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COSTLY OFFERS AND THE EQUILIBRATION PROPERTIES OF THE MULTIPLE UNIT DOUBLE AUCTION UNDER CONDITIONS OF UNPREDICTABLE SHIFTS OF DEMAND AND SUPPLY

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Abstract

The paper reports on the behavior of markets in which a transactions cost is imposed in the form of a tax on bids and asks that are tendered in the market. That is, in the markets studied communication with the other side of the market was costly. The markets were nonstationary in the sense that market demand and market supply shifted unpredictably each period and the markets were organized by the computerized Multiple Unit Double Auction. The results are as follow. (1) A market equilibration process is observed across the periods of nonstationary markets. (2) The imposition of the cost on offers did not negate the tendency toward market equilibration but the price discovery process was "incomplete" relative to the free offer case. (3) Price equilibration with the offer cost was slower and efficiencies were reduced.

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INTRODUCTION

The primary focus of this study is the effect of a transaction cost on the equilibration properties of an otherwise competitive market. Does the existence of a transaction cost prevent convergence? Does it necessarily cause a change of the price to which the system converges? Theoretically the answer is yes if the transaction cost is sufficiently high or possibly if the transaction cost is embedded in the market institutions or organization in a manner that alters the nature of the game. However, if the transaction cost is not sufficiently high to prevent marginal trades and if the market is of a form that readily "discovers" the competitive equilibrium price, the answer is unknown even theoretically. In part, the open question stems from the fact that we have no solid theory about the price discovery process of markets and the convergence features of market equilibration. This study poses the question for the multiple unit double auction with a hope that the data will reveal some insights about the process with which the competitive price is discovered within this form of organization.

The multiple unit double auction organization is a natural mechanism for which the study of transactions costs can be posed. This particular mechanism has some of the major features of almost all other mechanisms. It is known that the evolution of price to the competitive equilibrium occurs with great reliability. Gains from trade become exhausted. Furthermore, modern experimental technology facilitates a detailed study of its operation and the mediums through which the consequences of costly offers might become manifest.

The organization of the research is to create a series of multiple unit double auction markets that are identical in every respect except for the particular subjects that are

[1]A special acknowledgment is due to the National Science Foundation and to the Caltech Laboratory for Experimental Economics and Political Science for funding support that made these experiments possible. This paper evolved from a project originating in the Caltech seminar on experimental economics. The comments of the students in the seminar have been especially helpful. We wish to thank graduate students John Keeling and Tanya Rosenblat of M.I.T., and undergraduate Theodore L. Turocy III of Caltech, for their help with the statistical computations.

participating and whether or not a cost is imposed on the process of making contracts. In particular, in some experiments bids, asks and contracts are freely tendered and executed without the imposition of any cost other than perhaps the subjective cost that accompanies the pressing of computer keys and devoting attention to the screens to process any information that might exist in the market. In other experiments a cost of making an offer was imposed. That is, any agent that tendered a bid was required to pay a cost of taking the action. Likewise any agent that tendered an ask was required to pay a cost of taking the action. Accepting the ask of a seller that had paid the cost of making the ask imposed no cost on the buyer. Likewise accepting a bid that had been tendered by a buyer imposed no cost on the seller. Thus, in the costly offer condition a cost was imposed on any agent that made the offer but no cost was involved in accepting an offer. So the cost was not on the transaction itself but on making an offer that lead to the transaction. In the free offer condition no cost was imposed on any bid, ask or the acceptance of a bid or ask.

The markets under consideration involved a shift of demand and supply (up or down) each period by non-constant amounts. Thus the price in any one period gave no indication of the price that might exist the next period. Furthermore, the redemption values and costs of each individual changed each period so the sheets of incentives given an individual could not be used to obtain information easily about what the competitive equilibrium price might be for the period. Thus the markets under consideration did not have the stationary property that is often studied and within which equilibration is commonly observed. The study of markets within such constantly and unpredictably changing environments has not been done so that feature of the experiments also offers something new.

The experiments thus are an attempt to uncover some of the features of the nature of market convergence and are a step in the investigation of the mystery of the price discovery process. Specifically four questions are posed.

(1) Does equilibration occur in a constantly changing environment? If no tendency exists for equilibration within a period, then learning across periods may not occur and market prices could wander randomly.
(2) Does equilibration occur in the presence of an offer cost? Such equilibration need not occur since the terms of offers in a bargaining process can be influenced by which party made the bid or ask. Anticipation of the fact that the other side might not want to bear the cost of another round of bidding might induce parties to offer on more self serving terms. Prices could therefore gyrate depending upon which side made the offer.
(3) If equilibration occurs, are the equilibrium magnitudes themselves influenced by the existence of the costly offer? The magnitudes are prices, volumes and efficiencies. Since the predictions of game theory can differ from demand and supply models, one might even expect that the equilibration be at something other than a competitive equilibrium.
(4) Is the speed of equilibration influenced by the costly offer?

The paper is organized into four sections, including this introduction. The second section contains the parameters and experimental design. Since the operations of the multiple unit

double auction are well known very little space is devoted to a description of the institution or the associated experimental setting. The third section is a brief discussion of the competitive model and some of the relevant behavioral properties of markets. The fourth section contains the major results and the final section contains a summary of conclusions.

EXPERIMENTAL DESIGN AND PARAMETERS

The general structure of the experiments is contained in Table 1. All parameters, including the time within each period, were maintained identically across six experiments. Each of the six experiments consisted of a double auction market mechanism, with three buyers and three sellers. The redemption values and costs were symmetric . The magnitudes for the parameters used during the first period of any experiment are contained in Figure 1. Each experiment had ten periods after the first period, except the first experiment, which had twelve periods. Subjects were students and staff from the California Institute of Technology who had previous experience in the operation of computerized MUDA markets but had no experience with the parameters or procedures of the experiments reported here.

There were three types of buyers and sellers, one of each in each period. The assignment of values to each of the buyer and seller types for period one of an experiment are in Figure 1. The actual table of numbers , the redemption values for buyers and costs for sellers, for each type and for period one are in Table 2-a. The individual subjects rotated among type . For example, a subject who was type 3 in period 2 became type 1 in period 3, type 2 in period 4 and was again type 3 in period 5. The individual schedules each period differed by a constant amount that is listed at the bottom of Table 2-b. For example, to get the schedules for all types in period 2 add a constant of -40 to the values of each entry of each schedule. The constant listed in Table 2-b is - 40 so the difference between periods one and two is that in period two each of the schedules is shifted downward by 40. In order to calculate the schedules for period 3 the constant of -200 must be added to each of the values that were computed for period 1, etc.

Thus, the changes in values and rotation that occurred each period made it very difficult for an individual to detect the nature of the general changes in demand and supply from the information on the incentive sheet. However, close examination and a comparison of periods would have revealed much. The sheets were presented in a manner that prevented an individual participating in any one period from knowing what the next period incentive parameter values might be. However, past parameters of an individual were available to that individual, which , if studied carefully, would contain information. Our belief is that these relationships went unnoticed by subjects.

For three of the six experiments, a cost of offering was introduced. This was a cost of 10 francs (generally about $0.25) for each bid or ask, i.e. each offer made in the market. The acceptance of a bid or ask did not incur the cost, nor was there any additional cost if quantities larger than one were offered. These costly offers are analogous to charging a

fee for market entry, advertising cost for reaching a buyer or for modeling transportation costs of getting units to or from the market.

