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An Experimental Study of Competitive Market Behavior

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AN EXPERIMENTAL STUDY OF COMPETITIVE MARKET BEHAVIOR[1]

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I. INTRODUCTION

Recent years have witnessed a growing interest in experimental games such as management decision-making games and games designed to simulate oligopolistic market phenomena. This article reports on a series of experimental games designed to study some of the hypotheses of neoclassical competitive market theory. Since the organized stock, bond, and commodity exchanges would seem to have the best chance of fulfilling the conditions of an operational theory of supply and demand, most of these experiments have been designed to simulate, on a modest scale, the multilateral auction-trading process characteristic of these organized markets. I would emphasize, however, that they are intended as simulations of certain key features of the organized markets and of competitive markets generally, rather than as direct, exhaustive simulations of any particular organized exchange. The experimental conditions of supply and demand in force in these markets are modeled closely upon the supply and demand curves generated by the limit price orders in the hands of stock and commodity market brokers at the opening of a trading day in any one stock or commodity, though I would consider them to be good general models of received short-run supply and demand theory. A similar experimental supply and demand model was first used by E. H. Chamberlin in an interesting set of experiments that pre-date contemporary interest in experimental games.[2]

[1] The experiments on which this report is based have been performed over a six-year period beginning in 1955. They are part of a continuing study, in which the next phase is to include experimentation with monetary payoffs and more complicated experimental designs to which passing references are made here and there in the present report. I wish to thank Mrs. Marilyn Schweizer for assistance in typing and in the preparation of charts in this paper, R. K. Davidson for performing one of the experiments for me, and G. Horwich, J. Hughes, H. Johnson, and J. Wolfe for reading an earlier version of the paper and enriching me with their comments and encouragement. This work was supported by the Institute for Quantitative Research at Purdue, the Purdue Research Foundation, and in part by National Science Foundation, Grant No. 16114, at Stanford University.

[2] "An Experimental Imperfect Market," *Journal of Political Economy*, LVI (April, 1948), 95–108. For an experimental study of bilateral monopoly, see S. Siegel and L. Fouraker, *Bargaining and Group Decision Making* (New York: McGraw-Hill Book Co., 1960).

Chamberlin's paper was highly suggestive in demonstrating the potentialities of experimental techniques in the study of applied market theory.

Parts II and III of this paper are devoted to a descriptive discussion of the experiments and some of their detailed results. Parts IV and V present an empirical analysis of various equilibrating hypotheses and a rationalization of the hypothesis found to be most successful in these experiments.

Part VI provides a brief summary which the reader may wish to consult before reading the main body of the paper.

II. EXPERIMENTAL PROCEDURE

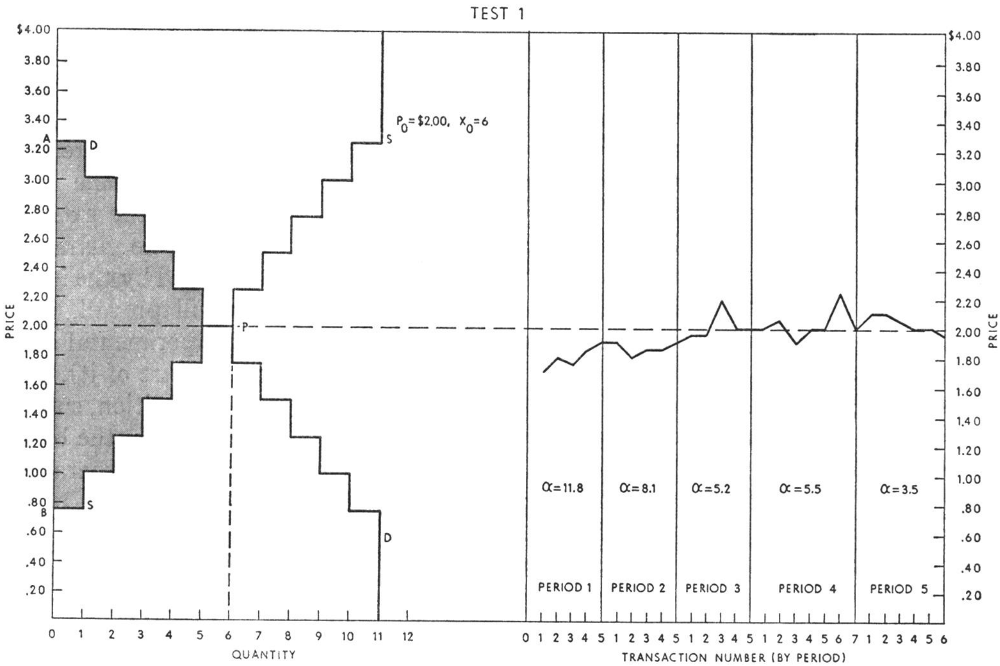
The experiments discussed in Parts III and IV have followed the same general design pattern. The group of subjects is divided at random into two subgroups, a group of buyers and a group of sellers. Each buyer receives a card containing a number, known only to that buyer, which represents the maximum price he is willing to pay for one unit of the fictitious commodity. It is explained that the buyers are not to buy a unit of the commodity at a price exceeding that appearing on their buyer's card; they would be quite happy to purchase a unit at any price below this number—the lower the better; but, they would be entirely willing to pay just this price for the commodity rather than have their wants go unsatisfied. It is further explained that each buyer should think of himself as making a pure profit equal to the difference between his actual contract price and the maximum reservation price on his card. These reservation prices generate a demand curve such as *DD* in the diagram on the left in Chart 1. At each price the corresponding quantity represents the maximum amount that could be purchased at that price. Thus, in Chart 1, the highest price buyer is willing to pay as much as \$3.25 for one unit. At a price above \$3.25 the demand quantity is zero, and at \$3.25 it cannot exceed one unit. The next highest price buyer is willing to pay \$3.00. Thus, at \$3.00 the demand quantity cannot exceed two units. The phrase "cannot exceed" rather than "is" will be seen to be of no small importance. How much is actually taken at any price depends upon such important things as how the market is organized, and various mechanical and bargaining considerations associated with the offer-acceptance process. The demand curve, therefore, defines the set (all points on or to the left of *DD*) of possible demand quantities at each, strictly hypothetical, ruling price.

Each seller receives a card containing a number, known only to that seller, which represents the minimum price at which he is willing to relinquish one unit of the commodity. It is explained that the sellers should be willing to sell at their minimum supply price rather than fail to make a sale, but they make a pure profit determined by the excess of their contract price over their minimum reservation price. Under no condition should they sell below this minimum. These minimum seller prices generate a supply curve such as *SS* in Chart 1. At each hypothetical price the corresponding quantity represents the maximum amount that could be sold at that price. The supply curve, therefore, defines the set of possible supply quantities at each hypothetical ruling price.

In experiments 1–8 each buyer and seller is allowed to make a contract for the exchange of only a single unit of the commodity during any one trading or market period. This rule was for the sake of simplicity and was relaxed in subsequent experiments.

Each experiment was conducted over a sequence of trading periods five to ten minutes long depending upon the number of participants in the test group. Since the experiments were conducted within a class period, the number of trading periods was not uniform among the various experiments. In the typical experiment, the market opens for trading period 1. This means that any buyer (or seller) is free at any time to raise his hand and make a verbal offer to buy (or sell) at any price which does not violate his maximum (or minimum) reservation price. Thus, in Chart 1, the buyer holding the $2.50 card might raise his hand and shout, "Buy at $1.00." The seller with the $1.50 card might then shout, "Sell at $3.60." Any seller (or buyer) is free to accept a bid (or offer), in which case a binding contract has been closed, and the buyer and seller making the deal drop out of the market in the sense of no longer being permitted to make bids, offers, or contracts for the remainder of that market period.[3] As soon as a bid or offer is accepted, the contract price is recorded together with the minimum supply price of the seller and the maximum demand price of the buyer involved in the transaction. These observations represent the recorded data of the experiment.[4] Within the time limit

CHART 1



[3] All purchases are for final consumption. There are no speculative purchases for resale in the same or later periods. There is nothing, however, to prevent one from designing an experiment in which purchases for resale are permitted if the objective is to study the role of speculation in the equilibrating process. One could, for example, permit the carry-over of stocks from one period to the next.

[4] Owing to limitations of manpower and equipment in experiments 1–8, bids and offers which did not lead to transactions could not be recorded. In subsequent experiments a tape recorder was used for this purpose.

of a trading period, this procedure is continued until bids and offers are no longer leading to contracts. One or two calls are made for final bids or offers and the market is officially closed. This ends period 1. The market is then immediately reopened for the second "day" of trading. All buyers, including those who did and those who did not make contracts in the preceding trading period, now (as explained previously to the subjects) have a renewed urge to buy one unit of the commodity. For each buyer, the same maximum buying price holds in the second period as prevailed in the first period. In this way the experimental demand curve represents a demand per unit time or per trading period. Similarly, each seller, we may imagine, has "overnight" acquired a fresh unit of the commodity which he desires to sell in period 2 under the same minimum price conditions as prevailed in period 1. The experimental supply curve thereby represents a willingness to supply per unit time. Trading period 2 is allowed to run its course, and then period 3, and so on. By this means we construct a prototype market in which there is a flow of a commodity onto and off the market. The stage is thereby set to study price behavior under given conditions of normal supply and demand.[5] Some buyers and sellers, it should be noted, may be unable to make contracts in any trading period, or perhaps only in certain periods. Insofar as these traders are submarginal buyers or sellers, this is to be expected. Indeed, the ability of these experimental markets to ration out submarginal buyers and sellers will be one measure of the effectiveness or competitive performance of the market.

The above design considerations define a rejection set of offers (and bids) for each buyer (and seller), which in turn defines a demand and a supply schedule for the market in question. These schedules do nothing beyond setting extreme limits to the observable price-quantity behavior in that market. All we can say is that the area above the supply curve is a region in which sales are feasible, while the area below the demand curve is a region in which purchases are feasible. Competitive price theory asserts that there will be a tendency for price-quantity equilibrium to occur at the extreme quantity point of the intersection of these two areas. For example, in Chart 1 the shaded triangular area APB represents the intersection of these feasible sales and purchase sets, with P the extreme point of this set. We have no guarantee that the equilibrium defined by the intersection of these sets will prevail, even approximately, in the experimental market (or any real counterpart of it). The mere fact that, by any definition, supply and demand schedules exist in the background of a market does not guarantee that any meaningful relationship exists

[5] The design of my experiments differs from that of Chamberlin (*op. cit.*) in several ways. In Chamberlin's experiment the buyers and sellers simply circulate and engage in bilateral higgling and bargaining until they make a contract or the trading period ends. As contracts are made the transaction price is recorded on the blackboard. Consequently, there is very little, if any, multilateral bidding. Each trader's attention is directed to the one person with whom he is bargaining, whereas in my experiments each trader's quotation is addressed to the entire trading group one quotation at a time. Also Chamberlin's experiment constitutes a pure exchange market operated for a single trading period. There is, therefore, less opportunity for traders to gain experience and to modify their subsequent behavior in the light of such experience. It is only through some learning mechanism of this kind that I can imagine the possibility of equilibrium being approached in any real market. Finally, in the present experiments I have varied the design from one experiment to another in a conscious attempt to study the effect of different conditions of supply and demand, changes in supply or demand, and changes in the rules of market organization on market-price behavior.

between those schedules and what is observed in the market they are presumed to represent. All the supply and demand schedules can do is set broad limits on the behavior of the market.[6] Thus, in the symmetrical supply and demand diagram of Chart 1, it is conceivable that every buyer and seller could make a contract. The \$3.25 buyer could buy from the \$3.25 seller, the \$3.00 buyer could buy from the \$3.00 seller, and so forth, without violating any restrictions on the behavior of buyers and sellers. Indeed, if we separately paired buyers and sellers in this special way, each pair could be expected to make a bilateral contract at the seller's minimum price which would be equal to the buyer's maximum price.

