MARKETS AS ECONOMIZERS OF INFORMATION:
EXPERIMENTAL EXAMINATION OF THE "HAYEK HYPOTHESIS"

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I. INTRODUCTION

Economics has tended to be long on theories (Hypotheses) and the use of "logical completeness" as a criterion for judging the value of a theory, but short on technologies for discriminating among theories on the basis of rigorous standards of empirical evidence. Consequently, the body of theory in economics tends to grow from a steady stream of additions, with replacements occurring only occasionally. It is sometimes claimed that our methodology is limited by the fact that economics is complicated and we cannot do experiments, with the result that logical completeness becomes a crucially important test criteria. Caricaturized, it is as if economics had tried to do the work of classical physics by a shortcut that bypassed Galileo and Kepler and started "at the top" with the intellectually more interesting methods of Isaac Newton. The consequences of this confusion of form with substance would be of less import were it not for the fact that as "experts" we have made, or fellow-traveled with, policy prescriptions requiring us to know more than indeed we can demonstrate that we know. This professional process seems to have led us to believe that our Keynesian prescriptions could fine-tune the economy, that regulation would solve the alleged monopoly problem, and that coercive action was implied ipso facto by the untested theorem that market institutions will "fail" in the presence of externality and public goods. In all these matters the profession is now undergoing an agonizing reappraisal, which is hopeful, because it carries the prospect that it will expose our illusions. As suggested by Kenneth Boulding, "The Scientific community... should be deeply concerned with the images of science that lie outside it and even those that lie within it... (and) try to dispel illusions about it, especially by better processes of testing" (1980, p. 833). Hopefully, in this reappraisal we will learn that the fuse between science and policy must be much longer than we have so impatiently believed and that if we are to salvage economics as a science we might have to be prepared to start over by rethinking and testing our most fundamental propositions.1

*Department of Economics, University of Arizona. I am grateful to Arlington Williams with whom I have collaborated in conducting most of the experiments presented in this paper, and to the National Science Foundation for research support. As indicated in the citations, this paper draws on several experiments that have appeared as part of larger joint studies on themes different from that developed herein. This paper is a substantially shortened version of an invited paper presented at the 50th Jubilee Congress of the Australian and New Zealand Association for the Advancement of Science, Adelaide, Australia, May 12-16, 1980.

1. I doubt that it will be sufficient to be more eclectic within the current state of the economics literature, which seems to be suggested by R. M. Solow (1980, p. 2).
Although experimental methods in economics had precursors in the papers by Chamberlin (1948), Thurston (1931) and others, it is only in the last two decades that a number of researchers [Hoggatt, 1959; Siegel and Fouraker, 1960; Smith, 1962; Friedman, 1963; Battilino, et al., 1973; Fiorina and Plott, 1978], have started to examine systematically the controlled experiment as a reconstructive vehicle for asking what it is that we can credibly claim to know. These two decades have produced some hard replicable results, including some Keplerian challenges to price theory, and shown that as economists we have not been on the wrong track in emphasizing the significance of individual incentives as an organizing principle in social economy. But there is much that we do not understand about the processes through which incentives do their work. Among our theories there seem to be some credible ones (in particular some of our static theories perform very well), if we will but have the patience and commitment to design experimental or other empirical filters to separate the wheat from the chaff. The need is not for less theory, but for theory inspired by hard evidence (albeit distilled into stylized facts). In the end this is likely to give us new and better theory, but in any case holds forth the possibility that we can be surer, and justifiably more confident, about what it is that we think we know.