Subjects were randomly assigned to be either a buyer or seller and to a seat at a computer. Each had an identical instruction sheet (see the Appendix). The instructions were passed out and then read aloud. Subjects in the costly offer condition had a box on their incentive sheet that said "postings" and were told to put a mark for each time they submitted a bid or ask which was accepted by the market. Bids or asks for multiple units counted only as one offer. At the end of each period subjects were to count their total number of offers and mark this on the sheet, subtracting 10 francs for each offer from their profit. Subsequent checks of the data verified the accuracy of these recordings.

All subjects were familiar with the basic market operation, so only a single practice period was necessary. After this practice session subjects were told that they were making decisions for actual money, and this continued for ten periods, with small breaks in between for accounting purposes. No subject knew that the experiment would last only ten periods until the last period was completed, at which time they were told to compute their total profits.

MODELS AND BEHAVIORAL PROPERTIES

The demand and supply and resulting competitive equilibrium for the first period of each experiment are in Figure 1. The demand and supply curves were shifted each period by a constant and as a result the competitive equilibrium prices differed each period and are produced in Table 3. A theoretical competitive equilibrium volume of nine units was the same across all periods and experiments.

Whether or not the market will "discover" the equilibrium price each period under conditions of unanticipated shifts of demand and supply is substantially unknown. The equilibration properties of constantly shifting markets have been studied but in previous studies the shifting properties themselves had a constant property. For example Daniels and Plott (1988) studied markets in which the demand shifted up each period by a constant percentage. Williams (1979) studied demands and supplies that had a constant cyclical behavior. In both cases the data suggest that markets converge to such "moving targets" but the case in which the target has little predictability from the past has not been studied. The consequences of one time shifts in markets has been often studied but the constantly shifting markets studied here is new. Thus, the data from the experiments with free offers will add new information about the convergence capacities of markets.

The existence of influences of certain types of transactions costs in experimental markets in well known and documented. Plott and Smith (1978) demonstrated that a natural transactions cost exists in experimental markets that can easily influence the volume component of an equilibrium. If agents are given no commission for trades and if the demand limit price for the marginal unit is exactly equal to the supply limit price of the marginal unit of supply, then these two units tend not to trade. The transaction cost can

be seen as restricting volume. The existence and implications of this natural transaction cost and certain undesirable properties of commissions to overcome it, lead to the use of parameters with an equilibrium "tunnel" property. The limit price of the marginal demander is typically strictly higher than the limit price of the marginal supplier so the possibility of strictly positive gains from trade exist at the margin.

Refer again to the demand and supply model in Figure 1. As discussed above the magnitudes were for period one parameters. As can be seen there is a "tunnel" twenty francs wide for the last two units, before supply and demand crossed. Thus, strictly speaking all prices in the range of the tunnel are equilibria. For purposes of discussion it is easy to discuss THE equilibrium and for this purpose the average price of the equilibria is used. That is, when the discussion refers to THE equilibrium price, the reference is to the middle of the tunnel. The equilibrium prices listed in Table 3 are these numbers.

As was mentioned above, the tunnel is customary because it is known that marginal units do not trade without some sort of reward. The particular "tunnel" represented by the parameters of the experiments and contained in Figure 1, is rather large given ordinary beliefs about subjective transaction costs. In the experiments to be studied here the gains from trade between marginal units are about $0.50 per unit as compared with the usual $0.05 implemented in experimental markets. The size of this "tunnel" means that even with the cost of offering of 10 francs or about $0.25 , there were prices that made a profit for both buyer and seller at every unit up to the competitive equilibrium quantity. Thus, even with the costly offers there were always gains from trade over a price range of about $0.25, which is well above what is ordinarily believed to be subjective transaction cost.

After having looked at the data, aspects of theory emerged that might be helpful in understanding what is observed in the convergence processes. These are regularities in the data that are understandable from a special theoretical point of view. In order to emphasize their importance we will refer to them as *principles*. This discussion has emerged after we studied the markets so the design cannot be construed as an attempt to test the ideas in some systematic way. Nevertheless, it is easier to discuss the ideas now, during a discussion of the models rather than later.

The behavior of the double auction in general, without costly offers, seems to conform to a *PRINCIPLE OF SUCCESSFUL PRICE DISCOVERY*. That means that during the operation of a market the prices at which trades can take place become widely known. All buyers know a range of prices that is clearly out of bounds because the sellers cannot or will not take less. Similarly sellers have a similar idea about what buyers are willing to take. Under such circumstances the placing of an order that is a likely candidate for execution is not a particularly difficult or artful task. In a sense the set of mutually beneficial net trades becomes public information. The path-breaking paper of Easley and Ledyard (1993) axiomatize a behavioral quality that can lead to such a property. They postulate that as the end of a period draws near, a tendency exists for individuals to reveal their limit prices in their offers. That is, for Easley and Ledyard the principle of successful price discovery operates through a *PRINCIPLE OF FULL REVELATION*.

The double auction has another property that was partially captured by an Easley and Ledyard axiom. For lack of a better term we will call it the *PRINCIPLE OF IMMEDIATE ACCEPTANCE.* As a period grows near the end, a tendency exists for individuals to accept whatever offer exists in the market if the offer is profitable for them. They wish to accept the terms immediately while the offer lasts and before the period ends.

Together the two principles capture much of the nature of the trading process. The area of gains from trade becomes known, especially near the end of a period. Furthermore, it becomes easier to tender offers that will be accepted as the principle of immediate acceptance takes over. No individual will fail to trade because of strategic reasons. Thus all gains form trade will be exhausted and the market volume will be at the competitive equilibrium quantity.

RESULTS

Figures 2 and 3 contain examples of the time series of contract prices for experiments with free offers (Figure 2, Experiment 0524) and with costly offers (Figure 3, Experiment 0217). The vertical lines indicate the different periods. The horizontal lines indicate the competitive equilibrium price for each period as calculated from parameters. The visual impression taken from these figures is that convergence occurs under both conditions but it is faster and more accurate under the condition of free offers as opposed to the condition of costly offers. The conclusions below will make that impression precise.

The first result is that convergence to the competitive equilibrium is occurring within each period even with the parameters shifting. Interestingly enough, in this case of unpredictable shifts the convergence to the competitive equilibrium does seem to improve with experience in the market. This occurs under conditions of free offers and also under conditions of costly offers.

RESULT 1. Under both conditions of free offers and costly offers the within period convergence of contract prices is to the equilibrium. Furthermore, there are slight improvements over time.

SUPPORT. The analysis will proceed by an examination of the case of free offers, and then will focus on the costly offer case. Table 4 contains the results of the estimation of the Ashenfelter/El-Gamal[2] model of market convergence.

$$P_{it} - P^{eq}_{it} = \Sigma_i \; D_i \, B_{1i} \; 1/t + B_2 \; (t-1)/t + \varepsilon_{it}$$

Where i is the experiment and t is the period. P_{it} is the average price of a contract in period t of experiment i. D_i takes value 1 if the experiment is i and zero otherwise. P^{eq}_{it}

[2] This model was first used in Noussair, Riezman and Plott (forthcoming) and resulted from discussions with and suggestions of Orley Aschenfelter and Mahmoud El-Gamal.

is the equilibrium price (the midpoint of a range) predicted by the competitive model in period t of experiment i. The error term is assumed to be normal with 0 mean and constant variance. The Table contains the results of estimation for the two data sets.

