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This article uses experimental methods to establish that greater uncertainty in the environment increases the naturally emerging bid-ask spread in double-auction trading. The opportunity to trade off floor is then introduced. Off-floor trading is greater in the environment with a wider bid-ask spread, increases with block trading, and increases still more with increasing subject experience. Finally, we find that the preponderance of off-floor trades are inside the bid-ask spread, supporting the hypothesis that a motive for such trades is to split privately the gain represented by the bid-ask spread without revealing publicly a willingness to make price concessions.

I. Introduction

This study has its origin in a series of meetings between the authors and various futures market exchange officials. Our interest was in identifying one or more research questions, arising in the ordinary operation of an exchange, that might be capable of examination using experimental methods. We wanted the scrutiny of exchange officials and their assistance in helping to define a set of questions that we thought would be researchable by laboratory experimentation. Initially we discussed a wide range of issues, including the problem of "off-floor" trading, which ultimately was the research focus that we mutually agreed would be a good starting candidate. We selected this problem for a number of reasons.

1) All futures and stock exchanges have rules that prohibit the members of an exchange from engaging in unauthorized off-floor trades.[1]

1. For example, rule 520 of the Chicago Mercantile Exchange (1985) states that "All trading for future delivery in commodities traded on the Exchange must be confined to transactions made on the Exchange floor in the designated trading area during trading hours. . . . Any member violating this rule shall be guilty of a major offense."

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Consequently, the problem is of general interest within the securities industry, and we are able to ask whether such rules are warranted by the results we obtain in laboratory experimentation.

2) Off-floor trading in futures markets is known to occur in spite of penalties that have been levied on exchange members who violate these rules. This suggests that there exist endogenous incentives strong enough to overcome the penalty strictures intended to prevent such trading activity.

3) The frequency of occurrence, as well as an understanding of the circumstance of individual violations, is not known precisely by exchange officials. The fact that off-floor trades are prohibited and punishable as a major offense, and therefore are clandestine, makes it impossible to gather systematic field data on off-floor trades. Essentially, experimental evidence is the only feasible source of observations on off-floor trading.

4) Off-floor trading illustrates a research problem that has not yet received attention in the published literature of experimental economics: if an individual voluntarily elects to forgo trade in an organized market and to trade instead by bilateral bargaining with another individual, then we have an example of endogenous choice between two institutions of exchange.

5) Finally, we judged that we would be able to develop a set of experimental procedures and designs that would make the off-floor trading problem researchable by laboratory methods.

II. Related Background Literature

The question of whether it is socially desirable to permit off-floor private trades is best understood by recognizing that securities and futures trading involves three different markets: the market for securities, the market for dealer services (see Schwartz [1988, pp. 427–28] for a discussion of these two), but also the market for the services of exchanges. Prior to 1975 the Securities and Exchange Commission had supported the industry's cartel for fixing minimum commission fees. This price-fixing was rendered viable to the extent of enforcement of the rules prohibiting off-exchange trading. The Securities Acts Amendments of 1975 sought two important changes: to eliminate all unjustified competitive constraints in securities trading, and to mandate the development of a National Market System. The result of the first proscription was to remove the fixing of commissions. This has resulted in a substantially more competitive market for *dealer services* and in lower commission rates. The mandate for a National Market System has resulted in the Intermarket Trading System linking the national and regional exchanges; also, we now have an over-the-counter automated quotation and trading system. This has increased competition in the market for *exchange services* (see Hamilton [1987, 1988] for studies of the trading of New York Stock Exchange [NYSE]-listed securities on the regional exchanges; also Garbade and Silber 1979).

These changes, which have increased dealer competition and market integration, have left unresolved the question, Should off-floor trading be permitted on a given exchange? Schwartz (1988, p. 498) suggests that "off-board trading restrictions appear to have some justification" because traders benefit socially (lower-bid spreads, price efficiency) from order consolidation. But because of a "public good" problem, individual incentives may not be compatible with order consolidation. Our explicit interpretation is as follows: contracts listed on an exchange are successful trading instruments only to the extent that they accommodate trading activities of agents that were previously unavailable (e.g., the Standard and Poor futures index) or only available at the higher transaction cost of a disintegrated market (e.g., the original over-the-counter trading of stock puts and calls). But on listing a new contract, an exchange also provides a central place where interested traders meet, making it possible to trade off floor at minimum search cost and to free ride on the available competitive price information to lower negotiation cost. Hence off-floor trades based on the bid-ask spread may be cost-efficient for certain traders who complement each other through reputation or block-trading frequency.

But why should off-floor trading qualify market performance? Cohen, Conroy, and Maier (1985) use a queuing-theory model of trading to show that disintegration (relative to order consolidation, which maintains price priority in double-auction trading) produces wider bid-ask spreads and increased price volatility. Using simulation methods, similar results are obtained by these authors when time priority is violated. Our computerized exchange maintains a strict price-priority rule with tied bid (or offer) prices ranked by a time-priority rule. Both price and time priority are violated in our experiments when traders negotiate off-floor bilateral contracts. Under a clearinghouse regime, Mendelson (1987) demonstrates that fragmentation (disintegration) reduces the expected volume and expected gains from exchange while increasing the price variance faced by traders. Although our market is a continuous auction, these predictions receive qualitative support by our results.

III. Design Considerations and Motivation

The research questions we investigate in this report did not spring full blown at the project's inception; they evolved and were articulated gradually over a series of experiments interspaced among feedback discussions with exchange officials. After our initial discussions we designed an experiment intended to provide an explicit exogenous transactions fee differential between on-floor computerized double-auction trading of single units and off-floor private bilateral block trades. This served as our first, baseline 1, experiment (1 in table 1) showing clearly what everybody expected, namely, that the a priori predicted division of trades between the two institutions would occur in the laboratory using reward-motivated subjects. This experiment provided a vehicle for focusing the next round of discussions on the elements driving off-floor trading as conjectured by exchange officials. A number of questions emerged from this and subsequent discussions. Will the phenomenon of off-floor trading be observed in an environment in which there is *no* explicit transactions cost saving and *no* block trades? How much off-floor trading occurs relative to on-floor trading? Does off-floor trading persist with experience over time? The challenge here was to create an environment in which the decision to trade off floor was entirely endogenous, unmotivated by exogenous conditions. Is the extent and persistence of off-floor trading influenced by design treatments that increase the (naturally emerging) bid-ask spread? This latter question resulted from the conjecture of exchange officials that off-floor trades were motivated by the mutual gains at prices inside the bid-ask spread. If off-floor trades are observed in the weakly motivating environment of single-unit trading, will such trades increase when subjects can trade blocks of units off floor?[2] The above questions led to the design and execution of the five new baseline 2 experiments and five treatment experiments listed in table 1. An "x" following an experiment number, for example, "5x," refers to the use of once-experienced subjects, while "xx" refers to twice-experienced subjects; otherwise subjects are inexperienced. Three of the baseline experiments (2, 3, 4) used an environment in which the static supply-and-demand equilibrium was unchanging over the 15 periods of trading; two (7, 8) used an environment in which the equilibrium was shifted randomly in each of the 15 periods of trading. In these baselines no off-floor trading opportunities were provided. The objective was to test our conjecture that the naturally emerging bid-ask spread in the static environment would be narrower than the bid-ask spread that emerged in the random environment. The purpose was to establish that we had indeed created two environments with different endogenous bid-ask spreads that were *independent* of the occurrence of off-floor trading. This provided baseline controls for comparison with subsequent "treatment" experiments in which subjects were given the

2. Of course, block trades can be executed on all exchanges, but traditionally under a rule that prohibits all-or-none bids or offers (see Chicago Mercantile Exchange 1985, rule 523; and New York Stock Exchange 1987, pp. 2061–62). Of course no such restriction would apply in rule-violating off-floor negotiation. Ironically, rules prohibiting all-or-none bids and offers might provide an incentive for violating rules against off-floor trading.