II. INFORMATION AND COMPETITIVE EQUILIBRIUM
IN PRIVATE GOODS MARKETS

The fundamental proposition of decentralized market theory is that a competitive equilibrium provides allocations that exhaust the gains from specialization and exchange (the allocations are Pareto optimal). But there is far less professional agreement as to the institutional and technical conditions necessary to achieve a competitive equilibrium (C. E.). One view, which has commanded a modest following since the classic work of Adam Smith, suggests that the attainment of C. E. allocations do not require any individual participant to have knowledge of the circumstances of other agents, or to have an understanding either of the market as an allocation system or of his/her role in promoting "and end which was no part of his intention" [Smith, 1937 (1776), p. 423]. Thus Alfred Marshall notes in his famous illustration of price determination in a local corn market, that "it is not indeed necessary for our argument that any dealers should have a thorough knowledge of the circumstances of the market" [Marshall, 1948 (1890), p. 334]. But it was Hayek who put the case more strongly and more influentially in recent decades, by emphasizing that "the most significant fact about this (price) system is the economy of knowledge with which it operates, or how little the individual participants need to know in order to be able to take the right action ..." [Hayek, 1945, p. 526-527]. The problem which is addressed by the price system "is precisely how to extend the span of our utilization of resources beyond the span of the control of any one mind; and, therefore, how to dispense with the need of conscious con-
control and how to provide inducements which will make the individuals do the desirable things without anyone having to tell them what to do" [Hayek, 1945, p. 527].

But how "little" need be the knowledge of each individual, and yet allow the market to do its work of efficient allocation? How is this relationship between the knowledge of individuals and the achievement of efficient market outcomes affected by the internal (formal or informal) rules of the market? How is it affected by external conditions such as the stationarity or dynamic nature of costs or tastes?

The extreme case of "little" knowledge is the circumstance of strict privacy wherein each buyer in a market knows only his/her own valuation of units of a commodity, and each seller knows only his/her own cost of the units that might be sold. Experimental markets have been used to test what we will call the Hayek Hypothesis: Strict privacy together with the trading rules of a market institution are sufficient to produce competitive market outcomes at or near 100% efficiency. Of those institutions that have been studied experimentally, the one which has been used most extensively to test the Hayek Hypothesis is the oral double auction characteristic of the organized stock and commodity markets. In this institution buyers and sellers announce price bids and offers subject to specified rules, and contracts are born, sequentially, of those bids and offers that are accepted.

The vast majority of economists in the main stream of British and American economic thought have not accepted, indeed have been openly skeptical of Hayek's claim that decentralized markets are able to function with such an extreme economy of information. In the absence of direct evidence such skepticism is warranted. Two contrary hypotheses have formed the core of main stream economic thought concerning the conditions for a competitive equilibrium. According to the price taking hypothesis, which seems to have been articulated first by Cournot (1838), the essential feature of a competitive market is that the number of buyers and sellers is so large that each individual has an imperceptible influence on price and, consequently, takes price as a given constant. This has been the standard textbook treatment of competitive price theory to which young minds have been exposed for many decades. Another theme in price theory specifies even stronger conditions for achieving competitive allocations, namely the complete knowledge hypothesis wherein it is asserted that competitive allocations require perfectly "foreseen" conditions of supply and demand [Samuelson, 1966, pp. 947, 949, passim]. Sometimes a definitional distinction is made between "pure" competition where the price taking hypothesis prevails, and perfect competition, where the complete knowledge hypothesis is assumed to apply.

2. The condition that there be perfect knowledge of the conditions of supply and demand, seems first to have been emphasized by Jevons (1871). See Stigler (1957) for a historical treatment of the concept of perfect competition.
III. EXPERIMENTS WITH STATIONARY ENVIRONMENTS

The design and execution of the experiments that have been used to examine the above hypotheses can be described under the following three headings:

1. Inducing specified supply and demand conditions.

In laboratory studies of market behavior a monetary reward system is used to induce whatever supply and demand conditions the experimenter wishes to administer as an experimental treatment. For example, consider the supply and demand schedules shown on the left of the experiment reported in figure 1. This experiment consisted of four buyers and four sellers, each with a capacity to buy or sell three units. Buyer 1 is assigned a value $8.50 for unit 1, $7.45 for unit 2, and $7.30 for unit 3, with the understanding that in each trading period he/she will earn the difference in cash between the assigned value and the purchase price for each unit bought. Consequently, buyer 1's schedule of valuations is a marginal valuation, or induced individual demand schedule. Buyer 1 will exhibit a maximum demand of 1 unit at any price above $7.45, but below $8.50; a demand for two units at prices above $7.30, but below $7.45, and so on. Similarly, seller 1 is assigned costs of $6.60 for unit 1, $7.65 for unit 2, and $7.80 for unit 3, and is guaranteed to pocket the cash difference between the selling price and cost of each unit sold. This defines a marginal cost or induced individual supply schedule. If we array these assigned valuations (costs) for all four buyers (sellers) from highest to lowest (lowest to highest), as indicated on the left of figure 1 (also, see figures 2-7) the resulting schedule corresponds to the demand (supply) schedule of economic theory. Note that demand (supply) is defined as if all economic agents were price takers, which perhaps accounts for the widespread professional acceptance of the price-taking hypothesis for competitive markets. It is easy to have the impression that price-taking behavior is inherent in the very concept of market demand (supply).

FIGURE 1

3. Buyers and sellers may also receive a small "commission," say 5 cents for making a trade. This provides a minimal inducement to trade a marginal unit at a price equal to its assigned value (or cost). In the experiments reported here subject buyers and sellers typically earn $12-$25 for participating in an experiment requiring two hours or less to complete.
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In this experimental design if it should happen that all exchanges take place at the C. E. market-clearing price, \( P_c \), the total earnings of the participants (not counting the commissions paid) is given by the shaded area shown on the left of figure 1. In particular, buyers earn the "consumer's surplus" labeled CS and sellers earn the "producer's surplus" labeled PS in figure 1. This total area, or surplus, provides a monetary measure of the aggregate gains from exchange and therefore, a measure of the ideal value of the market process itself. If the earnings actually realized in the market by all buyers and sellers is divided by the theoretical earnings given by the shaded area in figure 1, this ratio provides a measure of the market's efficiency. If and only if a market is 100% efficient, will the gains from exchange be exhausted.

2. The double auction as an institution of contract.

We define an institution of contract as the complete set of rules (or customs) which specify the process through which economic agents communicate, exchange information and negotiate contracts for the exchange of items or services of value. The experiments reported here use a computerized form of some key double auction rules that govern trading on the New York Stock Exchange.\(^4\) This computerized experimental market is a real-time trading institution in which the market is open for a specified interval of time, during which any buyer of the commodity is free to announce at any instant a bid price for the commodity. This bid is admissible to the "floor," i.e., displayed on each participant's computer terminal, only if it provides a better (higher) price than the outstanding bid. Similarly, sellers are free to announce price offers except that an offer is admissible only if it provides a better (lower) price than the outstanding offer. A bid or offer, once established, is binding until it is either displaced by a better bid or offer, or a bid or offer is accepted to form a contract. Each bid, offer, or contract is understood to refer to a single unit. The "auction" for a unit ends with a contract, and the market (or computer) waits for a new bid or offer. This process continues until the trading period countdown is ended, at which time, after a short pause, the experimental market is reopened for a new "day" of trading on the same terms. The experiment in figure 1 represents a case in which the buyer valuations and seller costs remain unchanged from period to period, corresponding to a well-defined stationary supply and demand environment, i.e., the supply and demand schedules represent flows per period of trading.

Note carefully in this institution that each agent is not in a price taking environment. The environment is one of multilateral negotiation in which each agent is as much a price maker (who actively announces bids or offers) as a price taker (who accepts bids or offers).

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4. For a more complete description see Smith and Williams (1980).
3. **The information state of the experimental market.**

From this description of the market institution it is clear that all bids, offers, and contracts represent public information available to all the participants. This is a characteristic feature of all organized stock and commodity markets. However, if we are to obtain a test of the Hayek hypothesis, all knowledge except this public price information must remain private to individuals. Hence in the experimental market, individual values (costs) are assigned privately, and remain private throughout the experiment. All information pertaining to the market supply and demand condition and the individual values (costs) of other participants is withheld from each agent.