The coefficient B_2 is an estimate of the asymptotic behavior of the time series that is to be compared with the equilibrium predictions of the competitive model. Given the parameters of the model, there is a "window" of 20 francs or equilibrium prices. P^{eq} is the midpoint of this window. Thus prices of 10 francs on either side of P^{eq} are still equilibria.

For the case of free offers B_2 is estimated to be 9.7 francs which is approximately 20 cents. This is within the 10 franc difference that is allowed by the non-uniqueness of the equilibrium prices. Thus we can conclude that experiments with free offers are converging to the equilibrium prices. A comparison of the data in the initial periods , the B_{1i} terms, further supports the conclusion of convergence. These terms estimate the initial starting points of the contract prices during the first period of the experiment. As can be seen two of the three experiment's price levels during the first periods were outside the equilibrium price range. Volumes are reported in Table 5 and as can be determined by inspection the equilibrium volume of 9 was attained in eighty percent of the periods.

The results of the experiments with costly offers are similar. As can be seen from an examination of Table 4 the estimate of B_2 is - 0.46 which is not significantly different from zero. Thus the convergence of these markets is to the competitive equilibrium price. An examination of the B_{1i} terms demonstrates that the prices in the initial periods of two of the three experiments are outside the equilibrium price range. The volumes in Table 5 are at the competitive equilibrium level of 9 units in seventeen percent of the periods (as opposed to eighty percent for the free offer condition). This divergence of the volume from the model will be discussed in detail later.•

The data presented above might lead to the impression that the costly offer markets are actually converging faster than are the free offer markets. The B_2 term for the costly offer case is almost zero, the middle of the competitive equilibria, whereas the measurement for the free offer case is nearer the boundary of the equilibria. The next result demonstrates that such an impression is not correct. The free offer markets converge more rapidly and are more efficient. The apparent relative success of the costly offer markets is probably due to the accident of the pattern of first period prices and the nature of the averaging process implicit in the statistical model. The next result summarizes some of the major effects of the costly offer on market performance.

RESULT 2. The imposition of a cost of offers lowers market efficiency, reduces volume and reduces the speed of convergence to the competitive equilibrium.

SUPPORT. The properties of the data will be explored in the order of efficiency, volume and speed. The efficiencies of each period of each experiment are contained in Table 6. On average the efficiency of the free offer experiments is 97.2% and on average the

efficiency level of the costly offer experiments is 91.9 %. Notice that the average efficiency of the free offer experiments is heavily influenced by one period of one experiment (It might have been due to a typo of a type that sometimes occur in electronic markets.). If this one period is removed from the data then the efficiency of the free offer case is on average 99.1%. With or without the "outlier" a test of a difference in efficiency levels between the two treatment conditions (free offer or costly offer) leads to a rejection of the hypothesis of equal means at the 0.02 level with the "outlier" and at the 0.01 level without it. The markets with costly offers operated less efficiently than did the markets with free offers.

Table 5 contains the volume in each period of each experiment. The competitive equilibrium volume should be nine units in any given period. The volume in the free offer experiments is on average 9.1 per period. The volume in the costly offer experiments is on average 7.8 per period. The hypothesis of equality can be rejected at the .01 level Since the average volume of the free offer case is above the average volume in the costly offer case we conclude that the impact of the costly offer is to lower volume.

Speed of convergence is measured by the following model.

$$|P_{ijt} - P^{eq}_{ij}| = \alpha e^{-\beta t + \varepsilon_{ijt}}$$

The variable P_{ijt} is the tth contract that occurred in period j of experiment i. The variable P^{eq}_{ij} is the competitive equilibrium price that prevailed during that period of the experiment. The use of the absolute value is used to measure the distance from the equilibrium and the form of the model implies that if the direction is toward the equilibrium on average then in the limit the difference will be zero. The β term measures the speed of convergence. If it is positive then the system is going toward zero and if it is large and positive then it is moving quickly toward zero. The comparison of speed of convergence is thus made with the comparison of β in the different experiments.

The estimated coefficients of the model are contained in Table 7. For the free offer case the β is estimated to be 0.12 and for the costly offer case the estimate is 0.05. Thus the speed of convergence in the free offer case is greater. The confidence in the difference is approximately 0.01. •

The next 2 results form the basis of conjectures about the mechanism through which the effects of the imposition of offer costs become manifest. Figures 4 and 5 contain a time series of offers for the two conditions of free offers and costly offers respectively. The contracts are omitted so only the patterns of bids and asks remain. The figures give two impressions. First the number of offers is much greater under the conditions of free offers. Secondly the "bargaining" activity in terms of new bids and asks continues with a flurry until the very end of the market period in the free offer case. On the other hand the density of activity in terms of bids and asks at the final moments of a period are much fewer when costly offers are imposed. The next two results make those impressions precise.

RESULT 3. The imposition of an offer cost reduces the number of offers and increases the quantity tendered in any given offer. However, the average size of a contract is not influenced by the existence of costly offers.

SUPPORT. Table 8 contains for each period of each experiment the number of offers (the number of bids plus the number of asks in a period),the average quantity offered and the average size of a contract each period . In the free offer case there are on average 51 offers per period. In the costly offer case there were on average 9. The difference in numbers of offers is dramatic in magnitude and significant at the 0.01 level. The number of offers falls with the imposition of the cost of offers. The table also contains the average size of offers which is 1.2 in the case of the free offer and is 1.9 in the case of the costly offers. The size of offers is significantly greater (0.01 level of significance) in the costly offer case than the free offer case. As can be seen in the table the average size of contracts is almost uniformly 1 in all cases (on average the size of contracts is 1.02 in the free offer case and 1.03 in the costly offer case).•

RESULT 4. The time left in the period at the last transaction increases as a result of the imposition of the costly offer and the number of offers after the last contract decreases as a result of the imposition of costly offers.

SUPPORT. Table 9 reports the difference in the time at which the last contract was made in a period and the time at which the period ended. The table also reports the number of offers that were made after the last contract. As can be seen from examination of the table the average time remaining after the last contract was 21.1 seconds in the case of the free offer experiments and was on average 73.5 seconds in the experiments with the costly offer. The difference is significant at the 0.01 level. The number of offers that occurred after the last contract was on average 2.8 in the case of free offers and it was on average 0.7 in the case of the costly offers. Again the difference is significant at the 0.01 level. Thus the imposition of costly offers had the effect of increasing the amount of time between the occurrence of the last transaction and the end of the period and also decreasing the number of offers after the last transaction was made.•

OBSERVATION: In both the cases of free offers and costly offers conditions, at the end of the period profitable trades are not possible at the prices that are offered.

SUPPORT. The observation is true of all periods of all experiments with the exceptions of period two of experiment 0524 and period 8 of experiment 0506. However, in these two cases the offer was made only within the final three and two seconds of the period respectively, so even in these two cases the observation tends to hold because there was, practically speaking, too little time remaining in the period to accept. There are many cases in which offers that would have left zero profits for the accepting party were left on the table, which is typical of the subjective transaction cost discovered by Plott and

Smith.•

CONJECTURE: The costly offer induces an incomplete price discovery process. The *principle of successful price discovery* is never fully operating. The *principle of immediate acceptance is operative* but the *principle of full revelation* is not operating.

