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Exchange, Economic Theory, and the Hayek Critique

Economics is about exchange. In modern economies this means that people trade tangible goods, services and rights, given and received for money, whose value is itself derived from the rights conveyed by the bearer. Money, however, is a recent social contrivance in the long dimly lighted history of trade among early peoples. Such trade predates the state and even agriculture, which is only some 10,000 years old. The archaeological evidence for trade survives in the durables – weapons, tools and ornaments – left behind in caves and campgrounds, such trade inferred largely from the fact that the geographical distribution of such artifacts is disjoined over great distances from the distribution of the raw materials from which they were manufactured.

Adam Smith saw that trade provided the foundation for specialization and a vast expansion in human productivity. Hence, the division of labor (among specialties) is limited by the extent of the market. It is the presence of market opportunities that permits one person to grow corn, another hogs, the baker to bake and the butcher to cut meat, as each specializes in that for which he is suited by temperament, experience or natural skills, then satisfies his general needs through markets. Smith understood that knowledge was dispersed in the market system, and that the individual, knowing his local situation, could better judge than the “statesmen or the lawgiver” how to employ his capital to its greatest value. But it remained for F. Hayek to articulate more fully the idea that the market order served to coordinate the utilization of this dispersed information through the price system, and to see that it constituted an extended order of cooperation among thousands, indeed millions, of uncomprehending individuals. Hayek saw economy as an example of a self-ordering system driven by cultural evolution, and in this had important parallels with other complex self-ordering systems in biology.

Economic theory traditionally has modeled the individual consumer in competitive markets as directed by the goal of maximizing his current period utility over a given commodity, and work effort space subject to a budget balance constraint requiring the income from sources, such as labor earnings, to equal expenditure on commodities, given commodity prices and wages. Similarly, producers maximize profit given wages, input and output prices, and their knowledge of technology. This way of representing the "economic problem of society" leads to mathematical conditions defining a competitive equilibrium (CE) and the analysis of its existence and properties. The history of economy theory has suggested two different (equally unsatisfactory) answers to the question of how economic agents might be able to achieve a CE. One was to assert that a CE is simply an ideal state achievable only if the agents all have complete information on each other's individual preferences and production opportunities; i.e. on all data the theorist needs to calculate a CE. The second was that if all agents were "price takers," having no power to control any price, then the CE would be attained.

The first begs the question of how an economy processes and utilizes information, while the second begs the question of how prices are formed.

Hayek (1945/1984, p. 217, 219) argues that the above description, although a useful conceptual framework, is <u>not</u> the economic problem of society, rather the problem "is mainly one of rapid adaptation to changes in the particular circumstances of time and place, (from which) … it would seem to follow that the ultimate decisions must be left to the people who are familiar with these circumstances… We need (some form) of decentralization because only thus can we insure that the knowledge of the particular circumstances . . . will be promptly used. But the ‘man on the spot’ cannot decide solely on the basis of his limited but intimate knowledge of (particulars) . . . There still remains the problem of communicating to him such further information as he needs to fit his decisions into . . . the larger economic system.” The solution to the problem is that all the myriad of circumstances of others that is relevant to him is summarized and conveyed in the prices he sees, and therefore . . . “we must look to the price system as such a mechanism for communicating information if we want to understand its real function . . . the most significant fact about this system is the economy of knowledge with which it operates, or how little the individuals need to know in order to be able to take the right action . . . only the most essential information is passed on, and . . . only to those concerned.” Thus, prices are claimed to be the carriers of all that the individual need know about others, and of the social and physical constraints on all the activities underlying those prices.

This is a powerful interpretation of the complex order of the market. Hayek articulates no detailed process model; rather he brings to our attention a description of what he thinks is the essential function served by his observation of the price system in action. But can his insights be demonstrated empirically? How does it happen? How is the work of markets mediated by institutions? There is not one price “system,” but <u>many</u> as each industry has its own peculiarities, and technological conditions and organizational features that may be reflected in the markets within the industry and the markets that connect it with others. Why are there so many different pricing institutions? Experimental economists have demonstrated Hayekian principles repeatedly in hundreds, perhaps thousands, of laboratory experiments studying the performance properties of different exchange institutions that exist in the world economy. My task here is to introduce the reader to some examples of this learning.

Economic Environment

People trade because there are (expectations of) gains from exchange. What the seller vends is worth more to the buyer than to the seller, and therefore the transfer can make each party better off. The term "economic environment" will be used to describe the set of all individual circumstances in a market that defines the total potential gains from exchange. For simplicity most of our discussion will be confined to a single market where these statements can be defined unambiguously.

In an experimental market we need to motivate real people (the subjects) with real money (or other reward medium) to make consequential choices in trade. Subjects are recruited to the laboratory with the understanding that they will earn real money, depending largely upon their decisions, and that such earnings will be paid to them in U.S. currency at the end of the experiment. Imagine that I have recruited you to an experiment. After being paid $5 for reporting to the lab at the designed time, you and several other people are assigned to a computer monitor separated from each other in a large room so that you can see only your own monitor screen. The instructions inform you that you will be a buyer (there are other buyers and sellers in the room but you do not know who is which). For example, as a buyer suppose that you learn that you will have a capacity to buy up to three units of the identical items to be traded, the first with value to you of $10, the second $7 and the third $4. The instructions explain that you will have the opportunity to buy units against these values in each of a series of market trading periods, and that you profit from selling below these values. Specifically, if in a given period you buy one unit for $6, a second for $5, and are unable to buy a third unit for less than $4, then I (the experimenter) owe you $6 (10 – 6 + 7 – 5). Hence, you are motivated to buy each unit in your assigned capacity at a low price, but if you attempt to buy at a price too low, you may not find a willing seller, and fail to earn a profit. Other buyers in the market have been assigned values privately, like you, but you know nothing of their values, and nothing of the costs assigned to sellers. Your values, $10, $7, and $4 are a means of summarizing in concrete terms Hayek's notion of an individual's "circumstances of time and place," represented here by a maximum willingness-to-pay for each of three successive units. This is your little fragment of the dispersed information among all participants in the market

Similarly, each seller is assigned values representing the costs incurred for transferring units owned by the seller to buyers. Sellers profit by selling at prices that are above these unit costs. Thus, a seller with unit costs of $1 and $3 for two units, if sold at the prices $6 and $5 respectfully makes a profit of $7 (6 – 1 + 5 – 3).

Methodologically, this technique of using monetary rewards for inducing value on abstract items makes plain the fundamental truth that buyers as well as sellers profit from exchange.

Looking ahead at the left panel of Figure 2 is shown the value/cost environment for an early experiment consisting of four buyers and three sellers. (Ketcham, Smith and Williamson, 1980; reprinted in Smith 1991, pp. 295-314). Note that the "economic environment" becomes the effective demand and supply in the experimental market when we sort all buyer values from highest to lowest (demand) and all seller costs from lowest to highest (supply) regardless of "ownership" identity. Thus "demand" is the maximum willingness-to-pay schedule in the market, just as "supply" is the minimum willingness-to-accept schedule. The sum total of all this information is not given, in any real market, to any one mind. But the experimenter can begin with a particular value/cost environment, known only to him, disperse it among motivated subjects, and study their behavior in the context of a particular institution using his omniscience, and the possible equilibrium state it implies, as a performance criterion to test the Hayekian hypothesis concerning the functional efficacy of a pricing system in achieving efficient ends. Clearly, such an achievement cannot be the intention of the participants since they know nothing about them, nor are they informed of other people's values and costs.

Observe for now that the sum total of this dispersed information in Figure 2 involves four buyers, each with a capacity to buy up to four units each (16 units total) and three sellers with a capacity to sell up to five units each (15 units total). Also note that the buyer's values are distinct for each unit demanded, while the sellers each incur a constant per unit cost up to their capacity, but these constant unit costs are distinct for each seller reflecting different individual circumstances, although each employs a constant unit cost technology.

Hayek's lifelong studies of the theme of complexity and order – how does order emerge without conscious design – found its best-known application in understanding markets. His comprehension of the basic question was articulated early: "How can the combination of fragments of knowledge existing in different minds bring about results which, if they were brought about deliberately, would require a knowledge on the part of the directing mind which no single person possesses" (Hayek, 1937/1948, p. 54).

Controlled experiments have been used to examine this phenomenon whose existence was postulated by Hayek. They have also been used to show that market institutions mediate the observed phenomena across many market forms. It is necessary, therefore, to turn next to the definition and discussion of institutions.