Under these experimental conditions if there is a pronounced tendency for these markets to converge to the competitive equilibrium, the Hayek hypothesis is supported in stationary environments. If these markets fail to converge or if convergence is weak, the Hayek hypothesis must be rejected (or is certainly suspect), and the alternative hypotheses seriously considered. That is, some form of price-taking behavior with a much larger number of buyers and sellers, or more complete participant knowledge of market conditions, may be necessary to produce C. E. states.

The experimental evidence, which at the present writing consists of perhaps 150 to 200 individual experiments conducted by many different investigators [For example, see Smith, 1976; Smith and Williams, 1980; Isaac and Plott, 1981], provides unequivocal support for the Hayek hypothesis. Double oral auctions with either inexperienced or experienced participants converge with astonishing speed to the C. E. price and quantity.\(^5\) Computerized forms of the double auction show similar rapid convergence when *experienced* subjects are used. (i.e., subjects who have participated in a previous double auction experiment that used different supply and demand conditions). The reasons for this difference are due, apparently, to the motor activities that must be learned in computerized trading, and to differences between the auditory and visual information processing ability of people [Williams, 1980]. Figures 1-4 illustrate typical patterns of contract price convergence in computerized double auction experiments. These figures plot contract prices in the order in which bids (or offers) were accepted.

The experiment in figure 1, using eight experienced subjects, converges essentially to the C. E. by the second trading period with very high efficiency in all periods. Figure 2 presents an experiment corresponding to a “thicker” market (six buyers, six sellers, twelve units exchanged at the C. E.), but with inexperienced subjects. Apparently, the slower convergence behavior of inexperienced subjects is offset somewhat, in this case, by the larger trading volume.

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5. Of the large number of double auction experiments reported, the only exception to this statement appears to be experiment II reported by Isaac and Plott (1981, p. 452).
In figure 3 two sellers constitute the supply schedule shown on the left while five buyers compose the indicated demand schedule. Average price in all but the first period is within five cents of the C. E. price ($3.80). Efficiency is 100 percent in all periods except 2 and 15. Hence the rapid convergence property of double auction trading is robust with respect to a reduction in the number of sellers to only two.  

6. The large decrease in efficiency in period 15 was due to the failure of buyer 2 (with first and second unit valuations of $4.30 and $5.80) to make a purchase. He entered no bids until near the end of the period. His first bid at $3.80 was "bumped" by an overbid from another buyer. He then re-entered a bid of $3.80 eight seconds before the market close, and seller 2 who had not yet sold his third unit (cost $3.70) refused to accept the bid or make a counter offer. Buyer 2 had followed a similar strategy in previous periods, i.e., holding out with low bids until near the market close, but only in period 15 did this strategy fail to yield a contract.
Figure 4 illustrates an experimental design that provides the most stringent of all reported tests of the equilibrating tendency in double auction trading. In this market four sellers all have identical unit costs ($5.70) and four buyers all have the same unit values ($6.80). In the first week of trading aggregate supply capacity is eleven units, while demand capacity is sixteen units. In the interface between period 5 and period 6, the total capacity of sellers is increased to sixteen units for week 2, while the demand capacity is reduced to eleven units. From the point of view of the participants this change is rather subtle in that their individual value and cost assignments remain constant. But the C. E. price shifts from $P_1 = \$6.80$ in week 1 to $P_2 = \$5.70$ in week 2. At the week 1 C. E. price all the exchange surplus ($\$12.10$ per trading period) is obtained by the sellers, with buyers receiving only the commission (10 percent per transaction). In week 2 at the C. E. price, all surplus goes to the buyers with the sellers receiving commissions only. In this "pathological case" buyers (sellers) in week 1 (in week 2) can be expected to offer exceptionally strong bargaining resistance to contract prices that converge to $P_1$ ($P_2$). As shown by the contract price sequence in Figure 4, the convergence is slow, but definitive in week 1, with all contracts at $P_2$ in period 5. In periods 6, 7 and the first half of 8 it is evident that the high price expectations and profit aspirations established in week 1 are slow to extinguish under the new week 2 conditions, but by period 10 all contracts except the first are at $P_2$. In this design the C. E. is not the unique efficient (Pareto optimal) allocation that exhausts the gains from trade. In fact, any allocation and set of prices such that eleven units are exchanged will be 100% efficient. Hence, the C. E. has no special "ethical" appeal in this case, but as an experimental design this case allows the boundary of performance in double auction trading to be tested.