The story that supports the conjecture is a straight-forward recounting of the results listed above. In the absence of costly offers, convergence to the competitive equilibrium price and quantity can be expected. In addition the system will operate at near 100% efficiency. The imposition of costly offers facilitates a general fall in the level of efficiency. Gains from trade are left on the table. This tendency to walk away from gains from trade is not due to an (perhaps strategic) unwillingness to trade. The cost on offers results in a reduction in the number of offers (but not the willingness to trade at a given price). It also reduces the propensity for offers to be encouraged by the approach of the end of the period. In other words, the Easley and Ledyard *principle of full revelation* is not at work.

At least two different models can be used to explain any reduction in limit price revelation. The first might be a simple search model that postulated an additional cost on search will reduce the amount of search in terms of offers that are made. A reduction in the number of offers is a reduction in the completeness of the price discovery process. The second has more of a bargaining flavor which has the two individuals engaged in a prisoner's dilemma over which one will bear the cost and tender the offer. The result is an offer by neither. The conjecture above implicitly suggests that the phenomena of incomplete price discovery is due to the former mechanism.

DISCUSSION AND CONCLUSIONS

This study was motivated by a series of questions the answers to which can now be summarized. First, the price discovery process typical of stationary markets extends itself to markets with no stationary properties. This is a particularly interesting result because it suggests that convergence to an equilibrium is due in part to what might be learned (or coordinated) with the particular *individuals* in the market *in addition to* knowledge about the particular parameters that might be present in the environment. This conclusion is particularly interesting because learning is generally thought to involve only information about environmental parameters and not about the complexities that might accompany particular individuals or individuals as a group.

It could be said that the equilibration properties observed are due to the fact that the competitive equilibrium was an "easy shot". That is, the equilibrium range was wide and the volumes were small relative to environments in which accuracy is ordinarily studied. The equilibrium "window" was $0.50 as opposed to $0.20 that is frequently used. To this criticism we have no real reply. It is not exactly obvious how to translate the criticism into

a program of experimentation without additional theory to guide the effort. To this end some speculations about theory are included at the end of the section of results.

The second question posed was related to the impact of costly offers. The existence of costly offers does not negate the tendency for the price to equilibrate. Gyrations, breakdown of trade, or other extreme phenomena were not observed. The prices tended to equilibrate at a level near the competitive equilibrium. By comparison with the free offer case, the price convergence process was slower and the market efficiency was lower in the costly offer case. These questions of comparative performance were the third and fourth questions initially posed and are now answered.

In addition, a type of paradox presents itself. If prices under the costly offer conditions converge to the competitive equilibrium how can it be that costly offers produce market inefficiencies? A conjecture is offered in the results section as a solution to the paradox. The conjecture is that the case of costly offers is one of incomplete price discovery fostered by the reduced search. The cost of offers reduces the number of offers and as a result, the ability of buyers and sellers to find each other is hampered. Even though the prices are in the range of the competitive equilibrium, this fact is not known to the agents who refrain from making offers for fear of "missing" the area of gains from trade and thereby suffering the offer cost with no offsetting gain. Thus, the conjecture has roots in an intuitive theory that is captured by the Easley and Ledyard model of the convergence process and thereby supports that model as central to an understanding of the price discovery process. Specifically, the imposition of the offer cost causes violations of the Easily and Ledyard axiom that we have named the *Principle of Full Revelation,* and accordingly, the inefficiencies are fostered by a reduction of information in the market.

REFERENCES

Daniels, B. P. and C. R. Plott, "Inflation and Expectations in Experimental Markets," *Bounded Rational Behavior in Experimental Games and Markets*, edited by R. Tietz, W. Albers, and R. Selten. Berlin Heidelberg: Springer-Verlag, 1988.

Easley, D. and J. O. Ledyard, "Theories of Price Formation and Exchange in Double Oral Auctions," *The Double Auction Market: Institutions, Theories and Evidence*, edited by D. Friedman, J. Geanakoplos, D. Lane, and J. Rust. Santa Fe Institute Studies in the Sciences of Complexity, Proceedings Volume XV., Addison-Wesley, 1992.

Plott, C. R. and V. L. Smith, "An Experimental Examination of Two Exchange Institutions," *The Review of Economic Studies*, Volume. XLV (1) (February 1978):133-153.

Williams, A. W., "Intertemporal Competitive Equilibrium: On Further Experimental Results," *Research in Experimental Economics*, Vol.1, edited by V. L. Smith. Greenwich, Connecticut. JAI Press, (1979):255-278.

Noussair, C. N. , C. R. Plott, and R. G. Riezman, "An Experimental Investigation of the Patterns of International Trade," Social Science Working Paper no. 799, Pasadena: California Institute of Technology. Revised August 1994. Forthcoming in *American Economic Review*.

APPENDIX A

The instructions for both treatments are contained below. The costly offer condition differed from the free offer condition only by the insertion of the sentences in the brackets [ ].

INSTRUCTIONS

GENERAL

This is an experiment in the economics of market decision making. The instructions are simple and if you follow them carefully and make good decisions you might earn money which will be paid to you in cash

In this experiment we are going to conduct a market in which some of you will be buyers and some of you will be sellers in a sequence of market days or trading periods. Enclosed with the instructions you will find a sheet labeled Buyer or Seller, which describes the value to you of any decisions you might make. You are not to reveal this information to anyone. It is your own private information.

The currency in these markets is francs. Each franc is worth _____ dollars to you.

SPECIFIC INSTRUCTIONS TO BUYERS

During each market period you are free to purchase from any seller or sellers as many units as you might want. For the first unit that you are buying during a trading period you will receive the amount listed in row (1) marked Redemption Value under Unit Number 1; if you buy a second unit you will receive the additional amount listed in row (4) marked Redemption Value under Unit Number 2, etc. The profits from each purchase (which are yours to keep) are computed by taking the difference between the redemption value and transaction cost, or purchase price, of the unit bought. That is,

[your earnings = (redemption value) - (transaction cost)].

Suppose, for example, that you buy two units and that your redemption value for the first unit is 200 and for the second unit is 180. If you pay 150 for your first unit and 160 for the second unit, your earnings are:

earnings from first	= 200 -150 = 50
earnings from second	= 180 -160 = 20
total earnings	= 50 + 20 = 70

The blanks on the table will help you record your profits. The purchase price of the first unit you buy during the first period should be recorded on row (2) at the time of

purchase. You should then record the profits on this purchase as directed on row (3). [At the end of the period record your total number of postings, find the posting fee as directed, and record your total profits on the last row on the page]. Subsequent periods should be recorded similarly.

SPECIFIC INSTRUCTIONS TO SELLERS

During each market period you are free to sell to any buyer or buyers as many units as you might want. The first unit that you sell during a trading period you obtain at a cost of the amount listed on the enclosed sheet in row (2) marked Buyback Cost under Unit Number 1; if you sell a second unit you incur the additional cost listed in row (5) marked Buyback Cost under Unit Number 2, etc. The profits from each sale (which are yours to keep) are computed by taking the difference between the transaction revenue, or price at which you sold the unit, and the cost of the unit. That is,

[your earnings = (transaction revenue) - (buyback cost)].