It should be noted that these experiments conform in several important ways to what we know must be true of many kinds of real markets. In a real competitive market such as a commodity or stock exchange, each marketer is likely to be ignorant of the reservation prices at which other buyers and sellers are willing to trade. Furthermore, the only way that a real marketer can obtain knowledge of market conditions is to observe the offers and bids that are tendered, and whether or not they are accepted. These are the public data of the market. A marketer can only know his own attitude, and, from observation, learn something about the objective behavior of others. This is a major feature of these experimental markets. We deliberately avoid placing at the disposal of our subjects any information which would not be practically attainable in a real market. Each experimental market is forced to provide all of its own "history." These markets are also a replica of real markets in that they are composed of a practical number of marketers, say twenty, thirty, or forty. We do not require an indefinitely large number of marketers, which is usually supposed necessary for the existence of "pure" competition.

One important condition operating in our experimental markets is not likely to prevail in real markets. The experimental conditions of supply and demand are held constant over several successive trading periods in order to give any equilibrating mechanisms an opportunity to establish an equilibrium over time. Real markets are likely to be continually subjected to changing conditions of supply and demand. Marshall was well aware of such problems and defined equilibrium as a condition toward which the market would move *if* the forces of supply and demand were to remain stationary for a sufficiently long time. It is this concept of equilibrium that this particular series of experiments is designed, in part, to test. There is nothing to prevent one from passing out new buyer and/or seller cards, representing changed demand and/or supply conditions, at the end of each trading period if the objective is to study the effect of such constantly changing conditions on market behavior.

[6] In fact, these schedules are modified as trading takes place. Whenever a buyer and a seller make a contract and "drop out" of the market, the demand and supply schedules are shifted to the left in a manner depending upon the buyer's and seller's position on the schedules. Hence, the supply and demand functions continually alter as the trading process occurs. It is difficult to imagine a real market process which does not exhibit this characteristic. This means that the intra-trading-period schedules are not independent of the transactions taking place. However, the *initial* schedules prevailing at the opening of each trading period are independent of the transactions, and it is these schedules that I identify with the "theoretical conditions of supply and demand," which the theorist defines independently of actual market prices and quantities. One of the important objectives in these experiments is to determine whether or not these initial schedules have any power to predict the observed behavior of the market.

In three of the nine experiments, once-for-all changes in demand and/or supply were made for purposes of studying the transient dynamics of a market's response to such stimuli.

III. DESCRIPTION AND DISCUSSION OF EXPERIMENTAL RESULTS

The supply and demand schedule for each experiment is shown in the diagram on the left of Charts 1–10. The price and quantity at which these schedules intersect will be referred to as the predicted or theoretical "equilibrium" price and quantity for the corresponding experimental market, though such an equilibrium will not necessarily be attained or approached in the market. The performance of each experimental market is summarized in the diagram on the right of Charts 1–10, and in Table 1. Each chart shows the sequence of contract or exchange prices in the order in which they occurred in each trading period. Thus, in Chart 1, the first transaction was effected at \$1.70, the second at \$1.80, and so on, with a total of five transactions occurring in trading period 1. These charts show contract price as a function of transaction number rather than calendar time, the latter of course being quite irrelevant to market dynamics.

The most striking general characteristic of tests 1–3, 5–7, 9, and 10 is the remarkably strong tendency for exchange prices to approach the predicted equilibrium for each of these markets. As the exchange process is repeated through successive trading periods with the same conditions of supply and demand prevailing initially in each period, the variation in exchange prices tends to decline, and to cluster more closely around the equilibrium. In Chart 1, for example, the variation in contract prices over the five trading periods is from \$1.70 to \$2.25. The maximum possible variation is from \$0.75 to \$3.25 as seen in the supply and demand schedules. As a means of measuring the convergence of exchange prices in each market, a "coefficient of convergence," α, has been computed for each trading period in each market. The α for each trading period is the ratio of the standard deviation of exchange prices, σ_0, to the predicted equilibrium price, P_0, the ratio being expressed as a percentage. That is, $\alpha = 100\ \sigma_0/P_0$ where σ_0 is the standard deviation of exchange prices around the equilibrium price rather than the mean exchange price. Hence, α provides a measure of exchange price variation relative to the predicted equilibrium exchange price. As is seen in Table 1 and the charts for all tests except test 8, α tends to decline from one trading period to the next, with tests 2, 4*A*, 5, 6*A*, 7, 9*A*, and 10 showing monotone convergence.

Turning now to the individual experimental results, it will be observed that the equilibrium price and quantity are approximately the same for the supply and demand curves of tests 2 and 3. The significant difference in the design of these two tests is that the supply and demand schedules for test 2 are relatively flat, while the corresponding schedules for test 3 are much more steeply inclined.

Under the Walrasian hypothesis (the rate of increase in exchange price is an increasing function of the excess demand at that price), one would expect the market in test 2 to converge more rapidly than that in test 3. As is evident from comparing the results in Charts 2 and 3, test 2 shows a more rapid and less erratic tendency toward equilibrium. These results are, of course, consistent with many other hypotheses, including the

TABLE 1

Test	Trading Period	Predicted Exchange Quantity (x_0)	Actual Exchange Quantity (x)	Predicted Exchange Price (P_0)	Average Actual Exchange Price ($\bar{P}$)	Coefficient of Convergence [$\alpha = (100\ \sigma_0)/(P_0)$]	No. of Submarginal Buyers Who Could Make Contracts	No. of Submarginal Buyers Who Made Contracts	No. of Submarginal Sellers Who Could Make Contracts	No. of Submarginal Sellers Who Made Contracts
1.......	1	6	5	2.00	1.80	11.8	5	0	5	0
	2	6	5	2.00	1.86	8.1	5	0	5	0
	3	6	5	2.00	2.02	5.2	5	0	5	0
	4	6	7	2.00	2.03	5.5	5	1	5	1
	5	6	6	2.00	2.03	3.5	5	0	5	0
2.......	1	15	16	3.425	3.47	9.9	4	2	3	1
	2	15	15	3.425	3.43	5.4	4	2	3	1
	3	15	16	3.425	3.42	2.2	4	2	3	0
3.......	1	16	17	3.50	3.49	16.5	5	1	6	2
	2	16	15	3.50	3.47	6.6	5	0	6	1
	3	16	15	3.50	3.56	3.7	5	0	6	0
	4	16	15	3.50	3.55	5.7	5	0	6	0
4*A*....	1	10	9	3.10	3.53	19.1	None	None	None	None
	2	10	9	3.10	3.37	10.4	None	None	None	None
	3	10	9	3.10	3.32	7.8	None	None	None	None
	4	10	9	3.10	3.32	7.6	None	None	None	None
4*B*......	1	8	8	3.10	3.25	6.9	None	None	None	None
	2	8	7	3.10	3.30	7.1	None	None	None	None
	3	8	6	3.10	3.29	6.5	None	None	None	None
5*A*......	1	10	11	3.125	3.12	2.0	7	0	7	0
	2	10	9	3.125	3.13	0.7	7	1	7	0
	3	10	10	3.125	3.11	0.7	7	1	7	0
	4	10	9	3.125	3.12	0.6	7	0	7	0
5*B*......	1	12	12	3.45	3.68	9.4	4	0	3	2
	2	12	12	3.45	3.52	4.3	4	0	3	0
6*A*......	1	12	12	10.75	5.29	53.8	5	3	None	None
	2	12	12	10.75	7.17	38.7	5	3	None	None
	3	12	12	10.75	9.06	21.1	5	2	None	None
	4	12	12	10.75	10.90	9.4	5	0	None	None
6*B*......	1	12	11	8.75	9.14	11.0	4	1	None	None
	2	12	6	8.75	....	....	4	1	None	None
7.......	1	9	8	3.40	2.12	49.1	3	1	None	None
	2	9	9	3.40	2.91	22.2	3	0	None	None
	3	9	9	3.40	3.23	7.1	3	1	None	None
	4	9	8	3.40	3.32	5.4	3	0	None	None
	5	9	9	3.40	3.33	3.0	3	0	None	None
	6	9	9	3.40	3.34	2.7	3	0	None	None
8*A*......	1	7	8	2.25	2.50	19.0	5	0	4	0
	2	7	5	2.25	2.20	2.9	5	0	4	0
	3	7	6	2.25	2.12	7.4	5	0	4	0
	4	7	5	2.25	2.12	7.0	5	0	4	0
8*B*......	1	7	6	2.25	2.23	7.8	5	0	4	0
	2	7	6	2.25	2.29	6.1	5	0	4	0
9*A*......	1	18	18	3.40	2.81	21.8	6	3	None	None
	2	18	18	3.40	2.97	15.4	6	2	None	None
	3	18	18	3.40	3.07	13.2	6	2	None	None
9*B*....	1	20	20	3.80	3.52	10.3	4	3	2	0
10.......	1	18	18	3.40	3.17	11.0	4	2	None	None
	2	18	17	3.40	3.36	3.2	4	1	None	None
	3	18	17	3.40	3.38	2.2	4	0	None	None