These results provide strong support for the Hayek hypothesis in stationary double auction environments with constant repetitive conditions of supply and demand; neither complete information nor price-taking behavior (with its "large number" implications) is necessary for C. E. convergence. But will the Hayek hypothesis receive similar support in other environments? The next section presents experimental data from environments that are either cyclical or subject to irregular shifts in supply and demand.

IV. EXPERIMENTS WITH DYNAMIC ENVIRONMENTS; CYCLIC DEMAND

Many markets are characterized by seasonal changes in demand (or supply). The demand for swimwear is concentrated in the summer; and the daytime demand for electricity exceeds the demand at night. Where the commodity (or service) is nonstorable, or storable only at prohibitive costs, the maximum output level is determined by the peak demand conditions. Where the commodity can be stored economically, substantial sav-
nings may be obtained by smoothing output over the cycle and allowing peak demand to be satisfied out of inventories accumulated during off-peak demand periods. An important function of markets is to establish price patterns over time that provide individual incentives for the optimal smoothing of supply responses over time.

The experiments shown in figures 5 and 6 [Williams, 1979, p. 258, 262] deal with the case in which demand cycles alternately between a "low" (B) and a "high" (Y) level. In figure 5 a distinct group of (two) "traders" are given the exclusive right to buy in one period for resale in the subsequent period, but without benefit of any information on demand except that which is revealed publically in the double auction bid-offer process of exchange. In this experiment traders incur a zero cost of storage. At the intertemporal C. E. price ($2.80) sellers should supply seven units per period, traders should buy four units in B for resale in Y, with consumption of three units in B, eleven units in Y. At the C. E. both buyers and sellers received a larger surplus due to the speculative activity of traders.

Referring to figure 5, in period 1B and 1Y the traders made no purchases and therefore no sales. Having observed lower contract prices in the "B season" than in the "Y season," traders purchased two units in period 2B for resale in 2Y. The carryover was expanded to four units in periods 3B and 3Y and in all subsequent periods. By periods 7B and 7Y most contract prices are near the intertemporal C. E. price, and trader's profits have been lowered from 50-60 cents per trade in period 2 to 5-10 cents per trade in period 7. Beginning with period 3 market efficiency is 100% of its theoretical intertemporal C. E. level.

No traders participated in the experiment shown in figure 6. In this autarky (no trade) market the C. E. price should cycle between $2.40 in the B period and $3.40 in the Y period with exchange quantities of five units and nine units respectively. At these prices, the theoretical efficiency would be 92% of the intertemporal C. E. with optimal carry-over. It will be noted that this market is very slow in approaching this cyclical equilibrium. Sellers have no reason to expect prices to change from the B to the Y seasons (their costs do not change) and in the bargaining process tend to negotiate prices above the C. E. price in B and below the C. E. price in Y. Gradually, however, this "hysteresis" effect diminishes with prices approaching their respective seasonal C. E. levels by period 7. Beginning with period 3 market efficiency attained its theoretical autarkic value.