Suppose, for example, your buyback cost of the first unit is 140 and your cost of the second unit is 160. For illustrative purposes we will consider only a two-unit case. If you sell the first unit at 200 and the second unit at 190, your earnings are:

earnings from first	= 200 - 140 = 60
earnings from second	= 190 - 160 = 30
total earnings	= 60 + 30 = 90

The blanks on the table will help you record your profits. The sale price of the first unit you sell during the first period should be recorded on row (1) at the time of sale. You should then record the profits on this sale as directed on row (3). [At the end of the period record your total number of postings, find the posting fee as directed], and record your total profits on the last row on the page. Subsequent periods should be recorded similarly.

Transaction Record for Buyer # ___

Period ___

	Unit Number	**1**
1	Redemption Value	
2	Transaction Cost	
3	Profit (line 1 - 2)	
	Unit Number	**2**
4	Redemption Value	
5	Transaction Cost	
6	Profit (line 4 - 5)	
	Unit Number	**3**
7	Redemption Value	
8	Transaction Cost	
9	Profit (line 7 - 8)	
	Unit Number	**4**
10	Redemption Value	
11	Transaction Cost	
12	Profit (line 10 - 11)	
	Unit Number	**5**
13	Redemption Value	
14	Transaction Cost	
15	Profit (line 13 - 14)	
	Unit Number	**6**
16	Redemption Value	
17	Transaction Cost	
18	Profit (line 16 - 17)	
	Unit Number	**7**
19	Redemption Value	
20	Transaction Cost	
21	Profit (line 19 - 20)	
	Unit Number	**8**
22	Redemption Value	
23	Transaction Cost	
24	Profit (line 22 - 23)	
	Unit Number	**9**
25	Redemption Value	
26	Transaction Cost	
27	Profit (line 25 - 26)	
	Unit Number	**10**
28	Redemption Value	
29	Transaction Cost	
30	Profit (line 28 - 29)	
31	Sum Profit (lines 3 + 6 + 9 + ...	
32	Number of Postings (Box)	
33	Posting Fee (line 32 x ___)	
34	Total Profit (line 31 - 33)	

Postings

Table 1

Experiments and Conditions

Experiment	Condition	Location	Experience of Subjects	Number of Subjects	Number of Periods
013194	Costly Offer	CIT	General Experienced	6	12
021794	Costly Offer	CIT	General Experienced	6	10
050394	Free Offer	CIT	General Experienced	6	10
050694	Free Offer	CIT	General Experienced	6	10
052494	Free Offer	CIT	General Experienced	6	10
053094*	Costly Offer	CIT	General Experienced	6	10

*This experiment was interrupted briefly by a computer shutdown

Table 2-a

Period 1 Redemption Values and Costs
by Subject Type

Unit \ Type	Buyer Redemption Values			Seller Costs		
	1	2	3	1	2	3
1	585	575	555	425	435	455
2	535	565	545	475	445	465
3	515	495	525	495	515	485
4	490	475	515	520	535	495
5	435	425	480	575	585	530
6	400	405	465	610	605	545
7	340	375	430	670	635	580
8	315	335	410	695	675	600
9	305	295	375	705	715	635
10	280	265	340	730	745	670

Table 2-b

Amount Added to Entries in Table 2-a to Obtain Corresponding Schedules for All Periods

Period	1	2	3	4	5	6	7	8	9	10	11	12
Amount Added	0	-40	-200	-120	80	120	-40	-120	-320	-240	-280	-360

Table 3

Expected Equilibrium Prices
By Period

Period	Price
0 (Practice)	505
1	505
2	465
3	305
4	385
5	585
6	625
7	465
8	385
9	185
10	265
11*	225
12*	145

*First experiment only

Table 4

Estimated Parameters for theAshenfelter/El-Gamal Model

$$P_{it} - P^{eq}_{it} = \Sigma_i D_i B_{1i}(1/t) + B_2((t-1)/t) + \varepsilon_{it}$$

Free Offer:

	B_{11}	B_{12}	B_{13}	B_2
Competitive Equilibrium Prediction	0	0	0	0
Estimated Coefficient	-22.7	-2.0	-14.7	9.7
Standard Error	7.4	7.4	7.4	2.4

Number of Observations	30
r^2	0.41
Corrected r^2	0.34
rho	-0.01

Costly Offer:

	B_{11}	B_{12}	B_{13}	B_2
Competitive Equilibrium Prediction	0	0	0	0
Estimated Coefficient	-28.5	7.6	-32.1	-0.46
Standard Error	9.9	9.6	9.6	3.3

Number of Observations	30
r^2	0.45
Corrected r^2	0.39
rho	0.21

Table 5

Volumes by Period

Period	Experiment					
	Free Offer			Costly Offer		
	0503	0506	0524	0131	0217	0530
1	9	9	11	7	7	6
2	9	8	9	8	7	8
3	9	11*	10	9	9	11
4	9	9	9	8	8	9
5	9	9	9	8	6	9
6	8	9	9	8	7	6
7	9	9	9	8	7	6
8	9	8	9	7	7	8
9	9	9	9	8	8	8
10	9	9	9	8	9	8
Average		9.1			7.8	

*Suspected type

Table 6

Efficiencies by Period

Period	Experiment					
	Free Offer			Costly Offer		
	0503	0506	0524	0131	0217	0530
1	100%	100%	97.3%	89.2%	91.9%	82.4%
2	100%	91.9%	93.9%	84.5%	93.2%	86.5%
3	100%	42.6%*	96.6%	95.3%	94.6%	77.0%
4	100%	100%	100%	97.3%	97.3%	97.3%
5	100%	100%	100%	97.3%	85.1%	100%
6	97.3%	100%	100%	97.3%	91.9%	82.4%
7	100%	100%	100%	97.3%	94.6%	77.0%
8	100%	97.3%	100%	82.4%	86.5%	97.3%
9	100%	100%	100%	97.3%	97.3%	93.2%
10	100%	100%	100%	97.3%	100%	97.3%
Average		97.2%			91.9%	

*Suspected typo

Table 7

Estimated Parameters for Speed of Convergence

$$|P_{ijt} - P^{eq}_{ij}| = \alpha e^{-\beta t + \varepsilon}$$

Free Offer:

	α	β
Competitive Equilibrium Prediction	0	-
Estimated Coefficient	17.2	0.12
Standard Error	0.14*	0.019

Number of Observations	272
r^2	0.33
Corrected r^2	0.32
rho	0.58

Costly Offer:

	α	β
Competitive Equilibrium Prediction	0	-
Estimated Coefficient	13.3	0.05
Standard Error	0.14*	0.023

Number of Observations	233
r^2	0.24
Corrected r^2	0.23
rho	0.51

*Actually the standard error is 0.14 out of ln 17.2 = 2.84
0.14 out of ln 13.3 = 2.58

