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Futures Markets and Informational Efficiency: A Laboratory Examination

ROBERT FORSYTHE, THOMAS R. PALFREY, and CHARLES R. PLOTT*

ABSTRACT

Through the use of laboratory market methodology, the effect of a futures market on the time path of asset prices is studied and competing models of asset pricing are analyzed. With replication of market conditions, the predictions of a rational expectations equilibrium model are relatively accurate whether or not futures markets are present. However, the presence of futures markets increases the speed with which an efficient equilibrium is achieved. While this more rapid adjustment can increase the variance of spot market prices as they move to equilibrium, this increased variance reflects efficiency gains due to better information.

FOR MORE THAN EIGHTY YEARS, the effect of futures markets on spot market prices and the resulting allocation of resources has remained an open question. This controversy has centered around the claim by some farmers, regulators, and economists that futures trading destabilizes spot prices and thus imposes efficiency losses upon consumers and producers. This rationale has been used by Congress to enact laws regulating trading in futures contracts and, in one instance, in the onion futures market, to prohibit trading altogether.[1]

Considerable theoretical and empirical research has been undertaken in an attempt to analyze this claim. Most of the relevant theoretical work has been focused on the informational role of prices and the effect of futures trading on the possibility of informationally efficient markets with mixed results.[2] In typical empirical studies, spot prices of commodities during periods of active futures trading have been compared with those prices when no futures trading took place.[3] By examining either the range or the variance of spot prices, they concluded that futures trading stabilized spot prices. None of this work provided any theoretical explanation for their results, and all had the difficulty that by

* The University of Iowa, Carnegie-Mellon University, and California Institute of Technology, respectively. Earlier versions of these results were presented at the Western Economic Association meeting in San Diego in June 1980 and at the World Congress meetings in Aix-en-Provence, France in September 1980. We thank those audiences for useful comments and discussion. We would also like to thank Forrest D. Nelson for his helpful suggestions.

[1] In August 1958, trading in onion futures was prohibited by Congress. Although no other prohibition has been initiated, many regulations about futures markets are with regard to variability of prices. In fact, trading in futures contracts may be suspended, at least temporarily, if prices vary too greatly.

[2] Besides the studies discussed below, these include Grossman and Stiglitz [5, 6].

[3] Working [16] and Gray [3] examined the effect of futures contracts on the onions market and concluded that they stabilized prices. Similar results were obtained by Tomek [15] for the wheat market and Powers [11] for the pork belly market.

examining periods as long as 30 years, their data were not immune to external events taking place in the economy.

This study reports the results of nine carefully controlled laboratory experiments which were designed to compare the performance of a number of models which make fundamentally different predictions about the effect of futures trading on resource allocation. All of these environments involved trading assets in a complete set of sequential spot markets, and five of the environments also included an institution for making futures contracts. The comparisons between prices and allocations observed with and without futures markets are striking. While both forms of market organization exhibited common regularities, a number of systematic differences with some of the theories are readily apparent.

Recently, a number of laboratory investigations of asset markets have been conducted (see Forsythe, Palfrey, and Plott [1], Friedman, Harrison, and Salmon [2], and Plott and Sunder [10, 10a]). An important departure from these previous studies involves changing the design of experiments in order to be able to systematically study the role of futures markets in asset valuation with time-interdependent preferences. These preferences introduce a number of complexities which are absent in other laboratory studies and require some elaboration. All previous laboratory studies have used preferences which were linear in asset holdings and have found strong support for the "swingback hypothesis" about the regularity of the convergence pattern in these markets. This hypothesis captures the idea that the final period of a market year converges first and the convergence works back from this to earlier periods as the years replicate. The linearity of the preferences used may well have biased previous results in favor of this hypothesis since the equilibrium price in the final period is independent of the trades which individuals have made in earlier periods. With time-interdependent preferences, such will not be the case. Indeed, the final period equilibrium price will depend directly on individuals' asset holdings at the beginning of that period. Unless the markets in both periods have equilibrated, individuals who revise their earlier period trading strategies, expecting that a previously observed final period price will not change, will find that their expectations are not fulfilled. Thus, with the preferences used in this paper, we should expect to find a "swingforward effect," which may possibly confound the "swingback effect," and conceivably prevent convergence altogether.

As noted above, in addition to providing a more challenging test of the rational expectations hypotheses vis-à-vis other hypotheses about pricing and resource allocation over time, this set of experiments was explicitly designed to sort out the predictions of a number of competing theories about the role of futures markets. One commonly held belief is that the futures market is just a socially acceptable form of gambling (see Hardy [7]). This view holds that, since futures markets are speculative, spot market price behavior is more volatile with futures markets than without them. To the extent that this volatility induces suboptimal intertemporal allocations of resources, this theory predicts that futures markets induce inefficiencies which would otherwise not be present.

More recently, Svensson [13, 14] has pointed to a potentially serious deficiency of market organization in which both sequential spot trading and futures trading is permitted. In a two-period model with no exogeneous uncertainty, he examines the case in which every individual in the market believes with certainty at date 1. This typically requires that all agents unanimously hold false expectations with certainty. Svensson then demonstrates that whereas there are efficient self-fulfilling equilibria, these constitute only a negligible proportion of all "temporary equilibria."

On the other hand, Hicks [8] argues that the presence of futures markets serves to overcome two potential sources of disequilibrium and/or inefficiencies: consistency across traders of future plans (e.g., consumption, trading, and production plans) and consistency of their price expectations. The operation of a futures market serves to make future plans and prices directly observable and, as a result, trading takes place in the current spot market in such a way that an efficient equilibrium is attained.

In a similar spirit, Grossman [4] considers the need for replication in rational expectations models in which only sequential spot markets are present. In stationary environments, he suggests that replication will allow investors to acquire information about the joint distribution of prices which, in turn, determines the equilibrium price function. An alternative means of acquiring such information is the focus of attention here. Traders learn about tomorrow's prices by directly observing the prices in today's futures markets for tomorrow's transactions. In this way, futures markets mitigate the necessity for replication.

Implicit in the Hicks and Grossman ideas is that futures markets publicize the private information which exists in an economy and, by doing so, markets will equilibrate more easily and the resulting allocation will be more efficient compared to the allocation if only spot trading occurred. Exactly how to check these notions against behavior is the task of the remainder of this paper.

The organization is as follows. In Section I, the laboratory markets are described along with the experimental procedures that are used. Section II sets up the model used to derive the rational expectations equilibrium. Specific hypotheses about the time path of prices, allocations, and market efficiency are formulated according to the claims of the competing theories. In Section III, the data are presented and analyzed to test these specific hypotheses. Some concluding remarks are made in Section IV.

I. The Laboratory Markets

As mentioned above, the markets we studied are simple but this does not mean the behavior is simple. By eliminating many of the sheer complexities of naturally occurring processes, the results should be less ambiguous. Nine laboratory markets were studied with the properties listed below. How these properties translate into individual decision models is reserved for the next section.

a) Each market year had two periods, A and B. All period A's (in a market) were identical in terms of the underlying distribution of returns and all period B's in a market were identical. Thus, each year was in a sense a replication of previous years.

b) Asset lives were for a period of one year only. The supply of assets was constant for all periods of all years.
c) Each experiment consisted of a fixed group of subjects who participated in a sequence of seven market years. Each period A and each period B was seven minutes long.
d) Individual monetary returns from assets in any year were a function of the number of units of the asset held in period A and the number of units of the asset held in period B. Specifically, if in a given year individuals held X_A^i units of the asset in period A and X_B^i units of the asset in period B, then their monetary return for that year was

$$R = (d_A^i X_A^i + d_B^i X_B^i)^{1/2}.$$

Each trader was informed of his or her own monetary returns for each possible pair of holdings (X_A^i, X_B^i), but was not informed of any other traders' pairs.
e) Individuals were partitioned into two trader "types." Individuals of a given trader type had identical returns but the returns differed across types.
f) The markets were organized as oral double auctions. All individuals were present for all periods. All bids, offers, and contracts were recorded publicly so the "cost" of gathering such information was minimal. Possibilities for explicit collusion did not exist.
g) Traders were required to cover short positions prior to sale. This means that there was a fixed supply of the asset.
h) In each year of each market, a period A spot market and a period B spot market occurred in sequence.
i) In experiments 1, 3, 5, 6, and 8 a futures market (henceforth referred to as a "period B futures") operated concurrently with the period A spot market.
j) No futures market existed in experiments 2, 4, 7, and 9.
k) In all markets there were eight traders.

The subjects in the experiments were male and female students at California Institute of Technology and Carnegie-Mellon University. In experiments 2, 4, 7, and 9 only subjects who had been in experiments 1, 3, 6, and 8, respectively, were used. We refer to these subjects as "experienced." In the remaining experiments (1, 3, 5, 6, and 8) subjects were inexperienced. The purpose of this feature of the design is explained in the next section.

At the beginning of each trading year, each trader was endowed with two or three "certificates" of ownership of the asset which had no face value but contributed to an individual's income according to the pair of valuation coefficients (d_A^i, d_B^i). Thus, the marginal valuation of ownership of a unit of the asset of trader i in a given period of a given year depended upon:

1) the period (i.e., it is possible that $d_A^i \neq d_B^i$);
2) the trader (i.e., for two traders, i, j, it is possible that $d_A^i \neq d_A^j$ and/or $d_B^i \neq d_B^j$); and
3) the total amount of any asset held by trader i in period A and in period B at the end of that year.

The difference in valuations across individuals was particularly important since this allowed for the existence of gains of exchange with one trader selling a certificate to another.

This difference in returns was adopted only after considerable thought. The importance of this feature for the laboratory market is clear enough—it fosters the existence of gains from exchange. Such differences are also found in more complicated naturally occurring markets, and may be due to a number of reasons. First of all, for actual physical assets such as durable consumption goods, the valuation of services by some consumers might be greatest during early periods while others place a greater value in later periods. Second, for financial assets potential investors might be in different tax brackets or risk classes. Third, the investors may all be risk neutral and simply have different expectations over the stream of returns.