CHART 2

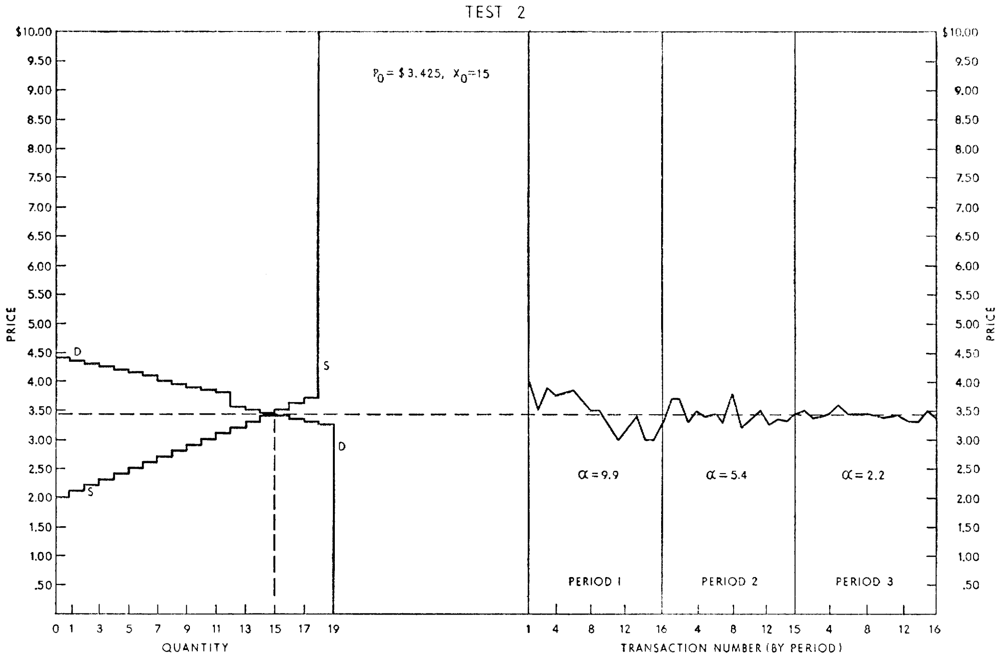
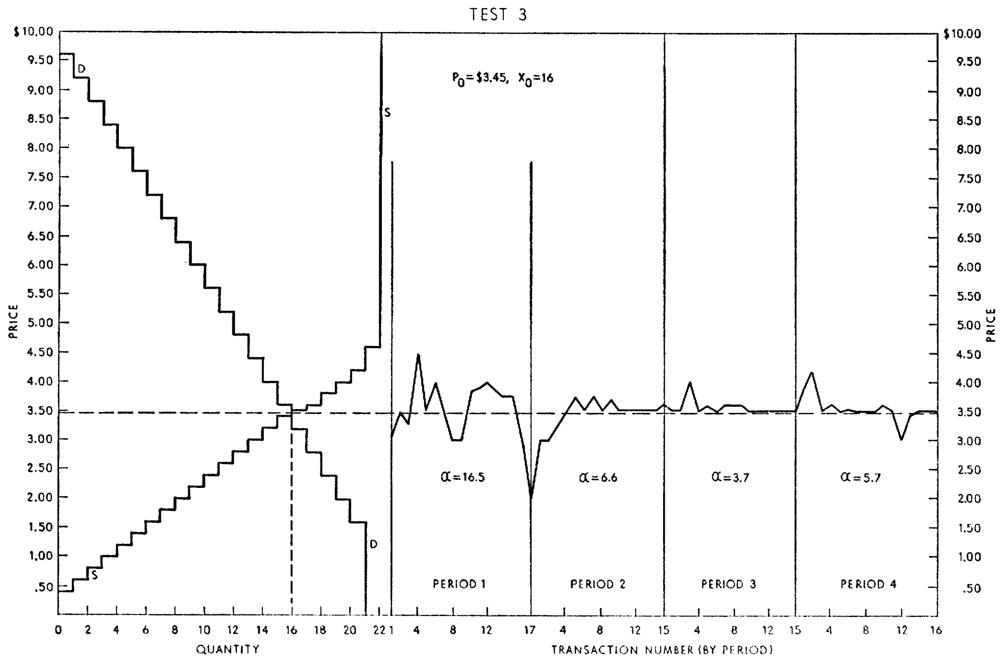


CHART 3

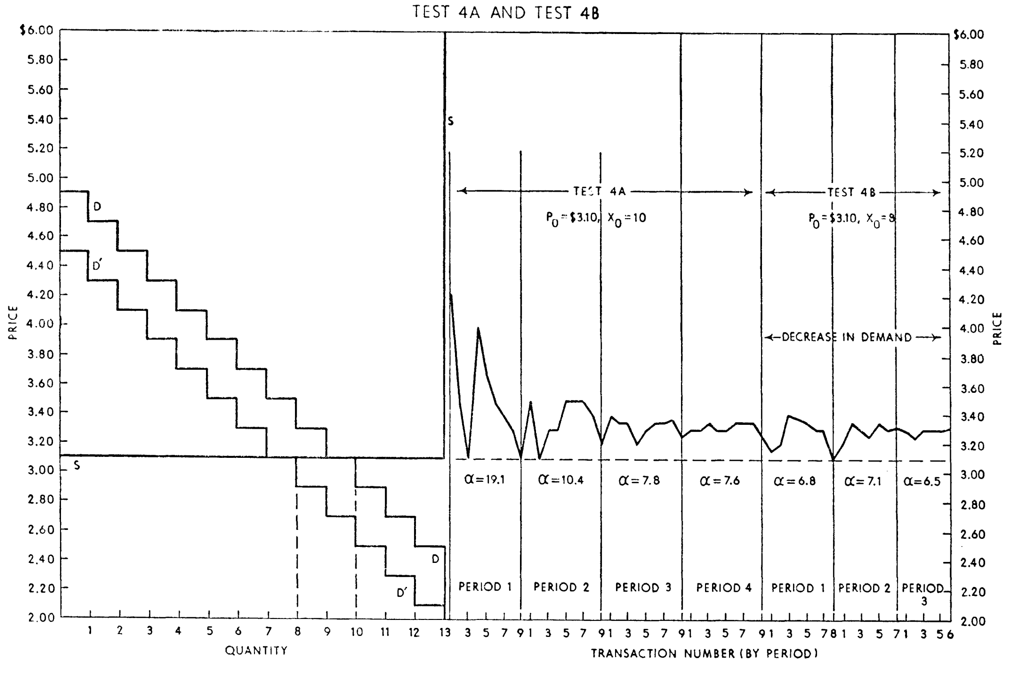


excess-rent hypothesis, to be discussed later.[7]

The tests in Chart 4 are of special interest from the point of view of the Walrasian hypothesis. In this case the supply curve is perfectly elastic—all sellers have cards containing the price $3.10. Each seller has the same lower bound on his reservation price acceptance set. In this sense, there is no divergence of attitude among the sellers, though there might be marked variation in their bargaining propensities. According to the Walrasian hypothesis this market should exhibit rapid convergence toward the equilibrium since there is a considerable excess supply at prices just barely above the equilibrium price. From the results we see that the market is not particularly slow in converging, but it converges to a fairly stable price about $0.20 above the predicted equilibrium. Furthermore, in test *4B*, which was an extension of *4A*, the interjection of a decrease in demand from *DD* to *D'D'* was ineffective as a means of shocking the market down to its supply and demand equilibrium. This decrease in demand was achieved by passing out new buyer cards corresponding to *D'D'* at the close of period 4 in test *4A*. As expected, the market approaches equilibrium from above, since contracts at prices below equilibrium are impossible.

The sellers in this market presented a solid front against price being lowered to "equilibrium." In the previous mar-

CHART 4



[7] The results are inconsistent with the so-called Marshallian hypothesis (the rate of increase in quantity exchanged is an increasing function of the excess of demand price over supply price), but this hypothesis would seem to be worth considering only in market processes in which some quantity-adjusting decision is made by the marketers. The results of a pilot experiment in "short-run" and "long-run" equilibrium are displayed in the Appendix.

kets there was a divergence of seller attitude, so that only a very few marginal and near-marginal sellers might offer serious resistance to price being forced to equilibrium. And this resistance tended to break down when any of the stronger intramarginal sellers accepted contracts below equilibrium.

From these results it is clear that the static competitive market equilibrium may depend not only on the intersection of the supply and demand schedules, but also upon the shapes of the schedules. Specifically, I was led from test 4 to the tentative hypothesis that there may be an upward bias in the equilibrium price of a market, which will be greater the more elastic is the supply schedule relative to demand.[8] For example, let A be the area under the demand schedule and above the theoretical equilibrium. This is Marshall's consumer surplus, but to avoid any welfare connotations of this term, I shall refer to the area as "buyers' rent." Let B be the area above the supply schedule and below the theoretical equilibrium (Marshall's producer surplus) which I shall call "sellers' rent." Now, the tentative hypothesis was that the actual market equilibrium will be above the theoretical equilibrium by an amount which depends upon how large A is relative to B. Similarly, there will be a downward bias if A is small relative to B.

Test 4 is of course an extreme case, since $B = 0$. In test 3, A is larger than B, and the trading periods 3 and 4 exhibit a slight upward bias in the average actual exchange price (see Table 1). This provides some slight evidence in favor of the hypothesis.

As a consequence of these considerations, test 7 was designed specifically to obtain additional information to support or contradict the indicated hypothesis. In this case, as is seen in Chart 7 (see below), buyers' rent is substantially smaller than sellers' rent. From the resulting course of contract prices over six trading periods in this experiment, it is evident that the convergence to equilibrium is very slow. From Table 1, the average exchange prices in the last three trading periods are, respectively, \$3.32, \$3.33, and \$3.34. Average contract prices are still exhibiting a gradual approach to equilibrium. Hence, it is entirely possible that the static equilibrium would eventually have been attained. A still smaller buyers' rent may be required to provide any clear downward bias in the static equilibrium. One thing, however, seems quite unmistakable from Chart 7, the relative magnitude of buyers' and sellers' rent affects the speed with which the actual market equilibrium is approached. One would expect sellers to present a somewhat weaker bargaining front, especially at first, if their rent potential is large relative to that of buyers. Thus, in Chart 7, it is seen that several low reservation price sellers in trading periods 1 and 2 made contracts at low exchange prices, which, no doubt, seemed quite profitable to these sellers. However, in both these trading periods the later exchange prices were much higher, revealing to the low-price sellers that, however profitable their initial sales had been, still greater profits were possible under stiffer bargaining.

A stronger test of the hypotheses that buyer and seller rents affect the speed of adjustment and that they affect the final equilibrium in the market would be obtainable by introducing actual mon-

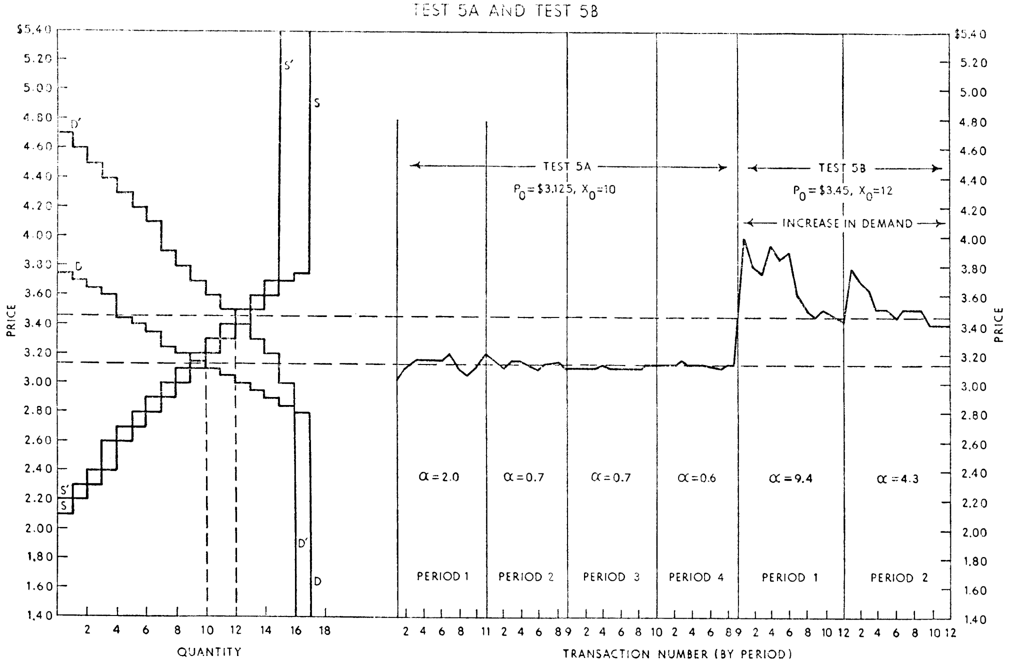
[8] Note that the Walrasian hypothesis might lead one to expect a downward bias since excess supply is very large at prices above equilibrium if supply is very elastic relative to demand.

etary payoffs in the experiment. Thus, one might offer to pay each seller the difference between his contract price and his reservation price and each buyer the difference between his reservation price and his contract price. In addition, one might pay each trader a small lump sum (say $0.05) just for making a contract in any period. This sum would represent any such reluctance that is attributable to artificial elements in the present experiments.[9]

The experiment summarized in Chart 5 was designed to study the effect on market behavior of changes in the conditions of demand and supply. As it happened, this experiment was performed on a considerably more mature group

CHART 5

TEST 5A AND TEST 5B



"normal profits," that is, a small return even if the good is sold at its minimum supply price or purchased at its maximum demand price. The present experiments have not seemed to provide any motivation problems. The subjects have shown high motivation to do their best even without monetary payoffs. But our experimental marginal buyers and sellers may be more reluctant to approach their reservation prices than their counterparts in real markets. The use of monetary payoffs, as suggested, should remove of subjects than any of the other experiments. Most of the experiments were performed on sophomore and junior engineering, economics, and business majors, while test 5 was performed on a

[9] Since this was written, an experiment has been tried using monetary payoffs and the same supply and demand design shown in Chart 4. The result, as conjectured in the text, was to remove the reluctance of sellers to sell at their reservation prices. By the second trading period the market was firmly in equilibrium. In the third period all trades were at $3.10! Apparently $0.05 per period was considered satisfactory normal profit.

graduate class in economic theory. In view of this difference, it is most interesting to find the phenomenally low values for α exhibited by test 5*A*. The coefficient of convergence is smaller for the opening and later periods of this market than for any period of any of the other tests. Furthermore, trading periods 2–4 show α's of less than 1 per cent, indicating an inordinately strong and rapid tendency toward equilibrium. In this case, no offers or bids were accepted until the bidding had converged to prices which were very near indeed to the equilibrium. Contract prices ranged from \$3.00 to \$3.20 as compared with a possible range from \$2.10 to \$3.75.