TABLE 1 Experimental Designs

Experiment Number	Market Size	Off-Floor Trading	P_e by Period	Value/Cost Assignment	Number of Periods
Baseline 1 (transaction cost):					
1	6 buyers 6 sellers	6-unit blocks	Constant	Constant	15
Baseline 2:					
2, 3, 4	5 buyers 5 sellers	None	Constant	Random	15
7, 8	5 buyers 5 sellers	None	Random	Random	15
Treatments:					
5x	5 buyers 5 sellers	Single units	Constant	Random	15
6x	5 buyers 5 sellers	Single units	Random	Random	15
9x, 10x	5 buyers 5 sellers	3-unit blocks	Random	Random	14
11xx	5 buyers 5 sellers	3-unit blocks	Random	Random	15

opportunity to make bilateral trades off floor. In the treatment experiments we ask: (1) will subjects trade off floor? (2) will off-floor trades be greater in the random than in the static supply-and-demand environment? (3) will off-floor trading in the random environment be greater for block trades than for single-unit trades?

Since our results provided generally affirmative answers to these questions, in our final experiment (11xx) we collected data designed to answer the question, Do off-floor trades occur at prices that are predominately inside the bid-ask spread standing at the time of execution? If so, this is confirmatory evidence that the motivation for off-floor trades is to split the gain measured by the bid-ask spread.

IV. Experimental Design and Trading Mechanisms

A. *Experimental Design*

We use standard monetary reward procedures to induce controlled supply-and-demand schedules in each period of every market experiment (see Smith 1976). Our experimental design uses the schedules shown in figure 1; these are known to the experimenter but are *not* known by any subject. In experiments 2–11xx (table 1), the induced supply and demand, measured in deviations from the center of the set of competitive equilibrium prices, is shown in figure 1*b*. There are five buyers and five sellers. Three of the buyers (B_i, B_k, B_n) each have a capacity to buy up to 6 units, while two of the buyers (B_j, B_m) have a capacity to buy up to 3 units in any single trading period. Symmetrically, three sellers (S_i, S_k, S_n) can sell up to 6 units, and two (S_j, S_m) can sell up to 3 units. Any particular buyer (seller) subject was assigned randomly to one of the step positions (*i*, *j*, *k*, *m*, *n*) at the beginning of each of the 3 weeks (5-day trading periods) in an experiment. A buyer's profit is determined by computing the difference between his/her assigned value and purchase price in the market for each unit bought. In figure 1*b*, if the equilibrium price is \$3.00, then B_i has 6 units valued at \$3.40. If a unit is purchased at \$3.05, then B_i makes a profit of \$3.40 − \$3.05 = \$0.35 on that unit. Consequently, B_i has a well-defined maximum willingness to pay of \$3.40 for each unit. The cumulative profit on all units purchased in all 15 periods is paid in cash to each buyer at the end of the experiment. Thus the incentive of each buyer is to buy as low as possible but to balance this gain against the increased uncertainty of making a trade at lower prices. A seller's profit is computed by subtracting his/her assigned cost from the selling price of each unit sold. If S_k was the seller of the unit at price \$3.05 to buyer B_i in the above example, then the seller's profit is \$3.05 − \$2.80 = \$0.25. The maximum possible profit that can be earned by the 10 subjects in an experiment is simply the area between the supply-and-demand schedules, which is shown as "Gains from Exchange" in fig-

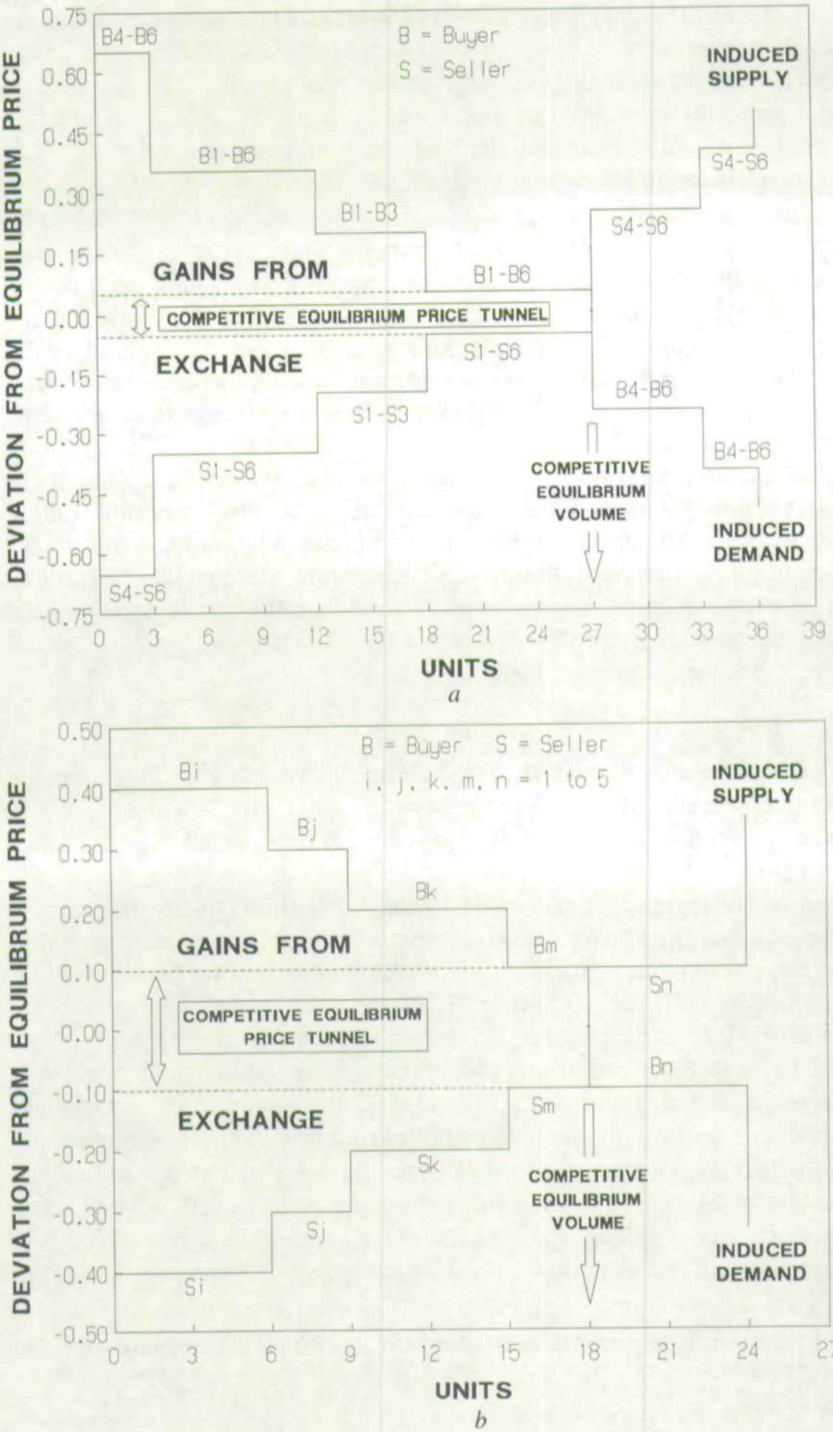


FIG. 1.—*a*, Supply and demand for experiment 1. *b*, Supply and demand for experiments 1–11xx.

ures 1*a* and 1*b*, since this measures the maximum aggregate gains from exchange achievable through market trade. Market efficiency is well defined as the ratio of the total profits actually realized in any trading period to the maximum profits shown in figure 1*b*. A market is 100% efficient if and only if 18 units trade and buyer B_n and seller S_n trade none of their units.

In experiments 6x–11xx (table 1) subjects were not only assigned randomly by 5-day weeks to the steps shown in figure 1*b*, but in addition a random constant (positive or negative) was added each period to all buyer values and all seller costs. Consequently, in these experiments, the competitive equilibrium price was shifted randomly each period. This provided increased price and transaction uncertainty relative to those experiments (2–5x) in which only the step assignments were randomized.