Institutions

All markets operate by rules, formal and explicit as in organized exchanges such as the Chicago Mercantile Exchange (Merc) for trading claims on assets or their derivatives, and the Automated Credit Exchange (ACE) for trading emission credits in Southern California, or by informal and implicit norms as in two-person social and economic exchange. Institutions define the language –the messages – of the market, such as bids, offers and acceptances, the rules that govern the exchange of messages, and the rules that define the conditions under which messages lead to allocations and prices. If there are n agents, $i = 1, 2, \ldots, n$, and each i chooses a message m_i, then the allocation x_i to agent i is defined by the institution as a rule that we can express in the generic functional form

$$x_i = h(m_1, \ldots, m_i, \ldots, m_n).$$

Where the institution recognizes different agent classes subject to different rules, we would write $x_i = h_i(\cdot)$ indicating by means of the subscript i that the allocation rule also depends upon i's classification. Thus specialists on a stock exchange are subject to rules that differ from those of member traders.

As an illustration of such institution-defining rules, in the ascending bid ("English") auction each new bid (message) must be higher than the standing bid, and the award is to the last bidder at a price equal to the last bid, when no new bids are forthcoming. That is, the English auction rules are

$$x_1 = h(m_1, \ldots, m_i, \ldots, m_n) = 1;\ x_k = 0 \text{ for all } k \neq 1,$$

where we have numbered the bidders so that $m_1 > m_2 > \ldots > m_n$, and $i = 1$ has the highest bid. Hence the single item for sale is awarded to Mr. 1, and all others receive nothing. <u>Note the</u>

important distinction between messages and awards: during the auction when Mr. 1 announces the bid m_1, no one yet knows who will be awarded the item. Subsequently, all learn that no other agent, k, is willing to raise the bid, so that then and only then do the rules of the institution tell us that $x_1 = 1, x_k = 0$. Mr. 1 does not choose to buy the item. He chooses to raise the standing bid. The institution subsequently declares him to be the buyer by virtue of the rules, under which it is discovered that no other bidder is willing to bid higher.

What is most significant about naturally occurring institutions is how little we know about their origin and evolution, and, (traditionally in economics) about their empirical performance characteristics. They are in part the visible residues, but also the carriers, of those cultural processes that allow markets to function. They embody the "rules of morality," which, as noted by David Hume, "are not the conclusions of our reason." This is because they are not created by conscious awareness. Individuals may propose modifications to the rules, and committees may vote them up or down (the Merc Constitution is a 3-ring loose leaf notebook, with pages regularly being pulled or inserted), but lost to both history and human comprehension, are the fine-grained forces that operate to eliminate some rules and preserve others in an ongoing evolutionary sorting process.

The advent of experimental economics in the mid twentieth century has created a technology allowing the performance properties of institutions to be studied in controlled induced value/cost environments. In this article some simple but powerful cases will be used to illustrate what has been learned from the techniques of experiment. As we shall see, however, the institutions that survive are not born equal on any one measure of performance: efficiency, price volatility, demand responsivity, dependence on external information channels and the (transactions) cost of participation. Rather, each seems to be an adaptation to environmental wrinkles, or niches, that are not evident to the naked eye.

By the mid 1970s experimental auction market studies had become automated by computer/communication technology, meaning that participant messages were communicated by keyboard input, displayed on monitor screens, the institutional rules were encoded as algorithms applied to messages, and the data were time-stamped and recorded as specified. As noted in Rassenti, Smith and Wilson (2001) this had far reaching consequences, one of the more significant of which was the introduction of "designer markets," of which ACE is a living, breathing, operating example. (Ishikida, Ledyard, Olson and Porter, 2001). This did not suddenly, nor will it eventually, render false the Hayekian idea of spontaneous (undesigned) institutional order. To the contrary the need for experiments to test bed rule systems in trial-and-error learning, followed by implementation in the economy, as illustrated by ACE, serves to reinforce the principles articulated in Hayek's work. Experimentalists have demonstrated repeatedly that reason alone is insufficient – even incompetent – in creating institutions that allow new markets to be introduced and to substitute for hierarchical systems in industries previously owned or regulated by governments. Laboratory test bedding is a valuable tool, but insufficient alone to establish that which will be an operating success either initially or after further evolution in the field. As I see it, experimental methods and their application to the testing of designer markets is simply an example of what Hayek describes as cultural evolution in the light of experience and technological change. They in no way invalidate the "fatal conceit: the idea that the ability to acquire skills stems from reason. For it is the other way around: our reason is as much the result of an evolutionary selection process as is our morality" (read: rules governing markets and conduct). (Hayek, 1988, p. 21). We learn from experiments, and they in turn help us to design more effective new market rule systems. I think it can be claimed that experimental methods confirm the genius of Hume, Smith and Hayek whose wisdom derived from careful observation, a patient desire to penetrate meaning, and remarkable powers of imagination for conducting mental experiments (a skill that Einstein used to revolutionize pre 1905 physics). Those of us with lesser powers have to actually do the experiments.

Behavior

Behavior connects motivation in the environment with the institution to yield decisions, and outcomes. Agents with differing circumstances have differing urgency (maximum willingness to pay) to acquire goods/services and differing priorities (minimum willingness to accept) for relinquishing goods/services. The trading process is one in which people choose messages based on their circumstances, and knowing the language and rules of the market. Thus, if agent *i*'s circumstances in the economic environment is represented by E_i and I is the set of institutional rules, behavior can be expressed by

$$m_i = \beta\,(E_i \mid I), i = 1, 2, ..., n.$$

Behavior is a mapping from individual circumstances, conditional on the market rules, into messages. The institution chooses outcomes by application of its rules to the messages, as indicated above by $x_i = h(m_1, \ldots, m_i, \ldots, m_n)$. This is illustrated in Figure 1. Each agent has an information state, preferences, costs, resources, knowledge, and, knowing the institutional rules, chooses messages. The institution processes the messages to determine allocations and prices. This pathway, from the economic environment down through choice and the institution, up to outcomes in Figure 1 represents the operation of the market. Across the top of Figure 1, the omniscient experimenter, whose information is not given to any one participant's mind, can use the information to compute the maximum gains from exchange, and CE. This allows the observed outcomes to be used to compute performance measures: efficiency (percent of maximum gains realized by the agents), and the volatility or stability of observed prices relative to the CE. Because the rules of the market affect incentives, we expect, and experiments confirm, that institutions matter in the behavior we observe and in the outcomes that result.

This methodology allows different environments to be compared using the same institution. It also allows different institutions to be compared while holding constant the economic environment.

The Double Auction Institution

This trading institution, used throughout the world in financial, commodity and currency markets, is a two-sided multiple unit generalization of the ascending bid auction for unique items. Buyers submit bids to buy, while sellers submit offers or asks to sell, with a rich rule structure for defining priority based on price, quantity and arrival time. We describe here a simple version used in the experiment shown in Figure 2, in which subjects trade single units in sequence. Each bid (ask) is understood to represent a buy (sell) order for a single unit. The moment that the first standing bid is entered by a subject it is displayed on all monitor screens. Any new bid is admissible only if it specifies a higher price than the standing bid, and so on in sequence as new bids are entered. Simultaneously, sellers are free to submit asks. When there is a standing ask, any new submission must specify a lower price. As soon as there is both a bid and an ask price, we have a bid/ask spread, say bid $4, ask $5. Under the rules the bid/ask spread can only narrow as new orders arrive for display. But behind the standing bid/ask spread is an electronic queue. Thus, if a bid price is lower than the standing bid price it is placed in a bid queue; if an ask price is higher than the standing ask it is placed in an ask queue. Bids in this queue are ordered from high to low price and asks from low to high. Consequently, the standing highest bid and lowest ask are displayed publically, while not displayed is the queue of bids below the highest, and asks above the lowest ask, as follows.

Bid Queue	Ask Queue	
	$8	
	$7	
	$6	Queue above line not displayed
	$5	Standing lowest ask
$4		Standing highest bid
$3		Queue below line not displayed
$1		

The bid ask spread is 4 to 5. A new ask must be less than $5 to be displayed, otherwise it goes into the queue. Similarly, a new bid must exceed $4 to be displayed, otherwise it is placed in the bid queue. In the "open book" version (not used here) these queues are displayed for all participants to see.