At the close of test 5*A* new cards were distributed corresponding to an increase in demand, from *DD* to *D'D'*, as shown in Chart 5.[10] The subjects, of course, could guess from the fact that new buyer cards were being distributed that a change in demand was in the wind. But they knew nothing of the direction of change in demand except what might be guessed by the buyers from the alteration of their individual reservation prices. When trading began (period 1, test 5*B*), the immediate response was a very considerable upward sweep in exchange prices with several contracts being closed in the first trading period well above the new higher equilibrium price. Indeed, the eagerness to buy was so strong that two sellers who were submarginal both before and after the increase in demand (their reservation prices were \$3.50 and \$3.70) were able to make contracts in this transient phase of the market. Consequently, the trading group showing the strongest equilibrating tendencies exhibited very erratic behavior in the transient phase following the increase in demand. Contract prices greatly overshot the new equilibrium and rationing by the market was less efficient in this transient phase. In the second trading period of test 5*B* no submarginal sellers or buyers made contracts and the market exhibited a narrowed movement toward the new equilibrium.

Test 6*A* was designed to determine whether market equilibrium was affected by a marked imbalance between the number of intramarginal sellers and the number of intramarginal buyers near the predicted equilibrium price. The demand curve, *DD*, in Chart 6 falls continuously to the right in one-unit steps, while the supply curve, *SS*, becomes perfectly inelastic at the price \$4.00, well below the equilibrium price \$10.75. The tentative hypothesis was that the large rent (\$6.75) enjoyed by the marginal seller, with still larger rents for the intramarginal sellers, might prevent the theoretical equilibrium from being established. From the results it is seen that the earlier conjecture concerning the effect of a divergence between buyer and seller rent on the approach to equilibrium is confirmed. The approach to equilibrium is from below, and the convergence is relatively slow. However, there is no indication that the lack of marginal sellers near the theoretical equilibrium has prevented the equilibrium from being attained. The average contract price in trading period 4 is \$10.90, only \$0.15 above the predicted equilibrium.

At the close of trading period 4 in test 6*A*, the old buyer cards corresponding to *DD* were replaced by new cards

[10] Note also that there was a small (one-unit) decrease in supply from *SS* to *S'S'*. This was not planned. It was due to the inability of one subject (the seller with the \$2.10 reservation price) in test 5*A* to participate in test 5*B*. Therefore, except for the deletion of this one seller from the market, the conditions of supply were not altered, that is, the sellers of test 5*B* retained the same reservation price cards as they had in test 5*A*.

CHART 6

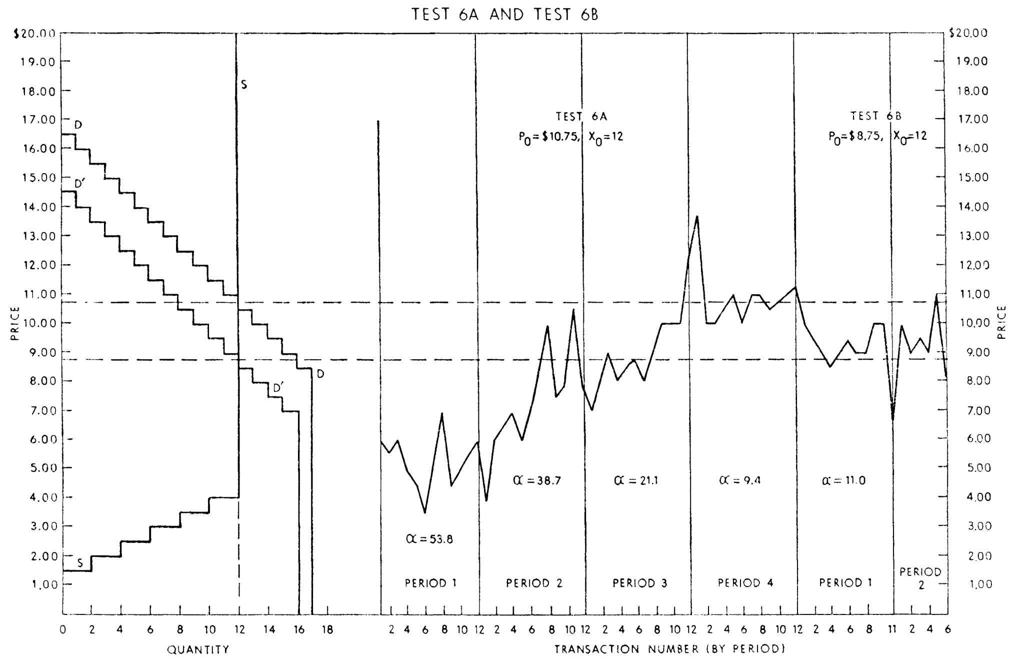
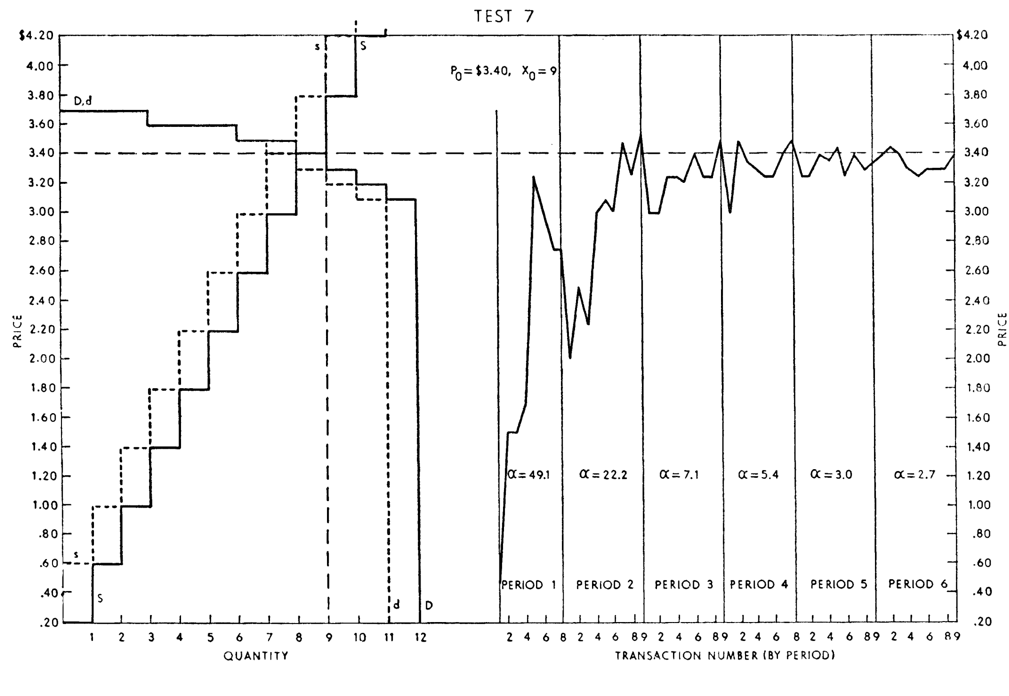
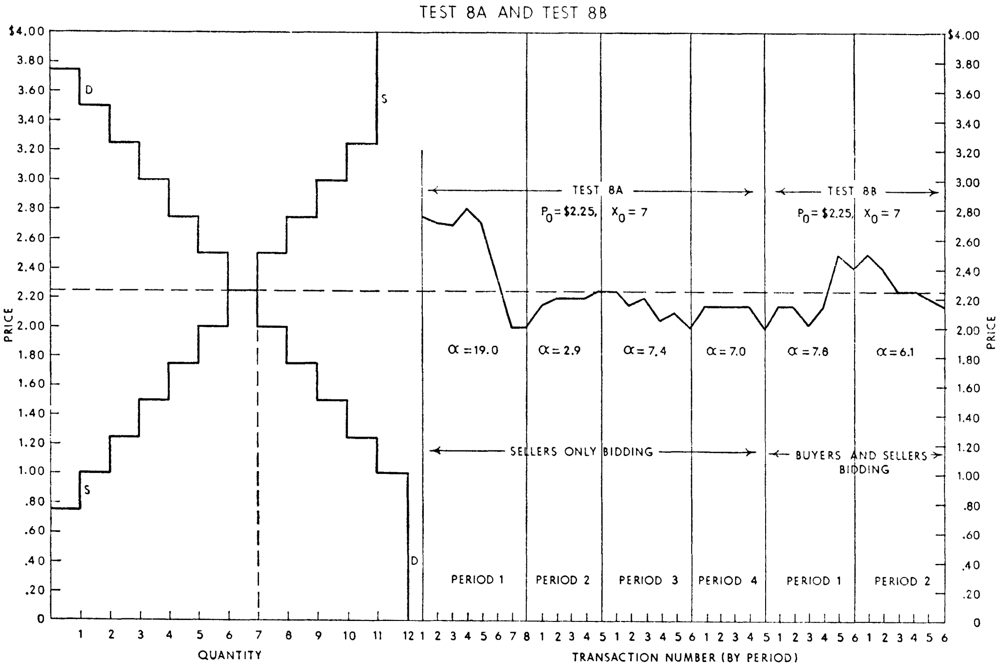


CHART 7



corresponding to $D'D'$ in Chart 6. Trading was resumed with the new conditions of decreased demand (test 6*B*). There was not sufficient time to permit two full trading periods of market experience to be obtained under the new demand conditions. However, from the results in Chart 6, it is evident that the market responded promptly to the decrease in demand by showing apparent convergence to the new equilibrium. Note in particular that there occurred no significant tendency for market prices to overshoot the new equilibrium as was observed in test 5*B*.