In our first baseline 1 experiment, the value and cost assignments to buyers and sellers remained constant over the entire 15-period trading horizon. The resulting supply-and-demand arrays are shown in figure 1*a*. In this experiment all on-floor "electronic" trades were subject to a 25 cent per unit "commission" fee. The supply-and-demand schedules in figure 1*a* are computed net of the 25 cent charges levied on the buyer and seller in each trade.[3]

B. *The PLATO Double-Auction Mechanism*

In each experiment exchange trading occurs via our PLATO computer double-auction software program written by Arlington Williams (1980). The screen display for a subject (buyer 5) in experiment 11xx is shown in figure 2. The upper panel of the screen contains buyer 5's private record sheet for all transactions in week 2 (periods 6–10). In period 6 buyer 5 had the capacity to buy a maximum of 6 units, each valued at \$6.83, but bought only 2 units via PLATO—the first for \$6.60, yielding a profit of \$.23, the second for \$6.67, giving a profit of \$.16. Buyer 5 in week 2 had the position B_k shown in figure 1*b* on the step that is \$.20 above the equilibrium price; that is, the equilibrium price was \$6.63 in period 6 and \$4.23 in period 7. Just below the record sheet appears the standing bid and/or offer, which is *public* information for all subjects. All traders see that currently a buyer has a standing bid to buy at \$4.12 and a seller has a standing offer to sell at \$4.43. Any buyer is free to accept the standing offer by touching the outlined box area labeled "accept offer"; he/she then has up to 5 seconds to confirm

3. In the static environment of baseline 1 (fig. 1*a*), the bid-ask spread converged to minuscule levels. In order to test the key hypothesis of the study we needed a design for the subsequent experiments in which the bid-ask spread would converge to a wider level than we had observed in experiment 1. This led us to widen the tunnel of competitive equilibrium prices (cf. figs. 1*a* and 1*b*) in addition to introducing the random supply-and-demand environment.

WEEK 2

RECORD SHEET for BUYER 5	6	7	8	9	1Ø
Unit 1 resale value	6.83	4.43			
Unit 1 purchase price	6.6Ø				
Profit	Ø.23				
Unit 2 resale value	6.83	4.43			
Unit 2 purchase price	6.67				
Profit	Ø.16				
Unit 3 resale value	6.83	4.43			
Unit 3 purchase price					
Profit					
Unit 4 resale value	6.83	4.43			
Unit 4 purchase price					
Profit					
Unit 5 resale value	6.83	4.43			
Unit 5 purchase price					
Profit					
Unit 6 resale value	6.83	4.43			
Unit 6 purchase price					
Profit					
Total Profit for Period	Ø.39				

TRADING PERIOD (columns)

A BUYER BIDS $4.12 **A SELLER OFFERS $4.43**

ENTER BID >$ ACCEPT OFFER CONFIRM CONTRACT

Contracts: 4.45, 4.44, 4.42, 4.35, 4.36, 4.28

Trading Period 7 now in progress. SECONDS REMAINING: 28

FIG. 2.—PLATO screen display for a buyer

by touching the box area labeled "confirm contract." Similarly any seller may touch his/her "accept bid" box, then confirm. The resulting contract is binding, and the auction for 1 unit ends. PLATO then waits for a new bid and offer from the "floor" if there are no bids or offers stored in the "electronic book." The box on the left allows a subject to enter a new bid (offer). Suppose buyer 5 desires to place a new bid at $4.35. He/she types this number on the keyboard and confirms that it has appeared (privately) to the right of the arrow pointed at the "$" symbol. By pressing the touch-sensitive box labeled "enter bid," this number, adjacent to the arrow, disappears and reappears publicly as the new standing bid, replacing the previous bid at $4.12.[4]

4. Note that the PLATO mechanism uses many of the New York Stock Exchange rules. As we see in this example a standing bid (offer) is subject to an improvement rule:

We want to emphasize that bids, offers, and acceptances are executed quickly on PLATO. There is no delay like that occurring in negotiating a trade off floor using the procedures described below. All our traders are principals operating for their own accounts; there are no dealers or specialists trading for the accounts of others. The bid-ask spread, if and when it exists at any time during an experiment, is entirely a naturally occurring endogenous event. The experimenters have no *direct control* over the bid-ask spread, only the possibility of indirect control via the introduction of induced supply-and-demand uncertainty in the environments.

At the bottom of the screen under the touch-sensitive boxes, the last several contracts (up to a maximum of eight) are listed in their historical sequence. Below this line of contracts the subject is reminded that period 7 is now in progress and that the number of seconds remaining is 28. In the experiments reported here the length of each period is 240 seconds.

C. *Off-Floor Bilateral Bargaining*

After reviewing the PLATO instructions in all off-floor trading experiments, supplemental instructions were read aloud while subjects followed their own printed handout sheets. In each period, subjects could trade the units on their screen either in the PLATO market or off floor. Buyers and sellers were seated alternatively so that each buyer (seller) had a seller (buyer) on each side with whom they could trade off floor. Each buyer (seller) was given bid (offer) tickets on which they could write a bid (offer). If a buyer (seller) wished to submit a bid (offer) off floor, he/she held the ticket in the direction of the seller (buyer) to whom they wished to submit the bid (offer). One of four experimenters then placed the ticket on the appropriate subject's table and the subject marked "accept" or "reject." The ticket was then returned forthwith to the person who submitted it. Off-floor trades and profits were recorded manually in tables supplied to each subject.

The seating arrangements and parameter randomization determined potential off-floor trading partners. In these experiments we made no attempt to match high-volume (i.e., 6-unit) buyers and sellers. In the off-floor block-trading experiments, subjects could trade units off floor in blocks of three. This means that agents endowed with only 3 units

any new bid must be higher and any new offer must be lower than the current standing bid and offer (see NYSE 1987, rules 70, 71). All bids and offers outside the standing bid-ask spread are placed in a price priority rank-queue or "electronic book"; tied prices are secondarily ranked by a time-priority rule. Bids and offers once standing cannot be withdrawn (see NYSE 1987, rule 72[e]), but those in the queue can be cancelled at any time by the maker. The standing bid (offer) is public, but the queue is not (see NYSE 1987, rule 115).

would trade their entire endowment if they traded off floor; others might trade 3 units off and 3 units on, or all 6 on (or off) the floor.

It should be noted that off-floor trading must inevitably take more time than electronic trading, and this would tend to inhibit off-floor trading, although less so for block trades. But this is true for naturally occurring markets as well as for our experimental markets. Our procedures were designed to minimize the mechanical (not negotiation) effort required to make off-floor trades since we did not want such trades to be unduly influenced by artifactual mechanical difficulties.[5]

V. Experimental Results

A. *Off-Floor Trading to Save Transactions Cost*

It is evident that, if block trades off floor can effect savings in transactions cost, this can provide an external incentive to choose bilateral off-floor exchange over electronic exchange. In experiment 1, 12 subjects were assigned randomly to the normalized value/cost positions shown in figure 1*a*. Each subject had the right to trade 6 units. The trading fee of $.25 on all PLATO trades was automatically deducted from each buyer and each seller's profit on each transaction. Net of commission fees the equilibrium price range, normalized on the competitive equilibrium price, is (−0.05, 0.05), and the corresponding volume is 27 units.

Supplemental instructions informed all subjects that after period 5 some buyers and sellers would have the option of executing 6-unit block trades outside PLATO at a flat commission fee of $.80. Thus if a subject traded 6 units per period in the PLATO market, total commission fees would be $1.50 as opposed to $.80 if those 6 units were traded off floor. Prior to each period (after period 5), three buyers and three sellers were allowed to submit off-floor block-trade contract proposals to one another via an experimenter. If a proposal was accepted, the buyer and seller involved traded all 6 units at a standard contract price

5. A referee poses the following substantive issue: "Was there any attempt to see how the thickness or thinness of the market affected off-floor exchange? If the PLATO market is thin, i.e., time between trades (is lengthened), is there a greater probability of trading off-floor?" Since the answer to the first question is "no," we have no empirical data for answering the second question. But an assumption underlying our experimental design was that market volume might indeed affect off-floor trading. Hence all of the experiments 2–11xx controlled for this using supply-and-demand designs with an equilibrium exchange volume of 18 units per period. Since each period lasted 240 seconds, the average time (theoretically) between contracts is 13.3 seconds, which was the same for all experiments. One could study this factor in a controlled manner by increasing the length of each of the induced price limit steps in fig. 1*b* by some multiple—2, 3, etc.—which would increase volume by the same amount and reduce average time between trades proportionately.