The contract rule is simple: either a buyer accepts the standing ask price, or a seller accepts a standing bid. After each acceptance the auction ends and the computer waits for the submission of new bids and asks, as above. Note that the language of the market is bids, asks and bid or ask acceptances. These are the only four messages that can be submitted by any subject agent to the trading system and the above filtering rules are applied to the messages immediately as they arrive.

A Double Auction Experiment: Environment and Behavior

As we have seen, an economic environment is illustrated in the left panel of Figure 2. Notice that the demand crosses the supply at a range of market clearing prices, where demand = supply = 10 units, given by the interval (356, 360). Any whole number in this interval is a CE price. Only you and I know this; the subjects in this experiment know nothing of these facts. What Buyer 2 (B2) knows is that he or she can buy up to four units profitably at any prices below the values 435, 370, 350 and 330 respectively. Similarly, each of the other buyers knows only their own values and each of the sellers knows only their own costs. Units not purchased or sold incur no penalty.

The subjects were inexperienced, meaning that none had previously been in a double auction experiment. After all had read the instructions they began trading in period 1 over a fixed time interval. At the end of the period they reviewed a summary of the period results – high, low and mean contract price, then commenced trading in period 2, and so on for 15 periods. In Figure 2 we plot the displayed bids, asks and contracts in time sequence within each trading period. We show here the data for only the first 7 of the 15 periods.

The behavior shown in the right panel of Figure 2 is typical. Efficiency in each period is the ratio of the total profits earned by all subjects in the period divided by the maximum possible profits (the area between the demand and supply schedules to the left of the intersection at 10 units). Note that after the first period, efficiency is always above 95%, implying that in each period the market participants realized at least 95% of the surplus due to exchange. Efficiency is

100% if and only if all buyer units valued at 360 and above are purchased and all seller units involving cost of 355 or below are sold. Efficiency is reduced if less than 10 units trade; it is also reduced if buyer valuation units at 355 or less are purchased and/or any seller cost units of 365 are sold. With experienced subjects efficiency tends to be 100% within the first few periods even for subjects facing new and unfamiliar environments.

But Figure 2 is a static environment with demand and supply repeated in each period without any change throughout the experiment. Does the double auction institution perform well in tracking random shifts, up or down in the values (costs) assigned to buyers (sellers)? The answer is illustrated in Figure 3 plotting all contracts, and their mean price, over 15 periods with CE prices shifted each period as shown. (Also see Table 1 below). Observe that the mean price tracks the random shifts in the CE very closely, showing how this institution solves the problem "of rapid adaptation to changes in the particular circumstances of time . . ." (Hayek, 1945/1984, p. 217). Figure 3 also neatly illustrates that price volatility in a market has two components: variation due to exogenous fluctuations arising from changes in the economic environment, and endogenous variation within the market as traders search for the new equilibrium each period. The former is represented by the random shifts in the CE, while the latter is represented by the dispersion of contract prices around their mean in each trading period.

Also, the example in Figure 2 is for a single isolated market. Do the strong equilibrating properties, demonstrated repeatedly in such examples, also hold for multiple markets? Yes, an example with two interdependent markets is reported in Smith (1986/2000, pp. 245-247). Also see Williams, Smith, Ledyard and Gjerstad (2000). In these markets what a buyer is willing to pay for commodity A depends upon the price of B – the demand for A and B are opportunity cost demands. The equilibrium is defined by four simultaneous nonlinear equations in the price and quantity produced for A and B. In 10 of 15 experiments the prices are within 1% of their equilibrium predictions in period 10. With no knowledge of the equilibrium, or of the underlying equations defining it, six buyers and six sellers, each motivated by profit, unintentionally "solve" the equations to reach the optimal equilibrium outcome. In effect subject behavior coordinated by the institution combine to provide algorithms that yield a competitive equilibrium.

All these examples show that it is not necessary for individuals to have complete information on the economic environment to achieve equilibrium outcomes. Some scholars may argue that the complete information condition was intended to provide only a strong sufficient, not necessary, condition for equilibrium to obtain. This has been tested. There are examples showing that when complete information on supply and demand is given to all individuals, the market performance is worse than with private information. (Smith, 1976/1991, pp. 103-5).

The Posted Offer Institution: Comparison with Double Auction

In ordinary retail trade the customer walks into the store (hardware, clothing, McDonalds) and observes a menu of take-it-or-leave-it price tags on each item offered for sale. Except for a few big-ticket items like houses, automobiles, and expensive appliances, there is no negotiation. The old Sears Roebuck mail order catalog published the prices of tens of thousands of items subject to change only twice a year with the publication of the Fall-Winter and Spring-Summer offerings.

The fixed take-it-or-leave-it price tradition in modern retailing dates back to the mass retailing department store innovations of F. W. Woolworth and R. H. Macey in the latter half of the nineteenth century which displaced the owner-operated general merchandise store, characterized by “haggling” (double auction?) over sale prices.

Ketcham, Smith and Williams (1984/Smith, 1991; hereafter KSW) provide comparisons between the posted offer pricing and double auction institutions using identical environments. One of the environments held constant across the two institutions is the one exhibited in the left panel of Figure 2. Six experiments were run under each of the two institutions using this environment, using either an independent sample of 8 subjects (5 buyers and 3 sellers), or the same subjects for experienced sessions.

In Figure 4 we plot the mean double auction contract price for the experiment reported in Figure 2, and, on the same scale, the mean posted price (weighted by number of contracts at each price) for a matched comparison experiment, both using inexperienced subjects, and therefore strictly comparable with only the institution being the prominent treatment difference.

Observe that in every period in sequence the mean posted contract price strictly dominates the mean double auction contract price. Five of the six posted offer markets reported by KSW tend to converge to a price of 365, the cost of seller 3 in Figure 2, which is above the CE price range. For the double auction experiments it was the reverse: five converged to the CE price range, only one to 365. (The experimental environments all differed from each other by a random constant added to all values and costs, but all were equivalent when normalized on a standard CE price).

In addition to prices being lower in the double auction, convergence to the CE price was more pronounced, the volume (number of units traded) was higher, and efficiency was higher. Thus as an exchange mechanism, double auction dominates posted offer in terms of efficiency and competitivity. Eventually, however, posted offer markets tend to converge to the CE, but the convergence is from initial prices that are above the CE price. In view of Figure 3 showing the good dynamic performance of the double auction, how does posted offer compare? The answer: very poorly. Posted offer markets do not track shifts in demand well. Unlike double auction such markets depend upon non-market sources of information concerning changes in the environment; double auction does not because of its capacity for rapid adaptation. See Davis and Holt, Chapter 4, 1993, for further discussion and references.

What accounts for the widespread popularity of post offer pricing? Does it have compensating advantages over double auction that are not part of measured performance when the comparison is entirely in terms of exchange properties? The answer is 'yes.' Posted offer markets do not require continuous active participation by price making agents. They set price once for each trading period (e.g. season). Therefore the transactions (negotiation) effort required of agents (subjects) in double auction trading is avoided in posted offer markets. In the latter goods are sold by clerks, who do not have to learn negotiation skills or be motivated to act in the interest of their principals. The distributional efficiencies of mass retail marketing tend to outweigh any inefficiencies in more centralized administered pricing. Such pricing inefficiencies give rise to an institution appended to posted offer pricing: the monthly or seasonal clearance sale in which the establishment corrects its pricing mistakes by clearing out unsold inventory at discount prices.

The Concept of a Strategy-Proof Equilibrium

Although we can think of an allocation mechanism as an institutional procedure that allows the preferences of individuals to be mapped into final allocations, this abstract formulation does not take explicit account of the fact that preferences are private and unobservable, and institutions have to rely upon the messages reported by agents, not their true preferences. This harks back to Hayek's point, that no one mind has all the information known together by all those in the market. Consequently, the standard theoretical proposition is that it is possible for an agent to affect prices and outcomes in a market by strategically misreporting his or her preferences. Thus, in our example above of a buyer with a maximum willingness-to-pay of $10, $7 and $4, respectively, for three units of a good, who believes sellers are willing to sell for less, might strategically bid for all three units at $3 in an attempt to lower his or her purchase cost of the three units. Allocation mechanisms are actually mappings from preferences, and each agent's information or beliefs about other agents, into allocations. This state of affairs has motivated the intensive theoretical study of strategy-proof mechanisms designed to overcome the problem of strategic misrepresentation, but the results are negative and not encouraging. Thus, stated informally, "an allocation mechanism is strategy-proof if every agent's utility-maximizing choice of what preferences to report depends only on his own preferences and not on his expectations concerning the preferences that other agents will report." (Satterthwaite, 1987, p. 519). This comes down to the strong requirement that each agent has a dominant strategy to report true preferences, and has led to impossibility theorems establishing the nonexistence of such a mechanism under certain minimal requirements.

