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Cyclical Double-Auction Markets with and without Speculators*

This study reports the results of 18 computerized "double-auction" market experiments characterized by cycling excess demand. Two such market designs are studied: one with stationary supply and cycling demand, the other with cycling supply and demand. Data from a series of control experiments under conditions of intertemporal isolation (autarky) are compared with data from experiments where the two cyclical market phases are linked by a subset of agents (speculators). Allowing intertemporal speculation is found to be a significant treatment variable in both market designs; however, price convergence patterns are not robust with respect to the design change.

I. Introduction

This paper reports on laboratory experimental research designed to study the behavioral properties of two different market environments governed by cycling excess demand: (1) a market in which successive market periods are temporally isolated (autarky), and (2) a market in which agents (speculators) are allowed to carry commodity units from one period to another, thus temporally linking the cyclical phases of the market. We analyze observations from a total of 18 markets, all organized under double auction trading rules. The markets employ the PLATO computer network as the medium of public information transfer and private information display.

Our research builds on the previous experimental findings of Miller, Plott, and Smith (1977) (hereinafter MPS) and Williams (1979). These studies employed a common design where a sequence of "trading years" governed by stable supply are divided into a blue (low-demand) season and a yellow (high-demand) season. The supply and demand arrays were cyclically stable and resulted in a unique intertemporal competitive equilibrium. The experiments employed six

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buyers, six sellers, and two agents called "traders" who, in equilibrium, carry four commodity units over from the blue to the yellow season in each trading year. Traders are restricted to buying in the blue season and selling in the yellow season and are not allowed to carry units over beyond a yellow season.

The MPS (1977) study initially demonstrated that, after several trading years, such markets generated contract prices near the intertemporal competitive equilibrium and significantly different from the seasonal competitive prices predicted under conditions from intertemporal autarky. Williams (1979) extended these results by replicating MPS's speculation experiment and comparing the results with actual contract prices from an autarky experiment using the same market design but without traders. The results of this potentially much more rigorous test of the ability of a class of speculators to reduce seasonal price fluctuations indicated that the existence of such agents was indeed a highly significant experimental treatment variable.[1]

After we describe the trading mechanism in Section II and our experimental subjects in Section III, Section IV reports the results of two speculation experiments and two autarky experiments that replicate the basic design used by Williams (1979) in his autarky-speculation comparison. We then report, in Section V, the results of 10 speculation experiments and four autarky experiments using an entirely new cyclical market design. This new design has a socially optimal intertemporal carry-over of nine units and is characterized by cycling demand and supply. In our PLATO computerized double-auction mechanism traders operate in a less restricted environment than in the previously cited laboratory markets. Most important, we are able to drop the explicit blue/yellow seasonal distinction entirely and allow traders to switch between buying mode and selling mode at will within or between trading periods. In addition, we explicitly introduce commodity perishability and scrap-value parameters.

While the previous experimental work with intertemporally linked double auctions clearly demonstrates that knowledge of the underlying market structure is unnecessary for the attainment of an observed behavioral equilibrium that is near the theoretical intertemporal com-

1. Hoffman and Plott (1981) have extended the MPS and Williams studies by comparing speculation experiments conducted under double-auction trading rules with similar experiments conducted under posted-offer trading rules. They conclude that contract prices tend to be higher under posted-offer rules and convergence toward the intertemporal competitive price slower than in double auctions. The result that, compared with the double auction, posted-offer pricing works to the disadvantage of the "silent side" of the market (buyers) is consistent with experimental evidence using stable supply and demand configurations without speculators reported by Ketcham, Smith, and Williams (1983). Plott and Uhl (1981) have also studied the behavior of a class of middlemen in a competitive market where direct exchange between buyers and sellers was not permitted.

petitive equilibrium, these studies provide important imformation to the participants concerning the cyclical nature of the market. In addition to dividing the market years explicitly into blue and yellow seasons, the buyers' (sellers') record sheets revealed their individual induced valuation (cost) structure for the entire experiment. In the experiments reported below, participants do not have "perfect foresight" into the future value or cost of their commodity units. Individual valuation and cost parameters are revealed privately by PLATO before the beginning of each period for that period only. Furthermore, participants do not know how many buyers, sellers, and traders are in the experiment, although they do know the total number of market participants. A priori, we were uncertain how these reductions in the subjects' information sets would affect market performance. Will speculators fail to perceive the profit opportunities inherent in the cyclical market? Even if speculators recognize the existence of potential opportunities for profit, will they choose to act on this in the presence of substantial perceived risk associated with inventory accumulation? Will intertemporal carry-over fall short of the socially optimal level? Given these possibilities, will markets with speculators behave differently from markets without speculators?

II. The PLATO Double-Auction Exchange Mechanism with Traders

Basic Trading Mechanics

The trading procedure employed in this study is a revised version of the PLATO computerized transformation of the oral double auction described in detail by Williams (1980). Buyers (sellers) are free at any time to enter a bid to buy (offer to sell) one unit of an undefined homogeneous commodity by typing their entry and then touching a rectangular area on their display screen (see fig. 1) labeled "ENTER BID" ("ENTER OFFER") at which time the entry is made public unless it violates some institutional rule. Any buyer (seller) is free to accept any seller's offer (buyer's bid) by touching a display screen area labeled "ACCEPT OFFER" ("ACCEPT BID"). The acceptor must then touch an area labeled "CONFIRM CONTRACT," at which time a binding contract is formed and the information is logged in both the maker's and taker's private record sheets. Bids, offers, and subsequent contracts are the only public information. The incorporation of PLATO's touch sensitive display screen into the double-auction software is not just an exercise in computer showmanship. The utilization of touch input serves to reduce the complexity of the task market participants confront. They are able to prepare a price quote for entry into the market and then to focus all their attention on the market information continually being presented on their display screen.

TRADING PERIOD (columns)

RECORD SHEET for TRADER 1	1	2	3	4	5
Unit 1 selling price	5.05	6.64	5.05	6.70	
Unit 1 purchase price	5.00	6.61	5.00	5.10	
Profit	0.05	0.03	0.05	1.60	
Unit 2 selling price				6.66	
Unit 2 purchase price				6.56	
Profit				0.10	
Unit 3 selling price					
Unit 3 purchase price					
Profit					
Unit 4 selling price					
Unit 4 purchase price					
Profit					
Unit 5 selling price					
Unit 5 purchase price					
Profit					
Total Profit (over all units)	0.05	0.03	0.05	1.70	

Current inventory=5, unit life=3, unit scrap value=$4.00

Period purchased	5	5	5	5	5
Purchase price	5.10	5.11	5.15	5.10	5.15

Working capital=$11.83 , inventory cost-scrap value=$ 5.61

A BUYER BIDS $5.08 A SELLER OFFERS $5.15

ENTER OFFER >$ SELLING -Data→switch ACCEPT BID CONFIRM CONTRACT

Contracts:5.25,5.20,5.10,5.15,5.20,5.10,5.11,5.15,5.10,5.15

Trading Period 5 now in progress. SECONDS REMAINING: 62

9 of 10 people have voted to end period 5: Press -LAB- to vote

FIG. 1.—Basic screen display for a trader

Price quotes must progress so as to reduce the bid-ask spread. Only the highest bid to buy and the lowest offer to sell are displayed to the entire market and are open to acceptance. Any quotation that does not provide better terms to the other side of the market is placed in a queue that ranks bids from highest to lowest (offers from lowest to highest). After a contract occurs the highest queued bid and the lowest queued offer are automatically entered as the new bid-ask spread. The maker of a queued price quote is given continuously updated information on the quote's position in the queue. Queued entries may be withdrawn at any time by pressing a key labeled -EDIT-.[2]

Trading occurs over a maximum of 15 market periods each lasting a prespecified number of seconds (either 300 or 330 in the experiments reported below.) The market participants can bypass this stopping rule by unanimously voting to end a period. Registering a vote to end a trading period does not affect the individual's ability to participate

2. Smith and Williams (1983*b*) found that this variation of the basic PLATO double-auction mechanism, which incorporates an electronic limit order file or "specialist's book" (the bid and offer queues) with the bid-ask spread reduction rule, tends to outperform several other computerized double auctions in price stability and the rapidity of convergence to the competitive equilibrium.

actively in the market. The number of seconds remaining and the current vote to end the period are presented as shown at the bottom of figure 1 and are updated about every 1 or 2 seconds.

Speculation Mechanics[3]

Market participants designated as traders have the unique ability to switch from buying mode to selling mode at any time by pressing a key labeled -DATA-. Traders are given a capital endowment to cover their initial inventory investment and can add to (subtract from) this amount over the course of the experiment by accumulating profits (incurring losses) from buying and then reselling commodity units for their own accounts.[4] Traders are paid in cash the amount of their final working capital defined as the capital endowment plus any accumulated profits or losses. The perishability of the commodity units is given by a pre-initialized "unit life," which determines the maximum number of periods that an inventory unit can be carried before it "expires." For example, if the unit life is set to three, as in the design II experiments reported below, a unit purchased during trading period 1 would expire at the end of trading period 4. Any inventory unit that expires is automatically sold at a pre-initialized scrap value and the resulting loss is subtracted from the trader's working capital. The scrap-value parameter allows us to normalize for the risk associated with inventory accumulation, when replicating specific supply and demand configurations that have been shifted by an arbitrary constant in order to disguise a design previously used within a given subject population. If at the end of any period a trader's working capital falls to zero he or she is automatically eliminated from the market and receives zero profit. Traders are informed of the final market period at the end of period X where X = (final period − unit life). At the end of the experiment all remaining inventory units are reimbursed at scrap value regardless of the period in which they were purchased.

When a trader buys a commodity unit the price and the period of purchase are logged in the trader's inventory table, as shown in figure 1. Inventory accumulation is governed by a financial inventory constraint and a physical inventory constraint. The financial constraint states that traders can continue accumulating inventory units as long as their working capital exceeds their total inventory cost net of scrap value (displayed on the trader's screen at all times). In other words, for the trader to continue buying, the working capital must cover the loss that would be incurred if all currently held inventory units were to

3. A set of screen prints displaying the instructions that PLATO presents to traders in preparation for the experiment is available from the authors.

4. Short sales are currently prohibited. If a trader attempts to enter an offer to sell a unit when his or her current inventory is zero, the following message appears on the viewing screen: "No units available for sale. Press -DATA- to become a buyer."

expire and be sold for their scrap value. We thus limit the amount of credit available to the traders. A physical inventory constraint exists because a maximum of seven units will fit in the inventory table given the horizontal space limitations of the display screen.