CHART 8



All of the above experiments were conducted under the same general rules of market organization. Test 8 was performed as an exploratory means of testing the effect of changes in market organization on market price. In the first four trading periods of this experiment (test 8*A*), only sellers were permitted to enunciate offers. In this market, buyers played a passive role; they could either accept or reject the offers of sellers but were not permitted to make bids. This market was intended to simulate approximately an ordinary retail market. In such markets, in the United States, sellers typically take the initiative in advertising their offer prices, with buyers electing to buy or not to buy rather than taking part in a higgling and bargaining process. Since sellers desire to sell at the highest prices they can get, one would expect the offer prices to be high, and, consequently, one might expect the exchange prices to show a persistent tendency to remain above the predicted equilibrium. The result was in accordance with this crude expectation in the first market period only (test 8*A*, Chart 8). Since sellers only were making offers, the price quotations tended to be very much above equilibrium. Five of these offers were accepted at prices ranging from \$2.69 to \$2.80 by the five buyers with maximum reservation prices of \$2.75 or more. This left only buyers with lower reservation prices. The competition of sellers pushed the offer prices lower and the remaining buyers made contracts at prices (\$2.35, \$2.00, and \$2.00) near or below the equilibrium price. The early buyers in that first market period never quite recovered from having subsequently seen exchange prices fall much below the prices at which they had bought. Having been badly fleeced, through ignorance, in that first trading period, they refrained from accepting any high price offers in the remaining three periods of the test. This action, together with seller offer price competition, kept exchange prices at levels persistently below equilibrium for the remainder of test 8*A*. Furthermore, the coefficient of convergence increased from 2.9 per cent in the second trading period to 7.4 and 7.0 per cent in the last two periods. At the close of the fourth trading period, the market rules were changed to allow buyers to make quotations as well as sellers. Under the new rules (test 8*B*) two trading periods were run. Exchange prices immediately moved toward equilibrium with the closing prices of period 1 and opening prices of period 2 being above the equilibrium for the first time since period 1 of test 8*A*.

It would seem to be of some significance that of the ten experiments reported on, test 8 shows the clearest lack of convergence toward equilibrium. More experiments are necessary to confirm or deny these results, but it would appear that important changes in market organization—such as permitting only sellers to make quotations—have a distinctly disturbing effect on the equilibrating process. In particular the conclusion is suggested that markets in which only sellers competitively publicize their offers tend to operate to the benefit of buyers at the expense of sellers.

Turning to tests 9*A* and 10 (shown in Charts 9 and 10), it should be noted that the buyers and sellers in these tests received the same cards as their counterparts in test 7. The only difference was that the former entered the market to effect two transactions each, instead of one. Thus the three buyers with \$3.70 cards could each buy two units at \$3.70 or less in tests 9 and 10. This change in the design of test 7 resulted in a doubling of the maximum demand and supply quantities at each hypothetical price.

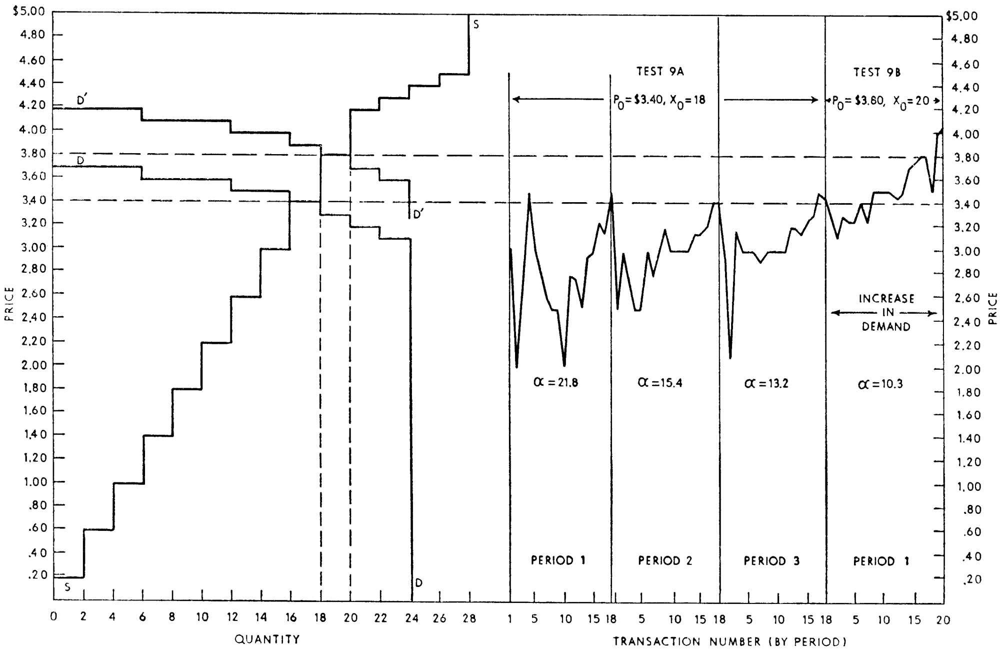
By permitting each buyer and seller to make two contracts per period, twice as much market "experience" is potentially to be gained by each trader in a given period. Each trader can experiment more in a given market—correcting his bids or offers in the light of any surprises or disappointments resulting from his first contract. In the previous experiments such corrections or alterations in the bargaining behavior of a trader had to await the next trading period once the trader had made a contract.[11]

[11] This process of correction over time, based upon observed price quotations and the actual contracts that are executed, is the underlying adjustment mechanism operating in all of these experiments. This is in contrast with the Walrasian *tâtonnement* or groping process in which "when a price is cried, and the effective demand and offer corresponding to this price are not equal, another price is cried for which there is another corresponding effective demand and offer" (see Leon Walras, *Elements of Pure Economics*, trans. William Jaffe [Chicago: Richard D. Irwin, Inc., 1954], p. 242). The Walrasian groping process suggests a centralized institutional means of trying different price quotations until the equilibrium is discovered. In our experiments, as in real markets, the groping process is decentralized, with all contracts binding whether they are at equilibrium or non-equilibrium prices.

Comparison of the results of the three trading periods in test 9*A* with the first three trading periods of test 7 shows that the tendencies toward equilibrium (as measured by α) were greater in test 9*A* during the first two periods and smaller in the third period. The same comparison between tests 7 and 10 reveals a stronger tendency toward equilibrium in test 10 than in the first three periods of trade increased to the new equilibrium rate of twenty units per period. Note that the equilibrium tendency in the trading period of test 9*B* was greater than in any of the perious periods of test 9*A*. The increase in demand, far from destabilizing the market as was the case in test 5*B*, tended to strengthen its relatively weak equilibrium tendencies.

CHART 9

TEST 9A AND TEST 9B



of 7. Hence an increase in volume appears to speed the equilibrating process. Indeed, the three trading periods of test 10 are roughly equivalent to the six trading periods of test 7, so that doubling volume in a given period is comparable to running two trading periods at the same volume.

In test 9*B* the consequences of an increase in demand were once again tested. Contract prices responded by moving upward immediately, and the volume

IV. EMPIRICAL ANALYSIS OF EXPERIMENTAL DATA: THE "EXCESS-RENT" HYPOTHESIS

The empirical analysis of these ten experiments rests upon the hypothesis that there exists a stochastic difference equation which "best" represents the price convergence tendencies apparent in Charts 1–10. The general hypothesis is that

$$\Delta p_t = p_{t+1} - p_t = f[x_1(p_t), x_2(p_t), \ldots] + \epsilon_t , \quad (1)$$

where the arguments x_1, x_2, . . . reflect characteristics of the experimental supply and demand curves and the bargaining characteristics of individual test groups, and ϵ_t is a random variable with zero mean. For a given experimental test group, under the so-called Walrasian hypothesis $x_1(p_t)$ might be the excess demand prevailing at p_t, with $f = 0$ when $x_1 = 0$.

My first empirical investigation is concerned with the measuremet of the equilibrating tendencies in these markets and the ability of supply and demand theory to predict the equilibrium price in each experiment. To this end note that equation (1) defines a stochastic phase function[12] of the form $p_{t+1} = g(p_t) + \epsilon_t$. An equilibrium price P_0 is attained when $P_0 = g(P_0)$. Rather than estimate the phase function for each experiment, it was found convenient to make linear estimates of its first difference, that is,

$$\Delta p_t = \alpha_0 + \alpha_1 p_t + \epsilon_t .$$

The corresponding linear phase function has slope $1 + \alpha_1$. The parameters α_0 and α_1 were estimated by linear regression techniques for each of the ten fundamental experiments and are tabulated in column 1 of Table 2.[13] Confidence

[12] See, for example, W. J. Baumol, *Economic Dynamics* (New York: Macmillan Co., 1959), pp. 257–65.

[13] The least squares estimate of α_1 in these experiments can be expected to be biased (see L. Hurwicz, "Least-Squares Bias in Time Series," chap. xv, in T. Koopmans, *Statistical Inference in Dynamic Economic Models* [New York: John Wiley & Sons, 1950]). However, since in all of the basic experiments there are twenty or more observations, the bias will not tend to be large.