Given these negative results, it is of particular interest to ask what people <u>actually do</u> in experimental environments in which the experimenter induces preferences on individual subjects so that the experimenter knows each agent's preferences, but the subjects know only their own preferences. Although it is possible that an agent can obtain an advantage by strategically underrevealing his/her demand or supply, whether or not such action is successful depends upon the actions -- possibly counter vailing -- of others. In particular, has society stumbled upon institutions in which forms of behavior arise that approximate practical solutions to the problem of strategy-proofness in economic environments with dispersed information?

The best-known example in which the answer to this question is ‘yes’ is the continuous double oral auction discussed above. Our theoretical understanding of why and how this is so is weak, and represents one of the outstanding unsolved problems in economic/game theory.

Are there other examples, offering good (if not perfect) solutions to the problem of achieving strategy-proof equilibria? If so, what are the strategic behavioral mechanisms that people adopt to solve it? A partial answer, based on what we have learned from experiments, is in the form of two versions of uniform price auctions: the uniform-price sealed bid-offer auction, and the uniform-price double auction (hereafter UPDA). For a more complete discussion see the chapters by Cason and Friedman, Friedman, and Wilson in Friedman and Rust (1991).

The Two-sided Sealed Bid-Offer Institution

The third mechanism for trading that we will examine is represented by the sealed bid-offer auction used commonly by the stock exchanges to open trading in each listed stock every morning. The purpose is to clear the overnight accumulation of buy and sell orders at a single price, then resume sequential continuous double auction trading throughout the day. The bids are ordered from highest to lowest, the offers (asks) from lowest to highest, with the intersection (cross) determining the uniform clearing price and volume exchanged.

Figure 5 plots the single uniform price (measured in deviations from the CE), period by period, for an 11 period sealed bid-offer auction with five buyers and five sellers. The exchange volume and efficiency is indicated for each period at the bottom of the chart. Note the very poor efficiency in the early periods and slow convergence of the blind bidding process even in a stationary supply and demand environment. See Smith, Williams, Bratton and Vannoni (1982/Smith, 1991) for comparative studies of the sealed bid-offer mechanism, sometimes called the Clearing House mechanism.

The bid-offer array cross for period 11, shown by the solid lines in Figure 6, reveals the strategies that each side evolves to insulate themselves from manipulation by the other side: on the buy side, bid units 9 through 15 in the ordered set of bids are only one cent or less above the clearing price (714); offer units 9 through 14 are one cent below the clearing price. Each side gives the other only a cent or two of room for price manipulation without risking lost trades. Since no buyer or seller has more than three intramarginal units, the seven units bid, and the six units offered that are within a cent of the clearing price prohibit any one buyer or seller (or any two) from manipulating the price. Thus do subjects grope around and latch on to a behavioral strategy-proof equilibrium.

The true induced supply and demand, shown by the dashed lines in Figure 6, compared with the bid-offer cross, illustrates the extent of underrevelation. All buyer units and all seller units, to the left of the CE are underrevealed; the high value (low cost) units are much underrevealed but those near the CE price are very near to the amounts bid (or asked).

These experimental results make it plain that the theoretical condition for a strategy-proof equilibrium -- that each agent have a dominate strategy to reveal true willingness-to-pay or willingness-to-accept for all units, and not just units near the margin -- is much too strong. The above results from blind two-sided auctions, however, also show that there is a cost to the achievement of a strategy-proof equilibrium: blind two-sided auctions converge more slowly to the competitive equilibrium than continuous double auctions, and upon converging, may not be quite as efficient.

Strategy-Proof Equilibria in the Uniform Price Double Auction (UPDA)

UPDA is a real-time continuous feedback mechanism clearing all trades at a single price in each trading period. This is a "designer market" invented by experimentalists who asked, "Can we combine the continuous information feedback advantages of the double auction with the uniform price (zero volatility) advantages of the sealed bid-offer auction?" As we have seen in Figure 5, with blind bidding several repeat interactions are required to reach optimality, with many lost trades in the process. Can we accelerate the price discovery process by continuously feeding back information on the tentative state of the market, and allowing bids (asks) to be adjusted within each period? UPDA is an institution made possible by high-speed computer/communication technology. It comes in several experimental forms depending upon whether there is a fixed time rule, or endogenous close rule (the market closes if there is no new trade after a prespecified period), an open or closed book (the list of all bids and offers is displayed or not), and whether accepted bids enjoy a conditional time priority (a better bid or offer cannot displace an accepted one unless it meets the terms of an offer or bid on the other side). See the chapter by McCabe, Rassenti and Smith in Friedman and Rust (1991, pp. 311-316) for a report of 49 UPDA experiments comparing these different versions with the continuous double auction. All of these versions yield even more underrevelation of demand and supply than the blind two-sided auction discussed above, but efficiency tends to be much higher, especially in the first periods, and, in one form, (endogenous close, open book, the "other side" rule with conditional time priority) exceeds that of the continuous double auction.

Table 1 lists a period-by-period summary of the results from a typical experiment (upda 43 with 5 buyers and 5 sellers). The market used a fixed close time, open book and the conditional time priority ("other side") rule. The environment is particularly demanding in that a random constant is added to all buyer values and seller costs, and the individual value/cost assignments are rerandomized, in each of 15 trading period. Figure 3 above showed the results of a double auction experiment using this environment. Column 2 in Table 1 lists the fluctuating competitive equilibrium prices, P_e, induced by these random shifts (the competitive equilibrium quantity remains constant at Q_e = 18 in column 3). Note that this equilibrium shifts randomly in a range of realizations from 260 up to 610 across the 15 trading periods and thereby exposes the subjects to extreme exogenous uncertainty. Column 4 shows the realized clearing price, P_r, and column 5 the quantity, Q_r, based on the reported bids and offers from all subjects. Finally, column 6 contains the market efficiency, Eff_e, achieved in each period, and column 7 the percentage of the true surplus that is revealed in the reported bids and offers, Eff_r. Efficiencies of 100% are achieved in 7 of 15 trading periods, and in 3 cases with less than 10% of the surplus revealed -- periods 2, 5, and 14; in period 14 only 5% is revealed. Efficiency averages 95% across all 15 periods, while the average percentage of the surplus revealed is only 27%.

Figure 7 plots the true demand and supply (shown dashed) and the realized bid and offer arrays (shown solid) for period 14 in Table 1. Note that the true demand and supply has the following property: if all agents reveal their true demand or supply with the exception of one intramarginal buyer or seller, then that agent can manipulate the price to his or her advantage. Thus, if the agent is a buyer he or she has only to reveal all units except the last, and bid that unit at 400. But this abstract property is irrelevant. The relevant question is what behavior is manifest when all agents have the potential for manipulating the price. In Figure 7 we observe that bid and offer units 6 through 18 are all tied at the midpoint of the set of competitive equilibrium clearing prices 410, and no agent has nearly enough capacity to alter this price. In effect each side erects a solid barrier against manipulation by the other side. In this example only 5% of the true surplus is revealed, yet the participants capture 100% of the possible gains from exchange.

Without knowledge or understanding of the whole, the participants use the rules at their disposal to achieve (1) efficient ends, and (2) protection from manipulation. The experiment illustrates the insight of Hayek (1988, p. 19-20), that "Rules alone can unite an extended order . . . Neither all ends pursued, nor all means used, are known or need be known to anybody, in order for them to be taken account of within a spontaneous order. Such an order forms of itself . . ."

Conclusions

This article has briefly examined three historically common trading institutions – continuous double auction, posted offer pricing, and the sealed bid offer procedure – plus a designer market (UPDA) combining the public information features of the double auction with the uniform price sealed bid offer auction. In each institution the experimental results show that order emerges out of an interaction between the choices of individuals with dispersed private information and the (property) rights to act specified by the institution. The institutions vary in terms of their exhaustion of the gains from trade, the speed and completeness of convergence to efficient, competitive outcomes, and the volatility of prices, but in all cases the participants are better off than if they were unable to trade.

Several propositions follow from these examples.