Traders' inventories are automatically maintained on a first in–first out basis. When an inventory unit is sold the unit is removed from the inventory table and the sale price, purchase price, and resulting profit are recorded in the trader's record sheet under the period in which the sale was made. Traders are limited to a maximum of five sales in any single period, again because the screen display area is limited.

III. Experimental Subjects

All of the experiments reported in the following sections use subjects drawn from the undergraduate and graduate student populations at the University of Arizona in Tucson and Indiana University in Bloomington. Most subjects were drawn from undergraduate economic theory classes. Many of the experiments were run "multisite" with subjects participating simultaneously at both locations. Except where explicitly noted, all subjects were experienced in the sense that they had participated in at least one previous double-auction experiment (with completely different market parameters) and had shown no significant problem grasping the institutional rules or trading mechanics of the computerized marketplace.[5] Experienced subjects are usually recruited by telephone, since they indicated a desire to participate again in such experiments by leaving their phone number with the experimenter at the conclusion of the first experiment. Our revolunteer rate is nearly 100%.

After arriving at the experiment site, participants are each paid $3 for keeping their appointment and are then randomly assigned to individual PLATO computer terminals. The double-auction program then (1) assigns each terminal to the condition of buyer, seller, or trader, (2) presents the instructions at an individually controlled pace, and (3) executes the experiment and stores the resulting data on disk for later recall and analysis. The role of buyer and seller were assigned randomly by PLATO. In the speculation experiments, however, the assignment of the trader's role was not random. Because of the complexity of the task confronted by traders, we chose for this role persons who were either very experienced with the basic mechanism or were otherwise considered unlikely to have difficulty understanding the mechanics of being a trader.

5. See Williams (1980), Ketcham et al. (1983), and Smith and Williams (1983*b*) for discussions of subject experience as an explicit experimental treatment variable in PLATO market experiments.

IV. Four Markets with Cycling Demand and Stationary Supply

Experimental Design I

So that our initial results may readily be compared with the previous experimental work, our first experiments employ the same induced supply and demand configurations as the studies by MPS (1977, experiment 2) and Williams (1979). These supply and demand arrays are displayed on the left portion of figure 2. The 12 units in each array are distributed among four buyers and four sellers such that each has three units potentially traded.[6] Demand cycles between D_o in the odd-numbered periods and D^o in the even-numbered periods while supply remains stationary. This results in theoretical price-quantity autarkic equilibria of (P_o = \$3.40, Q_o = 5) in the odd-numbered periods and (P^o = \$4.20, Q^o = 9) in even-numbered periods. The intertemporal competitive equilibrium price, P^*, is \$3.80 with seven units exchanged in the odd-numbered periods (Q_* = 7), 11 units exchanged in even-numbered periods (Q^* = 11), and four units carried over from each odd- to the next even-numbered period. In each 300-second trading period buyers (sellers) earn the difference between their induced marginal valuation (sale price) and purchase price (marginal cost) for each unit purchased (sold) plus a 5-cent commission to cover subjective transaction costs and minimally to induce the trading of marginal units.

In experiments 1t-1 and 1t-2 reported below, two traders participated in the market in addition to the four buyers and sellers. The traders were given a \$5 capital endowment to cover their initial purchases. The commodity perishability parameter (unit life) was set to allow commodity units to be carried over a maximum of two trading periods beyond the period purchased. The scrap value was set at \$1.[7] Experiments 1a-1 and 1a-2 are autarkic markets replicating experiments 1t-1 and 1t-2, but with no traders.

Experimental Results

The upper part of figure 2 displays sequential contract prices and descriptive statistics for experiment 1t-1. The rapidity with which prices converge to a range very close to P^* is striking. The seasonal price fluctuations predicted under autarky are almost nonexistent from the very beginning of the experiment. There are 132 contracts over the seven market cycles in periods 1–14, compared with 126 contracts predicted by the intertemporal competitive model. Traders are involved in 53% (70) of the contracts, somewhat more than the 44.4%

6. The earlier studies cited used six buyers and six sellers, each having two units potentially traded.

7. The MPS and Williams studies used a \$3 capital endowment and had no scrap-value parameter. Our design I supply and demand arrays have been shifted up by a constant of \$1 (our scrap value) relative to those used in these earlier studies.

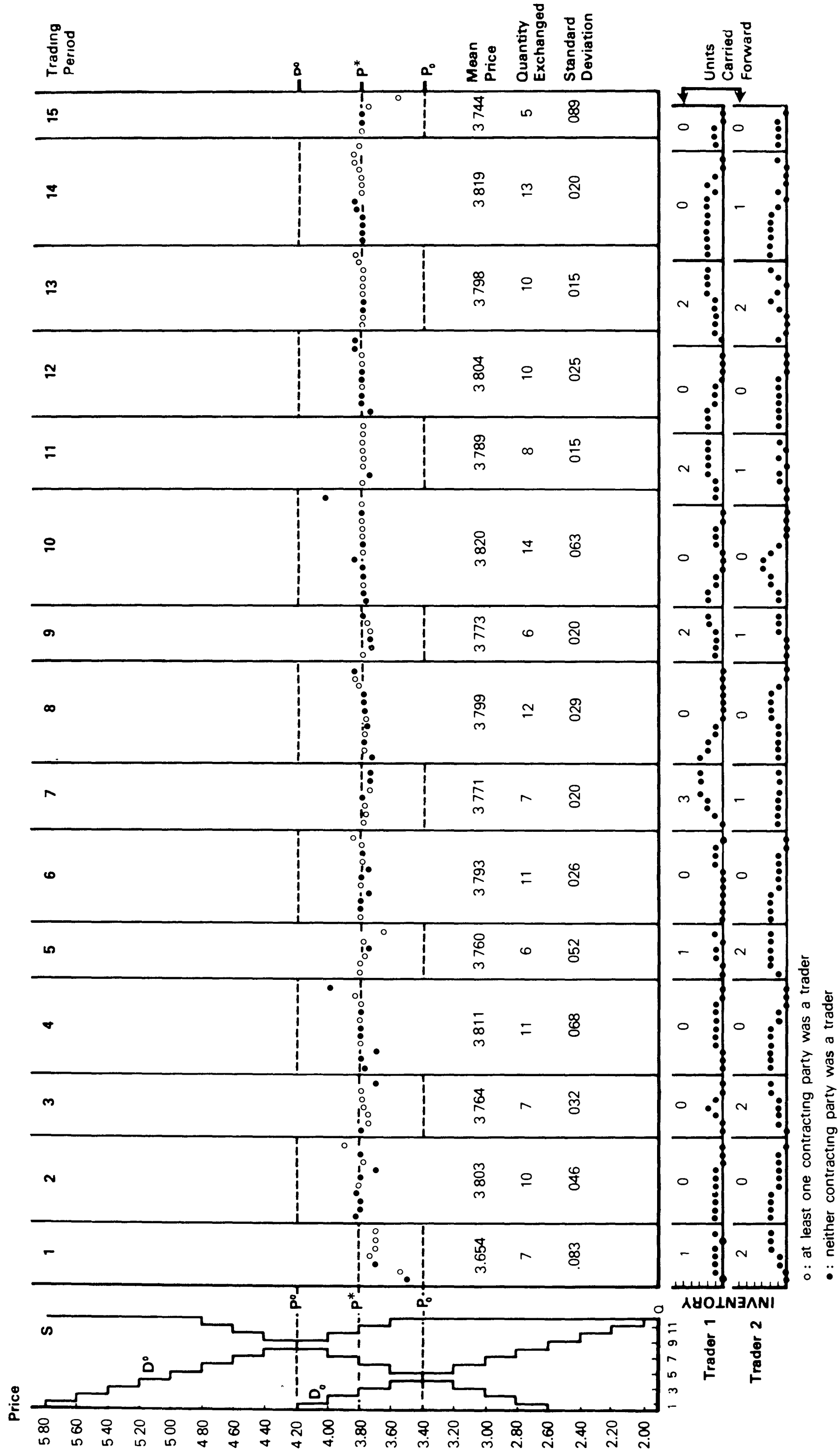


FIG. 2.—Experiment 1t-1 (design I, speculation)

(eight of every 18) predicted at the theoretical intertemporal equilibrium price.

The lower part of figure 2 displays the level of traders' inventories after each contract occurs. It follows that if a contract is plotted as an open circle (a trader was involved in the exchange) there must be a corresponding increase or decrease in a trader's inventory. We see that the traders were immediately active in the market, being involved in five of the first seven contracts. Note that a unit purchased by trader 1 during the first period was sold the same period. The practice of intraperiod trading became quite common throughout the entire experiment, since the traders were able to gain the 5-cent commission for sales of inventory units regardless of the capital gain.[8] There are even instances where traders are on both ends of an exchange (e.g., the sixth contract in period 8.) The "doomsday" effect built into the market by having all inventory units expire after the final trading period is evident in the period 15 price series. When the traders reduce their usual odd-period purchasing, prices immediately drop toward the autarkic equilibrium.

Figure 3 displays sequential contract prices, traders' inventory levels, and descriptive statistics for experiment 1t-2. The price variance is much greater and convergence toward P^* much slower than in experiment 1t-1. With the exception of periods 2 and 4, prices tend to lag away from P^* in the direction of the autarkic equilibrium. By the seventh complete market cycle (periods 13 and 14) prices appear to have stabilized near P^*. As in experiment 1t-1, the built-in doomsday effect is evident in period 15 where prices clearly diverge from P^* toward P_o. Over periods 1–14 traders are involved in 43% (52) of the 121 total contracts. Both total exchange volume and the percentage of contracts involving traders are less than the theoretical prediction as well as what was observed in experiment 1t-1.

Figures 4 and 5 display sequential contract prices and descriptive statistics for experiment 1a-1 and experiment 1a-2 (design I, autarky), respectively. Prices in both markets display a clear tendency to lag behind the cyclical demand shifts, converging toward P_o from above in the odd periods and toward P^o from below in the even periods. This "hysteresis" effect was also present in the autarky experiment conducted by Williams (1979) and in two experiments with growing demand reported by Smith (1980) and to some extent in experiments with

8. Elsewhere (Smith and Williams 1983*a*), we report experimental results in which participants can be interpreted as revealing the subjective cost associated with double-auction trading. This measure indicates that such costs average between 5 and 10 cents per trade. However, many trades occur that yield a gain of less than 5 cents, indicating that for some individuals a 5-cent commission is more than sufficient compensation for transactions costs.