Table 8

Number of Offers, Average Quantity Offered, and Average Contract Size by Period

	Experiment					
Period	Free Offer			Costly Offer		
	0503	0506	0524	0131	0217	0530
1	53,1.0,1.0	64,1.1,1.1	57,1.4,1.0	19,1.3,1.0	9,2.7,1.2	8,1.5,1.0
2	54,1.1,1.0	74,1.1,1.0	45,1.2,1.0	13,1.3,1.1	12,1.8,1.0	10,2.2,1.0
3	60,1.2,1.0	48,1.2,1.1	37,1.6,1.0	16,1.6,1.1	9,2.3,1.1	6,3.2,1.0
4	51,1.0,1.0	61,1.3,1.0	46,1.3,1.0	11,1.8,1.1	8,2.1,1.0	6,2.3,1.1
5	48,1.1,1.0	57,1.3,1.0	48,1.3,1.0	12,1.8,1.0	9,1.6,1.2	5,3.0,1.0
6	58,1.0,1.0	59,1.3,1.0	44,1.4,1.0	10,1.3,1.0	7,2.1,1.0	5,1.6,1.0
7	35,1.0,1.0	64,1.1,1.0	32,1.3,1.1	9,1.4,1.0	9,2.4,1.0	4,2.5,1.0
8	53,1.0,1.0	61,1.2,1.0	47.1.6.1.0	11.1.8,1.0	7,1.7,1.0	6,2.3,1.0
9	56,1.1,1.0	48.1.2,1.0	48,1.5,1.0	8,1.8,1.0	8,1.9,1.0	5,2.0,1.0
10	25,1.3,1.0	53,1.3,1.0	38,1.7,1.1	11,1.5,1.0	5,2.8,1.1	11,1.8,1.0
Average		50.5, 1.2, 1.02			9.0, 1.9, 1.03	

Table 9

Number of Seconds Remaining and Number of Subsequent Offers
for the Last Transaction in a Period

Period	Experiment					
	Free Offer			Costly Offer		
	0503	0506	0524	0131	0217	0530
1	6,1	2,0	23,7	1,0	150,2	11,0
2	3,0	36,4	59,7	1,0	133,3	9,0
3	9,2	157,4	5,1	124,2	15,0	12,0
4	15,2	2,0	5,1	115,1	52,1	179,1
5	6,1	109,18	14,4	152,2	33,1	165,0
6	15,2	16,3	8,2	57,1	3,0	17,0
7	2,0	17,4	6,3	117,2	51,0	220,0
8	10,3	2,1	2,0	145,1	16,0	48,0
9	60,7	7,1	21,3	174,1	55,0	101,1
10	9,2	1,0	8,2	1,0	1,0	48,2
Average	21.1 seconds 2.8 offers			73.5 seconds 0.7 offers		