1. Many market institutions exist in the economy that are a complex product of cultural evolution, each invented by no one yet by everyone, and which exhibit the capacity to produce an exchange order from dispersed information.
2. What emerges is a form of "social mind" that solves complex organization problems without conscious cognition. This "social mind" is born of the interaction among all individuals through the rules of the institution.
3. In these institutions some are price takers, some price makers, some both. Hence, the idea that all must be price takers is neither necessary nor sufficient to yield an extended cooperative order of the market.
4. Participant knowledge of the circumstances of others is neither necessary nor sufficient to yield an extended order of cooperation.
5. Both the double auction and the designer UPDA markets, provide rapid adaptation to random dynamic changes in individual circumstances.

Markets are rule governed institutions representing algorithms that select, process and order the exploratory messages of agents who are better informed as to their personal circumstances than that of others. As precautionary probes yield to contracts, agents become more sure of what they must give in order to receive and the gains they can hope to capture. Out of this interaction between minds through the intermediary of rules the process tends to converge more-or-less rapidly to an equilibrium if it exists. The emergent order is invisible to the participants, unlike the visible gains they reap. They find out what they need to know to achieve outcomes optimal against the constraining limits imposed by the actions of others. The resulting order accommodates trade offs between the cost of transacting, attending and monitoring and the efficiency of the allocations so that the institution itself generates an order that fits the problem it evolved to solve. Hence, the hundreds of variations on the fine structure of institutions, each designed without a designer to accommodate disparate conditions, but all of them subservient to the reality of dispersed agent information.

The examples of market institutions presented here illustrate in a small way the "super-individual structures within which individuals found great opportunities…(and that)…could take account of more factual circumstances than individuals could perceive, and in consequence…is in some respects superior to, or 'wiser' than, human reason…(as)...nobody can communicate to another all that he knows, because much of the information he can make use of he himself will elicit only in the process of making plans for action…(as he will)…not merely… make use of given knowledge, but…discover as much information as is worth searching for in prevailing conditions." (Hayek, 1988, p 75, 77).

Although emerging new "designer" institutions have designers, they require extensive modifications in the light of test bedding experience, and even then, if adopted in the field, will have an evolutionary life of their own.

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Summary of Results: up43;5,5

	P_e	Q_e	P_r	Q_r	Eff_e	Eff_r
1	295	18	300	16	91%	22%
2	405	18	400	18	100%	7%
3	545	18	540	18	100%	14%
4	460	18	448	18	92%	14%
5	360	18	350	18	100%	9%
6	500	18	500	18	98%	12%
7	260	18	250	17	96%	26%
8	565	18	553	15	92%	28%
9	300	18	300	18	100%	28%
10	610	18	610	18	100%	33%
11	365	18	350	15	85%	88%
12	550	18	558	15	88%	55%
13	450	18	450	18	100%	31%
14	410	18	410	18	100%	5%
15	485	18	484	19	89%	39%
			$\mu =$	17.3	95%	27%
			$\sigma =$	1.3	5	21

Table 1. The trading period 1-15 is shown in column 1. The randomly shifting midpoint of the set of competitive equilibrium prices is listed under P_e, Q_e. The reported UPDA outcomes are listed under P_r, Q_r. Market efficiency is shown under Eff_e, while Eff_r is the percentage of the available surplus that is revealed by the reported bid and offer arrays. μ and σ are the means and standard deviations of the column data.

Figure 1. The components of every market: Environment, Institution and Behavior.