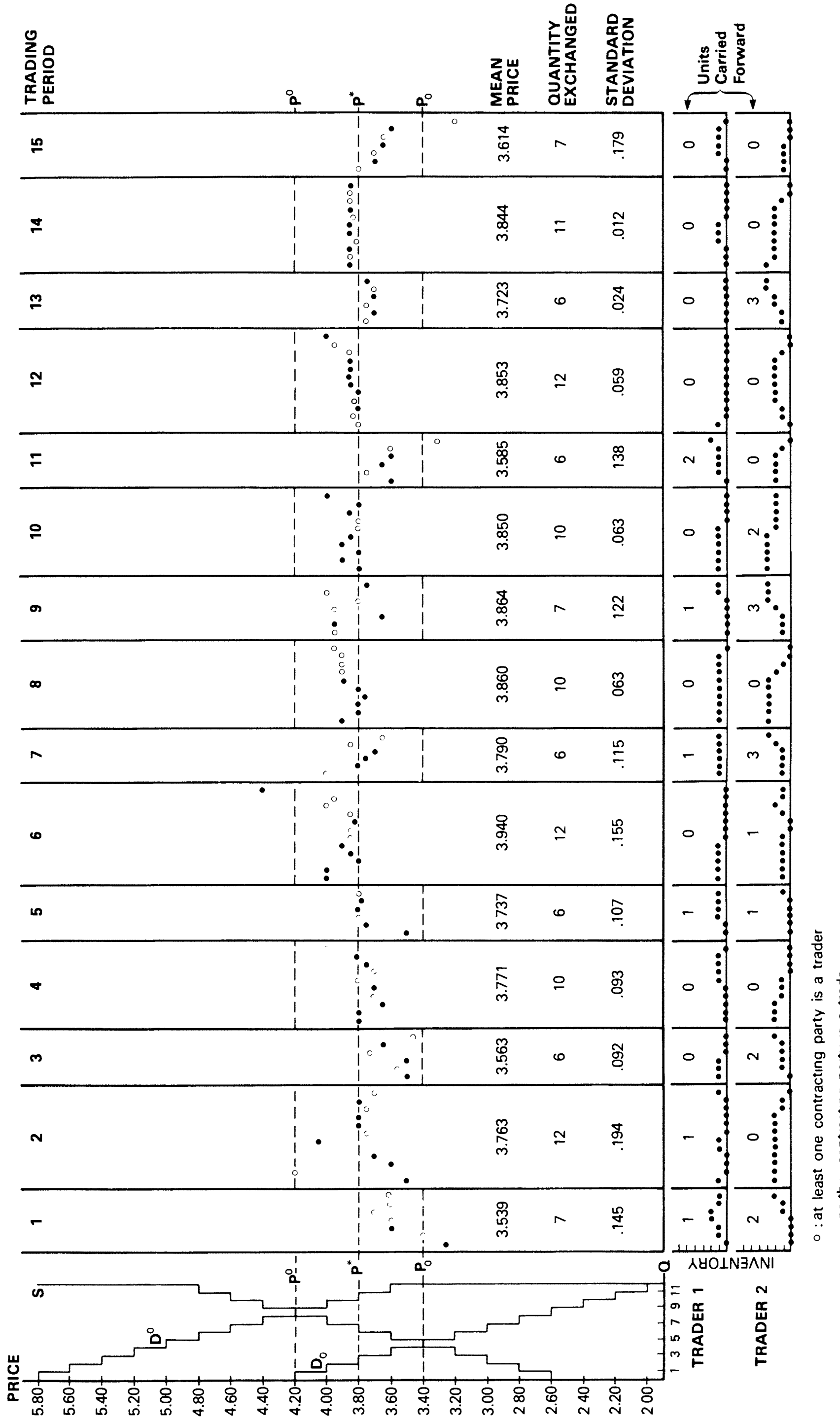


FIG. 3.—Experiment 1t-2 (design I, speculation)

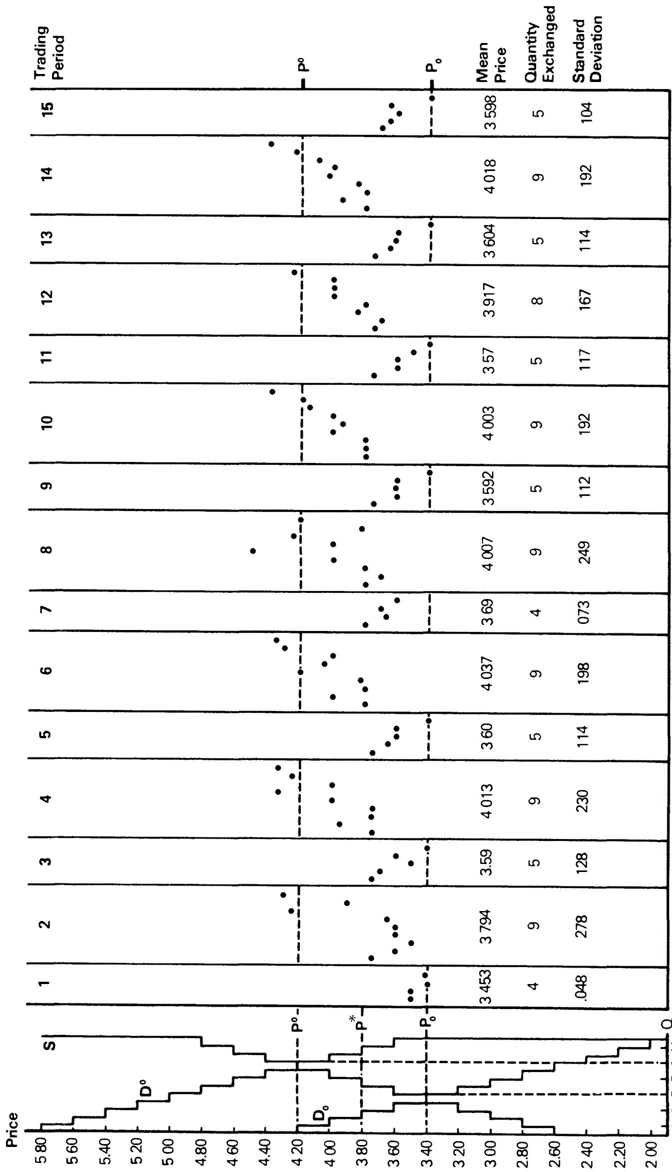


FIG. 4.—Experiment 1a-1 (design I, autarky)

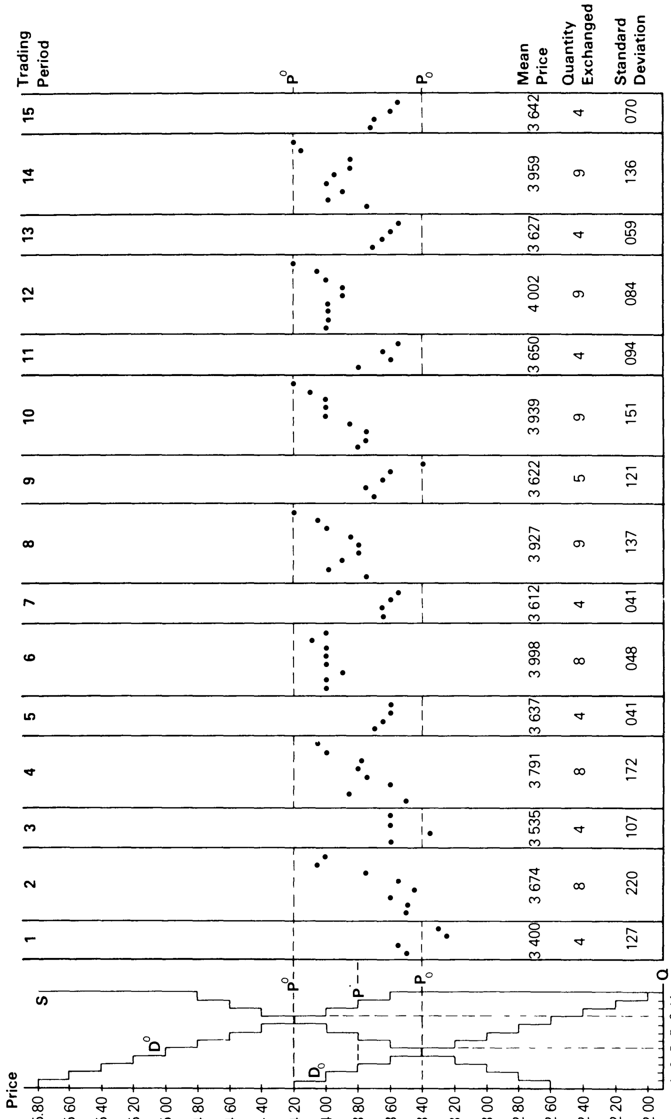


FIG. 5.—Experiment 1a-2 (design I, autarky)

TABLE 1 Contract Price Comparison: Speculation Experiments 1t-1, 1t-2 versus Autarky Experiments 1a-1, 1a-2

Trading Period	Mean ($\bar{P} - P^*$) 1t-1,2	Mean ($\bar{P} - P^*$) 1a-1,2	SD 1t-1,2	SD 1a-1,2	Z_u
1	−.204	−.374	.136	.106	2.74***
2	−.019	−.062	.151	.268	1.48*
3	−.128	−.234	.125	.130	1.81**
4	−.008	.109	.085	.240	1.30*
5	−.052	−.183	.089	.097	2.99***
6	.070	.218	.138	.153	3.36***
7	−.020	−.149	.083	.076	2.76***
8	.027	.167	.058	.211	2.45***
9	.022	−.193	.105	.124	3.67***
10	.033	.174	.066	.181	2.40***
11	−.099	−.194	.141	.121	1.91**
12	.031	.162	.054	.141	3.23***
13	−.027	−.186	.044	.100	3.63***
14	.030	.188	.021	.174	3.44***
15	−.132	−.182	.168	.099	1.50*
All odd	−.080	−.210	.132	.120	6.92***
All even	.024	.137	.095	.213	5.27***

* Reject H_o, P = .10 (direction predicted).
** Reject H_o, P = .05 (direction predicted).
*** Reject H_o, P = .01 (direction predicted).

growing and then declining demand reported by Harrison, Smith, and Williams (1983).

Note that the first contract in periods 2–15 of experiment 1a-1 occurs in the 10-cent interval centered on $3.75. From this starting point slightly below P^* prices tend to move toward the relevant autarkic equilibrium. The first price in each period is less stable in experiment 1a-2 but the general tendency for the price series to be negatively (positively) sloped during odd (even) periods is evident. In both experiments, monotonicity of price changes is somewhat more evident in odd periods than in even periods. The sustained lagging of price series throughout both autarky experiments suggest that a behavioral equilibrium may be characterized by a nonzero variance price pattern rather than the fixed price equilibrium of traditional competitive price theory.