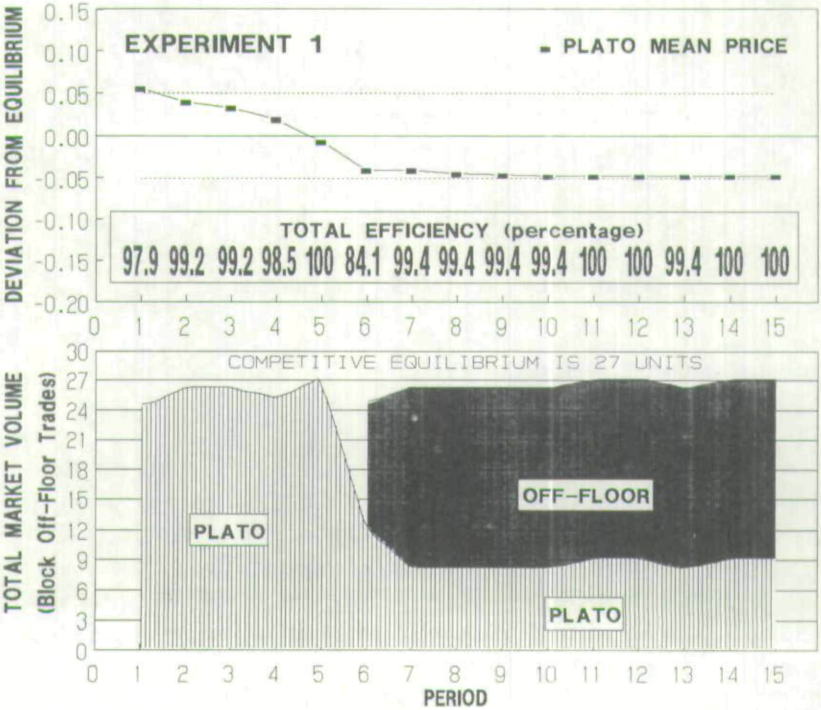


FIG. 3.—Baseline 1 experiment; block off-floor trading at reduced fee

determined by the average PLATO price in the period.[6] The mean price, PLATO and off-floor volume, and total market efficiency in each period are shown in figure 3. The average PLATO price is always within the competitive range, and the total (PLATO plus off-floor) volume is always within 3 units of the equilibrium level. In periods 7–15 all subjects with the opportunity to trade off floor did so. The prediction was for 18 units to trade off floor, and for 9 units to trade via the PLATO terminals. In period 6, one buyer did not accept an off-floor proposal and only 12 units were traded off floor. Since mean prices declined in each of the first 6 periods, it was reasonable for this buyer to expect that by trading on floor he might beat the standard

6. This "standard-contract," average-floor-price rule was imposed by the experimenters to represent the kind of informal agreement that might arise among block traders for after-hours trading. After preliminary discussions, experiment 1 was developed as the pilot experiment we used to focus our dialogue with exchange officials to demonstrate one set of incentive conditions under which off-floor trading might occur and to calibrate their thinking with ours on the potential for using experimental methods. It also provided pilot experience for the experimenters in a new area of research. Once we saw how to fashion the procedures for the auxiliary market, we eliminated the idea of a "standard contract" and allowed all off-floor trades to be freely negotiated.

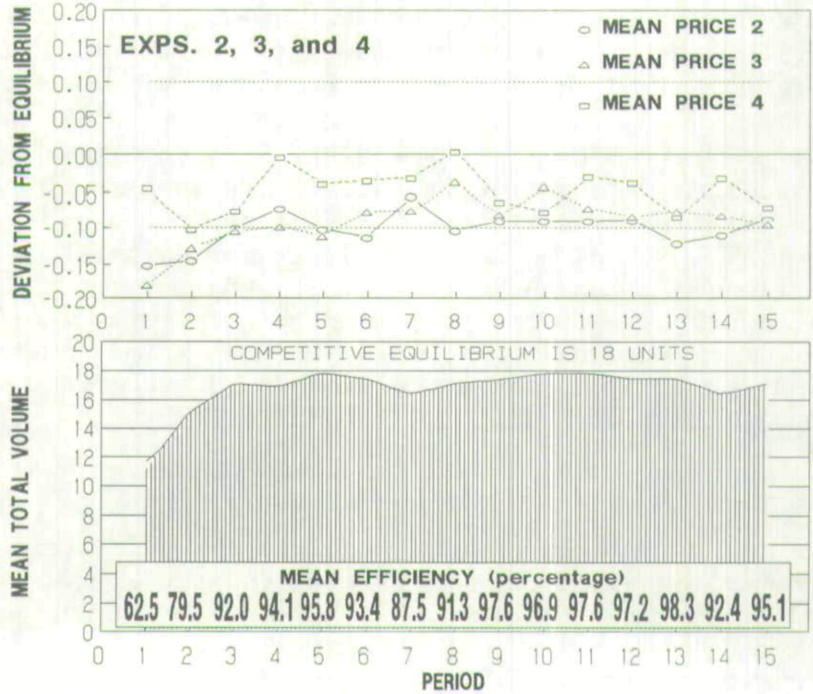
mean contract price applying to off-floor trades. After period 6, PLATO prices are nearly constant and within the competitive range even though two-thirds of the volume was off floor. The failure to observe a degradation in market efficiency with 60% of all trades off floor simply illustrates the robustness of the double-auction institution in producing competitive outcomes in *stationary* environments. This has been demonstrated in hundreds of experiments over the years (see Smith 1976, 1982; and Williams 1980). The use of an afterperiod standard contract to price off-floor trades controlled for any interference between off-floor and electronic trading. When we relax this control and also introduce greater uncertainty in the supply/demand environment, as in the experiments reported below, we shall find more degradation in market efficiency.

B. Establishing the Performance Characteristics of Baseline Environments without Off-Floor Trading

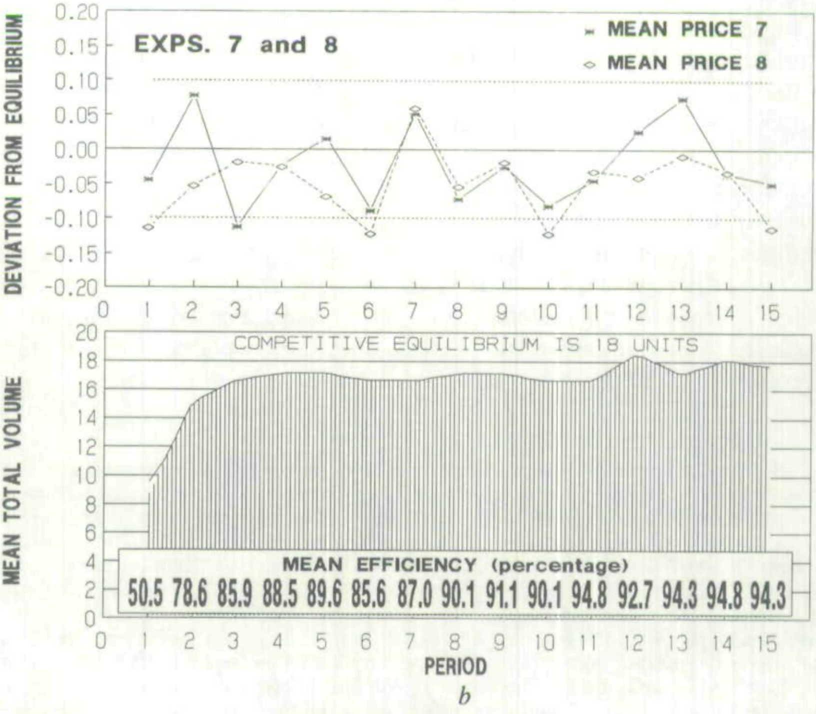
We next studied the performance characteristics of two different environments with differing degrees of external induced supply-and-demand uncertainty. In experiments 2–4 the competitive equilibrium price and quantity were constant over all periods, while in experiments 7 and 8 the competitive equilibrium price level shifted at random each period. Our a priori prediction was that the second condition would yield greater price volatility than the first. We also expected the bid-ask spread, when it exists, to widen under the second condition relative to the first. A measurement problem with the latter prediction is that contracts may and often do occur without a defined bid-ask spread, or before that spread has a chance to narrow. Thus, a bid may be entered and accepted before an ask price is established. Figure 4 provides charts of mean prices by period for all the baseline 2 experiments and summaries of mean volume and efficiency by period across each of the two groups of experiments.[7]

Table 2 lists the mean volume per period, mean price deviation, price variance, mean square error of prices (variance relative to predicted equilibrium), and the mean and median observed bid-ask spread at the

7. Notice the tendency of the mean price to lie in the lower half of the tunnel in both treatments. The hypothesis that the mean prices are greater than or equal to zero is rejected at the .01 level ($t(14) = -32.3$, constant; -5.98, random). The ability of buyers in double-auction trading to extract a larger share of the surplus has been noted before (see Smith and Williams 1982). Although explanations have been conjectured (subjects are more likely to have experience as buyers than as sellers), the cause is unknown. The experienced sessions reported below exhibit less bias in favor of buyers. In the baselines the equilibrium volume was traded 24 times, but 100% efficiency was reached only six of those times. A necessary and sufficient condition for 100% efficiency is that *all* intramarginal units trade. The relatively low prices allow trading of extramarginal units, resulting in less-than-complete realization of the maximum gains from exchange (profits).



a



b

FIG. 4.—*a*, Baseline 2 experiments with constant equilibrium. *b*, Baseline 2 experiments with random equilibrium.