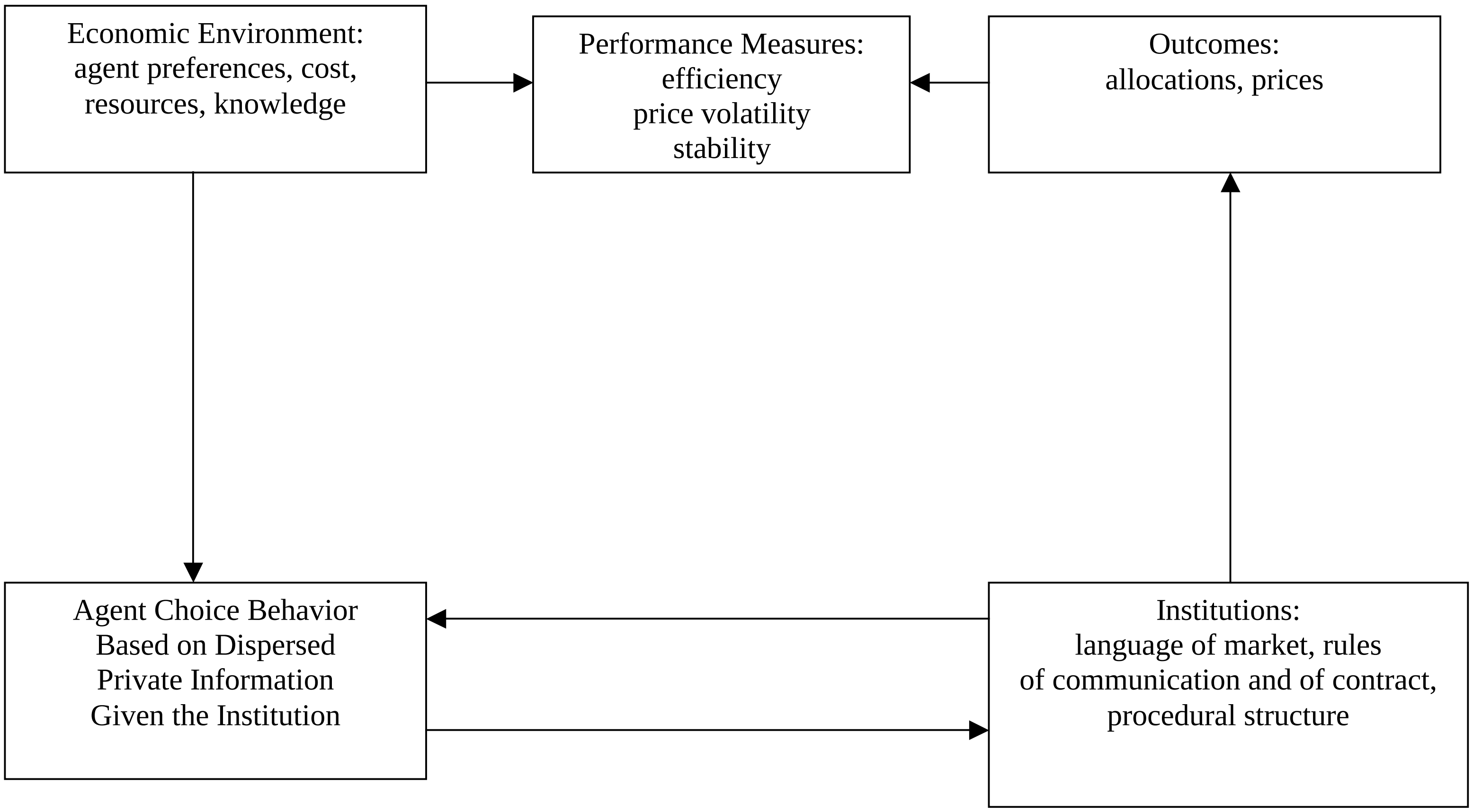
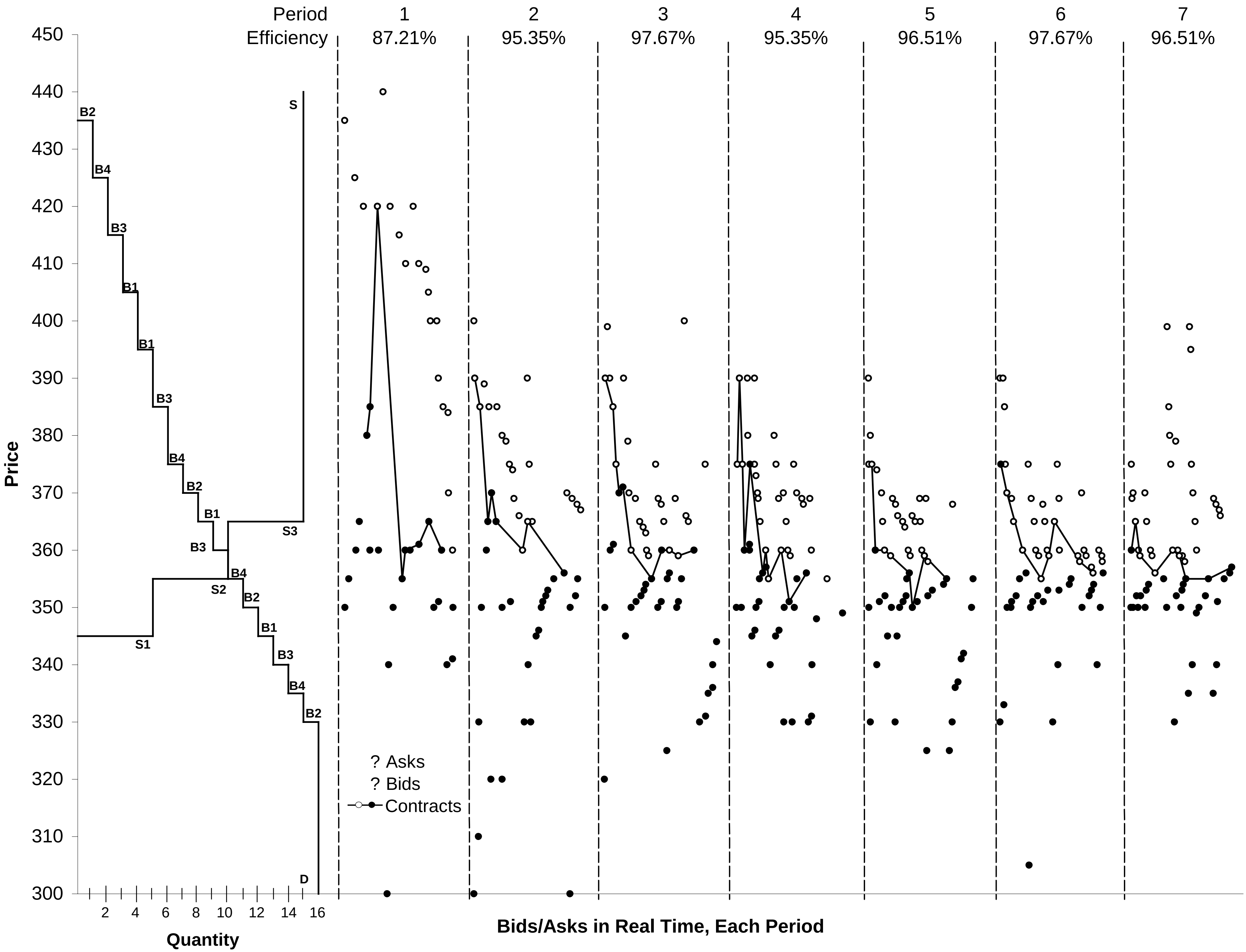
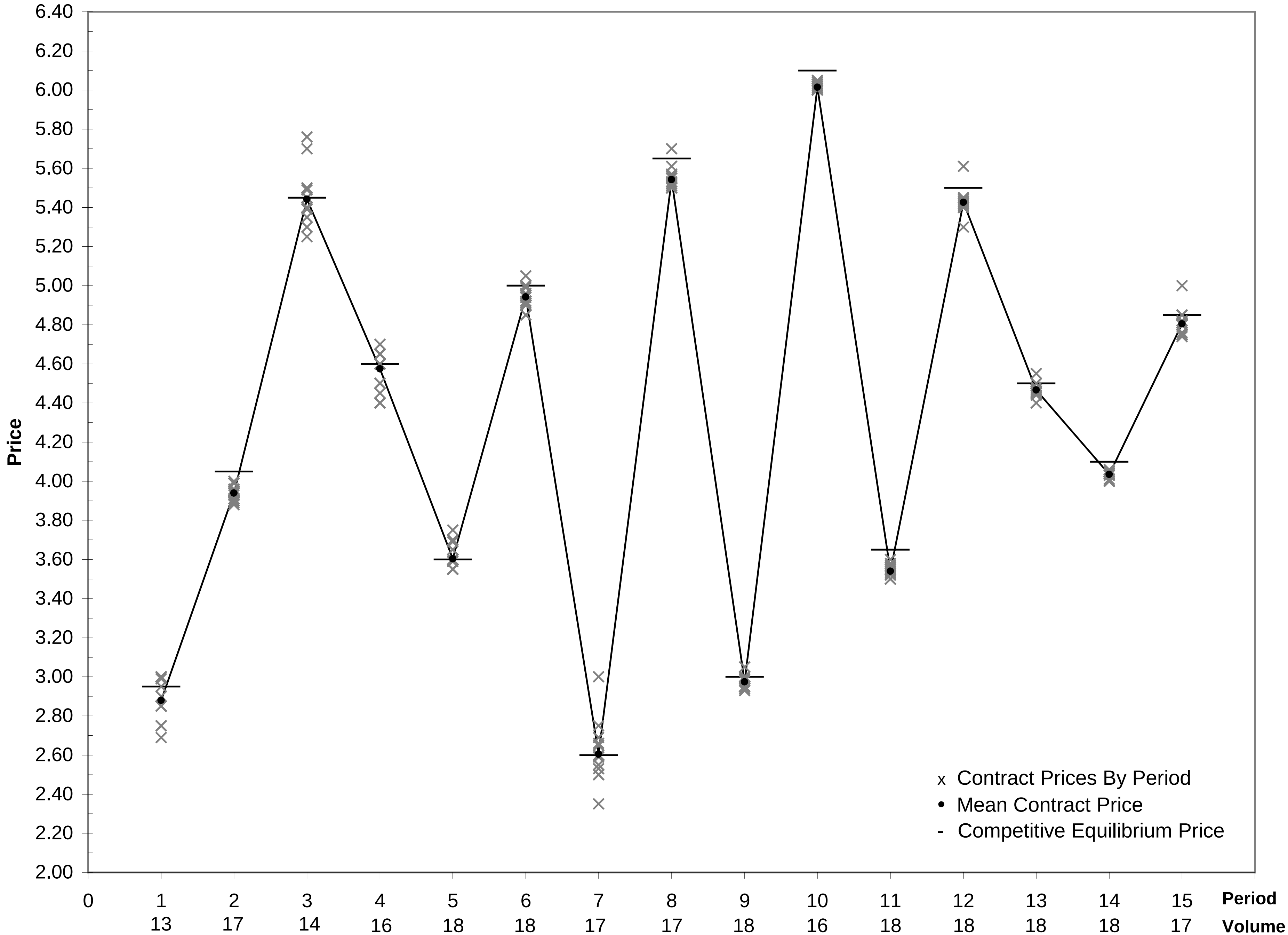

Economic Environment:
agent preferences, cost,
resources, knowledge
Performance Measures:
efficiency
price volatility
stability
Outcomes:
allocations, prices
Agent Choice Behavior
Based on Dispersed
Private Information
Given the Institution
Institutions:
language of market, rules
of communication and of contract,
procedural structure

Figure 2. A double auction experiment. The economic environment for four buyers and three sellers is shown on the left. On the right is shown the sequence of bids, asks and contracts in each of the first seven periods of trading.