Figure 1

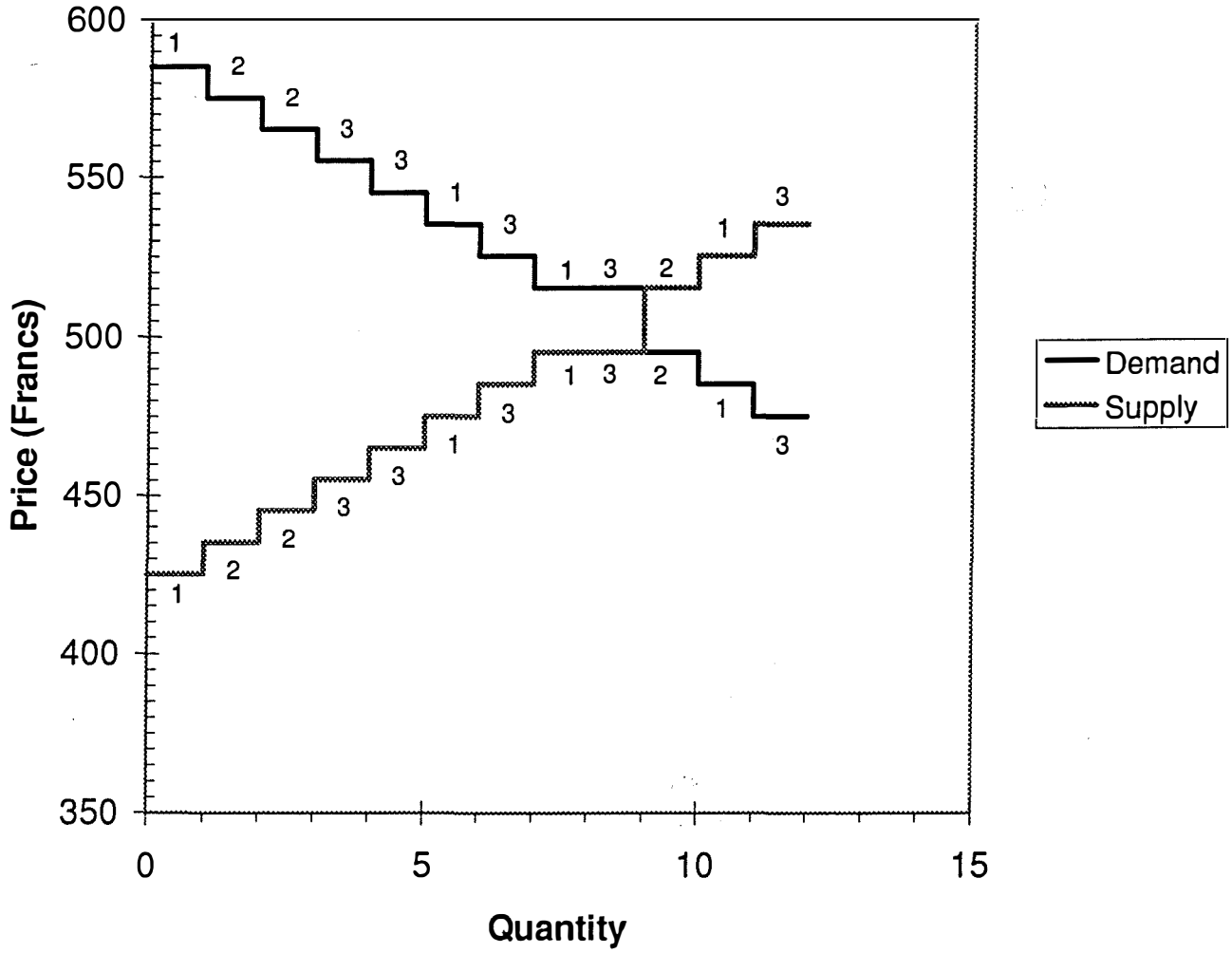

600
550
500
450
400
350
Price (Francs)
0
5
10
15
Quantity
Demand
Supply

Figure 2

Contract Prices Experiment 0524 with Free Offers

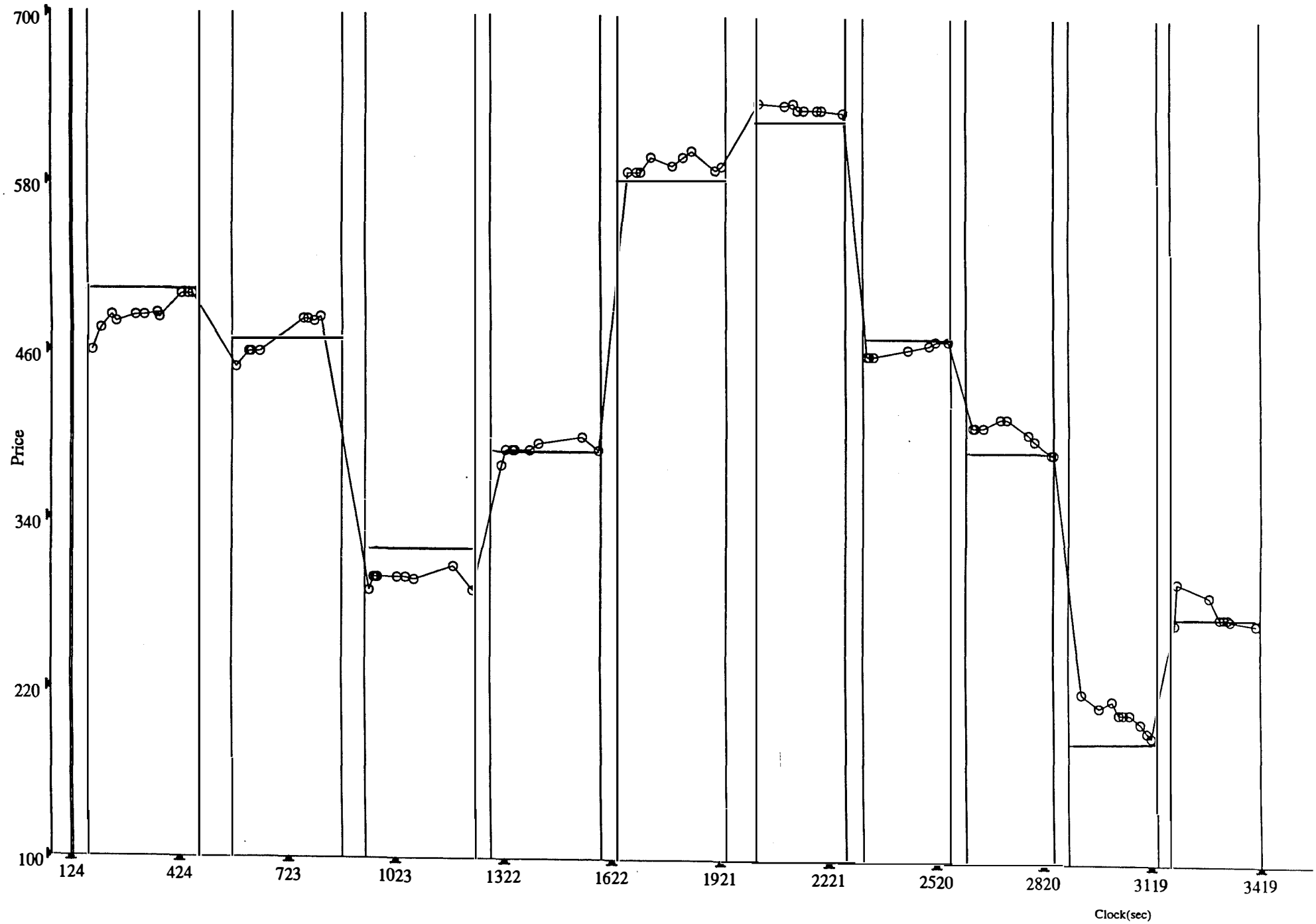


Figure 3

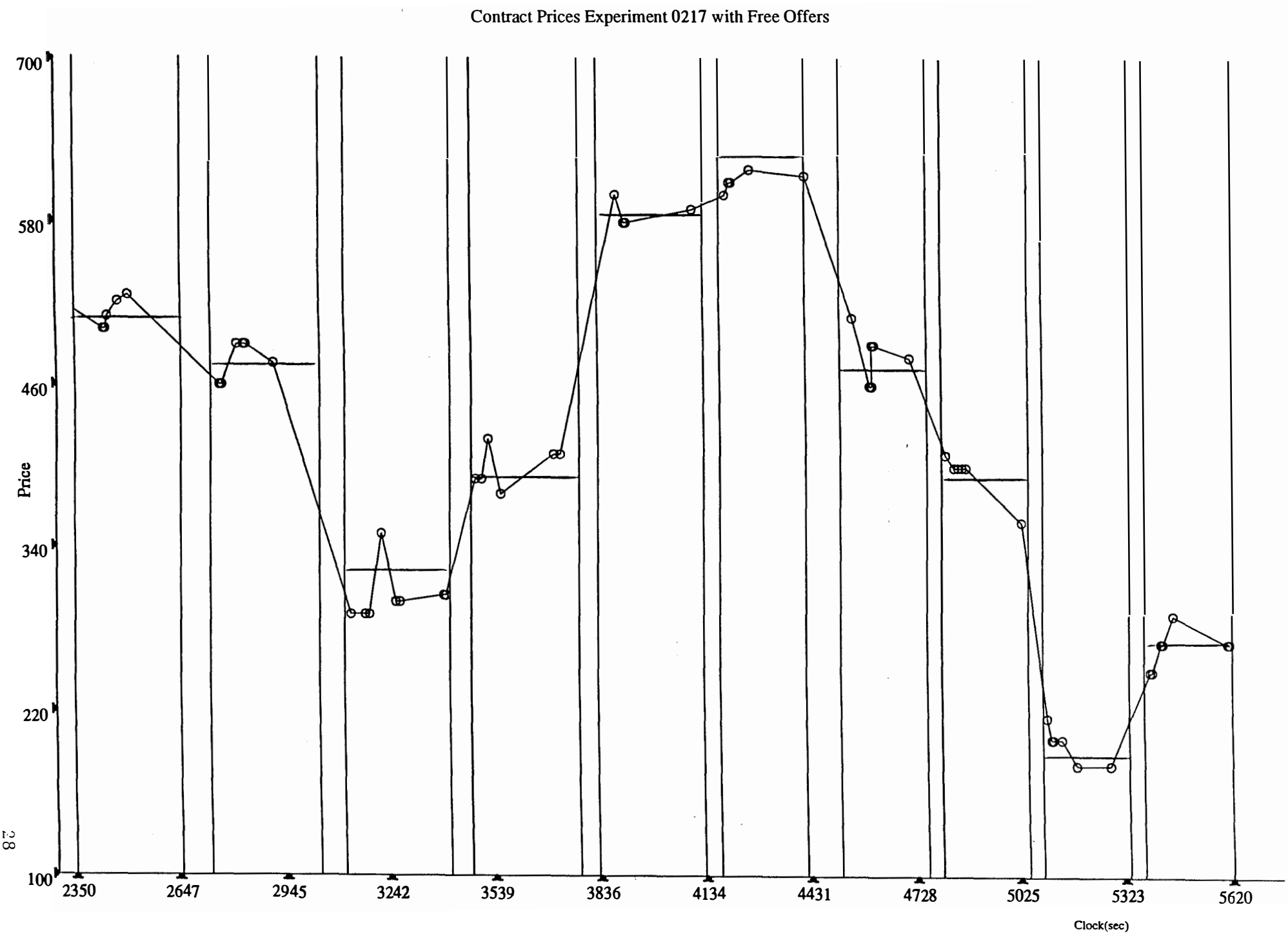

Contract Prices Experiment 0217 with Free Offers
Price
700
580
460
340
220
100
2350
2647
2945
3242
3539
3836
4134
4431
4728
5025
5323
5620
Clock(sec)