Table 1 displays a period-by-period comparison of price observations pooled across the two experimental replications in each of the two treatment groups. The Z_U statistic presented is the unit normal deviate of the nonparametric Mann-Whitney U statistic. The test statistic indicates that we must reject central tendency equality (at the .05 level, direction predicted) in 12 of the 15 trading periods. In the other three periods the null hypothesis is rejected at the .1 level, direction predicted. Pooling experimental observations across all odd periods or all even periods results in strong rejection of the null hypothesis at the .01 level.

TABLE 2 **Efficiency Comparison: Speculation Experiments 1t-1, 1t-2 versus Autarky Experiments 1a-1, 1a-2**

Trading Period	E^o 1a-1	E^o 1a-2	E^o 1t-1	E^o 1t-2	E^* 1a-1	E^* 1a-2	E^* 1t-1	E^* 1t-2
1	100.00	100.00	113.25	108.00	83.33	83.33	94.38	90.00
2	98.61	100.00	107.43	106.81	93.42	94.74	101.78	101.19
3	95.00	100.00	108.50	97.75	79.17	83.33	90.42	81.46
4	98.61	100.00	104.58	108.26	93.42	94.74	99.08	102.56
5	95.00	90.00	96.25	117.75	79.17	75.00	80.21	95.63
6	98.61	97.22	106.60	102.85	93.42	92.10	100.99	97.44
7	75.00	100.00	117.50	122.50	62.50	83.33	97.92	102.08
8	94.44	100.00	106.25	95.14	89.47	94.74	100.66	90.13
9	75.00	95.00	118.25	127.50	62.50	79.17	98.54	106.25
10	100.00	100.00	104.65	101.74	94.74	94.74	99.14	96.39
11	95.00	100.00	119.50	62.50	79.17	83.33	99.58	52.08
12	100.00	100.00	105.69	107.99	94.74	94.74	100.13	102.31
13	95.00	100.00	121.00	115.00	79.17	83.33	100.83	95.83
14	98.61	100.00	105.42	106.94	93.42	94.74	99.87	101.31
15	75.00	80.00	49.50	95.00	62.50	66.67	41.25	79.17
1–15	92.93	97.48	105.62	104.85	82.67	86.53	93.65	92.92

In spite of the informational and procedural differences introduced by the computerized trading environment, these results strongly support the basic conclusion that the existence of speculative agents tends to reduce price fluctuations in a market governed by cyclical demand and stationary supply. This result holds for a comparison either with autarky-theoretic prices or with actual observed autarky prices even in the presence of a very pronounced hysteresis effect.

A second and perhaps more important criterion for the comparison of market performance in the two treatment groups is allocative efficiency. Table 2 presents two efficiency measures (E^o and E^*) for each period of the four design I experiments. The first measure, E^o, is defined as the actual profit (exclusive of commissions) earned by all market participants expressed as a percentage of the maximum potential profit available under intertemporal autarky; E^* expresses actual profit (exclusive of commissions) as a percentage of the total profit earned at the intertemporal competitive equilibrium.

Under autarky the total surplus available to the participants (excluding commissions) is $4.00 in odd periods and $14.40 in even periods and is split equally between buyers and sellers. At an intertemporal competitive equilibrium the total surplus available is $4.80 in the odd periods ($.60 to buyers, $4.20 to sellers) and $15.20 in even periods ($11.00 to buyers, $4.20 to sellers). Thus, the maximum value of E^* possible under autarky is 83.33 in odd periods and 94.74 in even periods or 92 over one market cycle. At an intertemporal equilibrium the value of E^o would be 120 in odd periods and 105.56 in even periods or 108.96 over a market cycle.

Table 2 clearly reveals that the efficiency of the speculative markets tends to exceed that observed in the autarkic markets. Twenty-four out of 30 observations on speculative market efficiency exceed the maximum possible value under autarky. In a period-by-period comparison of mean efficiency the speculative mean exceeds the autarkic mean in all except period 11. A matched pairs t-test on the period 1–14 means yields $t_{(13)} = 3.53$. Using raw unpaired data yields $t_{(54)} = 4.34$ and $Z_U = 5.05$. The introduction of intertemporal speculators results in a highly significant increase in allocative efficiency.

V. Fourteen Markets with Cycling Demand and Supply

Having demonstrated an ability to replicate the basic results of the previous double-auction speculation and autarky experiments using our subject pool and computerized trading mechanism, we now turn to an investigation of the behavioral characteristics of speculative and autarkic markets governed by an entirely new cyclical market design.

Experimental Design II

Figure 6 displays the market supply and demand configurations induced on four buyers and four sellers in design II. This design is characterized by a stable cycling of both the supply and demand arrays where $(D^o, S^o) = (D_o + 1.80, S_o + 1.80)$. Note that the autarkic and intertemporal equilibrium prices are not unique but are defined over a 10-cent interval centered on P_o, P^o, and P^*, where $P^* = (P_o + .80) = (P^o - .80)$. The autarkic and intertemporal competitive quantities are $Q^o = Q_o = 7$ and $Q^* = 11$ with nine units carried over from each odd to the next even period by traders. The autarkic price spread is thus double that of design I and the optimal carry-over is one unit more than double that in design I. In all of the design II experiments traders were given a capital endowment of \$10. The unit life was set for three periods and the scrap value was set at $(P^* - 1.80)$. Each trading period lasted 330 seconds and, unlike the design I experiments, no commission was paid on traded units.

Table 3 displays additional information for each of the fourteen design II experiments.[9] The first four experiments, 2a-1, 2a-2, 2a-3, and 2a-4 are autarkic markets. The other 10 markets included speculators; two in experiment 2t-1 and three in the other nine experiments. All but one of the experiments used participants who were experienced with

9. The expression in parenthesis in col. 1 of table 4 is the name we have given the particular experiment for disk storage and recall. For example, 2a-1 (3pda13) means that experiment 2a-1 in this report was the thirteenth run on version 3 of the PLATO Double Auction TUTOR software. The correspondence for the design I experiments is as follows: 1t-1 (3pda05), 1t-2 (3pda82), 1a-1 (3pda07), 1a-2 (3pda81). The experiments were conducted over a span of more than 3¼ years beginning in June 1979.

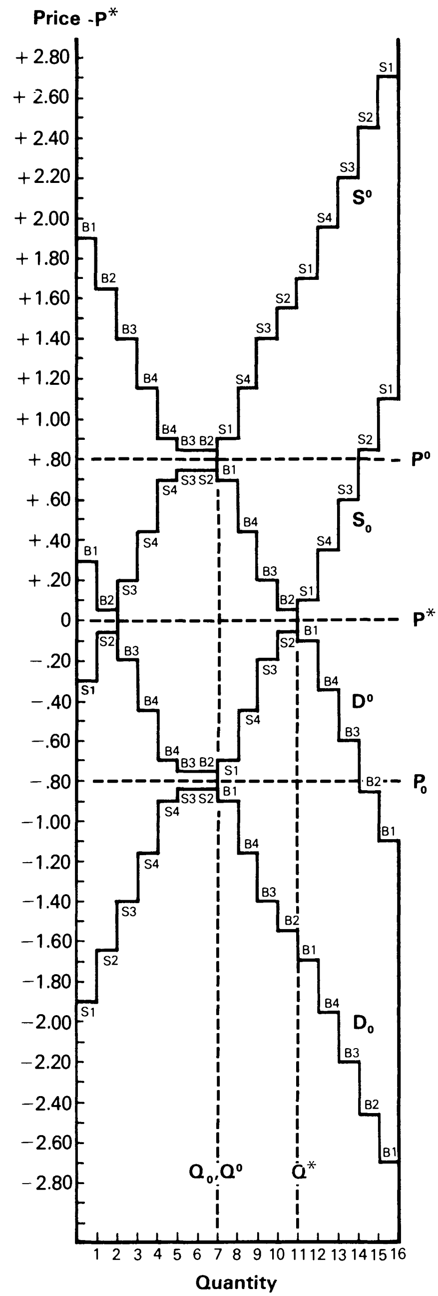


FIG. 6.—Design II–induced supply and demand arrays

TABLE 3 Experiment Classification: Design II

Experiment	Number of Speculators	Experienced Buyers and Sellers?	Summary Price Information?	Final Period	P^*
2a-1 (3pda13)	0	yes	no	14	3.80
2a-2 (3pda14)	0	yes	no	13	3.80
2a-3 (3pda56)	0	yes	no	14	6.60
2a-4 (3pda57)	0	yes	no	14	5.30
2t-1 (3pda17)	2	yes	no	12	5.80
2t-2 (3pda22)	3	yes	no	14	4.50
2t-3 (3pda23)	3	no	no	14	5.80
2t-4 (3pda29)	3	yes	no	12	4.50
2t-5 (3pda34)	3	yes	no	8*	5.80
2t-6 (3pda37)	3	yes	no	14	6.80
2tp-1 (3pda42)	3	yes	yes	14	6.80
2tp-2 (3pda43)	3	yes	yes	9†	4.50
2tp-3 (3pda48)	3	yes	yes	15	6.80
2tp-4 (3pda50)	3	yes	yes	15	4.50

* Terminated after period 8 because of computer problems.
† Terminated after period 9 because of computer problems.

PLATO double-auction trading mechanics; the exception was experiment 2t-3, which employed inexperienced buyers and sellers but experienced speculators. In experiments 2tp-1 through 2tp-4 all subjects were given access between trading periods to a table containing the quantity exchanged and the average, highest, and lowest contract price in all previous periods. The reasoning behind the introduction of this additional information will become clear in the next section. With the exception of experiments 2t-5 and 2tp-2 (which were terminated because of computer problems) the final period of trading was governed by a 2-hour time limit on our exclusive use of the PLATO facilities at our respective institutions.