The parameters for the nine markets are given in Table I. The currency used in the experiments was called *francs*. Value for francs was established by application of the theory of induced value (Smith [12], and Plott [9]). The use of this artificial currency in asset studies was initiated in Forsythe, Palfrey, and Plott [1]. Since initial endowments of certificates were distributed costlessly and due to the fact that separation of theoretical predictions required the use of high nominal prices, the costs of using dollars directly would have been prohibitive. The use of francs also provides a convenient way of permitting prices to be quoted in fractions of a cent. Thus, payoffs here for a given year are in the form $\$ = a + bz$, where $b > 0$ is the conversion value of francs into dollars, $a < 0$ is a fixed cost charged each trader, and z is the total francs held by a trader at the

Table I

Experimental Parameters and Equilibrium Predictions

	Experiments 1, 4, 5, 7, 8 (Parameter Set I)		Experiments 2, 3, 6, 9 (Parameter Set II)	
Trader Type	I	II	I	II
Initial Francs on Hand	10,000	10,000	10,000	10,000
Initial Certificate Holdings	3	3	2	3
Dollar Value of Francs	0.015	0.008	0.005	0.003
Fixed Cost	12,000	11,500	14,700	14,500
d_A^i	480,000	540,000	4,320,000	4,860,000
d_B^i	960,000	180,000	8,640,000	1,620,000
Number of Traders	4	4	4	4
Naive Equilibrium Predictions				
Period	*A*	*B*	*A*	*B*
Price	[283,322]	[168,179]	[965,1055]	[556,600]
Type I Holdings	4	6	3	5
Type II Holdings	2	0	2	0
REE Predictions				
Price	[336,367]	[192,210]	[1100,1214]	[628,694]
Type I Holdings	0	6	0	5
Type II Holdings	6	0	5	0

end of a market year. The conversion value of each franc differed by trader type and by experiment. The conversion values may seem small at first, but in fact the transaction prices in terms of francs were sufficiently high to make the dollar payoffs and value of decisions comparable to other experiments which have been successfully completed in these subject pools. For example, the average amount earned was about $16.00 for two and one-half hours participation.

Table I is read as follows. In all experiments there were two different types of investors and there were four individuals of each type. Consider the type I investor in experiment 1. Each of the four were given 10,000 francs and three certificates at the beginning of each year. They were allowed to trade freely. Although cash borrowing was not permitted, parameters were chosen so that this constraint was never binding. Each certificate held at the end of period A had a coefficient of valuation of $d_A^I = 480{,}000$ and each held at the end of period B had a coefficient of valuation of $d_B^I = 960{,}000$. Thus, a type I investor in experiment 1 who held X_A certificates at the end of period A and X_B certificates at the end of period B would have earned $R = 100(48X_A + 96X_B)^{1/2}$ in certificate earnings. A trader could add to his or her franc holdings by purchasing certificates for the dividends or for potentially profitable resale, and/or selling certificates. All francs held in excess of 12,000 francs were translated into dollars at a rate of $0.015 per franc and this was the amount of money the individual kept. The payoff for all other groups and all other experiments should be interpreted similarly. Each trader was given a copy of a table listing R for all combinations of X_A and X_B in order to reduce the computational burden. The tables are illustrated in the Appendix.

Our experimental design allows for some possible cross-checks on results. With the exception of experiment 5, the experiments are paired (e.g., experiment 1 and experiment 2). The first experiment in a pair is always one with a futures market and with inexperienced subjects. The second experiment in a pair uses the same subjects but no futures market is added. The second experiment in a pair uses the parameter set not used in the first so subjects are unfamiliar with the parameters at the beginning of all experiments.

The experimental procedures were those which have become standard in the experimental literature. The instruction sets (which are reproduced in the Appendix)[4] were distributed to subjects and read aloud. The experimenter illustrated a sequence of hypothetical transactions on the blackboard so each subject would understand how transactions were to be recorded on the information and record sheet and how profit would be calculated. The example was designed to minimize its normative effect on bidding behavior. Importance of accurate records of all transactions was emphasized. A log of bids, offers, and transactions was kept on the blackboard for the traders' information. At the end of the experiment each trader's profit calculations were checked and each was paid individually.

[4] In experiments 1–7, the units were referred to as "certificates" and in experiments 8 and 9 they were referred to as "marbles." Only the latter instructions are reproduced here. The others are available from the authors on request.

II. Specific Models

As Svensson [13, 14] has pointed out, depending upon the expectations of the traders at time 0, there are an infinite number of temporary equilibria which can occur. For reasons which are given below, it seems natural to focus attention on two particular equilibria in these experiments. These will be referred to as the "naive expectations equilibrium" and the "perfect foresight equilibrium," respectively.

The naive expectations equilibrium is developed from a maintained hypothesis that traders assume in period A that prices in period B will be such that capital gains are never possible. That is, each trader predicts prices in period B which will be unfavorable to his or her desired position. Thus, they behave as if any trades they make in period A will constitute their final position at the end of a given year. The market then clears in period A, given these expectations about future prices. When the period B spot market opens, the traders will make some transactions if in fact their expectations are not correct. In the markets we study, there will be transactions in period B, due to the gains from exchange that have been created by the differential valuations. Perhaps better terms for this equilibrium would be "autarchic" equilibrium or "maximin" equilibrium: autarchic because the period A equilibrium prices are those that would prevail if a period B market never operated; maximin because traders in period A value the asset assuming the worst possible prices in period B.

The reason for drawing attention to this equilibrium is that, in the first year of an experiment, traders have no information about period B prices (or about period A prices). However, they do know that in period A they can guarantee themselves a certain level of earnings precisely equal to the amount they earn if they are unable to make any transactions in period B. This hypothesis about initial expectations predicted prices quite well in the first year or two in previous experiments reported in Forsythe, Palfrey, and Plott [1].

This equilibrium leads to predictions about the allocation of units of the asset across periods and the efficiency of this allocation, as well as the average price at which trades will take place. Each trader is assumed to maximize his or her wealth at the end of each market year. The form of this maximization problem depends upon the specific behavioral model of expectations. Under the naive equilibrium hypothesis, traders will choose asset holdings in period A as if they believe that these holdings will remain unchanged in period B. Thus, traders choose money holdings in period A, M_A^i, and asset holdings in period A, X_A^i, in order to maximize end-of-year wealth given by:

$$\Pi^i = [(d_A^i + d_B^i)X_A^i]^{1/2} + M_A^i$$

subject to the budget constraint and no short sales constraint:

$$M_A^i = M_0^i + p_A(X_0^i - X_A^i) \geq 0, \qquad X_A^i \geq 0,$$

where M_0^i = initial money holdings and X_0^i = initial asset holdings. The first-order condition from this naive expectations maximization problem is

$$\tfrac{1}{2}(d_A^i + d_B^i)^{1/2}(X_A^i)^{-1/2} \le P_A, \qquad \text{with equality if} \quad X_A^i > 0.$$

In equilibrium, this condition must be satisfied by all traders and the market must clear, i.e., $\sum_{i=1}^{8} X_A^i = \sum_{i=1}^{8} X_0^i$. Solving this system of equations yields a "naive" equilibrium price in period A, p_A^N, and equilibrium period A asset holdings and money holdings, X_A^{iN} and M_A^{iN}, $i = 1, \cdots, 8$, respectively.

Given the period A equilibrium, a period B equilibrium is solved for in a similar way. For an individual holding M_A^{iN} and X_A^{iN}, the problem is to choose X_B^i to maximize

$$\Pi^i = (d_A^i X_A^{iN} + d_B^i X_B^i)^{1/2} + M_A^{iN} + p_B(X_A^{iN} - X_B^i)$$

subject to $X_B^i > 0$. The first-order condition is:

$$\tfrac{1}{2} d_B^i (d_A^i X_A^{iN} + d_B^i X_B^i)^{-1/2} \le p_B, \qquad \text{with equality if} \quad X_B^i > 0.$$

Again in equilibrium this condition must be satisfied by all traders and $\sum_{i=1}^{8} X_0^i = \sum_{i=1}^{8} X_B^i$. Solving this system of equations yields a period B equilibrium price, p_B^N, equilibrium period B asset holdings, $X_B^N = (X_B^{1N}, \cdots, X_B^{8N})$, and period B money holdings.

Substituting the parameters of the experiments into these conditions allows one to solve for the predicted naive equilibrium. However, due to the fact that traders can only trade in discrete integral units, there are a range of prices which support the naive equilibrium. When these adjustments are made, the equilibrium price ranges and allocations are as shown in Table I.

The second model for predicting market outcomes is the rational expectations model. In this case with no exogeneous uncertainty, the rational expectations model corresponds to the perfect foresight model. The difference between this and the naive expectations model is two-fold. First of all, investors bring *public market information* (price) as well as private information to bear on their trading decisions. Second, investors use the *true* equilibrium prices in periods A and B to compute potential capital gains or losses from holding units of the asset in period A and reselling in period B.

In these markets, the actual decision problem for investors is extremely complex. Not only must they accurately predict market prices in both periods, but they must coordinate their holdings in the two periods, since the payoff from holding units in one period is significantly affected by their holdings in the other period. Thus, when making trading decisions in the period A market, they must make accurate predictions about what their period B holdings will be. Inaccuracies may result in a substantial decrease in their earnings.

