taken by the close of the next thirty years is impossible 10 predict, but the solid knowledge achieved so far will leave its footprints on a future, more comprehensive, understanding of the operation of markets.

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