TABLE 2 **Summary Data, All Experiments**

Experiment	PLATO Contracts						Off-Floor Contracts				All Contracts	
	Mean Volume per Period	Mean Price*	Price Variance	Mean Square Error†	Mean Spread	Median Spread	Mean Volume per Period	Mean Price*	Price Variance	Mean Square Error†	Fraction of Volume Off-Floor	Trading Efficiency
Baseline 1:												
1 (periods 1–5)	25.6	.03	.0014	.0022	.11	.05	. . .	. . .	. . .	. . .	. . .	.99
1 (periods 6–10)	8.8	−.05	.0000	.0021	.01	.01	17.40	−.05	.0000	.0021	.66	.98
Baseline 2:												
Constant:												
2	16.9	−.10	.0023	.0125	.25	.14	. . .	. . .	. . .	. . .	. . .	.94
3	16.1	−.09	.0035	.0109	.16	.10	. . .	. . .	. . .	. . .	. . .	.89
4	16.7	−.05	.0056	.0077	.13	.10	. . .	. . .	. . .	. . .	. . .	.92
Random:												
7	15.9	−.02	.0169	.0173	.36	.24	. . .	. . .	. . .	. . .	. . .	.86
8	16.8	−.05	.0154	.0176	.28	.18	. . .	. . .	. . .	. . .	. . .	.89
Off-floor trading:												
Single units:												
Constant:												
5x	15.5	−.05	.0021	.0042	.05	.02	1.73	−.03	.0023	.0029	.10	.97
Random:												
6x	14.8	−.02	.0048	.0051	.13	.06	2.47	−.01	.0059	.0059	.14	.96
Blocks, random:												
9x	11.6	−.04	.0063	.0077	.12	.09	4.50	−.05	.0052	.0072	.28	.91
10x	13.9	.01	.0023	.0023	.09	.05	3.64	.01	.0053	.0053	.21	.98
11xx	9.3	.02	.0087	.0091	.13	.10	7.00	.05	.0072	.0093	.43	.90

* Mean prices are expressed as deviations:

$$\overline{P} = \frac{1}{Q}\sum_{i=1}^{Q}(P_i - P_{ce}),$$

where Q is total contracts, P_i is the ith contract price, and P_{ce} is the midpoint of the set of competitive equilibrium prices.

† Mean square error is the variance of price deviations from the competitive equilibrium:

$$\text{MSE} = \frac{1}{Q}\sum_{i=1}^{Q}(P_i - P_{ce})^2.$$

time of contract for all PLATO trades. The same data (except for the spread) are listed for all off-floor contracts. Finally, the fraction of total volume that occurs off floor, and market efficiency, are listed in the last two columns. All statistics are computed across all periods and contracts in each experiment. We measure "the spread" in two ways. First, where a bid is accepted to form a contract but no ask is entered, we define the standing offer as \$9.99, the maximum possible price that PLATO will accept; if there is an offer price being accepted, but no bid, we define the "standing bid" as \$.01, the minimum possible price that PLATO will accept. In this way we are able to utilize all the information content of our data; this definition requires only the weak assumption that any seller would be willing to sell at \$9.99 and any buyer would be willing to buy for \$.01. Defining the spread in this way for outlier cases leads to some large erratic observations under all treatment conditions. In order not to weight such observations unduly, we use the median as the measure of central tendency. Second, when there is either no bid or no ask at the time of contract, we exclude the observation and compute the mean spread using the remaining observations.

From table 2, comparing the constant and random environments (experiments 2–4 with 7–8), the latter increases the price variance, mean square error, and the mean and median spread, all by a factor of about two. Further comparisons will be provided below in Section *F*.

C. Will Off-Floor Trades Occur When Single Units Can Be Traded?

From these results we were satisfied that we had successfully created two environments with differing bid-ask spreads. Recall that the importance of this resides in the fact that we exercise no direct control over the naturally occurring bid-ask spread. Given two environments with differing levels for the bid-ask spread, we ask, Will we observe off-floor trading? Will we observe more off-floor trading in the environment known independently to yield a wider bid-ask spread?

In both questions we restrict off-floor trades to the single-unit condition judged to provide the weakest incentive to trade off floor. We were skeptical as to whether off-floor trades would occur in these environments. Our skepticism grew out of the fact that for a trader to opt for off-floor trading he/she had to substitute a market with a lesser trading opportunity for one with a greater trading opportunity. Any off-floor bid (offer) could always be entered more quickly on PLATO and exposed to a larger number of potential acceptors. The disadvantage of such action might be to "spoil" the market by advertising *to all* a willingness to trade at a concessionary price. Making the bid (offer) off floor maintains privacy *without* forgoing the option of returning to the floor.

Figure 5 charts the mean price deviation and volume by period both off floor and on PLATO for experiments 5x and 6x. In table 2 the price variance and mean square error are greater in 6x than in 5x for both PLATO and off-floor contracts; the mean and median spread are both greater in 6x than in 5x. Note that the spread data for 5x–6x are not comparable with 2–4 and 7–8 because of differences in subject experience (see n. 9 below). Finally, the mean off-floor volume increases from 1.7 to 2.5 going from the constant to the random environment.

D. *Does Off-Floor Volume Increase with Block Trading?*

Having established that off-floor trades occur under the weak endogenous incentive condition of single-unit trades, we turned to a replication of the random equilibrium environment but with block trading. The hypothesis was that off-floor trading volume would increase in this environment with block trading. We conducted two replications, 9x and 10x, with different groups of once-experienced subjects, as in 6x. The results are charted in figure 6. Comparing 9x and 10x with 6x in table 2, the mean off-floor volume is increased with the introduction of block trading from 2.5 in 6x to 4.5 and 3.6, respectively, in 9x and 10x. The volatility and spread data suggest that these measures are not systematically affected by the introduction of block trading.

E. *Do Off-Floor Trades Persist with Increased Experience? At Prices Inside the Standing Bid-Ask Spread?*

We now seek to examine the persistence of off-floor trading with increased experience and to obtain direct evidence that off-floor trades occur at prices within the bid-ask spread.