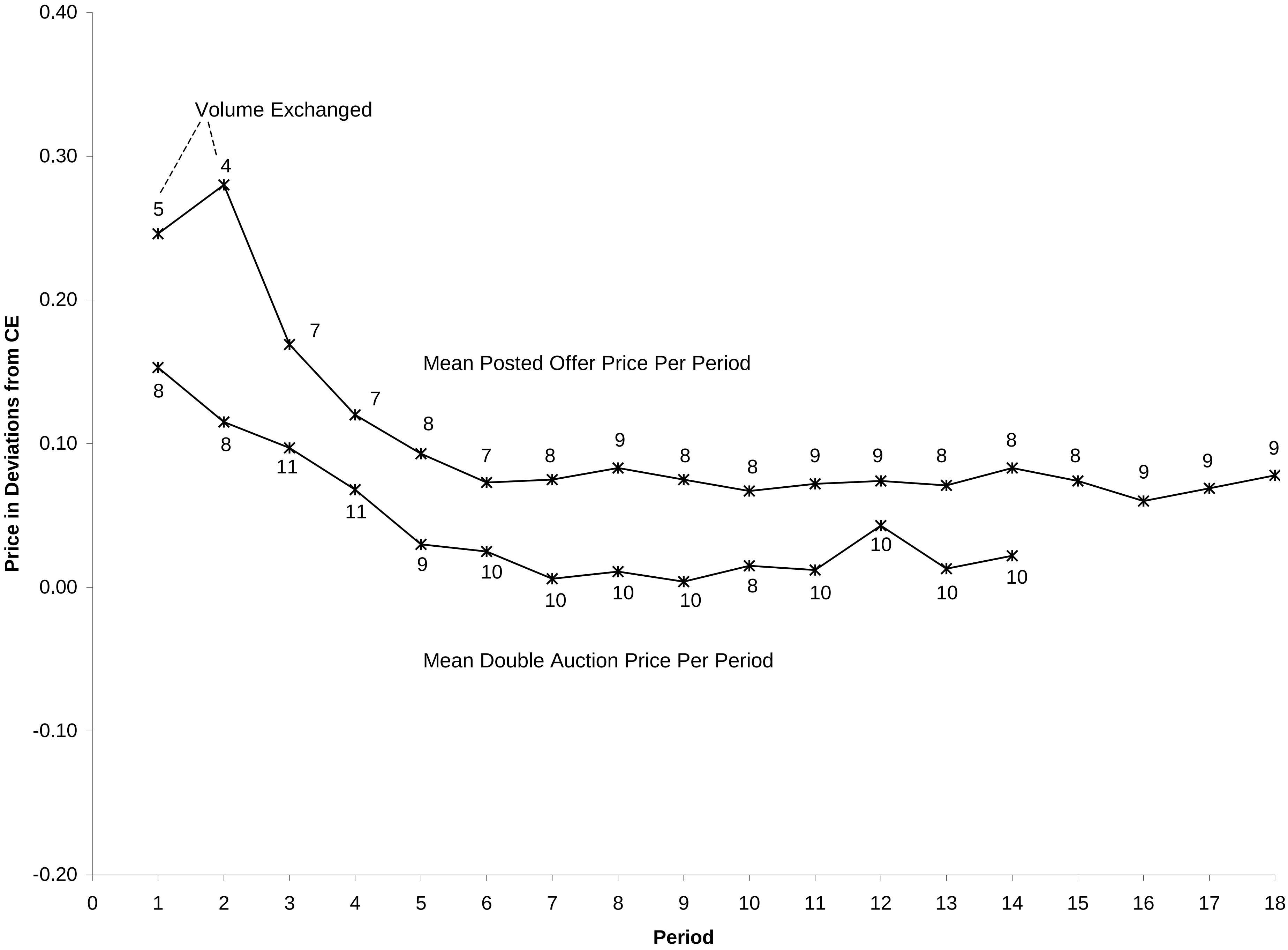
Period
Efficiency
1
87.21%
2
95.35%
3
97.67%
4
95.35%
5
96.51%
6
97.67%
7
96.51%
Price
Quantity
Bids/Asks in Real Time, Each Period
? Asks
? Bids
Contracts
S
S1
S2
S3
D
B1
B2
B3
B4

Figure 3. Effect of random shifts up or down in the supply and demand environment under double auction trading. Only the CE price was shifted, with CE volume always 18 units.



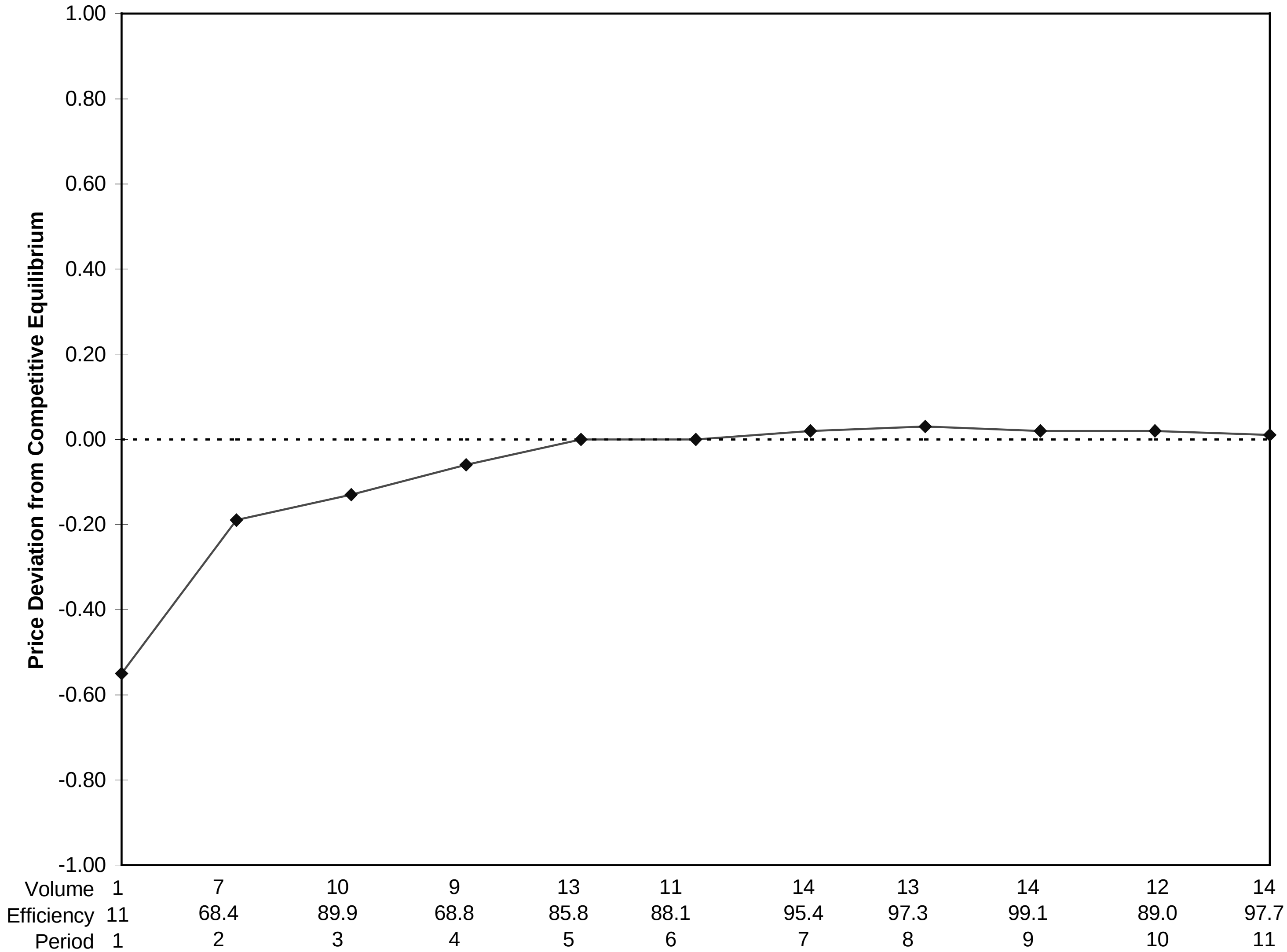
Price
6.40
6.20
6.00
5.80
5.60
5.40
5.20
5.00
4.80
4.60
4.40
4.20
4.00
3.80
3.60
3.40
3.20
3.00
2.80
2.60
2.40
2.20
2.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Period
13 17 14 16 18 18 17 17 18 16 18 18 18 18 17 Volume
x Contract Prices By Period
• Mean Contract Price
- Competitive Equilibrium Price

Figure 4. Plot of mean double auction price and volume (lower chart) for experiment shown in Figure 2, compared with posted offer mean price and volume (upper chart) with the same environment as in Figure 2.