Figure 4

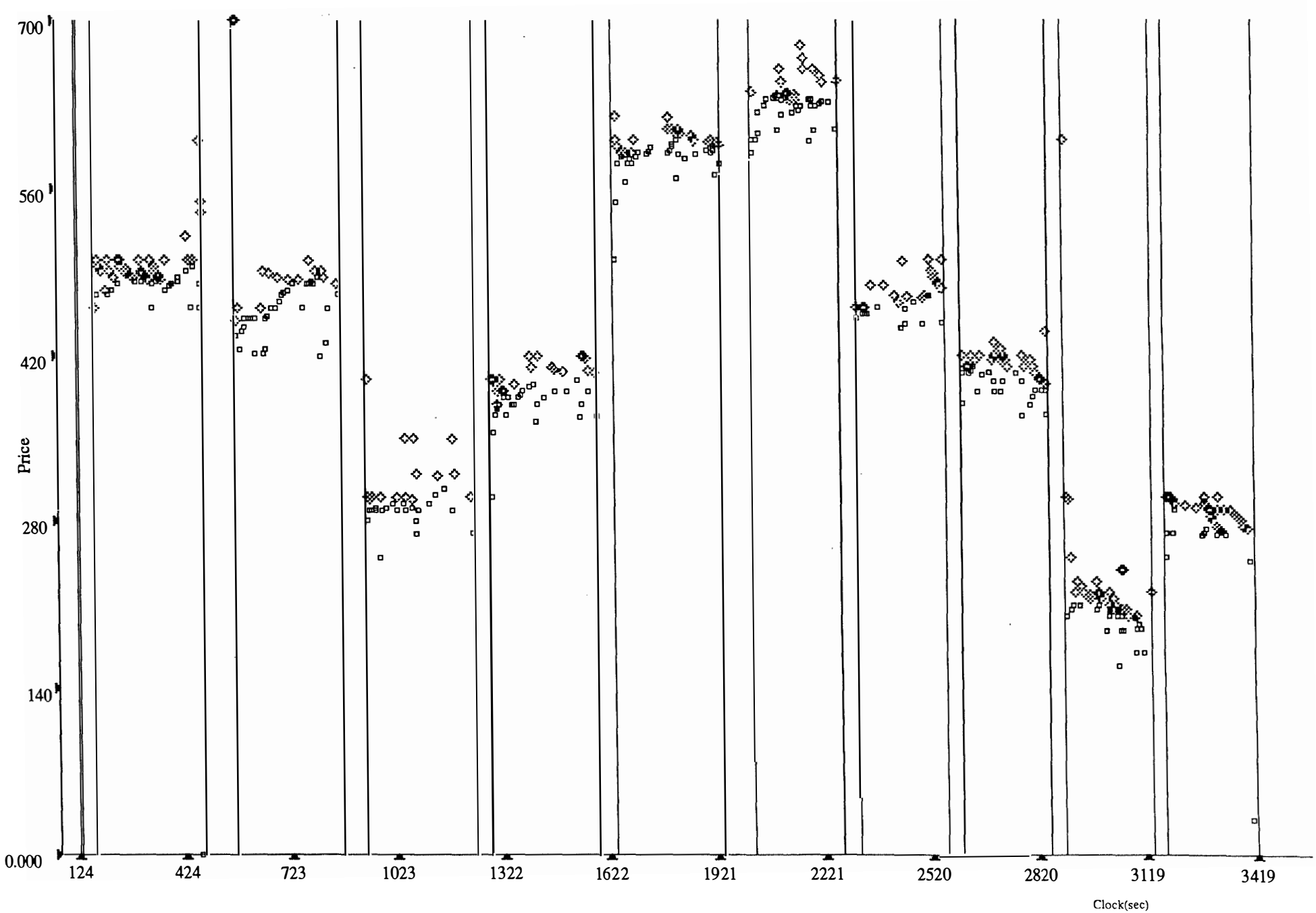
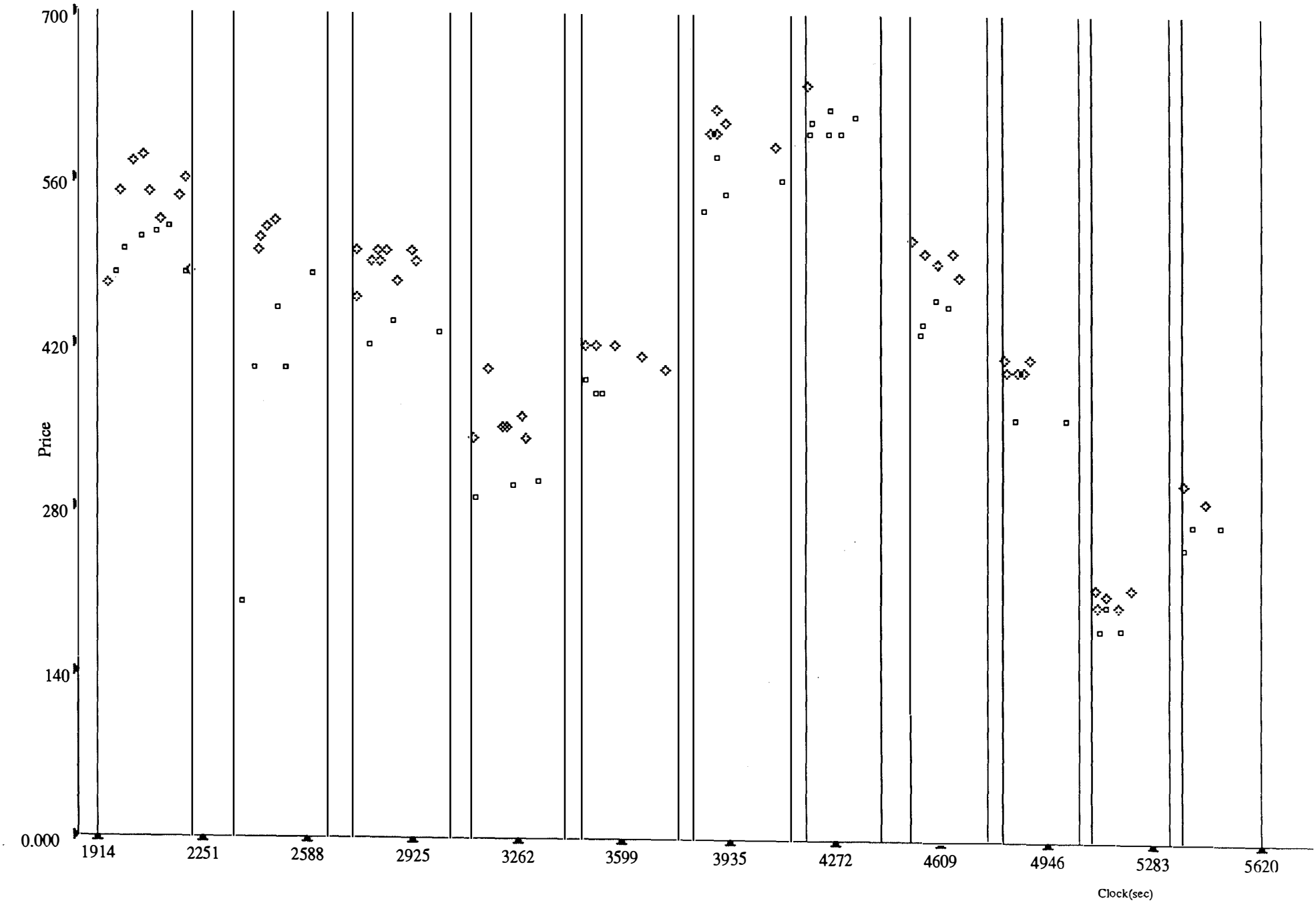

700
560
420
280
140
0.000
Price
124
424
723
1023
1322
1622
1921
2221
2520
2820
3119
3419
Clock(sec)

Figure 5


700
560
420
280
140
0.000
Price
1914
2251
2588
2925
3262
3599
3935
4272
4609
4946
5283
5620
Clock(sec)