Under the rational expectations hypothesis, traders in period A behave as if they correctly anticipate the market clearing price in period B. To maximize their end-of-year wealth, given their initial holdings M_0^i and X_0^i, traders choose M_A^i, M_B^i, X_A^i, and X_B^i to maximize

$$\Pi^i = (d_A^i X_A^i + d_B^i X_B^i)^{1/2} + M_B^i$$

subject to the constraints:

$$M_A^i = M_0^i + p_A(X_0^i - X_A^i) \ge 0$$

$$M_B^i = M_A^i + p_B(X_A^i - X_B^i) \geq 0$$

$$X_A^i \geq 0, \qquad X_B^i \geq 0.$$

Substituting the first two budget constraints into the objective function and solving the problem yields the following first-order conditions:

$$\tfrac{1}{2} d_A^i (d_A^i X_A^i + d_B^i X_B^i)^{-1/2} \leq p_A - p_B, \qquad \text{with equality if} \quad X_A^i > 0,$$

$$\tfrac{1}{2} d_B^i (d_A^i X_A^i + d_B^i X_B^i)^{-1/2} \leq p_B, \qquad \text{with equality if} \quad X_B^i > 0.$$

Solving these conditions for the eight traders, along with the market clearing conditions gives the rational expectations equilibrium (REE) prices (p_A^F, p_B^F) and asset holdings. Again due to discreteness, the perfect foresight equilibrium is supported by a range of prices. These predictions also appear in Table I. For any particular p_B in its REE interval, the corresponding interval for period A REE prices is narrower than shown. The listed intervals for period A are the union of these intervals, taken over all p_B^F.

III. Hypotheses and Results

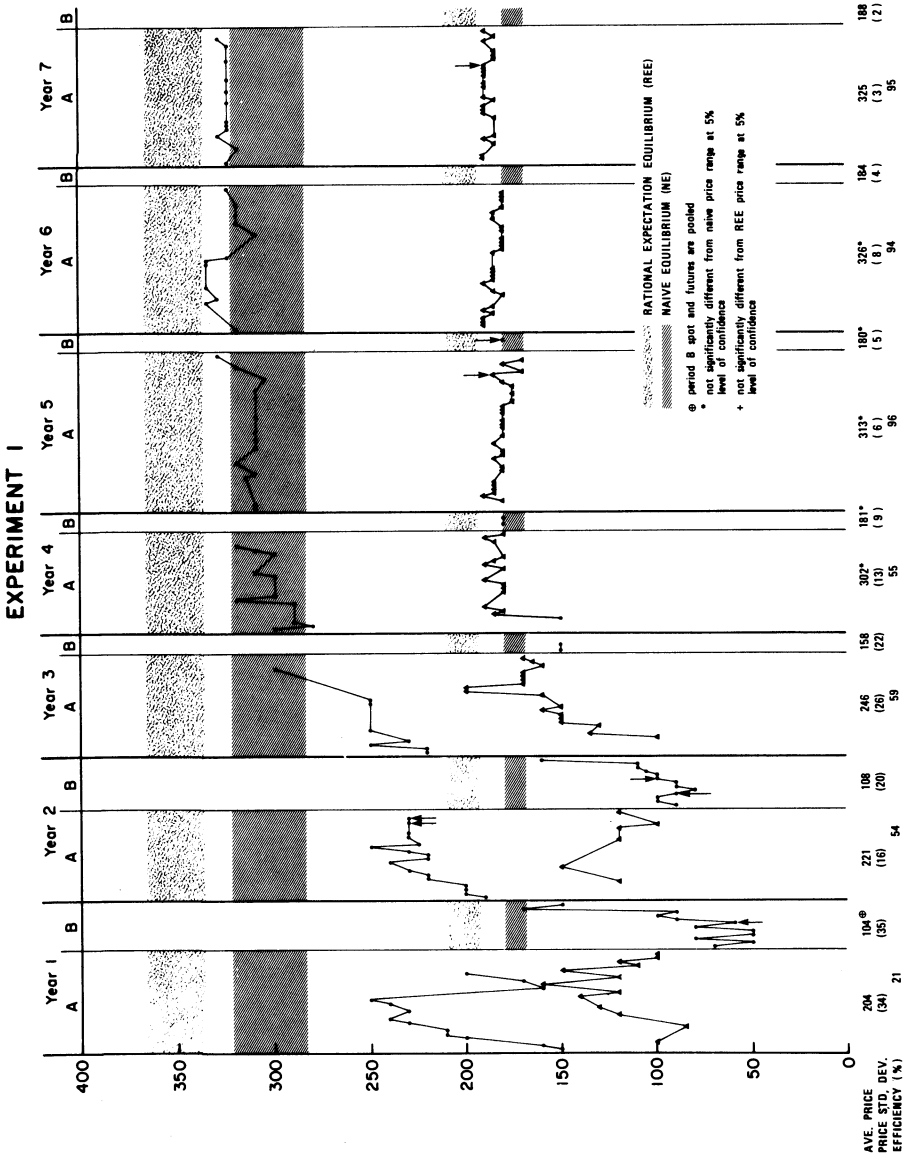
As discussed in the introduction, the purpose of this experimental design is not only to examine the reliability of the rational expectations hypothesis in a more complex laboratory environment than has previously been done, but primarily to assess the role of futures markets in facilitating the attainment of equilibrium and efficiency as predicted by Hicks, Grossman, and others. Instead of focusing on the effect of futures prices on the volatility of spot prices alone, we also examine whether or not an efficient rational expectations equilibrium is attained. To explore these ideas, we examine the data from the markets in three parts: the time path of prices through the seven-year replications of each market, the time path of the allocations in each market, and the variance of spot market prices.

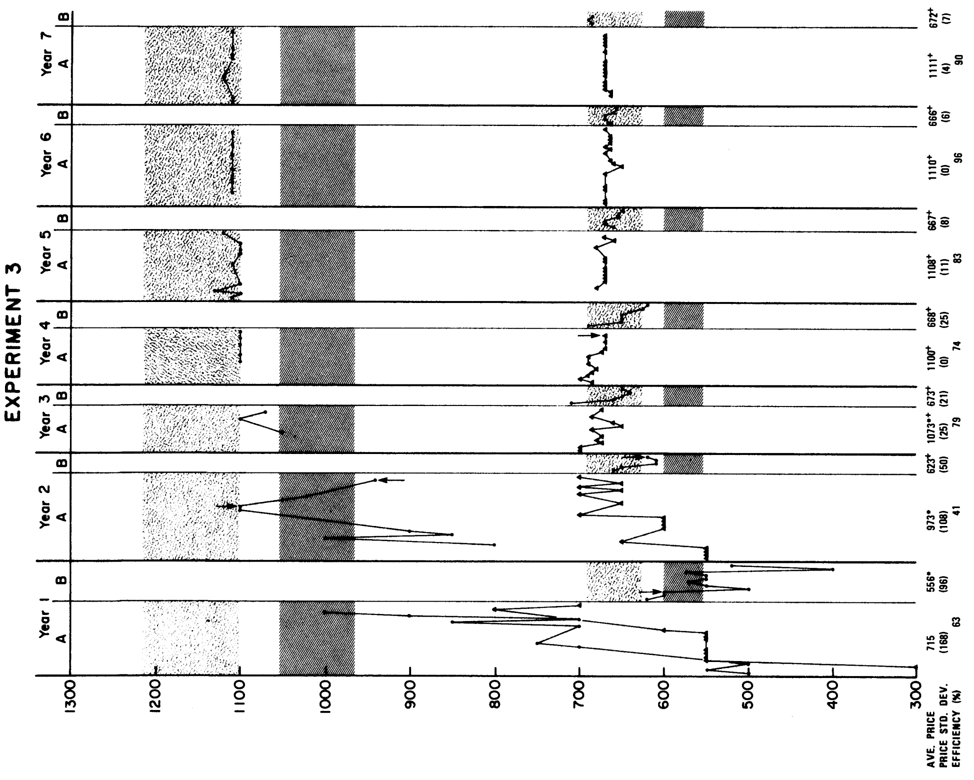
In what follows, we present the formal statements of our hypotheses and test their validity. In conducting these tests, we found some open problems in applying standard statistical techniques. In the following figures, the entire time series for each period of each year of each experiment is presented.[5] Examining them, it is apparent that there is a high degree of serial correlation of prices in a given experiment, both within a period and across periods. Since these transacted prices are obviously not i.i.d. samples from a stationary normal distribution, the statistical tests we used below should be regarded more as descriptive statistics than as classical hypothesis tests.

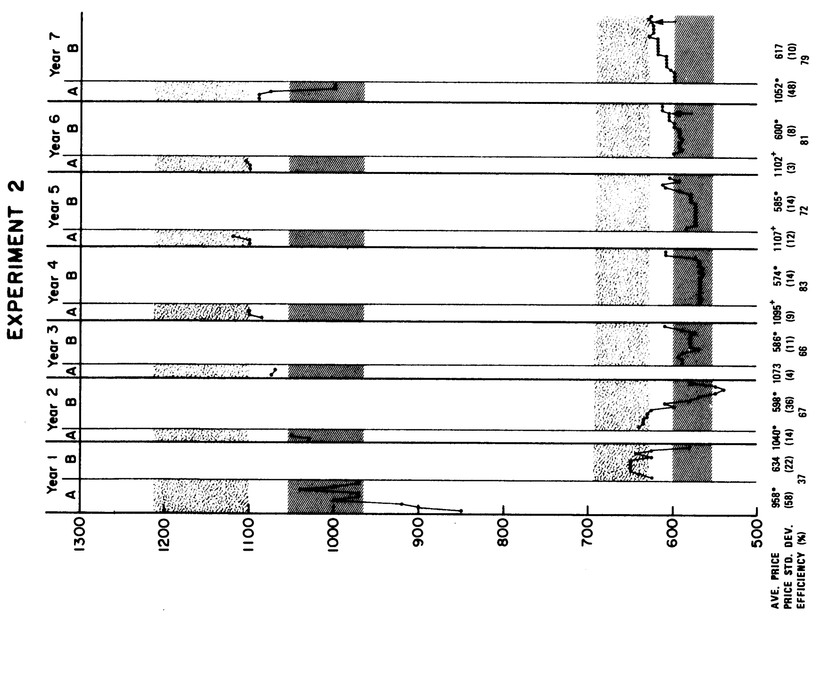
A. Price Behavior

The predictions about price behavior are made in terms of the average prices ($\bar{p}_A^t$, $\bar{p}_B^t$) in each year t. Our first hypothesis is that the average prices observed