Experimental Results

Figures 7*a*, 7*b*, and 7*c* plot the sequence of mean contract prices and the quantity exchanged for all 14 of the design II experiments. One observation that is immediately clear from figures 7*a* and 7*b* is that the rapid convergence of speculative market prices to the intertemporal competitive equilibrium, so apparent in experiment 1t, is not generally observed using the design II parameters. Experiment 2t-2 is the only market that appears to have stabilized at a price near (actually slightly below) P^*. The other nine speculation experiments exhibit various degrees of partial convergence to P^*; however, mean prices are clearly closer to P^* than in the four autarky experiments (fig. 7*a*). This conclusion is supported by figure 8, which displays 99% confidence bands for the mean contract price in each trading period for both the pooled speculation and pooled autarky samples. Note that the bands do not

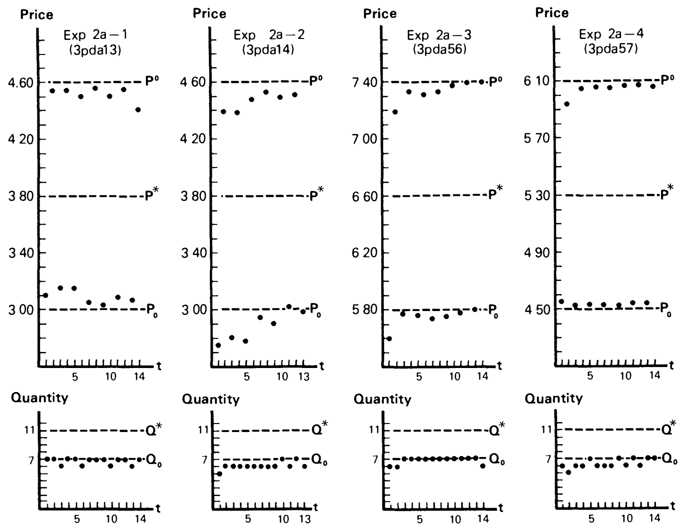


FIG. 7*a*.—Sequential mean contract prices: autarky experiments

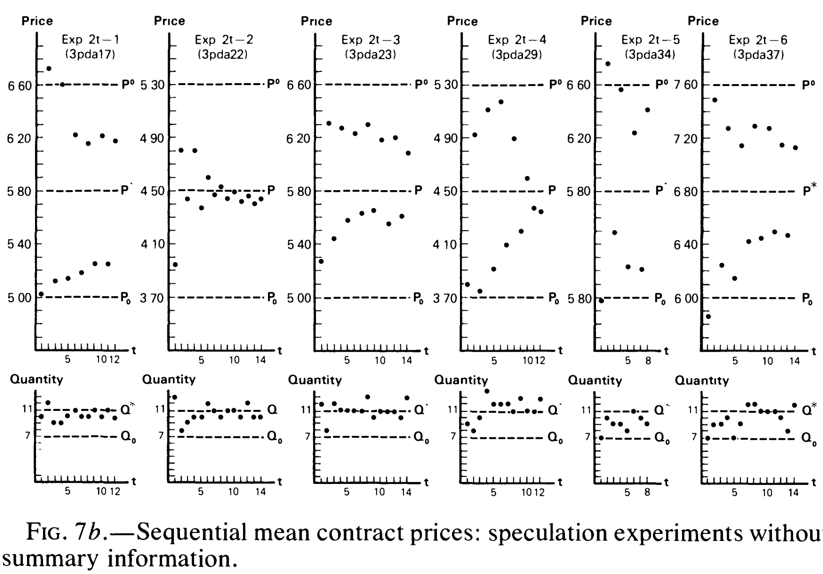


FIG. 7*b*.—Sequential mean contract prices: speculation experiments without summary information.

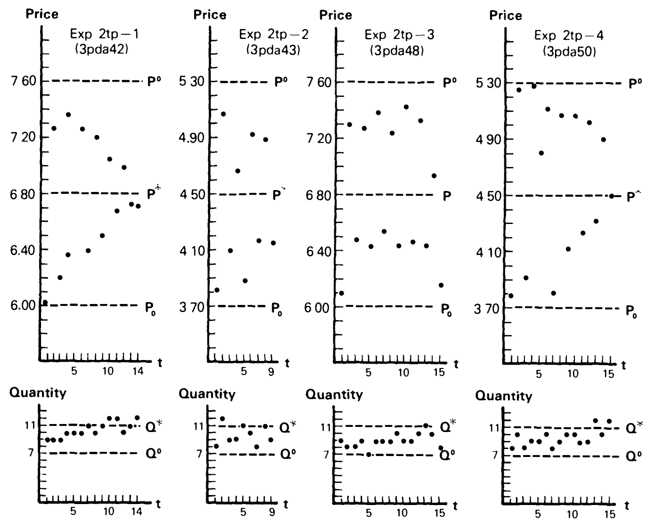


FIG. 7*c*.—Sequential mean contract prices: speculation experiments with summary information

intersect after period 2, which marks the end of the first market cycle. This is because of a gradual movement of the mean price in the speculative markets away from the autarkic equilibrium toward P^* as traders become active in the market.

The autarkic market price data presented in figures 7*a* and 8 is further summarized by the pooled contract price frequency polygons presented in figure 9. Note that these sample distributions are derived from market cycles 3 through 7 and thus exclude contracts that occurred during the initial periods of trading. The distribution of odd-

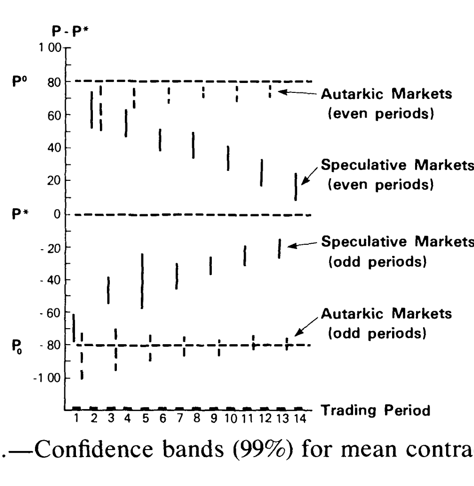


FIG. 8.—Confidence bands (99%) for mean contract price

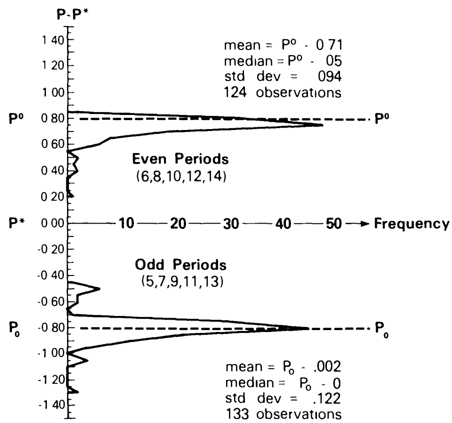


FIG. 9.—Contract price frequency polygons: autarky experiments

period contract prices can be characterized as symmetric with mean, median, and mode at the midpoint of the range of autarkic competitive equilibrium prices. In sharp contrast with this, the distribution of even-period prices can be characterized as asymmetric (downward skewed) with a mean 2.1 cents below the minimum of the range of competitive equilibrium prices and a median and mode at the minimum competitive equilibrium price. A comparison of the two sample distributions, expressed as deviations from the appropriate autarkic equilibrium price, yields $Z_U = 6.473$ (reject the null hypothesis, $p < .01$). The data clearly indicate that the hysteresis effect, noted in experiment 1a, is present in the even-period data but not in the odd-period data. We find this rather surprising and offer no formal behavioral-theoretic explanation for this empirical result.[10] We can, however, point out that this phenomenon can be interpreted as consistent with recent experimental evidence offered by us (Smith and Williams 1982) in support of what we might call a "weak-sellers" hypothesis. This simply states that, over a large number of experimental replications, there appears to be a tendency for contract prices to converge to a static, symmetric-rent, competitive equilibrium from below and that this effect can combine with certain design parameters (e.g., the distribution of exchange surplus) to determine the observed price convergence path. One explanation of the dissimilarities displayed by the figure 9 frequency polygons is that the weak-seller effect tends to offset the lagging of prices above P_o predicted by the hysteresis effect during odd periods. But the weak-seller

10. A comparison of pooled price data from market cycles 5–7 of the two design I autarky experiments shows that there is no significant difference in the mean absolute price deviation from P^* across market phases ($Z_U = .41$). Significantly higher price variance is, however, observed in even periods ($F_{78,44} = 2.8$) relative to odd periods.

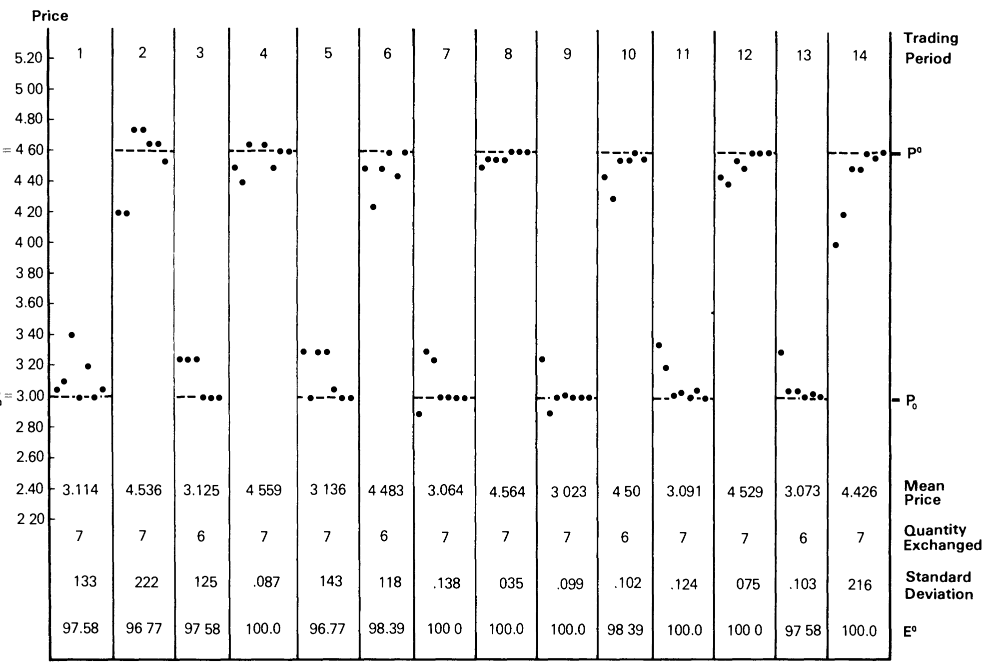


FIG. 10.—Experiment 2a-1 (design II, autarky)

and hysteresis effects combine during even periods to produce the distinct lagging of prices below P^o. An alternative explanation is that the first phase of the market cycle is somehow weighted more heavily than the second in the price expectation formation process. This could easily be tested by conducting a set of experiments with the cyclical phases reversed.