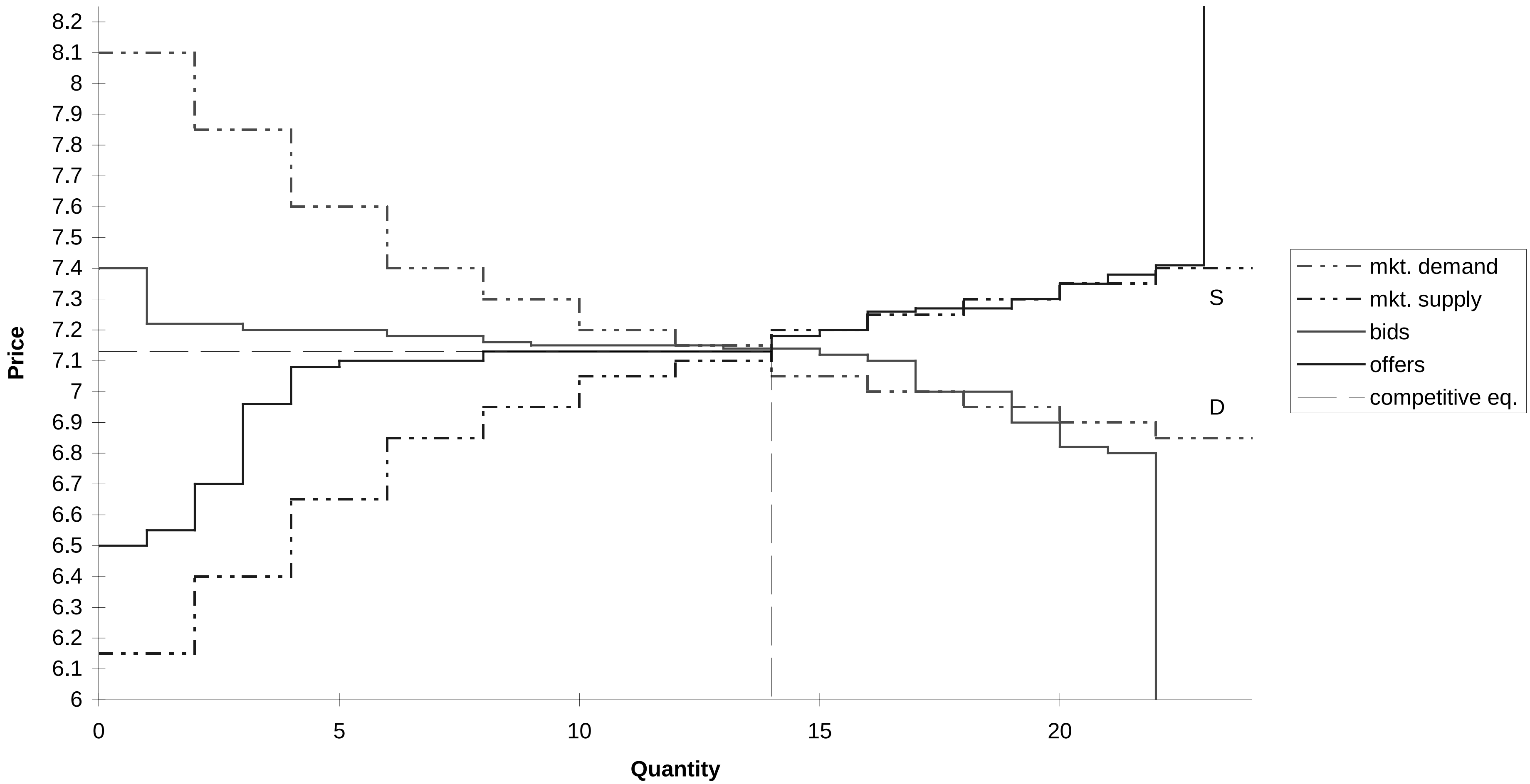
Volume Exchanged
Mean Posted Offer Price Per Period
Mean Double Auction Price Per Period
Price in Deviations from CE
Period

Figure 5. Uniform Prices, plotted in deviations from the competitive equilibrium, in each of 11 periods in a sealed bid-offer experiment with stationary demand and supply. The realized exchange volume and efficiency is indicated for each period. The slow convergence to the C.E. is typical of the sealed bid-offer mechanism.



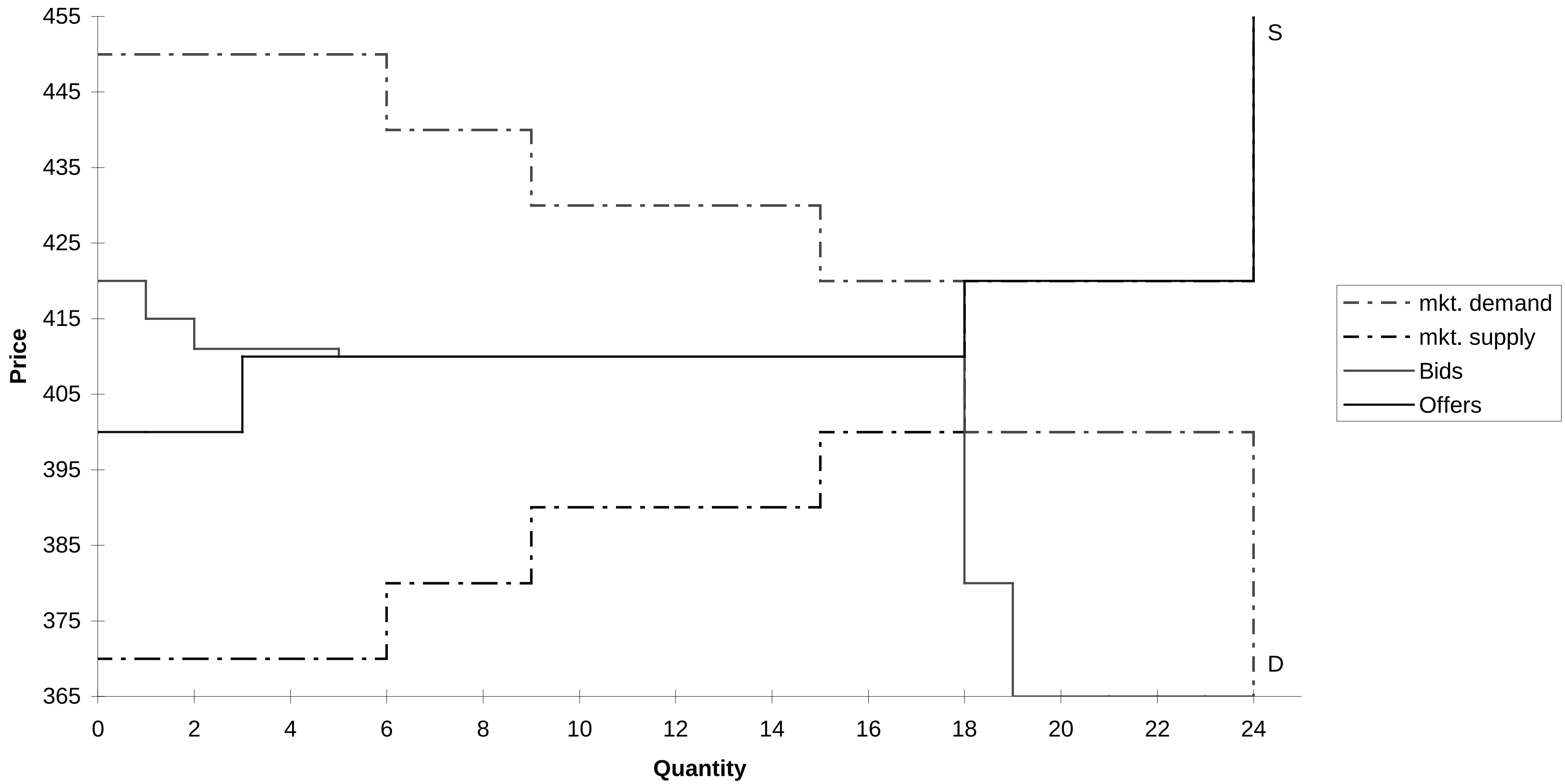
Price Deviation from Competitive Equilibrium
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
Volume 1 7 10 9 13 11 14 13 14 12 14
Efficiency 11 68.4 89.9 68.8 85.8 88.1 95.4 97.3 99.1 89.0 97.7
Period 1 2 3 4 5 6 7 8 9 10 11

Figure 6. Chart shows the true supply (S) and demand (D) overlaid by the reported array of bids and offers for period 11 of the experiment shown in Figure 4. Bid units 9 to 15 are within one cent of the clearing price ($714) and offer units 9 to 14 are one cent below this price. Since no buyer or seller has more than 3 intramarginal units, this bid-offer strategy allows each side of the market to prevents the other side from moving the price by more than one or two cents.



Price
Quantity
8.2
8.1
8
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7
6.9
6.8
6.7
6.6
6.5
6.4
6.3
6.2
6.1
6
0
5
10
15
20
S
D
mkt. demand
mkt. supply
bids
offers
competitive eq.

Figure 7. Chart shows the true supply and demand (dashed lines) and the reported array of bids and offers (solid lines) for period 14 of UPDA experiment 43 with 5 buyers and 5 sellers (Table 1). S and D shifts randomly each period, each buyer (seller) has all the units on a step, with their locations randomized each period.



455
445
435
425
415
405
395
385
375
365
Price
0
2
4
6
8
10
12
14
16
18
20
22
24
Quantity
S
D
mkt. demand
mkt. supply
Bids
Offers