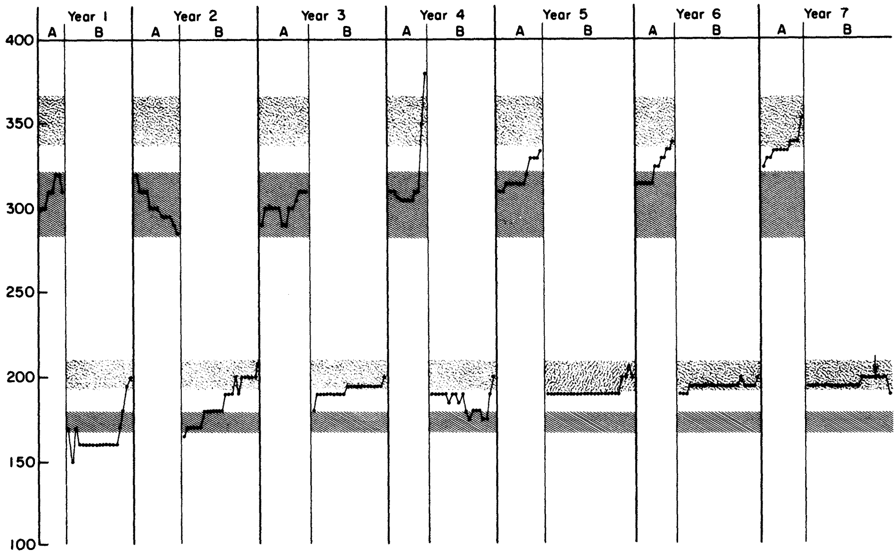
[5] Occasionally, a trader made a recording error which resulted in a short sale. These few cases are marked with arrows in Figures 1–9. In the analysis of market prices and allocations which follows, these trades are considered void.


EXPERIMENT I
Year 1 A B
Year 2 A B
Year 3 A B
Year 4 A B
Year 5 A B
Year 6 A B
Year 7 A B
RATIONAL EXPECTATION EQUILIBRIUM (REE)
NAIVE EQUILIBRIUM (NE)
⊕ period B spot and futures are pooled
* not significantly different from naive price range at 5% level of confidence
+ not significantly different from REE price range at 5% level of confidence
AVE. PRICE
PRICE STD. DEV.
EFFICIENCY (%)
400
350
300
250
200
150
100
50
0
204 (34) 21
104⊕ (35)
221 (16) 54
108 (20)
246 (26) 59
158 (22)
302* (13) 55
181* (9)
313* (6) 96
180* (5)
326* (8) 94
184 (4)
325 (3) 95
188 (2)


EXPERIMENT 3
Year 1 A B
Year 2 A B
Year 3 A B
Year 4 A B
Year 5 A B
Year 6 A B
Year 7 A B
1300
1200
1100
1000
900
800
700
600
500
400
300
AVE. PRICE
PRICE STD. DEV.
EFFICIENCY (%)
715 (168) 63
556* (96)
973* (108) 41
623+ (50)
1073*+ (25) 79
673+ (21)
1100+ (0) 74
668+ (25)
1108+ (11) 83
667+ (8)
1110+ (0) 96
666+ (6)
1111+ (4) 90
672+ (7)

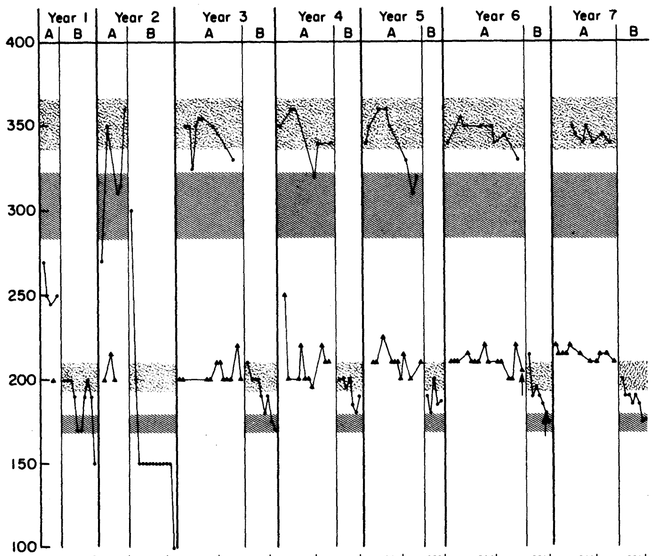

EXPERIMENT 2
Year 1 A B
Year 2 A B
Year 3 A B
Year 4 A B
Year 5 A B
Year 6 A B
Year 7 A B
1300
1200
1100
1000
900
800
700
600
500
AVE. PRICE
PRICE STD. DEV.
EFFICIENCY (%)
958* (58) 37
634 (22)
1040* (14)
598* (36) 67
1073 (4)
586* (11) 66
1095+ (9)
574* (14) 83
1107+ (12)
585* (14) 72
1102+ (3)
600* (8) 81
1052* (48)
617 (10) 79

EXPERIMENT 4



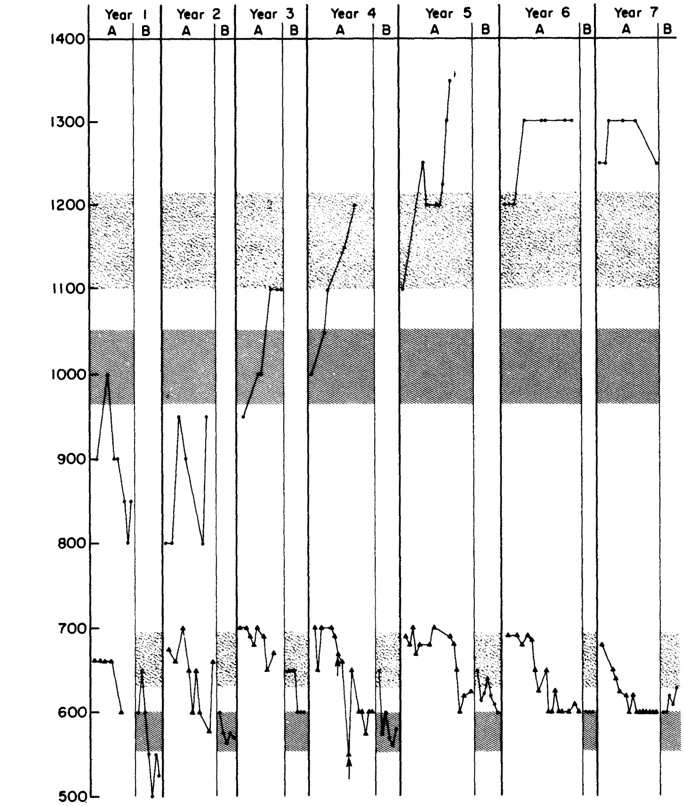
	Year 1 A	Year 1 B	Year 2 A	Year 2 B	Year 3 A	Year 3 B	Year 4 A	Year 4 B	Year 5 A	Year 5 B	Year 6 A	Year 6 B	Year 7 A	Year 7 B
AVE. PRICE	310*	166*	301*	185	300*	193+	317*	186	320*	192+	325*	195+	336+	196+
PRICE STD. DEV.	(8)	(13)	(10)	(13)	(7)	(4)	(24)	(7)	(9)	(4)	(9)	(2)	(7)	(3)
EFFICIENCY (%)	60		93		95		85		99		93		99	

EXPERIMENT 5



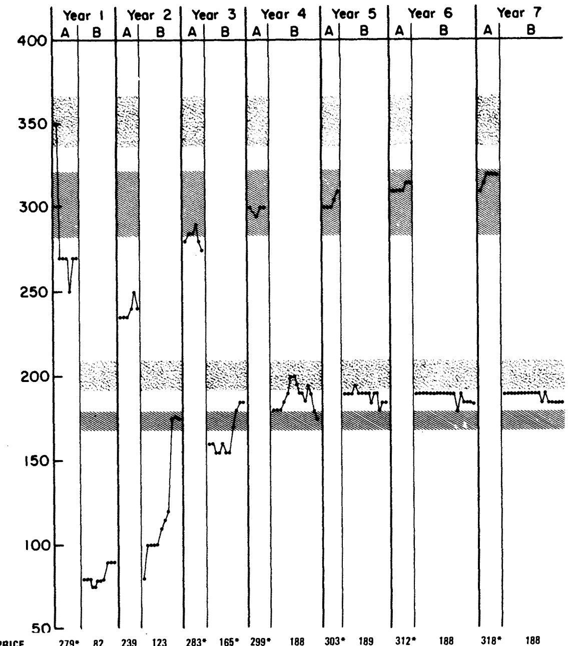
	Year 1 A	Year 1 B	Year 2 A	Year 2 B	Year 3 A	Year 3 B	Year 4 A	Year 4 B	Year 5 A	Year 5 B	Year 6 A	Year 6 B	Year 7 A	Year 7 B
AVE. PRICE	254	187*+	321*+	170*+	346+	198+	345+	203+	338+	203+	345+	203+	344+	203+
PRICE STD. DEV.	(11)	(17)	(36)	(45)	(11)	(12)	(15)	(16)	(23)	(13)	(8)	(13)	(5)	(15)
EFFICIENCY (%)	22		38		62		74		53		79		75	