Figures 10, 11, 12, and 13 display the actual sequence of contract prices and descriptive statistics for autarky experiments 2a-1, 2a-2, 2a-3, and 2a-4, respectively. Note that the markets are extremely efficient regardless of the cyclical phase. Prices in 2a-1 exhibit a hysteresis effect in both the odd-period and even-period phases. However, price convergence in 2a-2 and 2a-3 is generally from below in both cyclical phases. Market prices in 2a-4 converge very rapidly to the upper (lower) bound of the odd (even) period range of competitive equilibrium prices.

From figure 7*b* we note that experiments 2t-1 through 2t-6 display varying degrees of partial convergence to P^*. After we conducted these first six speculation experiments it seemed apparent that traders were quite frequently not fully aware of the market's cyclical nature or the opportunities for profit available to them through interperiod carry-over of inventories. In an attempt to help focus the subjects' attention on the low-high (odd-even) price cycle we decided to provide them

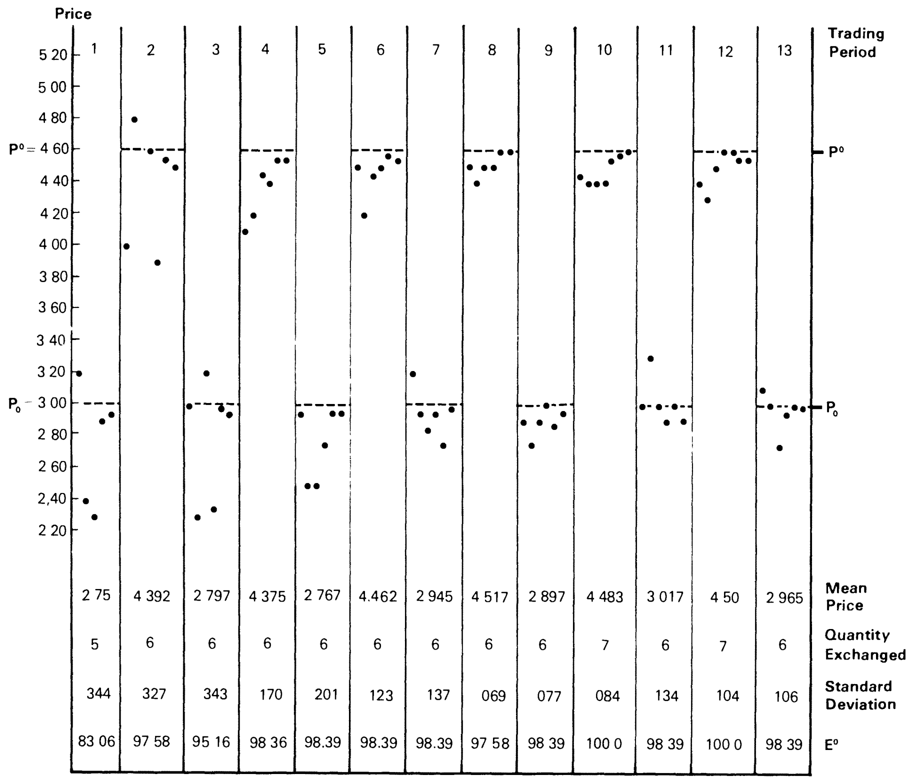


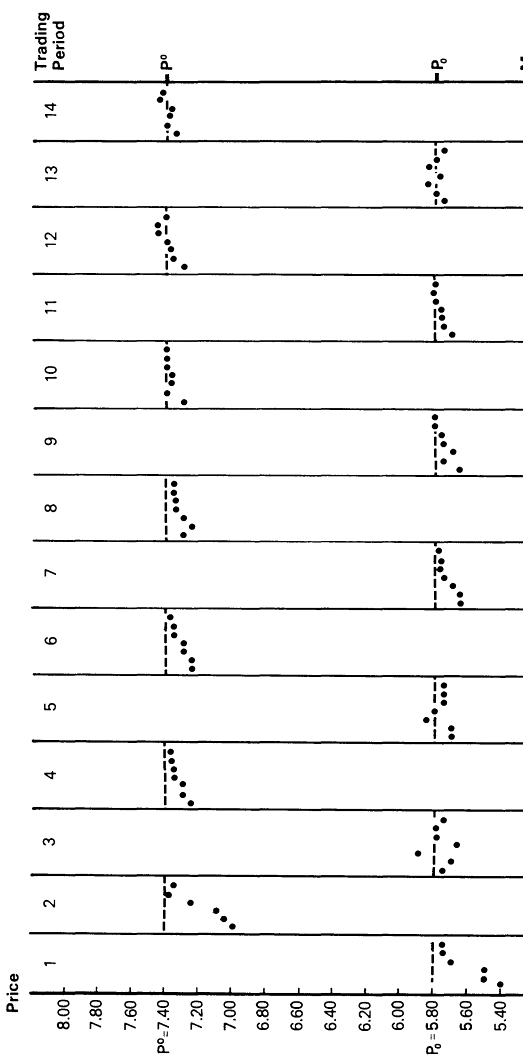
FIG. 11.—Experiment 2a-2 (design II, autarky)

(after each trading period) with a table containing the average, high, and low contract price from all past periods. It is evident from figures 7*b* and 7*c* that this additional information did not have a dramatic impact on the price convergence behavior in experiments 2tp-1 through 2tp-4 compared with experiments 2t-1 through 2t-6. We interpret the continued tendency for speculative markets to fail to converge to P^* as evidence that speculators are unwilling to bear the risk required to eliminate the autarkic price spread completely. Not surprisingly, we have found that perceptive risk takers are the most successful speculators!

A statistical test of the effect on convergence speed of providing summary price information can be generated via estimation of the coefficients given in the following exponential decay function used to characterize the price convergence process:[11]

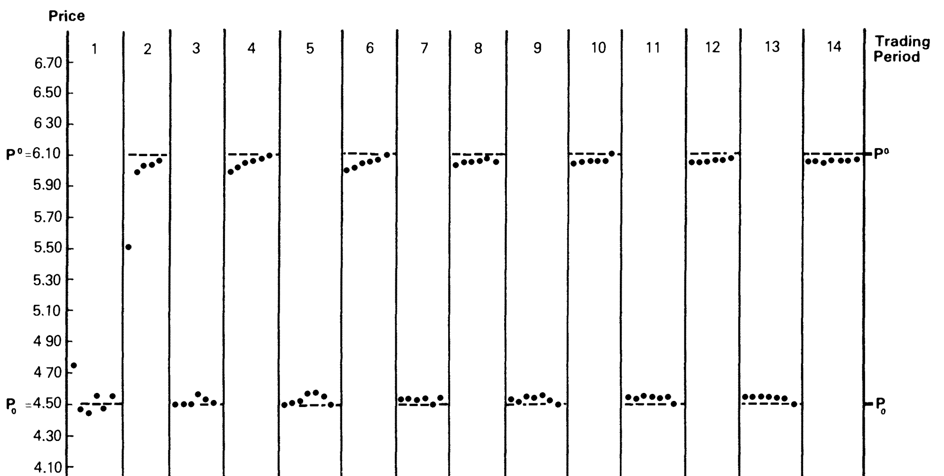
$$\ln \alpha(t) = a + bt + cI + d(t \times I),$$

11. Observations from the final trading period in an experiment were not included in the following estimates in order to eliminate price observations generated by end effects.



Trading Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Mean Price	5.60	7.188	5.763	7.326	5.76	7.309	5.723	7.324	5.743	7.379	5.769	7.391	5.796	7.398
Quantity Exchanged	6	6	7	7	7	7	7	7	7	7	7	7	7	6
Standard Deviation	.138	.147	.071	.040	.049	.043	.052	.039	.051	.034	.036	.049	.037	.031
E°	97.58	95.16	100.0	97.58	100.0	100.0	97.58	96.77	96.77	100.0	100.0	100.0	100.0	97.58

FIG. 12.—Experiment 2a-3 (design II, autarky)



Trading Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Mean Price	4.457	5.934	4.520	6.050	4 529	6.052	4 523	6.053	4.527	6 063	4.536	6 062	4 539	6 060
Quantity Exchanged	6	5	6	6	7	6	6	6	7	6	7	6	7	7
Standard Deviation	100	.213	.026	.033	.025	.031	011	015	017	.017	016	.004	017	005
E°	98.39	87.90	98.39	98 39	100.0	98 39	98.39	98.39	100 0	81.45	100.0	98.39	100 0	100 0

FIG. 13.—Experiment 2a-4 (design II, autarky)

where

$$\alpha^2(t) = \frac{1}{Q}\sum_{i=1}^{Q}[P_i(t) - P^*]^2;$$

$P_i(t) \equiv$ the ith contract price in trading period t;
$Q \equiv$ the total quantity exchanged during period t;
$P^* \equiv$ intertemporal competitive equilibrium price; and
$I = 1$ if summary price information was provided, 0 otherwise.

Thus, the price series in a particular period of trading is "close" to P^* only if the price variance is low and the mean price is near P^*. Least-squares estimation of the equation specified above yields:

$$\ln \alpha = -.161 - \underset{(p = 0)}{.118t} - \underset{(p = .652)}{.090I} + \underset{(p = .0921)}{.044(t \times I)}$$

$$R^2 = .348,\ F_{(3,115)} = 20.5.$$

The rather surprising result is that the presentation of summary price information tends to retard slightly, rather than to speed up, the rate of price convergence to P^*. Both sets of experiments start the convergence process from an α value very close to .75 (note that the minimum autarkic equilibrium price spread is $-.75$ to $+.75$ in fig. 4). Choosing a

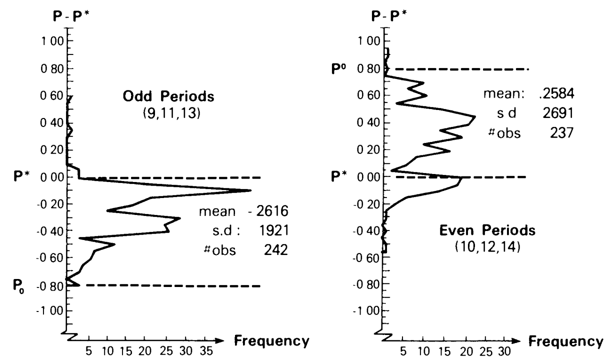


FIG. 14.—Contract price frequency polygons: speculation experiments

target value of $\alpha = .05$ (the range of intertemporal equilibrium prices is from $-.05$ to $+.05$) we find that α would decay to the target value after 25 periods of trading under the "no summary information" treatment and after 38 periods of trading when summary information is provided.