CHART 10

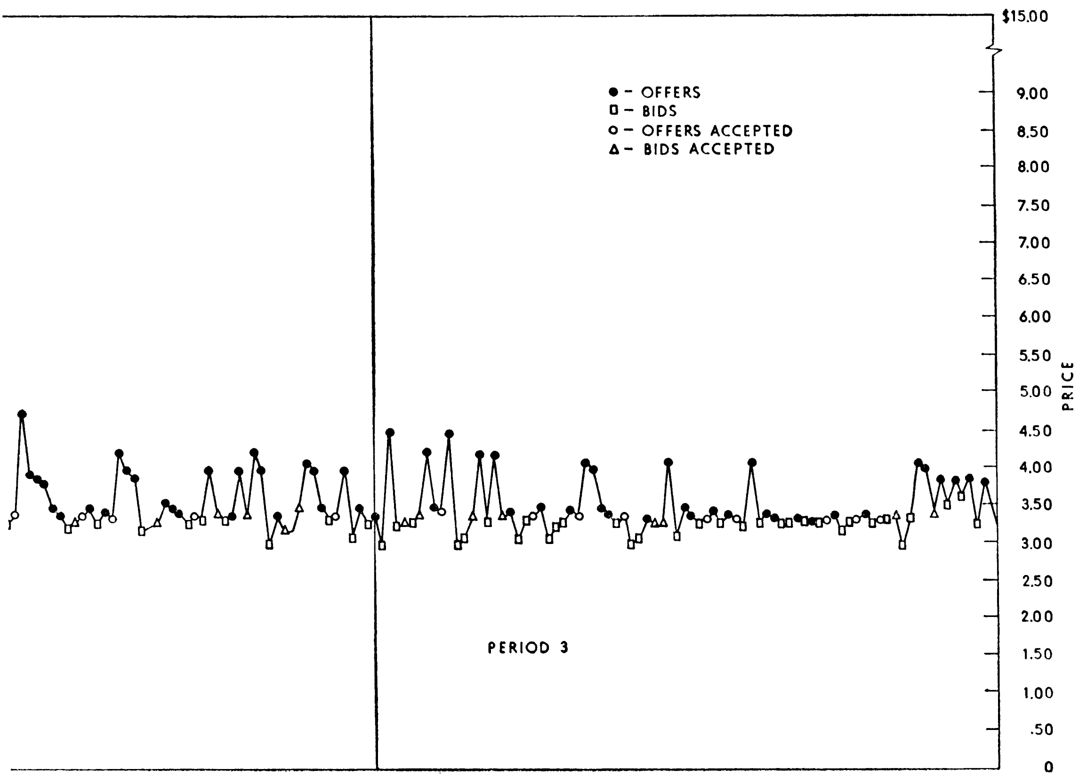


TABLE 2

Experiment	($\Delta p_t = \alpha_0 + \alpha_1 p_t$)	Walrasian ($\Delta p_t = \beta_{01} + \beta_{11} x_{1t}$)	Modified Walrasian ($\Delta p_t = \beta_{03} + \beta_{13} x_{1t} + \beta_{33} x_{3t}$)	Excess Rent ($\Delta p_t = \beta_{02} + \beta_{22} x_{2t}$)	Modified Excess Rent ($\Delta p_t = \beta_{04} + \beta_{24} x_{2t} + \beta_{34} x_{3t}$)
1.	$0.933 - 0.474\ p_t$ (± 0.329)	$-0.026 + 0.070\ x_{1t}$ (± 0.042)	$-0.027 + 0.068\ x_{1t} - 0.0056\ x_{3t}$ $(\pm 0.015)\ (\pm 0.0220)$	$-0.028 + 0.486\ x_{2t}$ (± 0.322)	$-0.031 + 0.491\ x_{2t} - 0.0054\ x_{3t}$ $(\pm 0.104)\ (\pm 0.0215)$
2.	$1.904 - 0.560\ p_t$ (± 0.250)	$.002 +\ .035\ x_{1t}$ $(\pm\ .015)$	$-\ .170 +\ .042\ x_{1t} -\ .0693\ x_{3t}$ $(\pm\ .006)\ (\pm\ .0311)$	$.008 +\ .141\ x_{2t}$ $(\pm\ .067)$	$-\ .070 +\ .152\ x_{2t} -\ .0313\ x_{3t}$ $(\pm\ .024)\ (\pm\ .0649)$
3.	$2.275 - 0.647\ p_t$ (± 0.292)	$.157 +\ .107\ x_{1t}$ $(\pm\ .045)$	$.093 +\ .105\ x_{1t} +\ .0042\ x_{3t}$ $(\pm\ .014)\ (\pm\ .0317)$	$.071 +\ .227\ x_{2t}$ $(\pm\ .097)$	$-\ .022 +\ .225\ x_{2t} +\ .0064\ x_{3t}$ $(\pm\ .031)\ (\pm\ .0315)$
4*A*	$2.852 - 0.849\ p_t$ (± 0.287)	$.761 +\ .168\ x_{1t}$ $(\pm\ .057)$	$.794 +\ .169\ x_{1t} -\ .0007\ x_{3t}$ $(\pm\ .018)\ (\pm\ .0564)$	$.145 +\ .129\ x_{2t}$ $(\pm\ .049)$	$.139 +\ .130\ x_{2t} +\ .0017\ x_{3t}$ $(\pm\ .016)\ (\pm\ .0641)$
5*A*	$2.448 - 0.784\ p_t$ (± 0.302)	$-\ .031 +\ .023\ x_{1t}$ $(\pm\ .009)$	$-\ .035 +\ .023\ x_{1t} -\ .0029\ x_{3t}$ $(\pm\ .003)\ (\pm\ .0043)$	$-\ .007 +\ .205\ x_{2t}$ $(\pm\ .098)$	$-\ .009 +\ .204\ x_{2t} +\ .0015\ x_{3t}$ $(\pm\ .032)\ (\pm\ .0048)$
6*A*	$1.913 - 0.220\ p_t$ (± 0.174)	$-\ .675 +\ .243\ x_{1t}$ $(\pm\ .175)$	$.010 +\ .285\ x_{1t} +\ .0211\ x_{3t}$ $(\pm\ .057)\ (\pm\ .0847)$	$-\ .309 +\ .038\ x_{2t}$ $(\pm\ .037)$	$.305 +\ .034\ x_{2t} +\ .0146\ x_{3t}$ $(\pm\ .013)\ (\pm\ .0906)$
7.	$1.216 - 0.368\ p_t$ (± 0.116)	$-\ .102 +\ .074\ x_{1t}$ $(\pm\ .049)$	$-\ .070 +\ .075\ x_{1t} +\ .0063\ x_{3t}$ $(\pm\ .009)\ (\pm\ .0738)$	$.007 +\ .051\ x_{2t}$ $(\pm\ .021)$	$.058 +\ .053\ x_{2t} +\ .0096\ x_{3t}$ $(\pm\ .007)\ (\pm\ .0750)$
8*A*	$0.225 - 0.121\ p_t$ (± 0.226)	$-\ .040 +\ .020\ x_{1t}$ $(\pm\ .030)$	$-\ .027 +\ .025\ x_{1t} -\ .0462\ x_{3t}$ $(\pm\ .011)\ (\pm\ .0487)$	$-\ .036 +\ .051\ x_{2t}$ $(\pm\ .094)$	$-\ .022 +\ .064\ x_{2t} -\ .0396\ x_{3t}$ $(\pm\ .035)\ (\pm\ .0505)$
9*A*	$1.653 - 0.554\ p_t$ (± 0.273)	$-\ .450 +\ .061\ x_{1t}$ $(\pm\ .036)$	$-\ .447 +\ .085\ x_{1t} +\ .0198\ x_{3t}$ $(\pm\ .012)\ (\pm\ .0423)$	$-\ .209 +\ .071\ x_{2t}$ $(\pm\ .029)$	$-\ .065 +\ .094\ x_{2t} +\ .0222\ x_{3t}$ $(\pm\ .009)\ (\pm\ .0356)$
10.	$1.188 - 0.356\ p_t$ (± 0.233)	$-0.039 + 0.020\ x_{1t}$ (± 0.014)	$-0.028 + 0.020\ x_{1t} + 0.0008\ x_{3t}$ $(\pm 0.004)\ (\pm 0.0199)$	$-0.022 + 0.055\ x_{2t}$ (± 0.032)	$-0.008 + 0.056\ x_{2t} + 0.0011\ x_{3t}$ $(\pm 0.014)\ (\pm 0.0194)$

intervals for a 95 per cent fiducial probability level are shown in parentheses under the estimate of a_1 for each experiment. With the exception of experiment 8*A*, the 95 per cent confidence interval for each regression coefficient is entirely contained in the interval $-2 < a_1 < 0$, which is required for market stability. Hence, of these ten experiments, 8*A* is the only one whose price movements are sufficiently erratic to prevent us from rejecting the null hypothesis of instability, and of the ten basic experiments this is the one in which the trading rules were altered to permit only sellers to quote prices.[14]

The regressions of column 1, Table 2, and associated computation provide a means of predicting the adjustment pressure on price, Δp_t, for any given p_t. In particular, we can compute

$$t = \frac{a_0 + a_1 P_0}{S(a_0 + a_1 P_0)}$$

for the sample estimates on the assumption that $\Delta p_t = 0$ when $p_t = P_0$ in the population. These t-values are shown in column 1, Table 3, for the ten primary and the five "*B*" auxilary experiments. Low absolute values of t imply that, relative to the error in the prediction, the predicted equilibrium is close to the theoretical. The four lowest absolute t-values are for experimental designs with the smallest difference between equilibrium buyers' and sellers' rent. These results provide some additional evidence in favor of our conjecture in Part III, that the equilibrium is influenced by the relative sizes of the areas *A* and *B*. However, from the t-values it would seem that the influence is small except for test 4, where $B = 0$. In this case, the null hypothesis ($\Delta p_t = 0$ when $p_t = P_0$) is rejected even at a significance level below .005.

TABLE 3

Experiment	$t=(a_0+a_1P_0)/[S(a_0+a_1P_0)]$ (1)	Walrasian			Excess Rent			Degrees of Freedom (8)
		$\|\beta_{01}\|$ (2)	$S(\beta_{01})$ (3)	$t=\beta_{01}/S(\beta_{01})$ (4)	$\|\beta_{02}\|$ (5)	$S(\beta_{02})$ (6)	$t=\beta_{02}/S(\beta_{02})$ (7)	
1	−0.673	0.026	0.019	−1.36	0.028	0.021	−0.66	21
2	0.460	.002	.029	0.08	.008	.030	0.25	42
3	1.008	.157	.055	2.88	.071	.046	1.56	57
4*A*	4.170	.761	.137	5.57	.145	.048	3.05	30
4*B*	3.219	.391	.284	1.37	.161	.052	3.08	16
5*A*	−0.333	.031	.008	−3.72	.007	.006	−1.16	33
5*B*	−0.230	.002	.034	0.05	.013	.026	−0.51	20
6*A*	−1.412	.675	.362	−1.87	.309	.311	−0.99	42
6*B*	2.176	.299	.314	0.95	.179	.290	0.62	13
7	−0.740	.102	.057	−1.78	.007	.045	0.15	44
8*A*	−1.597	.040	.029	−1.40	.036	.032	−1.13	18
8*B*	−0.140	.010	.042	−0.24	.016	.043	−0.37	8
9*A*	−0.647	.450	.151	−2.99	.209	.065	−3.21	49
9*B*	−0.021	.012	.112	0.11	.016	.071	−0.23	17
10	−0.731	0.039	0.033	−1.19	0.022	0.028	−0.80	47

Four specific forms for the difference equation (1) were studied in detail and tested for their ability to predict the

[14] Three of the five auxiliary "*B*" experiments demonstrated a similar instability (in the fiducial probability sense), but the samples were considerably smaller than their "*A*" counterparts, they represented considerably fewer trading periods, and they had different and varying objectives. The unstable ones were 4*B*, 8*B*, and 9*B*.

theoretical equilibrium price. These will be referred to as the Walrasian, the excess-rent, the modified Walrasian, and the modified excess-rent hypotheses, respectively. The Walrasian hypothesis is $\Delta p_t = \beta_{01} + \beta_{11}x_{1t}$, where x_{1t} is the excess demand prevailing at the price, p_t, at which the tth transaction occurred. Because of the conjecture that buyers' and sellers' rent might have an effect on individual and market adjustment, an excess-rent hypothesis was introduced. This hypothesis is $\Delta p_t = \beta_{02} + \beta_{22}x_{2t}$, where x_{2t} is the algebraic area

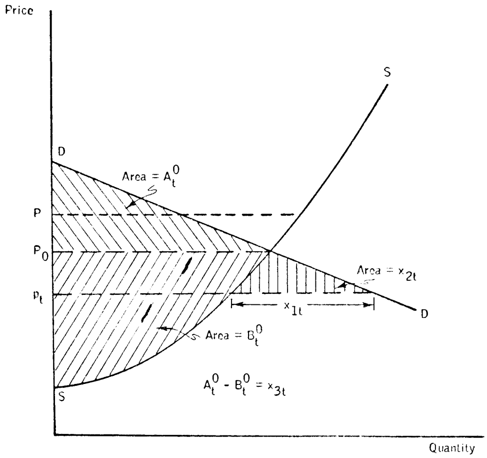


FIG. 1

between the supply and demand curves, and extends from the equilibrium price down to the price of the tth transaction, as shown in Figure 1. The modified Walrasian hypothesis is $\Delta p_t = \beta_{03} + \beta_{13}x_{1t} + \beta_{33}x_{3t}$, where $x_{3t} = A_t^0 - B_t^0$, the algebraic difference between the equilibrium buyers' rent, A_t^0, and the equilibrium sellers' rent, B_t^0. The motivation here was to introduce a term in the adjustment equation which would permit the actual equilibrium price to be biased above or below the theoretical equilibrium, by an amount proportional to the algebraic difference between buyers' and sellers' rent at the theoretical equilibrium. It was believed that such a general hypothesis might be necessary to account for the obvious price equilibrium bias in experiment 4 and the slight apparent bias in experiments 3, 6*A*, 7, and 9*A*. A similar motivation suggested the modified excess-rent hypothesis, $\Delta p_t = \beta_{04} + \beta_{24}x_{2t} + \beta_{34}x_{3t}$.