EXPERIMENT 6



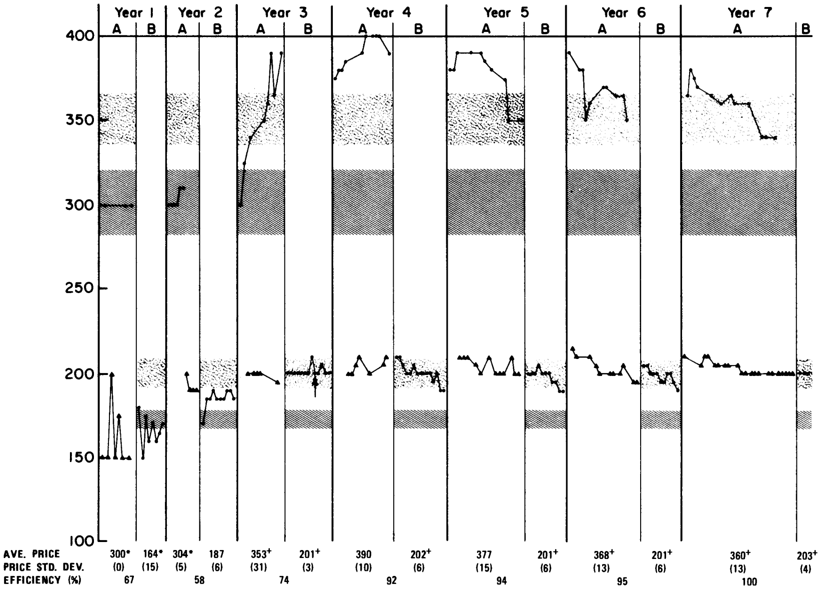
	Year 1 A	Year 1 B	Year 2 A	Year 2 B	Year 3 A	Year 3 B	Year 4 A	Year 4 B	Year 5 A	Year 5 B	Year 6 A	Year 6 B	Year 7 A	Year 7 B
AVE. PRICE	886	601*	867*	618*	1042*	659+	1100+	626+	1228+	651+	1256+	631+	1275	616
PRICE STD. DEV.	(63)	(59)	(75)	(46)	(66)	(38)	(79)	(49)	(75)	(35)	(62)	(38)	(27)	(22)
EFFICIENCY (%)	38		63		58		84		93		93		91	

EXPERIMENT 7

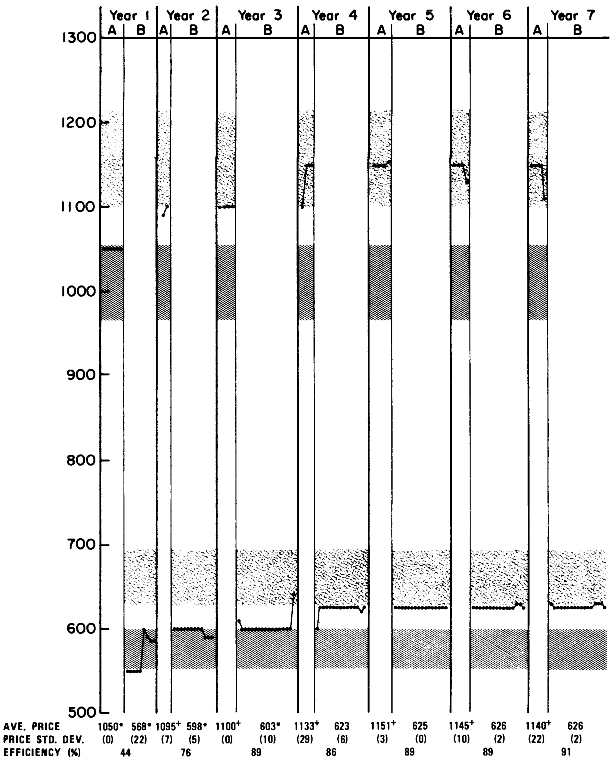


	Year 1 A	Year 1 B	Year 2 A	Year 2 B	Year 3 A	Year 3 B	Year 4 A	Year 4 B	Year 5 A	Year 5 B	Year 6 A	Year 6 B	Year 7 A	Year 7 B
AVE. PRICE	279*	82	239	123	283*	165*	299*	188	303*	189	312*	188	318*	188
PRICE STD. DEV.	(32)	(6)	(6)	(35)	(5)	(12)	(3)	(8)	(4)	(4)	(3)	(3)	(4)	(2)
EFFICIENCY (%)	43		33		56		75		70		81		84	

EXPERIMENT 8



EXPERIMENT 9



in each period[6] are consistent with the naive model.

H1: $(\bar{p}_A^t, \bar{p}_B^t)$ is in the range predicted by the naive model, $t = 1, \cdots, 7$ (see average price and standard deviation statistics at the bottom of each figure).

This hypothesis is rejected at the 5% significance level, using standard two-tailed t-tests,[7] in almost all cases (55 out of 63 total years). Most cases where it cannot be rejected are in early years. This is consistent with previous results (Forsythe, Palfrey, and Plott [1]) that subjects often begin at or near the naive equilibrium prior to acquiring information about period B prices.

Our next hypothesis is that the price data conform to the perfect foresight model.

H2: $(\bar{p}_A^t, \bar{p}_B^t)$ is in the range predicted by the REE model, $t = 1, \cdots, 7$ (see figures).

Again referring to the figures, it can be seen that there is strong support for this hypothesis in experiments 3, 5, 6, and 8. In early years (1–3), t-tests at the 5% level fail to reject H2 in only 4 out of 27 years, which is consistent with previous thinking that replication is necessary to achieve REE prices. In later years (4–7), the REE hypothesis cannot be rejected at the 5% level 14 out of 36 times and cannot be rejected at *any* significance level in 10 of 36 total years.

The conclusion from the price data as applied to H1 and H2 together is quite clear. The naive model is rejected in favor of the REE model as the better one for predicting the equilibrium to which these markets converge. In 16 of the 18 final year periods A and B, average prices were closer to the range predicted by the REE model than the range predicted by the naive model. The null hypothesis that the naive model predicts final year prices at least as well as the REE model is rejected outright.

An interesting observation and one which is not consistent with any theoretical model examined here is that, in early market years, the prices for futures contracts traded in period A tended to be higher than the spot market prices in the corresponding period B. This phenomenon tends to dissipate as the market nears the rational expectations equilibrium. One might conjecture that this is at least in part due to traders' inferences based on period A spot prices. Without a theory about how such inferences are made, we cannot offer a formal explanation for this observation.

The next hypothesis advances the proposition that in the presence of a futures market, spot markets converge more rapidly to an efficient REE. Our experimental design is intentionally biased against this hypothesis because individuals participating in experiments with futures markets had no previous experience in

[6] To test hypotheses about period B prices, we pooled the data from the futures market and period B spot market for each market year. This was necessitated by the fact that many period B spot markets had between zero and three observations (for example, see the last five market years in experiment 1). Theoretically this should not be a problem since, according to both of the models presented in the previous section, period B spot prices and futures prices should coincide in equilibrium. The data presented here suggest that this might be a more serious problem than pure theory indicates.

[7] That is, we reject H1 if the mean transacted price in period A is significantly different from the closest price in the range of period A prices predicted by the naive model *or* if the mean transacted price in period B is significantly different from the range of period B prices predicted by the naive model. This note also applies to our statistical tests of H2.

laboratory asset markets. Individuals who participated in sequential markets all had previous experience. As indicated by earlier experimental work, markets in which the traders have experience tend to equilibrate more quickly. Thus, these markets were designed to provide a strong test of the proposition.

H3: $(\bar{p}_A^t, \bar{p}_B^t)$ is in the range predicted by REE more frequently in experiments with a futures market (1, 3, 5, 6, and 8) than experiments without a futures market (2, 4, 7, and 9).

With a futures market, the hypothesis that prices are transacted in the REE range cannot be rejected at the 5% significance level in 17 out of 35 years of trading (see figures). Without a futures market, this hypothesis is rejected 27 out of 28 times. This result is unambiguous. We find very strong support for H3 in these nine experiments. The convergence results here are much stronger than those previously reported in all previous experimental studies of asset markets and demonstrate convincingly that futures markets do speed convergence. Apparently even experience with these markets does not allow traders to easily overcome the coordination problem when futures markets are absent.

The above discussion is not intended to say that the REE model fails miserably in predicting prices when futures markets are absent. Rather, it should be interpreted as saying that futures markets facilitate more rapid convergence to REE prices. In all experiments, the final year prices were "close" to the REE prices, relative to the naive expectations price predictions and relative to transactions at the outset of the experiment.

In comparing our results to the empirical work discussed in the introduction (see footnote 3), it is interesting to note from the figures that, in early market years, spot prices exhibit a considerable amount more variability in experiments with a futures market than without them. This is what is to be expected, however, if futures prices do play a role in publicizing private information. If this were true, then *prior to* attaining a REE in which all information is fully incorporated in period A spot prices, one might expect period A spot prices to more quickly adjust and therefore have a higher variance. This reasoning leads to the next hypothesis.

H4: The variance of period A spot prices in each year of experiments 1, 3, 5, 6, and 8 is greater than the variance of period A spot prices in each year of experiments 2, 4, 7, and 9.

To test this hypothesis, we first divided the experiments into two groups, according to the parameter set used in order to allow comparability. For each parameter set, we performed an F-test in each market year comparing the total variance of period A prices in the group for which a futures market was present with the total price variance in the corresponding group of sequential market experiments.[8] These total variances and the sample sizes are given in Table II.

[8] Total variance was calculated by summing the squared deviations from mean transaction prices in each year of each experiment, adding these sums across the appropriate experiments, and dividing by the total number of observations minus the number of experiments (to adjust for degrees of freedom). It was done in this fashion since different experiments had different mean transaction prices in different years.

Table II

Price Variances

	Market Year						
	1	2	3	4	5	6	7
Experiments 1, 5, 8 (Parameter Set I; Futures)							
Total Variance	849.81	384.59	581.48	148.48	211.93	100.03	66.45
N	20	27	24	27	32	30	31
Experiments 4, 7 (Parameter Set I; Sequential)							
Total Variance	557.20	77.54	42.21	426.25	64.11	62.83	43.31
N	14	17	20	15	18	18	18
Experiments 3, 6 (Parameter Set II; Futures)							
Total Variance	18588.66	9303.10	335.96	3125.24	2620.17	2091.26	348.8
N	17	15	9	10	17	15	13
Experiments 2, 9 (Parameter Set II; Sequential)							
Total Variance	2088.76	124.96	1678.36	454.24	57.11	63.34	1399.59
N	15	4	6	6	7	7	10

Altogether seven F-tests were performed for each of the two parameter sets (one for each year) giving a total of 14 tests. In only two of these cases, could we reject H4 at a significance level of 1%. In the first three years, when experiments with a futures market were converging very rapidly to REE prices, future markets always had significantly greater price variation than the corresponding sequential markets.