The substantial variation in prices generated during the final market cycles of the speculation experiments is illustrated by the separate odd- and even-period frequency polygons and descriptive summary statistics for pooled period 9–14 data, shown in figure 14.

Figures 15–18 plot the sequence of contract prices, each trader's inventory level, and descriptive statistics for speculation experiments 2t-1, 2t-2, 2t-3, and 2tp-3, respectively. In experiment 2t-1 we observe a partial elimination of the autarkic price spread with prices being fairly stable during the sixth market cycle (periods 11 and 12) at $(P_o + .27)$ and $(P^o - .41)$. It is tempting to conjecture that the traders were sophisticated enough to realize that it was in their combined best interest to maintain such a price spread.[12] However, the reason for its existence is clear after examining the sequence of traders' inventory levels presented in the lower part of figure 15. We note that trader 1 was responsible for most of the successful speculative activity in this market and that trader 2 was, after repeated losses, almost completely inactive over the last two market cycles. The net aggregate change in traders' inventories, starting with period 1, is +2, +2, +1, −1, +4, −6, +5, −6, +4, −5, +5, −5. This is insufficient to eliminate the cyclical price swings.

Trader 1 is very conservative over the first two market cycles, buying and then selling one unit in both periods 1 and 2. He then carries one unit over from period 3 to period 4, earns a sizable profit ($1.60) on this unit, and then falls into a pattern of buying in the odd periods and

12. The price spread that would maximize traders' joint profits is $(P_o + .35) - (P^o - .35)$ with a total of six units carried over from each odd- to each even-numbered period.

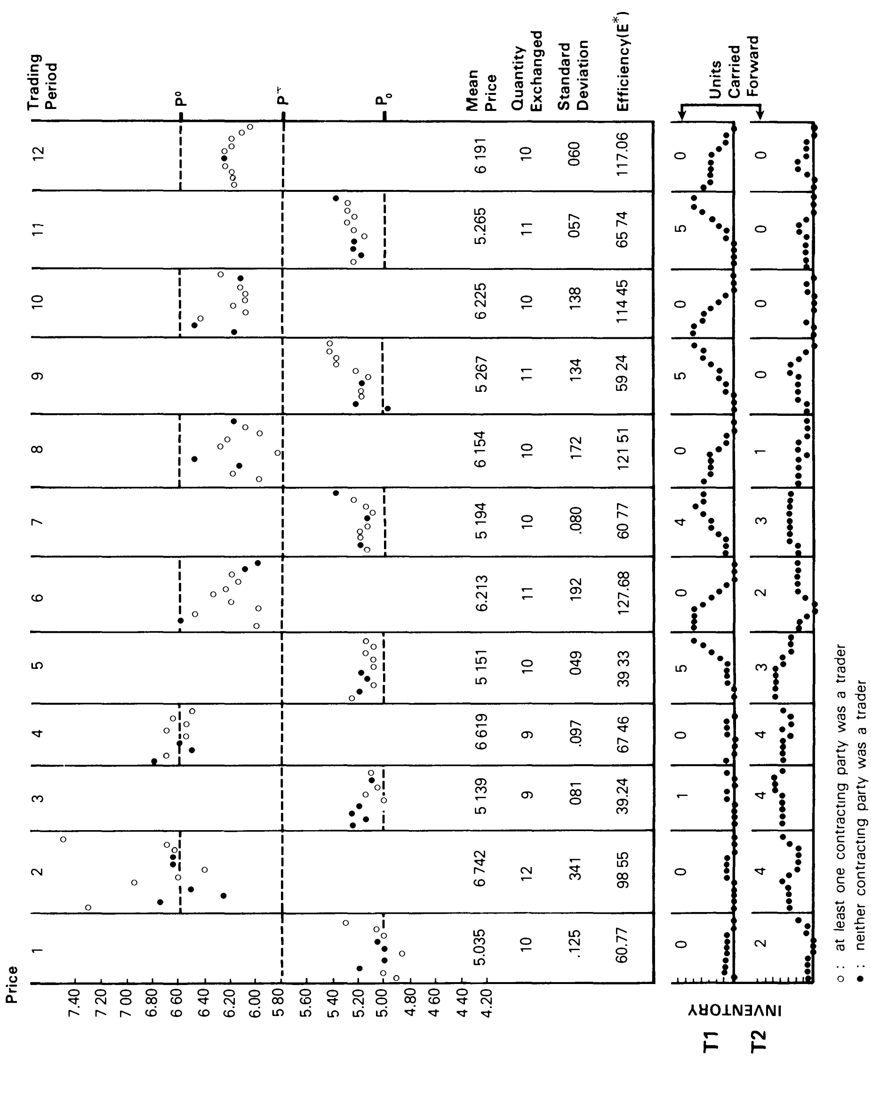


FIG. 15.—Experiment 2t-1 (design II, speculation)

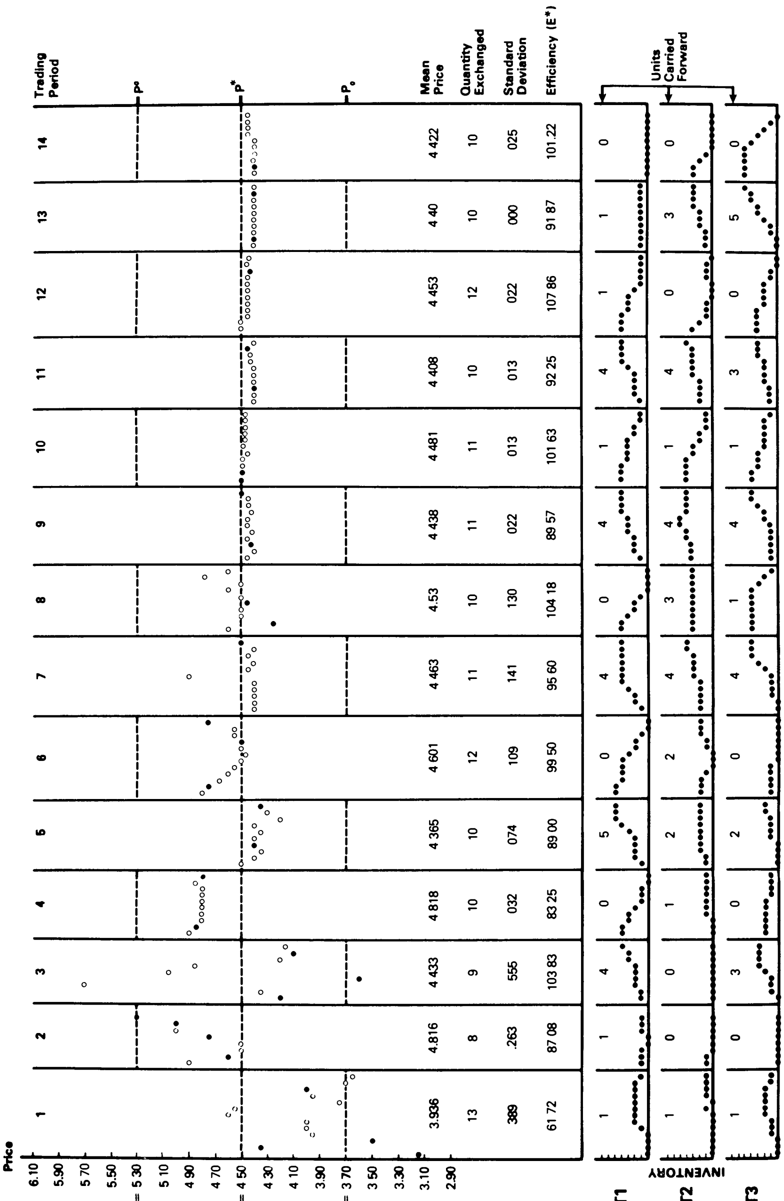


FIG. 16.—Experiment 2t-2 (design II, speculation)

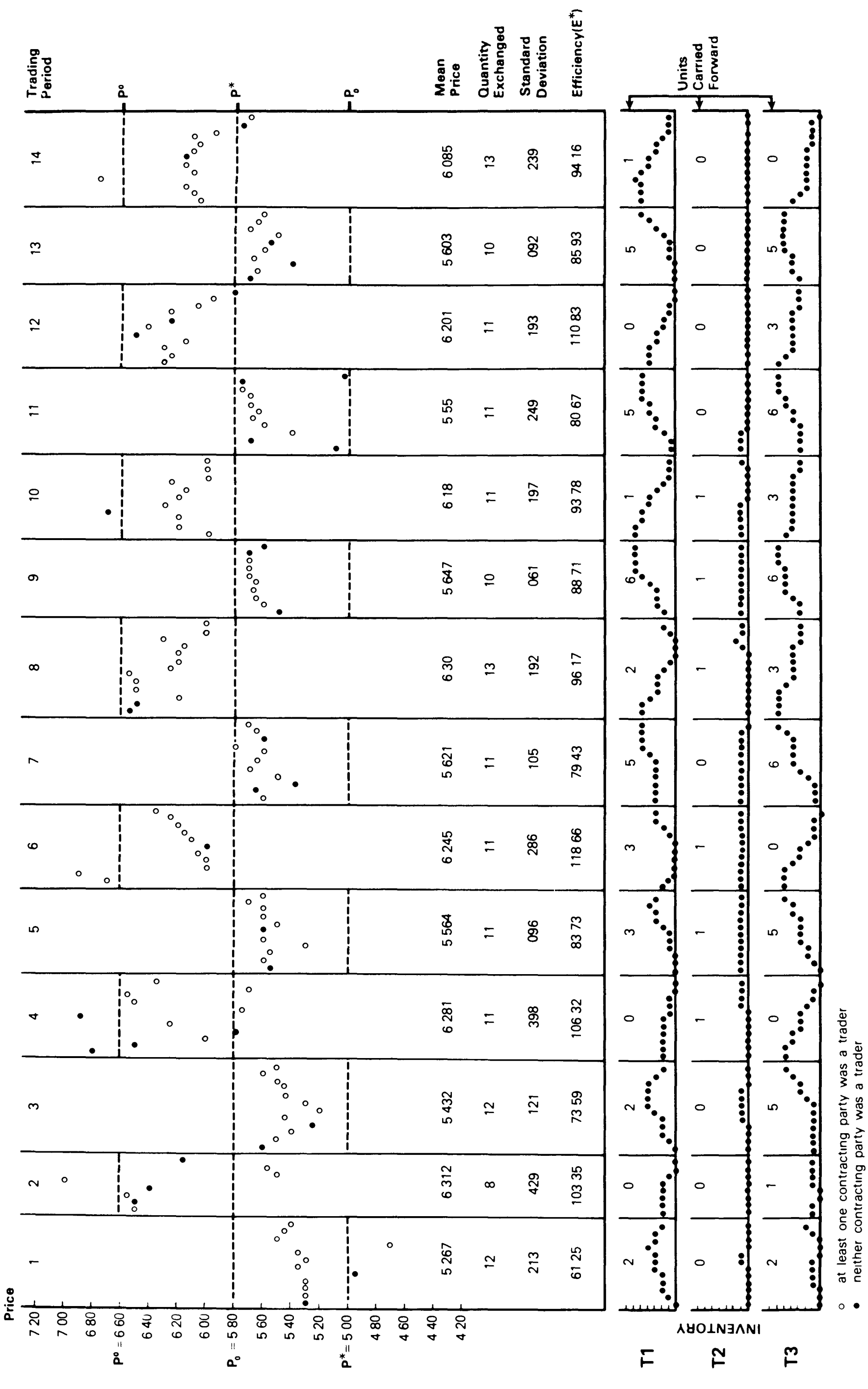


FIG. 17.—Experiment 2t-3 (design II, speculation)