Since the trading process in these experiments was such that transactions might and generally did take place at non-equilibrium prices, the supply and demand curves shift after each transaction. Hence, in generating observations on x_{1t}, x_{2t}, and x_{3t}, the supply and demand curves were adjusted after each transaction for the effect of the pairing of a buyer and a seller in reducing their effective demand and supply. Thus, in Chart 7, the first transaction was at \$0.50 between the seller with reservation price \$0.20 and a buyer with reservation price \$3.50. Following this trasaction the new effective demand and supply curves become *Dd* and *ss* as shown. The next transaction is at \$1.50. Our hypothesis is that the increase in price from \$0.50 to \$1.50 is due to the conditions represented by *Dd* and *ss* at the price \$0.50. Thus, for the first set of observations $\Delta p_1 = p_1 - p_0 = \$1.50 - \$0.50 = \$1.00$, $x_{11} = 11$, $x_{21} = 20.10$, and $x_{31} = -9.60$ as can be determined from Chart 7. The second transaction paired a \$3.70 buyer and a \$0.60 seller. The next set of observations is then obtained by removing this buyer and seller from *Dd* and *ss* to obtain x_{12}, x_{22}, and x_{32} at $p_2 = 1.50$, with $\Delta p_2 = p_2 - p_1 = 0$, and so on.

Using observations obtained in this manner, regressions for the four different equilibrating hypotheses were computed for the ten fundamental experiments as shown in Table 2, columns 2–5. A 95 per cent confidence interval is shown in parentheses under each regression coefficient. With the exception of experiment 8*A*, the regression coefficients for every experiment are significant under both the Walrasian and the excess-rent hypotheses. On the other hand, β_{33} in the modified Walrasian hypothesis is significant only in experiment 2. In none of the experiments is β_{34} significant for the modified excess-rent hypothesis. These highly unambiguous results seem to suggest that little significance can be attached to the effect of a difference between equilibrium buyers' and sellers' rent in biasing the price equilibrium tendencies.

On this reasoning, we are left with the closely competing Walrasian and excess-rent hypotheses, showing highly significant adjustment speeds, β_{11} and β_{22}. In discriminating between these two hypotheses we shall compare them on two important counts: (1) their ability to predict zero price change in equilibrium, and (2) the standard errors of said predictions. Since $x_{1t}^0 = x_{2t}^0 = 0$, in equilibrium, this requires a comparison between the absolute values of the intercepts of the Walrasian and the excess-rent regressions, $|\beta_{01}|$ and $|\beta_{02}|$, and between $S(\beta_{01})$ and $S(\beta_{02})$. Under the first comparison we can think of $|\beta_{01}|$, shown in column 2, Table 3, as a "score" for the Walrasian hypothesis, and $|\beta_{02}|$, shown in column 5, as a "score" for the excess-rent hypothesis. A low intercept represents a good score. Thus, for experiment 1, in equilibrium, there is a residual tendency for price to change (in this case fall) at the rate of 2.6 cents per transaction by the Walrasian and 2.8 cents by the excess-rent regressions. A casual comparison of columns 2 and 5 reveals that in most of the experiments $|\beta_{01}| > |\beta_{02}|$, and in those for which the reverse is true the difference is quite small, tending thereby to support the excess-rent hypothesis. A more exact discrimination can be made by applying the Wilcoxon[15] paired-sample rank test for related samples to the "scores" of columns 2 and 5. This test applies to the differences $|\beta_{01}| - |\beta_{02}|$, and tests the null hypothesis, H_0, that the Walrasian and excess-rent alternatives are equivalent (the distribution of the differences is symmetric about zero). If applied to all the experiments, including the "*B*'s" ($N = 15$), H_0 is rejected at the $< .02$ significance level. The difference between our paired series of "scores" in favor of the excess-rent hypothesis is therefore significant. It is highly debatable whether all the experiments should be included in such a test, especially 4, which did not tend to the predicted equilibrium, 8, which represented a different organization of the bargaining, and possibly the "*B*" experiments, where the samples were small. Therefore, the test was run omitting all these experiments ($N = 8$), giving a rejection of H_0 at the .05 level. Omitting only 4 and 8 ($N = 11$) allowed H_0 still to be rejected at the $< .02$ level.

If we compare the standard errors $S(\beta_{01})$ and $S(\beta_{02})$ in Table 3, columns 3 and 6, we see that again the excess-rent hypothesis tends to score higher (smaller standard errors). Applying the Wilcoxon test to $S(\beta_{01}) - S(\beta_{02})$ for all the experiments ($N = 15$), we find that this difference, in favor of the excess-rent hypothesis, is significant at the $<.01$ level. The difference is still significant at the $<.01$ level if we omit 4 and 8 from the test, and it is significant at the .05 level if we also eliminate all the "*B*" experiments.

The *t*-values for the two hypotheses

[15] See, for example, K. A. Brownlee, *Statistical Theory and Methodology in Science and Engineering* (New York: John Wiley & Sons, 1960), pp. 196–99.

are shown in columns 4 and 7 of Table 3. They tend also to be lower for the excess-rent hypothesis.

Bearing in mind that our analysis is based upon a limited number of experiments, and that revisions may be required in the light of further experiments with different subjects or with monetary payoffs, we conclude the following: Of the four hypotheses tested, the two modified forms show highly insignificant regression coefficients for the added explanatory variable. As between the Walrasian and the excess-rent hypotheses, the evidence is sharply in favor of the latter.

V. RATIONALIZATION OF THE EXCESS-RENT HYPOTHESIS

Having provided a tentative empirical verification of the hypothesis that price in a competitve (auction) market tends to rise or fall in proportion to the excess buyer plus seller rent corresponding to any contract price, it remains to provide some theoretical rationale for such a hypothesis. From the description of the above experiments and their results, the excess-rent hypothesis would seem to have some plausibility from an individual decision-making point of view. Given that a particular contract price has just been executed, it is reasonable to expect each trader to compare that price with his own reservation price, the difference being a "profit" or rent which he considers achievable, and to present a degree of bargaining resistance in the auction process which is greater, the smaller is this rent. Such resistance may tend to give way, even where the rents on one side or the other are very small, if it becomes clear that such rents are unattainable. Thus, if equilibrium buyers' rent exceeds sellers' rent, any early tendency for contract prices to remain above equilibrium (and balance the rents achieved on both sides) might be expected to break down, as it becomes evident that the "paper" rents at those prices may not be attainable by all of the sellers. By this argument, it is suggested that the propensity of sellers to reduce their offers when price is above equilibrium is related to their attempts to obtain some—even if a "small"—amount of rent rather than to a direct influence of excess supply.

A particularly interesting aspect of the excess-rent hypothesis is that it leads naturally to an interesting optimality interpretation of the static competitive market equilibrium. The principle is this: in static equilibrium a competitive market minimizes the total virtual rent received by buyers and sellers. By "virtual rent" I mean the rent that would be enjoyed if all buyers and sellers could be satisfied at any given disequilibrium price. To see this optimality principle, let $D(p)$ be the demand function and $S(p)$ the supply function. At $p = P$, the sum of buyer and seller virtual rent is

$$R = \int_P^\infty D(p)\,dp + \int_0^P S(p)\,dp$$

and is represented by the area from DD down to P and from SS up to P in Figure 1. R is a minimum for normal supply and demand functions when

$$\frac{dR}{dP} = -D(P) + S(P) = 0,$$

that is, when demand equals supply with $P = P_0$. Note particularly that there is nothing artificial about this conversion of the statement of an ordinary competitive market equilibrium into a corresponding minimum problem. Whether one desires to attach any welfare significance to the concepts of consumer and producer surplus or not, it is completely plausible to require, in the interests of strict market efficiency, that no trader be imputed more rent than is absolutely necessary to perform the exchange mechanics. Hence, at price P in Figure 1, virtual rent exceeds equilibrium rent, and if this price persists, some sellers get more rent than they "should."

It should perhaps be pointed out that the excess-rent and Walrasian hypotheses are close analogues in that both deal with virtual, unattainable quantities. Thus, under the Walrasian hypothesis the "virtual" excess supply at P in Figure 1 is unattainable. Indeed, it is this fact that presumably causes price to fall. Similarly, at P, the excess rent area above S and D is unattainable, and leads to price cutting. Also note that the Walrasian hypothesis bears a gradient relationship, while the excess-rent hypothesis shows a global adjusting relationship, to the rent minimization principle. At $P > P_0$ the Walrasian hypothesis says that price tends to fall at a time rate which is proportional to the marginal rent, dR/dP, at that price. The excess-rent hypothesis states that price tends to fall at a time rate which is proportional to the global difference between total rent at P and at P_0.

Samuelson has shown how one may convert the Cournot-Enke problem of spatial price equilibrium into a maximum problem.[16] The criterion to be maximized in a single market would be what he calls social payoff, defined as the algebraic area under the excess-demand curve. In spatially separated markets the criterion is to maximize net social payoff, defined as the sum of the social payoffs in all regions minus the total transport costs of all interregional shipments. But, according to Samuelson, "this magnitude is artificial in the sense that no competitor in the market will be aware of or concerned with it. It is artificial in the sense that after an Invisible Hand has led us to its maximization, we need not necessarily attach any social welfare significance to the result."[17] I think the formulation of competitive market equilibrium as a rent minimization problem makes the "Invisible Hand" distinctly more visible and more teleological.[18] It also has great social (though not necessarily welfare) significance in relation to "frictionless" market efficiency. Rent is an "unearned" increment which literally cries out for minimization in an efficient economic organization. Furthermore, as we have seen with the excess-rent and Walrasian hypotheses, both the abstract teleological goal of the competitive market and the dynamics of its *tâtonnement* process are branches of the same market mechanism.

In view of the electrical circuit analogue so often mentioned in connection with spatially separated markets, a final bonus of the minimum rent formulation is the fact that it represents a more direct analogy with the principle of minimum heat loss in electric circuits.[19] Nature has devised a set of laws to govern the flow of electrical energy, which, it

[16] P. A. Samuelson, "Spatial Price Equilibrium and Linear Programming," *American Economic Review*, XLII (June, 1952), 284–92.

[17] *Ibid.*, p. 288.

[18] The discovery of the excess-rent hypothesis draws me nearer to the camp of "Invisible Hand" enthusiasts, but only because of the greater visibility of the Hand. I cannot quite carry my market metaphysics as far as does Samuelson. It is well known that any problem in economic equilibrium can be converted into a maximum (or minimum) problem, but I question the value of such a transformation (beyond technical advantages) if it is purely artificial without any meaningful interpretation; and if we work at it, such a meaningful transformation may often be found.

[19] Samuelson, *op. cit.*, p. 285.

can be shown, minimizes the inefficient, wasteful loss of heat energy from electrical systems. Similarly, the market mechanism provides a set of "laws" which minimizes the "wasteful" payment of excessive economic rent.