An alternative way of testing H4 does not involve aggregation across experiments. Instead one can make pairwise comparisons between each experiment with a futures market and each of those sequential market experiments which uses the same parameters. Altogether there are 10 pairs of experiments from which comparisons of this sort can be made. We performed similar F-tests comparing each pair of variances in each year for a total of 70 pairwise comparisons. The hypothesis is rejected at a 5% significance level in only six of these 70 pairwise comparisons.[9] All but two of the rejections of the hypothesis occurred in later years, after those experiments with futures markets had converged to the REE price range.

A final hypothesis about price behavior regards the swingback hypothesis about the dynamics of convergence. This hypothesis explained the time path of prices perfectly when all traders had time-independent (linear) preferences.[10] As

[9] H4 is rejected at the 5% level for the following market years: (1) year 7 when comparing experiments 1 and 4; (2) year 1 when comparing experiments 8 and 4; (3) year 1 when comparing experiments 8 and 7; (4) year 4 when comparing experiments 3 and 9; and (5) years 4 and 7 when comparing experiments 3 and 2.

[10] See Forsythe, Palfrey, and Plott [1] and Friedman, Harrison, and Salmon [2].

mentioned in the introduction, we suspect that with time-dependent (nonlinear) preferences the swingback hypothesis will not be as strongly supported, at least in the absence of futures markets, because of the more complicated coordination problem discussed earlier. On the other hand, as hypothesized by Hicks [8], the presence of a futures market may mitigate this problem. The swingback hypothesis we test is:

H5: $|\bar{p}_A^t - \bar{p}_A^F| > [\bar{p}_B^t - p_B^F|, \qquad t = 1, \cdots, 7.$

This hypothesis was correct in 97% (34/35) of the years in experiments with a futures market and only 57% (16/28) of the years in experiments without a futures market. In fact, in experiment 9 it failed every single year. These data are consistent with our earlier conjectures and thus support the Hicksian explanation that a futures market speeds convergence by removing two of the "sources of disequilibrium."

Thus, based only on the price data, our initial conclusions are:

(1) The rational expectations model predicts, with small inaccuracies, final year prices in the sequential markets;
(2) The rational expectations model predicts, with great accuracy, not only the final year prices, but prices in the last several years, if futures markets operate; and
(3) A futures market facilitates and speeds up convergence to the rational expectations equilibrium.

Before making more definite conclusions, the data on the actual allocations of the assets across time and the efficiency of these allocations need to be examined.

B. Allocations

The time series of the allocation of asset holdings mirrors the time series of prices. The allocation converges to near the efficient allocation predicted by the rational expectations model. While the absence of a market did not result in outrageously inefficient allocations in the final year, a futures market clearly increased the speed at which it approached the efficient allocation. In view of the price data, this is not surprising.

Our first hypothesis about allocations is the following:

H6: Final year allocations predicted by the REE model are more accurate than final year predictions by the naive model.

Table III presents the final year allocations for each experiment. Since period B predictions are the same under both hypotheses, we limit the comparisons to period A predictions. In all nine experiments, the final allocation is much closer to the REE prediction than the naive prediction in the final year. In order to obtain a numerical measure of closeness to the predicted allocation, we calculated for each year of each experiment the number of units which were "misallocated" in period A according to the naive and REE models, respectively.

Using this measure, the REE model predicts allocations very well in late years (*always* better in years 6 and 7). The naive model predicts fairly accurately,

Table III

Final Year Allocations and Predicted Allocations

Experiment No.		Trader No. 1	2	3	4	5	6	7	8
1	Actual	(1, 6)	(0, 6)	(5, 0)	(5, 0)	(6, 0)	(0, 7)	(1, 5)	(6, 0)
	Naive	(4, 6)	(4, 6)	(2, 0)	(2, 0)	(2, 0)	(4, 6)	(4, 6)	(2, 0)
	REE	(0, 6)	(0, 6)	(6, 0)	(6, 0)	(6, 0)	(0, 6)	(0, 6)	(6, 0)
2	Actual	(1, 5)	(4, 0)	(1, 5)	(0, 5)	(4, 0)	(5, 2)	(1, 3)	(4, 0)
	Naive	(3, 5)	(2, 0)	(3, 5)	(3, 5)	(2, 0)	(2, 0)	(3, 5)	(2, 0)
	REE	(0, 5)	(5, 0)	(0, 5)	(0, 5)	(5, 0)	(5, 0)	(0, 5)	(5, 0)
3	Actual	(6, 1)	(0, 5)	(5, 0)	(1, 4)	(3, 0)	(5, 0)	(0, 5)	(0, 5)
	Naive	(2, 0)	(3, 5)	(2, 0)	(3, 5)	(2, 0)	(2, 0)	(3, 5)	(3, 5)
	REE	(5, 0)	(0, 5)	(5, 0)	(0, 5)	(5, 0)	(5, 0)	(0, 5)	(0, 5)
4	Actual	(7, 0)	(0, 6)	(0, 5)	(6, 0)	(0, 7)	(5, 0)	(6, 0)	(0, 6)
	Naive	(2, 0)	(4, 6)	(4, 6)	(2, 0)	(4, 6)	(2, 0)	(2, 0)	(4, 6)
	REE	(6, 0)	(0, 6)	(0, 6)	(6, 0)	(0, 6)	(6, 0)	(6, 0)	(0, 6)
5	Actual	(2, 5)	(6, 0)	(4, 0)	(0, 7)	(2, 6)	(6, 1)	(2, 0)	(2, 5)
	Naive	(4, 6)	(2, 0)	(2, 0)	(4, 6)	(4, 6)	(2, 0)	(2, 0)	(4, 6)
	REE	(0, 6)	(6, 0)	(6, 0)	(0, 6)	(0, 6)	(6, 0)	(6, 0)	(0, 6)
6	Actual	(3, 0)	(0, 4)	(2, 4)	(6, 0)	(3, 0)	(0, 6)	(0, 6)	(6, 0)
	Naive	(2, 0)	(3, 5)	(3, 5)	(2, 0)	(2, 0)	(3, 5)	(3, 5)	(2, 0)
	REE	(5, 0)	(0, 5)	(0, 5)	(5, 0)	(5, 0)	(0, 5)	(0, 5)	(5, 0)
7	Actual	(1, 6)	(6, 0)	(4, 0)	(0, 7)	(2, 6)	(4, 0)	(4, 0)	(3, 5)
	Naive	(4, 6)	(2, 0)	(2, 0)	(4, 6)	(4, 6)	(2, 0)	(2, 0)	(4, 6)
	REE	(0, 6)	(6, 0)	(6, 0)	(0, 6)	(0, 6)	(6, 0)	(6, 0)	(0, 6)
8	Actual	(0, 6)	(0, 6)	(5, 0)	(6, 0)	(7, 0)	(0, 6)	(0, 6)	(6, 0)
	Naive	(4, 6)	(4, 6)	(2, 0)	(2, 0)	(2, 0)	(4, 6)	(4, 6)	(2, 0)
	REE	(0, 6)	(0, 6)	(6, 0)	(6, 0)	(6, 0)	(0, 6)	(0, 6)	(6, 0)
9	Actual	(4, 0)	(1, 5)	(3, 0)	(0, 6)	(4, 0)	(6, 0)	(0, 5)	(2, 4)
	Naive	(2, 0)	(3, 5)	(2, 0)	(3, 5)	(2, 0)	(2, 0)	(3, 5)	(3, 5)
	REE	(5, 0)	(0, 5)	(5, 0)	(0, 5)	(5, 0)	(5, 0)	(0, 5)	(0, 5)

particularly compared to the REE model, in the early years (always better in years 1 and 2 except for experiment 4). This is consistent with earlier results (Forsythe, Palfrey, and Plott [1]) and adds further support to the notion advanced by Grossman [4] and others that investors bring only their private information to the market and only after traders have observed prices will they learn the information necessary to achieve the REE.

Price and allocation convergence is only one way to measure how satisfactorily these markets operated. An additional consideration is the efficiency of the final allocation. Even though prices are in equilibrium there is no practical reason why gains from trade will have been fully exploited. Our economic models, however, tell us that if prices are in equilibrium then incentives should operate on traders in such a way that trading will continue until there are no further gains to be made through exchange. We measure the efficiency of the allocations by using this as a benchmark, which we refer to as 100% efficiency. As the other benchmark (0% efficiency) we use the initial allocation, *before* any trading has occurred.[11] To operationalize this measure, we define the total surplus of an allocation as the sum across all traders of the dividend earnings (in francs) under that allocation.[12] Call W_0 the total surplus in the initial allocation, W_t the total surplus in the *actual* allocation in year t of an experiment, and W_E the total surplus of the perfectly efficient allocation. Our measure of efficiency, E_t^j, for experiment j and year t, is given below.

$$E_t^j = \frac{W_t^j - W_0^j}{W_E^j - W_0^j}, \qquad t = 1, \cdots, T.$$

Using this measure, our final hypothesis is:

H7: Final year allocations in experiments with a futures market yield higher total surplus to traders than final year allocations without a futures market.

The efficiency of each final year allocation is measured by calculating actual improvement in total surplus over the endowment and dividing by the maximum possible improvement over the initial endowment (% of possible gains from trade realized). These are given above the price series for each experiment in Figures 1–9. There is weak support for hypothesis H7. In 12 of 20 possible pairwise comparisons between experiments with a futures market and experiments without a futures market, futures markets led to greater efficiency in the final year.