FIGURE 5

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FIGURE 6

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V. IRREGULAR SHIFTS IN SUPPLY AND DEMAND

In figure 7 is shown a double auction experiment in which demand and supply were stationary for five periods; then both were shifted down, again remained stationary for five periods; and finally both were shifted up, remaining stationary for the final five periods of the experimental session. In each week of trading this market converged to the temporary C. E. price before a new week brought a shift in the supply and demand schedules. In week 3 convergence was very rapid with all contracts "locked" into the C. E. price in periods 13, 14 and 15. It should be noted that in this environment, consisting of a simultaneous shift in both supply and demand, there is some tendency to overshoot the new C. E. price (see periods 6 and 11).

VI. DISCUSSION

In all three of the double auction environments studied experimentally (stationary, cyclical, and irregular shifts in demand and supply) the evidence is consistent with the Hayek hypothesis and inconsistent with both the "large numbers" price-taking hypothesis and the much stronger complete-information hypothesis. Does this mean that markets will always perform in accordance with competitive price theory under the
low information Hayek conditions? Not necessarily — certainly not without more empirical evidence. For example, the Hayek hypothesis performs better under double auction exchange than under some alternative exchange institutions. In experiments with "posted offer" pricing in which sellers independently select prices that are then administered to buyers on a take-it-or-leave-it (not negotiable) basis, price convergence is slower and allocations less efficient than is typical of double auction exchange [See, for example, Williams, 1973]. Also, recent experiments comparing double auction (continuous) trading with various forms of the sealed-bid auction show the former to be more efficient than some forms of the latter [Smith, Williams, et al. 1982]. Finally, multiple interdependent double auction markets have been studied in only one exploratory probe [Easley and Ledyard, 1979], and although the reported results are generally consistent with those reported above, they are too tentative to provide hard further evidence on the Hayek hypothesis.

What has been established is, that in the simple environments studied to date, the attainment of C. E. outcomes is possible under much less stringent conditions than has been thought necessary by the overwhelming majority of professional economists. A priori these experimental results have not been considered intuitively plausible. In this sense, Hayek's claims concerning the price system as an economizer of information, must be classified as an "outrageous" hypothesis contrary to what the common sense of most scholars had led them to expect. But it is not uncommon in the history of science for an initially "outrageous" hypothesis eventually to become credible — even widely accepted. Two recent examples in geology are the Continental Drift and Greak Spokane Flood hypotheses. The most famous example is probably the hypothesis that all falling bodies, as well as the motion of the planets and the stars are subject to the same inverse square law of attraction. For a sixteenth century natural philosopher it would be difficult to imagine a more outrageous theory.

But even if our Hayek hypothesis continues to outperform its competitors in laboratory experiments, does this mean that it will do comparably well in the "field" environment of the economy? On the assumption of parallelism, namely that the same physical (and behavioral) laws hold everywhere, it is a reasonable working hypothesis, provisionally, to make this extension, but independent field observations, or experiments, are the appropriate vehicle for testing the extended hypothesis. Comparisons of laboratory bidding behavior with that of participants in the market for new issues of U.S. Treasury bond support the assumption of behavioral parallelism in sealed-bid auctions [Tsao and Vignola, 1977], but few such field experiments have been attempted. There is much casual evidence to suggest that the Hayek hypothesis applies to markets in the economy; e.g., prior to the energy department's gasoline allocation program, with its con-

7. For a discussion of these "outrageous" hypotheses in geological science, see Baker (1978).
sequent disruptive misallocations, the right amount of gasoline appears to have been continuously supplied to the right place at the right time. But this evidence is indirect, and based on correlations and is not of the same quality as the experimental evidence. For example, in field environments we can never know whether observed allocations are optimal. However, indirect field evidence acquires added significance when controlled experiments confirm the effectiveness of price mechanisms in coordinating allocations under conditions of privacy. Our confidence in interpreting this field evidence should be increased for the same reason that we have greater confidence in our interpretation of the correlation between lung cancer and cigarette smoking after laboratory experiments establish that rats, injected with cigarette tars, show an increased incidence of tumors. But of course the scientist in us should always remain just a little skeptical even of those propositions that appear to receive very convincing, replicable, evidential support.

REFERENCES


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