VI. SUMMARY

It would be premature to assert any broad generalizations based upon the ten experiments we have discussed. Yet conclusions are important for purposes of specifying the exact character of any findings, whether those findings are ultimately verified or not. In this spirit, the following tentative conclusions are offered concerning these experiments:

1. Even where numbers are "small," there are strong tendencies for a supply and demand competitive equilibrium to be attained as long as one is able to prohibit collusion and to maintain absolute publicity of all bids, offers, and transactions. Publicity of quotations and absence of collusion were major characteristics of these experimental markets.

2. Changes in the conditions of supply or demand cause changes in the volume of transactions per period and the general level of contract prices. These latter correspond reasonably well with the predictions of competitive price theory. The response to such changes may, however, produce a transient phase of very erratic contract price behavior.

3. Some slight evidence has been provided to suggest that a prediction of the static equilibrium of a competitive market requires knowledge of the shapes of the supply and demand schedules as well as the intersection of such schedules. The evidence is strongest in the extreme case in which the supply curve is perfectly elastic, with the result that the empirical equilibrium is higher than the theoretical equilibrium.

4. Markets whose institutional organization is such that only sellers make price quotations may exhibit weaker equilibrium tendencies than markets in which both buyers and sellers make price quotations—perhaps even disequilibrium tendencies. Such one-sided markets may operate to the benefit of buyers. A possible explanation is that in the price-formation process buyers reveal a minimum of information concerning their eagerness to buy.

5. The so-called Walrasian hypothesis concerning the mechanism of market adjustment seems not to be confirmed. A more adequate hypothesis is the excess-rent hypothesis which relates the "speed" of contract price adjustment to the algebraic excess of buyer plus seller "virtual" rent over the equilibrium buyer plus seller rent. This new hypothesis becomes particularly intriguing in view of the fact that a competitive market for a single commodity can be interpreted as seeking to minimize total rent.

APPENDIX

In the course of this experimental study and its analysis several additional or peripheral issues were investigated, a discussion of which would not fit clearly into the main body of this report. Three such issues will be discussed briefly in this appendix for the benefit of readers interested in some of the numerous additional lines of inquiry that might be pursued.

I. EVIDENCE OF INTER-TRADING-PERIOD LEARNING

In testing the various equilibrating hypotheses under investigation in this paper, no attempt was made to distinguish the effects of different trading periods. The sample of observations for each experiment embraced all the trading periods of that experiment with transactions running continuously from the first trading period through the last. It would appear, however, that learning occurs as the experiment progresses in such a way as to alter the parameters of each equilibrating hypothesis from one trading period to the next. To obtain some idea of the extent of these alterations, regressions for the excess-rent hypothesis were computed by individual trading period for tests 6*A*, 9*A*, and 10. These regression equations are summarized in Table 4. It is evident that there is a tendency for the intercepts of these regressions to converge toward zero as the number of trading periods increases. Convergence of the intercepts suggests that the later trading period regressions may be better equilibrating equations (better predictors of zero price change when excess rent is zero) than the earlier period regressions.

II. CONVERGENCE OF BID, OFFER, AND CONTRACT PRICES

In experiments 9 and 10 a tape-recorder was used for the first time to obtain a record of all bid and offer prices as well as the contract prices. No analysis has as yet been attempted with these additional data. However, a graph of the bid, offer, and contract prices in their serial sequence of occurrence is suggestive. Such a sample graph is shown in Chart 11 for experiment 10. Perhaps the most interesting fact revealed in this

TABLE 4

EXCESS-RENT REGRESSIONS $\Delta p_t = \beta_{02} + \beta_{22}x_{2t}$ BY TRADING PERIOD

Trading Period	Experiment 6A	Experiment 9A	Experiment 10
1.	$-2.769+0.101\,x_{2t}$	$-0.335+0.078\,x_{2t}$	$-0.160+0.087\,x_{2t}$
2.	$-2.876+0.216\,x_{2t}$	$-0.148+0.061\,x_{2t}$	$-0.053+0.408\,x_{2t}$
3.	$0.273+0.029\,x_{2t}$	$-0.191+0.093\,x_{2t}$	$0.007+0.349\,x_{2t}$
4.	$0.121+0.391\,x_{2t}$		

CHART 11

BIDS, OFFERS, AND TRANSACTIONS ON TEST 10

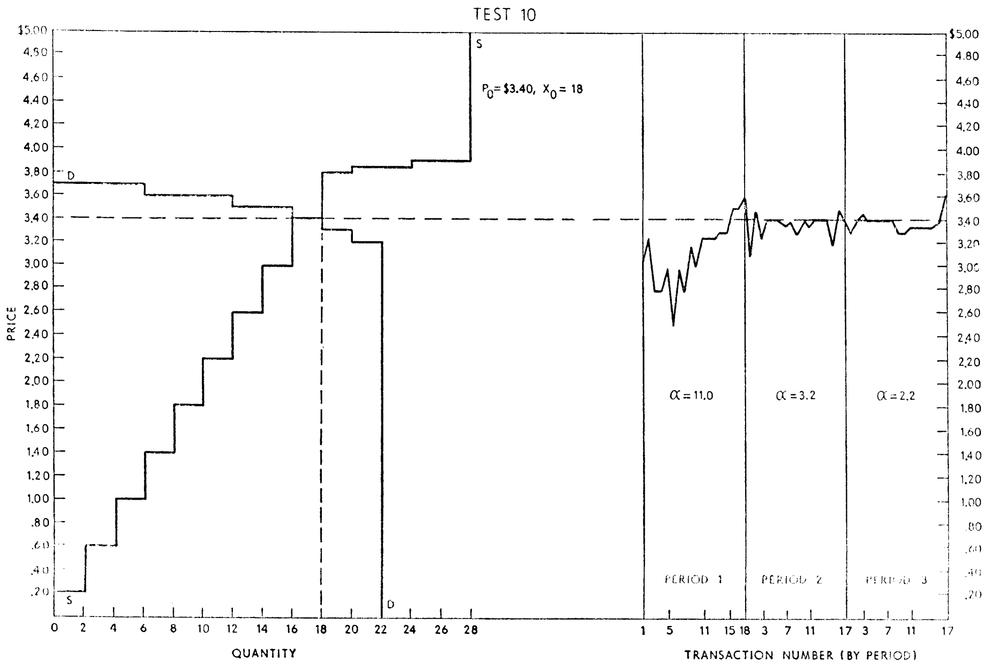
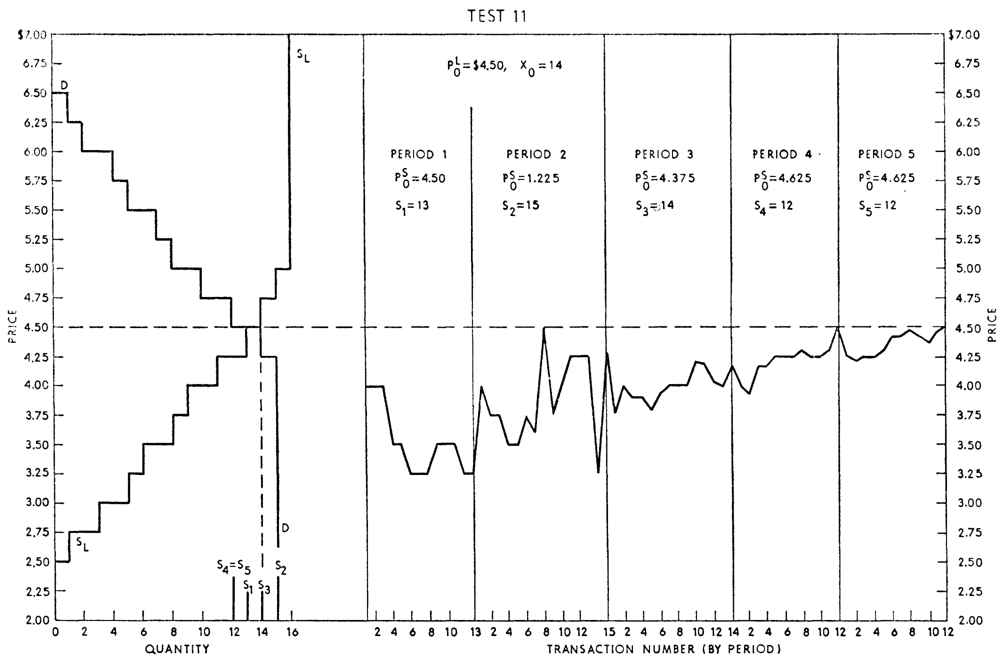


chart is the apparent tendency for the variance of the bids and offers to stabilize early, with the contract prices continuing to converge within this variation in bids and offers. Thus it is at the beginning of period 1, up to about the eighth transaction, that the bids and offers seem to show the most pronounced variation. This variation then remains reasonably steady to the very end of the last trading period. Contract prices converge, but the traders continue to attempt to get better terms by making repeatedly high offers and low bids. In this connection note that the unaccepted offers are further above the contract prive level than the unaccepted bids are below the contract price level. Similar results were evident in a corresponding chart (not shown) for experiment 9. This, apparently, is the auction market's way of compensating for the fact that, in this particular experiment, sellers were in a "softer" (higher rent) position than buyers.

III. A PILOT EXPERIMENT IN "SHORT-RUN" AND "LONG-RUN" EQUILIBRIUM

An important characteristic of the ten experiments discussed in this paper was the absence of any quantity-adjusting decision-making behavior on the part of either buyers or sellers. Such experiments represent the simulation of markets for commodities which do not have to be delivered or even produced until after the sale contract is executed. Hence, the possibility of distress sales, leading to losses by sellers, is ruled out by experimental design. In long-run price theory we think of producers entering or leaving an industry in response to the profits or losses they expect to make. The results of one pilot experiment to simulate this process is shown in Chart 12. The significant new element in this experiment was giving all sellers the option at the beginning of each trading period of entering the market or remaining "out of produc-

CHART 12



tion." It was understood that if they entered the market it was at a cost equal to the price on their card, and this cost was a net loss to any seller failing to make a sale. Also in this experiment some sellers were producers of two units and some of one unit. Specifically, there were six sellers with one unit and five with two units. Similarly, some buyers were two-unit buyers and some were one-unit buyers. It was not known to the traders generally how many or who were traders in one or in two units. This procedure was employed primarily to prevent traders from having exact knowledge of short-run supply by simply counting the number of sellers in the market in any trading period. Buyers in particular were thereby faced with some uncertainty to temper their knowledge that sellers were under strong selling pressure once they entered the market.

The experiment was conducted over five trading periods. In period 1 two sellers with a capacity to produce three units (the $4.75 and $3.00 sellers in Chart 12) elected to remain out of production. They were market observers only. Therefore the period 1 short-run theoretical supply was perfectly inelastic at $S_1 = 13$. In period 2 only the $4.50 seller, who sold at a loss the first time, remained out, giving $S_2 = 15$. In period 3 the $5.00 and $4.50 sellers remained out giving $S_3 = 14$, and in periods 4 and 5 production stabilized with the $5.00, $4.50, and $4.25 producers out of the market, giving $S_4 = S_5 = 12$.

From the results is it clear that this market approaches its "long-run" equilibrium price, $4.50, more slowly than was the case in the previous experiments. The approach is from below as might be expected by the "distress sale" characteristic of the market. The pressure on producers to sell seems to have had its strongest effect in period 1, in which market prices tended to decline from their opening. Prices moved erratically in period 2, and in the remaining periods climbed steadily in the direction of equilibrium.