Looking at the efficiencies for every year of every experiment, futures markets clearly enhance efficiency in later years. In year 6, for example, in 70% of the pairwise comparisons between experiments with and without a futures market, futures markets led to greater efficiency. In early years, sequential markets appear to have greater efficiency, which we believe is likely due to the design feature that traders in sequential markets are all experienced, while traders in futures markets are all inexperienced.

IV. Conclusions

Futures markets have a pronounced and positive effect on the behavior of the simple markets we studied. By utilizing experimental techniques to control the underlying economic parameters, we are able to identify the independent influence of a futures market and measure market performance against known economic parameters. This allows us to address a new set of questions which are very difficult if not impossible to answer using conventional empirical methods.

Consistent with previous studies, we do observe that the existence of a futures market affects spot market prices in general and the variance of spot market prices in particular. A futures market increases the speed with which information

[11] It should be recognized that efficiency can become negative with this benchmark, although this never occurred.

[12] Alternatively, we could have defined the total surplus of an allocation as the total profits (in francs) by all traders in that market year. This gives an identical measure of efficiency.

about future demand and supply conditions becomes incorporated in spot market decisions. The effect of a futures market is to increase the speed with which a REE is achieved. The more rapid adjustment to a REE can have the effect of increasing the variance of spot market prices as they move to equilibrium, but this increased variance reflects efficiency gains due to better information. Thus, any call for government intervention into futures markets in order to stabilize prices may impede the fundamental way in which futures markets improve resource allocation.

The theoretical work of Svensson has shown the theoretical possibility of an infinity of temporary equilibria in these simple environments. We find it truly remarkable that, with a small number of replications, the combination of the market process with each individual's learning process consistently drives the market towards a rational expectations equilibrium. It seems that the "generic" Svensson equilibria in which agents hold *false* expectations will not persist over time in stationary environments. As also shown in Forsythe, Palfrey, and Plott [1], a *strict* rational expectations theory which does not require replication is inconsistent with the data. As Grossman [4] has argued, replication is necessary for the existence of a rational expectations equilibrium, since only with replication do investors acquire information about future prices.

It is hoped that the experiments reported here are only the beginning of an experimental examination of asset markets. We believe that the data obtained by such methods will importantly augment existing empirical bases and will provide observations for fresh analysis about the study of asset prices.

Appendix

Instructions for experiments 8 and 9. (Note: Portions in brackets were deleted from instructions for experiment without a futures market.)

General: This is an experiment in the economics of market decision-making. Various research foundations have provided funds for this research. The instructions are simple, and if you follow them carefully and make good decisions, you might earn a considerable amount of money which will be paid to you in cash.

In this experiment, we are going to conduct a market in which you will buy and sell marbles in a sequence of market years. Each year consists of two periods, the first of which will be called *A*, and the second *B*. Attached to the instructions you will find a sheet, labeled "Value of Marbles." This will help determine the value to you of any decisions you might make. You are not to reveal this information to anyone. It is your own private information.

The type of currency used in this market is francs. All trading and earnings will be in terms of francs. Each franc is worth ____ dollars to you. Do not reveal this number to anyone. Notice that the more francs you earn, the more dollars you earn.

Specific Instructions: One source of profits comes from being paid a certain amount of francs each year for the number of red marbles and blue marbles you hold at the end of the year. These are called your marble earnings. Each year these earnings can be computed from the table labeled "Value of Marbles."

The following example will demonstrate how to use the table. Suppose that your earnings from value of marbles table looks as follows.

Value of Marbles

Blue

		0		1		2
Red	0	0	(45)	45	(10)	55
		(40)	(75)	(30)	(33)	(27)
	1	40	(35)	75	(7)	82
		(20)	(50)	(19)	(25)	(18)
	2	60	(34)	94	(6)	100

Suppose further that at the end of the year you own one red marble and one blue marble. Your marble earnings in this case are determined as follows. Find the row corresponding to one red marble and find the column corresponding to one blue marble and read the entry; the amount is 75 francs. This would be your total marble earnings for that year.

If at the end of the year you owned two red marbles instead of one but still had one blue marble, then your marble earnings would be 94 francs rather than 75. The numbers in parentheses indicate the effect on earnings of one unit changes in marbles. For example, difference in earnings from holding one red and one blue and two red and two blue is 25 francs as shown.

A second source of profits is from buying and selling marbles. Selling marbles increases your francs on hand by the amount of the sale price. Similarly, purchases reduce your francs on hand by the amount of the purchase price. Thus you can gain *or* lose money on the purchase and resale of marbles.

At the beginning of each year you start with a certain number of red marbles, blue marbles, and francs. These amounts are given in row 0 of your information sheets each year. Ownership of marbles does not carry over from year to year. All francs on hand at the end of a year in excess of ____ francs are yours to keep. These are your profits for the year.

Market Organization: The markets are organized as follows. Each market will be conducted in a series of years each consisting of two periods (A and B). Period A will last ____ minutes and period B will last ____ minutes. Anyone wishing to purchase marbles is free to raise his or her hand and make a verbal bid to buy at a specified price, and anyone with marbles to sell is free to accept or not accept the bid. Likewise, anyone wishing to sell marbles is free to raise his or her hand and make a verbal offer to sell at a specified price. A bid (offer) remains outstanding until accepted or until a better bid (offer) is tendered.

Only certain kinds of transactions can be made. In period A, reds and blues cannot be bought or sold separately. All transactions must be for either a pair consisting of one red and one blue [or for a single blue]. In period B transactions can only be made for blues.

If a bid or offer is accepted, a binding contract has been made, and the contracting parties will record the transaction on their information and record sheets. Any ties in bids or acceptances will be resolved by random choice. Except for the bids, offers, and their acceptances, you are not to speak to any other subject. There are likely to be many bids and offers that are not accepted, but you are free to keep trying. You are free to make as much profit as you can.

Trading and Recording Instructions:

(1) After each of your sales or purchases, you must record the transaction price, whether it was a sale (S) or purchase (P), and whether the transaction was for a red-blue pair or a single blue. The first transaction is recorded on row 1, and succeeding transactions are recorded on subsequent rows.

(2) After each transaction you must calculate and record your new ownership of red and blue marbles and your new francs on hand. Neither your ownership of red marbles nor your ownership of blue marbles may go below zero in either period.

(3) At the end of each year, list your ownership of reds and blues on row 31.

(4) At the end of each year, compute your marble earnings from your table and enter them on row 32. Add francs on hand (row 31) to marble earnings (row 32). This is your end-of-year franc balance (enter on row 33). Your individual profit depends upon the amount by which this number exceeds the number listed on row 34. Enter this difference on row 35. This is your profit for the market year and is yours to keep. At the end of each market year, record this number on your profit sheet.

(5) At the end of the experiment, add up your total profit on your profit sheet and enter this sum on row 15 of your profit sheet. To convert this number into dollars, multiply by the number on row 16 and record the product on row 17. The experimenter will pay you this amount of money.

Practice Calculations:

(1) Assume that at the beginning of the year your initial holding of marbles is one red and one blue and your initial francs on hand are 100; your marble earnings are given in the table on page 1 of the instructions; and each year you are allowed to keep all the francs on hand in excess of 100.

Determine your end-of-year ownership of red and blue marbles and your profit for the year for each of the following actions: sell one red-blue pair in period A; buy one red-blue pair in period A; sell one blue in period B; buy one blue in period B; [sell one blue in period A; buy one blue in period A;] sell one red-blue pair in period A and buy one blue in period B; [sell one red-blue pair in period A and buy one blue in period A;] buy one red-blue pair in period A and sell one blue in period B; [buy one red-blue pair in period A and sell one blue in period A].

(2) Indicate the transactions listed above that would: increase end-of-year ownership of reds and blues by one marble each; increase end-of-year ownership of blues by one marble and leave end-of-year ownership of reds unchanged; increase end-of-year ownership of reds by one marble and leave end-of-year ownership of blues unchanged; decrease end-of-year ownership of reds and blues by one marble each; decrease end-of-year ownership of reds by one unit and leave end-of-year ownership of blues unchanged; decrease end-of-year ownership of blues by one and leave end-of-year ownership of reds unchanged.

(3) Again suppose that at the beginning of the year your initial ownership of reds and blues is one each and your initial francs on hand are 100. Each year you

are allowed to keep all francs on hand in excess of 100. Suppose further that your marble earnings are given in the table on page 1. (a) The following is a list of three possible sequences of trades which are legal for you to do. For each sequence, calculate your profit as if those trades were the only trades you made during a year: purchase one red-blue pair in period A for 50 and sell one blue in period B for 40; purchase one red-blue pair in period A for 60 and sell one blue in period B for 40; purchase one red-blue pair in period A for 60 and sell one blue in period B for 40. (b) Do the same for the following three pairs of trades: sell one red-blue pair in period A for 60 and purchase one blue in period B for 40; sell one red-blue pair in period A for 75 and purchase one blue in period B for 40; sell one red-blue pair in period A for 80 and purchase one blue in period B for 40. (c) Do the same for the following three pairs of trades: purchase one red-blue pair in period A for 65 and sell one blue in period B for 40; purchase one red-blue pair in period A for 65 and sell one blue in period B for 45; purchase one red-blue pair in period A for 65 and sell one blue in period B for 50. (d) Do the same for the following three pairs of trades: sell one red-blue pair in period A for 65 and purchase one blue in period B for 30; sell one red-blue pair in period A for 65 and purchase one blue in period B for 35; sell one red-blue pair in period A for 65 and purchase one blue in period B for 40. (e) What is your profit if you do not trade at all during the year? (f) Which sequences of trades in (a) make you better off than not trading at all? (g) Which sequences of trades in (b) make you better off than not trading at all? (h) Which sequences of trades in (c) make you better off than not trading at all? (i) Which sequences of trades in (d) make you better off than not trading at all?

(4) Do your answers in (3) change if each purchase (sale) of "one blue in period B" is replaced by a purchase (sale) of "one blue in period A"?