Our final experiment used 10 subjects recruited from the pool of subjects that had participated in experiments 9x and 10x. They were therefore experienced in two of the previous 15-period experiments reported here. We thought such experienced subjects would be able to handle the additional recording demands we placed on them. In particular, with our monitoring assistance, we thought a subject would be able to record quickly the PLATO clock time at which a bid (offer) was tendered to an adjacent trader and that the receiving trader could record the PLATO clock time at which the bid (offer) was accepted or rejected. In fact, this extra procedural task worked smoothly with little apparent interference in the process. This procedure can be illustrated by the example we chose for display in figure 2. Note that buyer 5 faces a standing bid-ask of $4.12–$4.43, with 28 seconds remaining. At time 28 buyer 5 conveyed a bid to seller 4, stating a willingness to buy a 3-unit block at $4.35 (8 cents below the standing offer and 23 cents above the standing bid). At time 20 seller 4 checked "accept" on the form and returned it to buyer number 5. These two traders

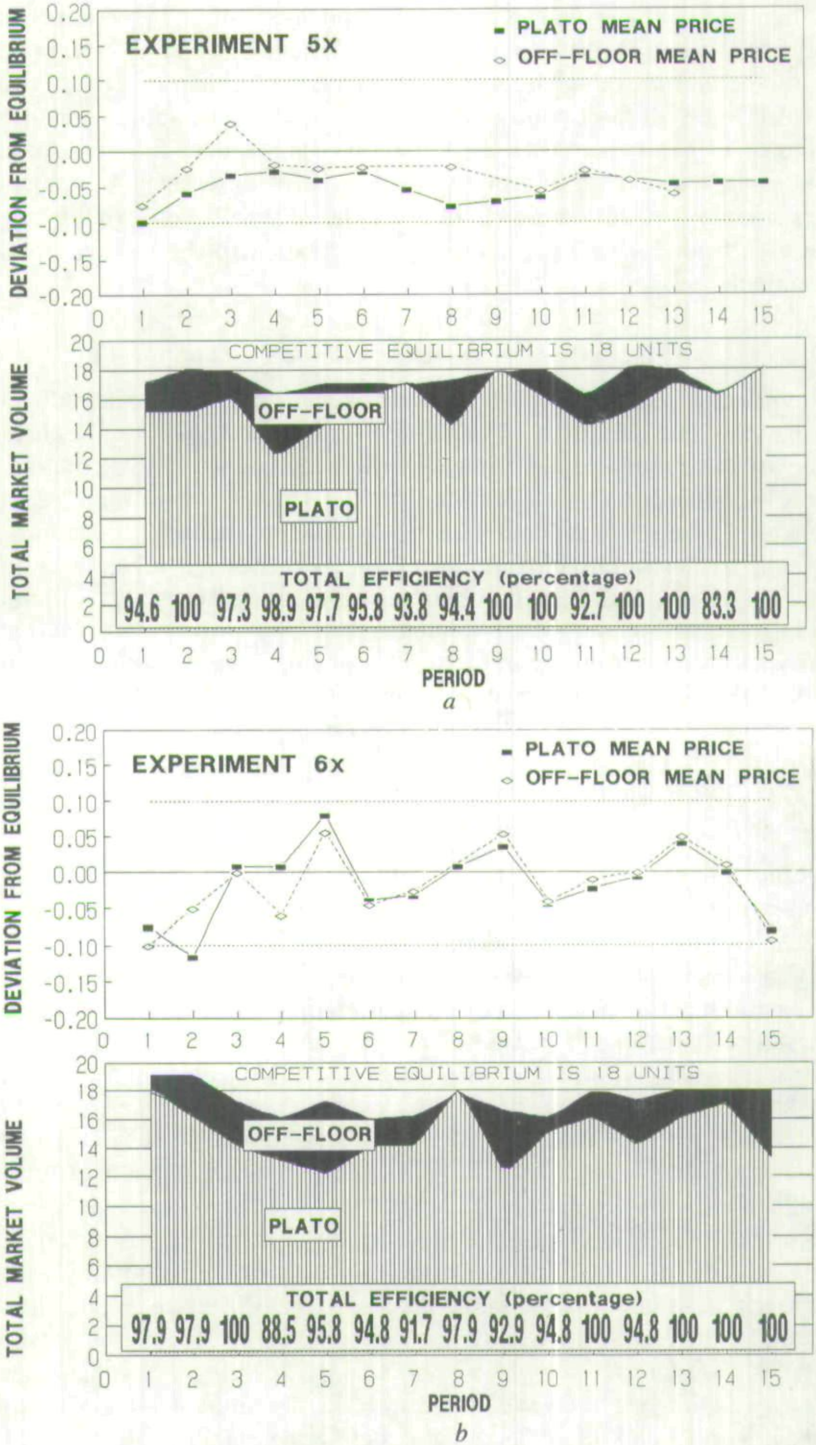
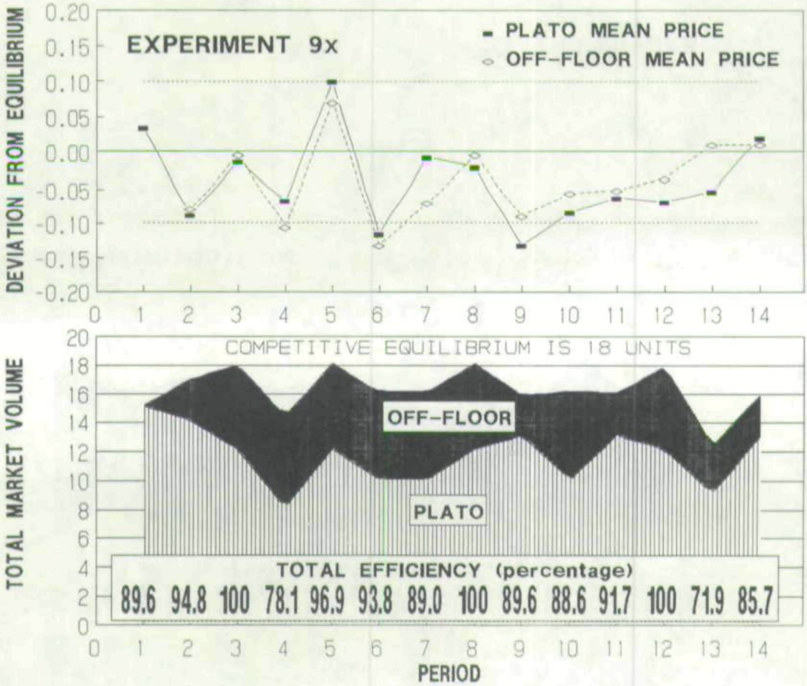
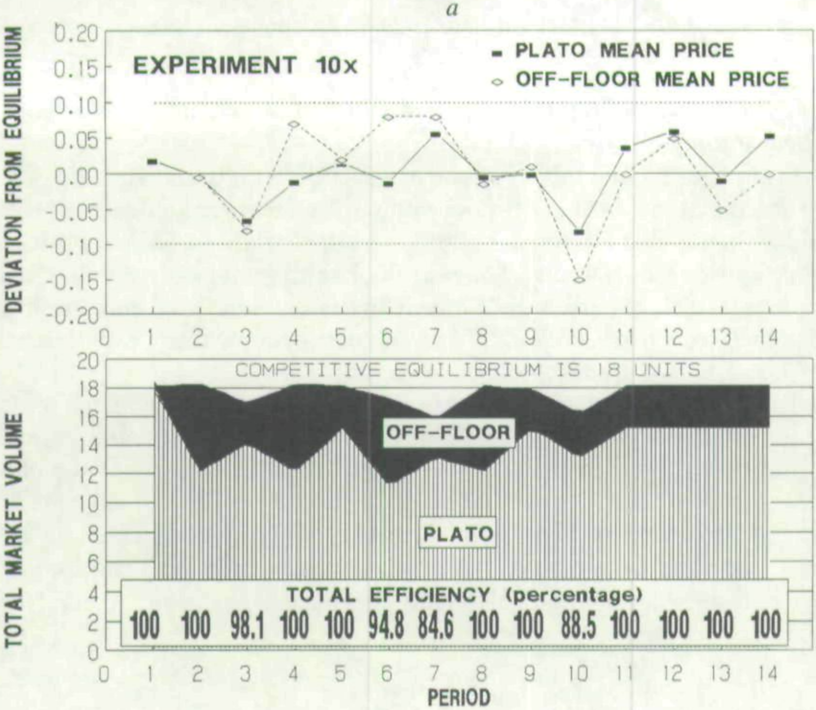


FIG. 5.—*a*, Single-unit off-floor trading, constant equilibrium. *b*, Single-unit off-floor trading, random equilibrium.



a



b

FIG. 6.—*a*, Block off-floor trading, constant equilibrium. *b*, Block off-floor trading, random equilibrium.