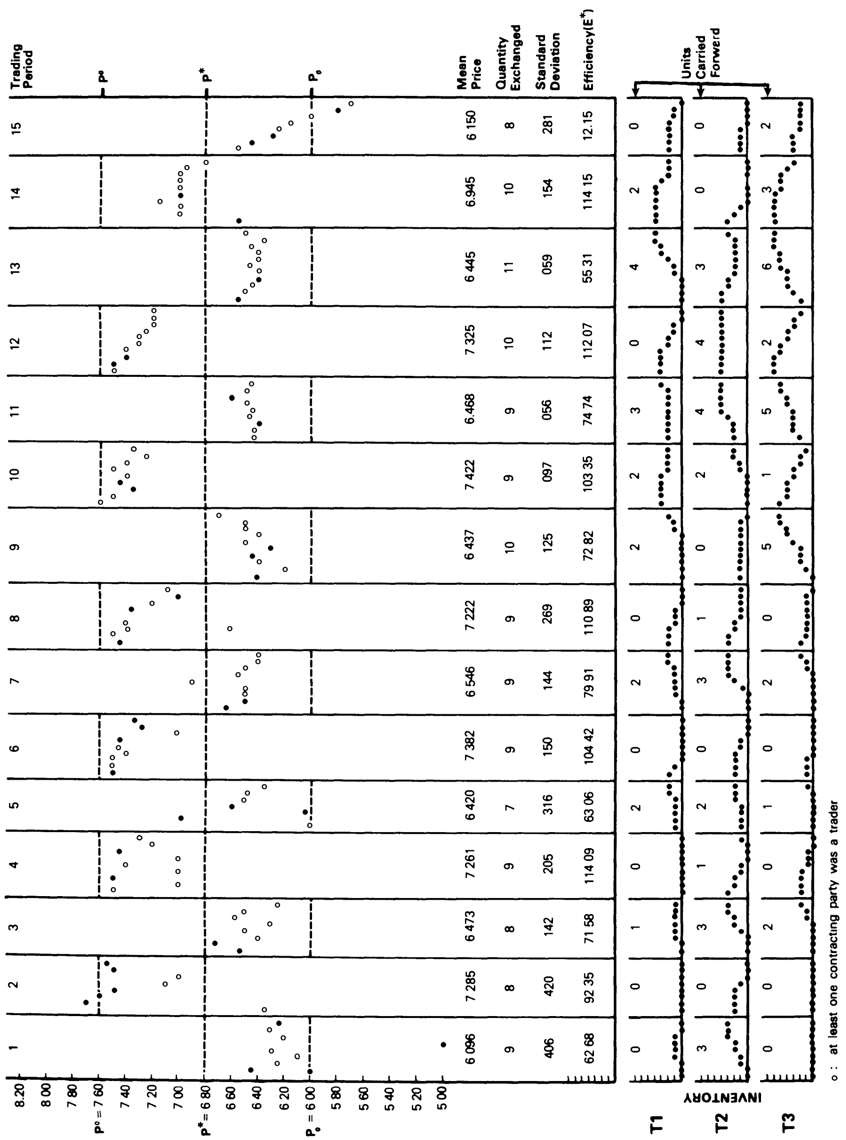


FIG. 18.—Experiment 2tp-3 (design II, speculation)

selling in the even periods for the remainder of the market. In contrast to this behavior, trader 2 quickly enters the market and carries two units over from period 1 to period 2; she then buys two additional units in period 2 and sells the two units purchased during period 1 for profits of \$1.61 and \$1.10, respectively. She then buys two more units in the high-price period for a total of four period 2 units carried over into period 3. One of these units is sold in the next period for a \$2.20 loss, two are sold in period 4 for losses of \$.39 and \$.15, and the final unit is sold at a loss of \$2.40 in period 5 (after which it would have been sold at its \$4.00 scrap value for a loss of \$3.50). For the remainder of the experiment trader 2 does not seem to recognize the proper buy-sell sequence, much to the advantage of trader 1, who amasses a working capital of \$30.63 over the course of the experiment. By contrast, trader 2's working capital falls from \$10.00 to \$6.92.

After running experiment 2t-1 we decided to use three traders in the subsequent speculation experiments. The socially optimal intertemporal carry-over would thus be obtained if each trader bought and sold three units in each odd-even market cycle. Figure 16 displays price and inventory data from experiment 2t-2. Prices approach P^* fairly rapidly, reflecting net inventory changes of +3, −2, +6, −6, +8, −7, +10, −8, +8, −9, +8, −10, +8, −9 for periods 1–14, respectively. Traders 1 and 3 are quite consistent in following a profitable buy-sell sequence but accumulate a working capital of only \$12.19 and \$11.99, respectively, for their efforts because the autarkic price spread is eliminated. Trader 2 does not follow the odd-even buy-sell pattern until period 11 and ends with a working capital of \$9.64.

Figure 17 displays the price and inventory data from experiment 2t-3 which exhibits partial convergence to P^* even though three traders were operating in the market. Net inventory changes for periods 1–14 are +4, −3, +6, −6, +8, −5, +7, −5, +7, −8, +6, −8, +7, −9. In this market trader 2 is almost totally inactive throughout the entire experiment but does manage to lose \$2 of his \$10 starting capital. In contrast to this, trader 1 is a very successful speculator earning \$21.71 by the end of period 14. Trader 1 failed to unload all of his inventory units during the final period of trading and consequently is forced to absorb a \$2.75 loss for selling a unit at scrap value. Trader 1 commented after the experiment that he had mistakenly purchased a unit at the beginning of period 14 when he meant to sell. This raised his inventory level to six units and since the maximum number of sales in any one period is limited to five, he was forced ultimately to pay for his error. Trader 3 is also quite successful in his speculative activities, earning \$24.60 during the experiment.

Figure 18 plots price and inventory data from experiment 2tp-3 where all subjects were provided summary price information between

TABLE 4 Autarky–Speculation Efficiency Comparison: Design II

Trading Period	E^o		E^*	
	Autarky	Speculation	Autarky	Speculation
1	94.15	103.15	55.86	61.20
2	94.35	148.90	55.98	88.34
3	97.78	113.61	58.01	67.40
4	98.59	154.24	58.49	91.51
5	98.79	97.14	58.61	57.63
6	98.79	177.29	58.61	105.19
7	98.59	108.18	58.49	64.18
8	98.18	189.02	58.25	112.15
9	98.79	122.73	58.61	72.82
10	94.96	187.28	56.34	111.11
11	99.60	128.63	59.09	76.32
12	99.60	179.37	59.09	106.42
13	98.99	128.39	58.73	76.17
14	99.19	164.05	58.85	97.33
1–14	97.88	142.99	58.07	89.84

periods. Net aggregate inventory changes for periods 1–15 are +3, −3, +6, −5, +4, −5, +7, −6, +6, −2, +7, −6, +7, −8, −3. Traders 1–3 ended with working capital of $17.66, $14.24, and $19.06, respectively. Note that trader 3 has two inventory units remaining when time expires in the final trading period and must cover a $2.93 loss on these units. A clear end effect is present in period 15 as traders 1 and 3 try to unload five inventory units in an odd period, causing prices to drop sharply back to and below the autarkic equilibrium.

Table 4 presents a pooled autarkic-speculative market efficiency comparison. The speculative markets generate a higher mean efficiency in all trading periods except period 5 (when they are almost identical). A matched pairs *t*-test using the mean value of E^o given in table 4 yields $t_{(13)} = 5.183$. The design II parameters are such that at the autarkic competitive equilibria buyers and sellers split $6.20 in surplus equally each period. At the intertemporal competitive equilibrium, total surplus available is $10.45, with buyers (sellers) receiving $.35 and sellers (buyers) receiving $10.10 during each odd (even) trading period. Thus, an E^o value of 100 implies a corresponding E^* value of 59.33 and an E^* value of 100 implies an E^o value of 168.55. Except for period 5, the mean efficiency in the speculative markets exceeds the maximum possible efficiency in an autarkic market ($E^o = 100, E^* = 59.33$). Also, it is instructive to note the low-high (odd-even) efficiency cycle in the speculation experiments. This is due to the fact that purchases by traders were generally made in odd (low price) periods and resulted in an immediate profit only for the seller. Traders generally made profits on the sale of inventory units in even (high-price) periods.

VI. Summary

Using observations from two cyclical market designs, we have shown that the inclusion of a class of speculative agents tends to reduce significantly the observed magnitude of cyclical price swings relative to those observed in markets without intertemporal speculation. Including speculators also results in a significant increase in market efficiency.

In a market with shifting demand and stable supply (design I) we observe convergence toward the zero excess demand intertemporal equilibrium price when speculative agents are active in the market. Without speculators, prices display a marked lagging in the adjustment from one cyclical phase to the other. When a considerably different market design with shifting supply and demand is used (design II), prices do not generally converge to the intertemporal competitive equilibrium within the seven-cycle duration of most experiments. This slow rate of price convergence is attributed to risk-averse behavior by speculators, resulting in intertemporal carry-over below the socially optimal level. Without speculators, prices tend to cycle between the two (autarkic) equilibria. An investigation of the price series and resulting frequency distributions generated in odd (low-price) and even (high-price) periods shows a tendency for prices to lag somewhat below the competitive equilibrium during even periods but not during odd periods. An informal explanation is offered to account for this empirical phenomenon.

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