Information and Record Sheet Period ______

Row/Trade Number	S/P	Red-Blue Pair or Single Blue	Transaction Price	Red Ownership	Blue Ownership	Francs on Hand
0						
1						
⋮						
30						
End Year Totals 31						
	32	Marble Earnings				
	33	End-of-Year Franc Balance (Row 31 + Row 32)				
	34					
	35	End-of-Year Profit (Row 33 − Row 34)				

Profit Sheet (Form is published in Forsythe, Palfrey, and Plott [1, p. 563]).

Type I Traders

VALUE OF MARBLES TABLES*

Blue

Trader No._______

		0		1		2		3		4		5		6		7		8 or more
	0	0	(979)	979	(406)	1385	(312)	1697	(262)	1959	(231)	2190	(210)	2400	(192)	2592	(179)	2771
		(692)	(1200)	(221)	(570)	(164)	(448)	(136)	(381)	(119)	(338)	(107)	(307)	(97)	(283)	(91)	(264)	(85)
	1	692	(508)	1200	(349)	1549	(284)	1833	(245)	2078	(219)	2297	(200)	2497	(186)	2683	(173)	2856
		(287)	(693)	(185)	(497)	(148)	(410)	(126)	(357)	(112)	(322)	(103)	(295)	(95)	(274)	(88)	(256)	(83)
	2	979	(406)	1385	(312)	1697	(262)	1959	(231)	2190	(210)	2400	(192)	2592	(179)	2771	(168)	2939
		(221)	(570)	(164)	(448)	(136)	(381)	(119)	(338)	(107)	(307)	(97)	(283)	(91)	(264)	(85)	(248)	(80)
	3	1200	(349)	1549	(284)	1833	(245)	2078	(219)	2297	(200)	2497	(186)	2683	(173)	2856	(163)	3019
		(185)	(497)	(148)	(410)	(126)	(357)	(112)	(322)	(103)	(295)	(95)	(274)	(88)	(256)	(83)	(242)	(79)
Red	4	1385	(312)	1697	(262)	1959	(231)	2190	(210)	2400	(192)	2592	(179)	2771	(168)	2939	(159)	3098
		(164)	(448)	(136)	(381)	(119)	(338)	(107)	(307)	(97)	(283)	(91)	(264)	(85)	(248)	(80)	(235)	(76)
	5	1549	(284)	1833	(245)	2078	(219)	2297	(200)	2497	(186)	2683	(173)	2856	(163)	3019	(155)	3174
		(148)	(410)	(126)	(357)	(112)	(322)	(103)	(295)	(95)	(274)	(88)	(256)	(83)	(242)	(79)	(230)	(75)
	6	1697	(262)	1959	(231)	2190	(210)	2400	(192)	2592	(179)	2771	(168)	2939	(159)	3098	(151)	3249
		(136)	(381)	(119)	(338)	(107)	(307)	(97)	(283)	(91)	(264)	(85)	(248)	(80)	(235)	(76)	(224)	(73)
	7	1833	(245)	2078	(219)	2297	(200)	2497	(186)	2683	(173)	2856	(163)	3019	(155)	3174	(148)	3322
		(126)	(357)	(112)	(322)	(103)	(295)	(95)	(274)	(88)	(256)	(83)	(242)	(79)	(230)	(75)	(220)	(72)
	8 or more	1959	(231)	2190	(210)	2400	(192)	2592	(179)	2771	(168)	2939	(159)	3098	(151)	3249	(145)	3394

*Entries in numbered rows and columns not in parentheses were highlighted in yellow.

Type II Traders

VALUE OF MARBLES TABLES*

Blue

Trader No._______

		0		1		2		3		4		5		6		7		8 or more
	0	0	(424)	424	(176)	600	(134)	734	(114)	848	(100)	948	(91)	1039	(83)	1122	(78)	1200
		(734)	848	(424)	524	(348)	439	(305)	388	(274)	352	(252)	324	(233)	302	(219)	285	(207)
	1	734	(114)	848	(100)	948	(91)	1039	(83)	1122	(78)	1200	(72)	1272	(69)	1341	(66)	1407
		(305)	388	(274)	352	(252)	324	(233)	302	(219)	285	(207)	269	(197)	257	(188)	246	(180)
	2	1039	(83)	1122	(78)	1200	(72)	1272	(69)	1341	(66)	1407	(62)	1469	(60)	1529	(58)	1587
		(233)	302	(219)	285	(207)	269	(197)	257	(188)	246	(180)	236	(174)	228	(168)	220	(162)
	3	1272	(69)	1341	(66)	1407	(62)	1469	(60)	1529	(58)	1587	(56)	1643	(54)	1697	(52)	1749
		(197)	257	(188)	246	(180)	236	(174)	228	(168)	220	(162)	213	(157)	206	(152)	200	(148)
Red	4	1469	(60)	1529	(58)	1587	(56)	1643	(54)	1697	(52)	1749	(51)	1800	(49)	1849	(48)	1897
		(174)	228	(168)	220	(162)	213	(157)	206	(152)	200	(148)	195	(144)	189	(140)	185	(137)
	5	1643	(54)	1697	(52)	1749	(51)	1800	(49)	1849	(48)	1897	(47)	1944	(45)	1989	(45)	2034
		(157)	206	(152)	200	(148)	195	(144)	189	(140)	185	(137)	181	(134)	177	(132)	174	(129)
	6	1800	(49)	1849	(48)	1897	(47)	1944	(45)	1989	(45)	2034	(44)	2078	(43)	2121	(42)	2163
		(144)	189	(140)	185	(137)	181	(134)	177	(132)	174	(129)	170	(126)	166	(123)	163	(121)
	7	1944	(45)	1989	(45)	2034	(44)	2078	(43)	2121	(42)	2163	(41)	2204	(40)	2244	(40)	2284
		(134)	177	(132)	174	(129)	170	(126)	166	(123)	163	(121)	160	(119)	158	(118)	156	(116)
	8 or more	2078	(43)	2121	(42)	2163	(41)	2204	(40)	2244	(40)	2284	(39)	2323	(39)	2362	(38)	2400

*Entries in numbered rows and columns not in parentheses were highlighted in yellow.

Parameter Set I

Type I Traders

VALUE OF MARBLES TABLES*

Trader No._______

Blue

Red	0		1		2		3		4		5		6		7		8 or more
0	0	2939	2939	1217	4156	935	5091	787	5878	694	6572	628	7200	576	7776	537	8313
	2078	3600	661	1708	491	1343	408	1144	357	1015	321	921	293	849	273	793	256
1	2078	1522	3600	1047	4647	852	5499	736	6235	658	6893	600	7493	556	8049	520	8569
	861	2078	556	1491	444	1231	379	1073	337	965	307	883	283	820	264	769	249
2	2939	1217	4156	935	5091	787	5878	694	6572	628	7200	576	7776	537	8313	505	8818
	661	1708	491	1343	408	1144	357	1015	321	921	293	849	273	793	256	746	241
3	3600	1047	4647	852	5499	736	6235	658	6893	600	7493	556	8049	520	8569	490	9059
	556	1491	444	1231	379	1073	337	965	307	883	283	820	264	769	249	726	236
4	4156	935	5091	787	5878	694	6572	628	7200	576	7776	537	8313	505	8818	477	9295
	491	1343	408	1144	357	1015	321	921	293	849	273	793	256	746	241	706	229
5	4647	852	5499	736	6235	658	6893	600	7493	556	8049	520	8569	490	9059	465	9524
	444	1231	379	1073	337	965	307	883	283	820	264	769	249	726	236	689	224
6	5091	787	5878	694	6572	628	7200	576	7776	537	8313	505	8818	477	9295	453	9748
	408	1144	357	1015	321	921	293	849	273	793	256	746	241	706	229	672	219
7	5499	736	6235	658	6893	600	7493	556	8049	520	8569	490	9059	465	9524	443	9967
	379	1073	337	965	307	883	283	820	264	769	249	726	236	689	224	658	215
8 or more	5878	694	6572	628	7200	576	7776	537	8313	505	8818	477	9295	453	9748	434	10182

*Entries were highlighted in yellow as in Parameter Set I.

Type II Traders

VALUE OF MARBLES TABLES*

Trader No._______

Blue

Red	0		1		2		3		4		5		6		7		8 or more
0	0	1272	1272	528	1800	404	2204	341	2545	301	2846	271	3117	250	3367	233	3600
	2204	2545	1273	1574	1046	1317	913	1163	822	1055	754	972	701	907	657	854	621
1	2204	341	2545	301	2846	271	3117	250	3367	233	3600	218	3818	206	4024	197	4221
	913	1163	822	1055	754	972	701	907	657	854	621	809	591	771	565	738	541
2	3117	250	3367	233	3600	218	3818	206	4024	197	4221	188	4409	180	4589	173	4762
	701	907	657	854	621	809	591	771	565	738	541	708	520	682	502	658	485
3	3818	206	4024	197	4221	188	4409	180	4589	173	4762	167	4929	162	5091	156	5247
	591	771	565	738	541	708	520	682	502	658	485	638	471	618	456	601	445
4	4409	180	4589	173	4762	167	4929	162	5091	156	5247	153	5400	147	5547	145	5692
	520	682	502	658	485	638	471	618	456	601	445	585	432	569	422	557	412
5	4929	162	5091	156	5247	153	5400	147	5547	145	5692	140	5832	137	5969	135	6104
	471	618	456	601	445	585	432	569	422	557	412	543	403	531	394	520	385
6	5400	147	5547	145	5692	140	5832	137	5969	135	6104	131	6235	128	6363	126	6489
	432	569	422	557	412	543	403	531	394	520	385	509	378	499	371	491	365
7	5832	137	5969	135	6104	131	6235	128	6363	126	6489	124	6613	121	6734	120	6854
	403	531	394	520	385	509	378	499	371	491	365	482	358	473	352	466	346
8 or more	6235	128	6363	126	6489	124	6613	121	6734	120	6854	117	6971	115	7086	114	7200

*Entries were highlighted in yellow as in Parameter Set I.

Parameter Set II

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