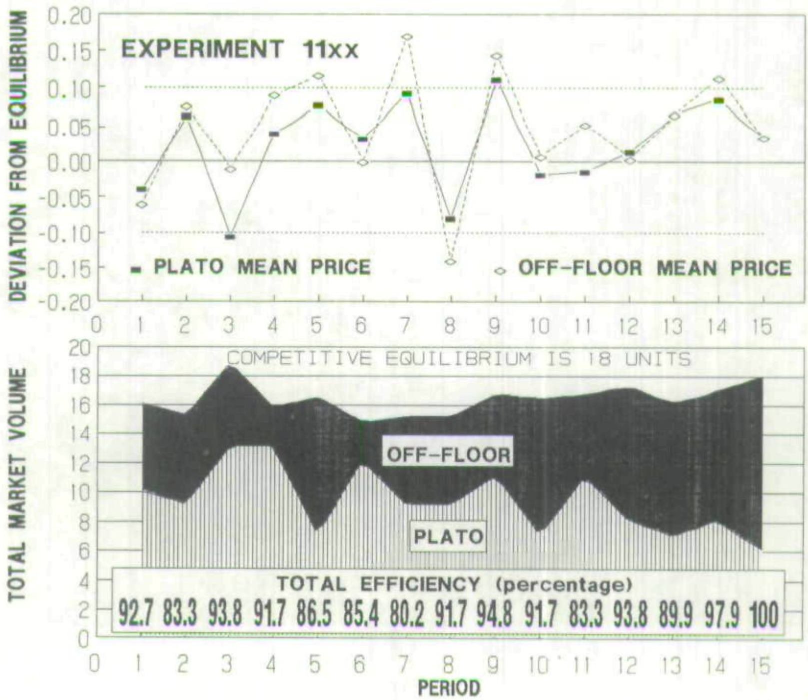


FIG. 7.—Block off-floor trading, random equilibrium

made a timely trade for 3 units and still had 20 seconds left for additional trading effort.

From figure 7 and table 2, comparing 11xx with 9x and 10x, we note a substantial increase in off-floor volume, an increased bid-ask spread, and an increase, both on and off floor, in the variance and mean square error of price deviations. Thus off-floor trading not only persists but increases with experience. Within experiment 11xx, off-floor trading also increases over time (fig. 7), as subjects become more experienced in repeat period trading.

Table 3 reveals that (1) a preponderance of accepted off-floor trade proposals are inside the bid-ask spread at the time of submission and at the time of acceptance; (2) the number of proposals inside the bid-ask spread, both accepted and rejected, and the mean bid-ask spread all tend to increase across the 3 weeks of the experiment; and (3) rejected proposals are much more likely to be outside the mean spread; but note that the number of rejected proposals is far larger than the number accepted.

F. Regression Tests of Hypotheses

Using dummy independent regression variables for the baseline and treatment conditions and observations from 10 experiments we shall

TABLE 3 Experiment 11xx Off-Floor Activity Relative to Standing PLATO Bid/Ask Spread*

		Off-Floor Activity Relative to Spread at Time of:							
		Submission				Response			
		Mean	Number†			Mean	Number†		
Periods	*N*	Spread	In	Out	Ind	Spread	In	Out	Ind
Accepted Proposals:									
1–5	10	.166	7	2	1	.195	6	3	1
6–10	10	.186	9	1	0	.138	7	3	0
11–15	15	.329	14	0	1	.239	14	0	1
Subtotal	35	.241	30	3	2	.197	27	6	2
Rejected Proposals:									
1–5	145	.237	55	77	13	.259	57	71	17
6–10	138	.291	63	64	11	.259	57	68	13
11–15	140	.323	80	54	6	.307	73	56	11
Subtotal	423	.284	198	195	30	.275	187	195	41
All proposals:									
1–5	155	.232	62	79	14	.254	63	74	18
6–10	148	.283	72	65	11	.250	64	71	13
11–15	155	.324	94	54	7	.301	87	56	12
Total	458	.280	228	198	32	.269	214	201	43

* Spread is the difference between standing PLATO bid and offer.

† "In/out" refers to the number of off-floor contract prices inside or outside, respectively, the relevant spread. "Ind" means indeterminant; there was no standing bid and/or offer at the time of the off-floor contract. In period 5 there was no standing offer on PLATO at the time of an off-floor contract, but the contract price was less than the standing bid; this trade is recorded as outside the spread.

report ordinary least squares (OLS) estimates and hypothesis tests for the questions posed in the previous discussion. The OLS regressions, evaluating the marginal effects of the treatments on the price variance, spread, per-period median spread, efficiency, and fraction of volume off-floor, are shown in the top panel of table 4. In each case the dependent variable is regressed on the baseline dummy variables, C (= 1 for a constant competitive equilibrium [ce] environment, 0 otherwise) and R (= 1 for a random ce environment, 0 otherwise), and the off-floor treatment variables, OSC (= 1 for single-unit constant ce, 0 otherwise), OSR (= 1 for single-unit random ce, 0 otherwise), OBX1 (= 1 for block trading once experienced, 0 otherwise), OBX2 (= 1 for block trading twice experienced, 0 otherwise).

Appearing in the lower panel of table 4 are the Bonferroni *t*-values and the nonparametric Mann-Whitney *U*-statistic for joint tests of the a priori ordering of the regression coefficients.[8] For example, in the

8. Since we are conducting multiple comparisons of coefficients estimated from the same data set, we use the Bonferroni *t*-test (see Miller 1981). In this application we report one-tailed *t*-values since the original experimental design allowed an a priori prediction of the sign of coefficient differences.

TABLE 4 **OLS Estimation of Treatment Effects and Pairwise Comparisons**

Independent Variable	PLATO Contracts			All Contracts	
	Price Variance*	Spread†	Median Spread*	Fraction of Volume Off-Floor*	Market Efficiency*
C	.003	.180	.150	. . .	.914
	(.0009)	(.0111)	(.0188)		(.0134)
R	.014	.316	.270	. . .	.875
	(.0011)	(.0135)	(.0230)		(.0165)
OSC	.001	.053	.044	.101	.966
	(.0016)	(.0194)	(.0325)	(.0277)	(.0233)
OSR	.002	.130	.081	.144	.965
	(.0016)	(.0203)	(.0325)	(.0277)	(.0233)
OBX1	.002	.101	.072	.242	.943
	(.0012)	(.0157)	(.0238)	(.0203)	(.0170)
OBX2	.005	.126	.119	.426	.904
	(.0016)	(.0256)	(.0325)	(.0277)	(.0233)
R^2	.380	.080	.271	.543	.109
N	148	2,083	148	73	148

C vs. R:‡					
H_0	C ≥ R	C ≥ R	C ≥ R		R ≥ C
t	−7.57 [.000]	−7.80 [.000]	−4.06 [.000]	. . .	1.82 [.281]
U	−5.96 [.000]	−12.0 [.000]	−4.01 [.000]	. . .	2.39 [.034]
OSC vs. OSR:‡					
H_0	OSC ≥ OSR	OSC ≥ OSR	OSC ≥ OSR	OSC ≥ OSR	OSR ≥ OSC
t	−.44 [.499]	−2.71 [.014]	−.82 [.499]	−1.10 [.411]	.03 [.499]
U	−2.34 [.038]	−6.40 [.000]	−2.28 [.045]	−1.31 [.287]	.17 [.499]
OSR vs. OBX1:‡					
H_0	OSR ≥ OBX1	OSR ≥ OBX1	OSR ≥ OBX1	OSR ≥ OBX1	OBX1 ≥ OSR
t	.33 [.505]	1.13 [.999]	.23 [.504]	−2.85 [.008]	.75 [.499]
U	−.03 [.499]	−1.11 [.499]	.14 [.499]	−2.93 [.002]	−.04 [.501]
OBX1 vs. OBX2:‡					
H_0	OBX1 ≥ OBX2	OBX1 ≥ OBX2	OBX1 ≥ OBX2	OBX1 ≥ OBX2	OBX2 ≥ OBX1
t	−1.49 [.276]	−.83 [.499]	−1.17 [.487]	−5.37 [.000]	1.34 [.368]
U	−1.96 [.100]	−2.95 [.006]	−2.12 [.069]	−3.95 [.000]	2.19 [.057]

NOTE.—Standard errors are in parentheses. Bonferroni p-values are in brackets. H_0: the null hypothesis is that the coefficient of the variable on the left is not smaller than the coefficient of the variable on the right; e.g., C ≥ R for price variance.

* One observation per period per experiment. Estimated coefficient is mean value per period for the given treatment.

† One observation per PLATO contract. Estimated coefficient is mean value for the given treatment. Spread is the difference between the standing PLATO bid and offer. One hundred and six of the 2,189 PLATO contracts occurred when there was either no standing bid or no standing offer.

‡ t is calculated from OLS results. U is the Mann-Whitney z-variate calculated from pairwise rank sums.

baselines, the prediction is that the median spread is wider and efficiency lower for R than for C; that is, the R environment is expected to yield wider spreads, and for the gains from exchange to be lower. Therefore the null hypothesis is that the median spread regression coefficient for C is greater than that for R. The Bonferroni t is -4.06 for this comparison, and the negative sign indicates that the R coefficient (.27) exceeds the C coefficient (.15). This is corroborated by the nonparametric Mann-Whitney U-test. Comparing the random (OSR) with the constant (OSC) environment for off-floor single-unit trading, the spread coefficients exhibit the predicted order, and in the U-test the difference is significant.[9] In contrast, there is no significant difference between the spread for block (OBX1) and for single- (OSR) unit trading, or between twice- (OBX2) and once- (OBX1) experienced traders. The efficiency coefficients decline monotonically as we proceed down the treatments from C to OBX2, as predicted. Two of the pairwise comparisons are significant using the Mann-Whitney U, and none are significant using the Bonferroni t-values. Finally, in the upper right panel of table 4 we note that the coefficients for fraction of off-floor trading increase, as predicted, with the successive off-floor treatments. In the lower right panel block trading significantly increases off-floor trades relative to single-unit trading, and the effect of experience is to further significantly increase off-floor trading. Finally, in the upper left panel of table 4 the coefficients for price variance in the constant relative to the random environment have the predicted direction, and significantly so, as shown in the lower left panel of table 4.

VI. Discussion and Conclusions

Our primary objective in this article was to investigate the incentive conditions under which the phenomenon of off-floor trading might occur. We began with the simplest and most transparent environment that might induce traders to leave an organized exchange to engage in bilateral private trades: an environment in which the rate structure provided lower transactions cost for block trades off floor than unit trades on floor. This environment parallels that of U.S. financial markets before 1975 when the schedule of minimum brokerage fees did not properly reflect the cost of block trades, and this helped to support the "third market" in off-exchange trades. In experiment 1 off-floor trading was permitted after period 5, and in periods 7–15 we observe the predicted number (18) of off-floor trades. It is clear from this exper-

9. Direct comparison between the coefficients of C or R and those of OSC or OSR are not meaningful since the latter use experienced subjects, the former inexperienced subjects. We only make comparisons after controlling for experience since experience is expected to reduce spreads and price volatility.

iment that by providing an off-floor cost advantage to all (or most) traders one might precipitate a type of market failure in which ultimately the on-floor trades were so thin that it would no longer provide competitive price information to facilitate off-floor bilateral bargaining. This experiment illustrates the important principle that on-floor brokerage commissions must be competitive with the off-floor costs of direct negotiation if market disintegration is to be avoided.

The environment of experiment 1 was that of stationary induced supply-and-demand schedules, with each trader assigned unchanging limit supply or demand prices. In this repeated static market, the naturally occurring bid-ask spread converged toward the minimum possible spread of 1 cent. In fact the median observed spread was only 1 cent (table 2) across trading periods 6–10. It followed that, if we were to study the incentive of traders to contract off floor at prices inside the bid-ask spread, then it would be essential that we create an environment in which the naturally occurring bid-ask spread converged to a larger level. We conjectured that this would be the case in supply/demand environments in which (1) the buyer (seller) induced value (cost) assignments were rerandomized repeatedly and (2) a random constant was added (or subtracted) each period to all values and costs to effect random shifts in supply and demand. We tested our conjecture in three experiments (2–4) using condition 1, yielding a constant competitive equilibrium price, and two experiments (7–8) using conditions 1 and 2, yielding a random competitive equilibrium price. In the constant environment, with only random reassignment of traders to value-cost steps, we observed a much wider bid-ask spread than in experiment 1: a median spread of 10–14 cents in experiments 2–4 compared with 1 cent in periods 6–10 of experiment 1. Under conditions 1 and 2, which added a random shifting competitive equilibrium price, the median observed bid-ask spread widened further to 24 and 18 cents, respectively, in experiments 7 and 8 (table 2).

These findings, though they are ancillary to the primary objective of the article, have important implications for modeling the bid-ask spread in double-auction trading institutions. Traditional theories of the bid-ask spread are of two kinds: (1) the bid-ask spread is a transactions cost of the dealer or a specialist for providing the services of immediacy (see Demsetz 1968), and (2) the bid-ask spread is due to the existence of traders with superior information to that of the specialist (see Copeland and Galai 1983; and Glosten and Milgrom 1985). One should be aware that these models provide *sufficient* not necessary conditions for the existence of a positive bid-ask spread. That they are not necessary is shown by the hundreds of experimental double-auction markets, and our baseline 2 experiments reported here, in which a positive bid-ask spread persists; yet these are principals markets, without intermediate dealers or specialists, and transactions cost is minuscule. In many of these experiments, all individuals have identical (although uncertain) information on the value of the securities traded (see Smith, Suchanek, and Williams 1988). Yet one observes a bid-ask spread. A third theory is based on establishing that "the probability of a limit order executing does not rise to unity as the price at which the order is placed gets infinitesimally close to a counterpart (bid or ask) market quote" (see Cohen, Maier, Schwartz, and Whitcomb 1981, p. 300). In terms of this theory, our success in inducing a wider bid-ask spread by increasing uncertainty in the environment can be attributed to the fact that we shifted the probability distribution that a limit order will execute.

The next step in our research was to allow off-floor trading using constant versus random supply-and-demand shifts, and single-unit versus block trading, as treatment variables (with no explicit trading cost in either the electronic or off-floor transactions). Comparing experiments with off-floor single-unit trading in the random environment with those in the constant environment, we find more off-floor trading in the former than in the latter (table 2), but the difference is not statistically significant (table 4). We attribute the increase in off-floor trading with the random environment to the fact that the bid-ask spread is wider than in the constant environment. But this is not documented because we collected no data on the extent to which off-floor trades occurred within the spread in experiments 5x–10x.

Comparing experiments using off-floor single-unit trading with those having block trading (both using the random environment) we observe more off-floor trading with blocks than with single units (table 2), and the difference is significant (table 4). The reason for this appears to be straightforward: in our experimental environment the subjective cost of an off-floor trade (the effort in writing a bid or an offer, deciding which of the two adjacent traders to give it to, then delivering the quotation) is the same for a 3-unit block as for a single unit. Consequently, an elementary transactions cost argument predicts more units will trade off-floor under block trading than under single-unit trading.

Our last experiment (11xx) used twice-experienced subjects and recorded the standing bid-ask spread at the time each off-floor block bilateral trade proposal was made and, again, at the time when the proposal was either rejected or accepted. In this experiment 27 of 35 off-floor (3-unit block) trades, or 77%, were inside the bid-ask spread at the time of acceptance. This supports the hypothesis that the primary motivation for such trades is to split the gains inherent in the standing bid-ask spread, although there may exist block-trading advantages, such as reduced uncertainty of execution, at prices outside the spread. Furthermore, comparing off-floor trading using twice-experienced subjects with that for only once-experienced subjects, we note a significant increase in off-floor trading with experience (tables 2 and 4). Consequently, the phenomenon is not an artifact of trader inexperience. We think this is because, with experience, traders become more skilled in moving back and forth between the two markets and are able to handle the demands of off-floor negotiation with less effort.

Finally, across treatments that are associated with an increase in off-floor trading, we observe a monotonic decline in market efficiency (table 4). This is evidence in favor of the hypothesis that off-floor trading is socially undesirable. (The fact that the decline is not significant [table 4] in the pairwise comparison of *adjacent* treatments moderates this conclusion, although this result might be altered with increased sample size.) But the results of this article are best interpreted as providing only weak support for market degradation in the presence of off-floor trading. Hence, off-floor trading may be less of a problem for the social objective of maximizing the gains from exchange than it is for the exchange firm that loses volume to bilateral traders who free ride on the public price information generated by the exchange.

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