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RATIONAL EXPECTATIONS AND THE AGGREGATION OF DIVERSE INFORMATION IN LABORATORY SECURITY MARKETS

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The idea that markets might aggregate and disseminate information and also resolve conflicts is central to the literature on decentralization (Hurwicz, 1972) and rational expectations (Lucas, 1972). We report on three series of experiments all of which were predicted to have performed identically by the theory of rational expectations. In two of the three series (one in which participants trade a complete set of Arrow-Debreu securities and a second in which all participants have identical preferences), double auction trading leads to efficient aggregation of diverse information and rational expectations equilibrium. Failure of the third series to exhibit such convergence demonstrates the importance of market institutions and trading instruments in achievement of equilibrium.

KEYWORDS: Rational expectations, aggregation of information, efficiency of security markets, experimental economics, completeness of security market, dynamics of rational expectations equilibrium, efficiency of contingent-claims markets.

INTRODUCTION

IN THIS PAPER we explore the information aggregation properties of market organization that recent mathematical theorizing suggests might exist. Economists have long recognized that markets, if properly structured, can be an efficient conflict resolution device for a given pattern of attitudes. In addition, the idea that market processes may involve value formation (the endogenous formation of limit prices and demand functions), thereby departing from an assumption of fixed attitudes, was introduced many years ago. However, the idea that value formation, to the extent it reflects expectations formation, may involve aspects of efficiency and that organizations might aggregate and disseminate information while also resolving conflicts is a product of the modern mathematical literature on decentralization (Hurwicz, 1972) and on rational expectations (Lucas, 1972).

That markets might reasonably be expected to efficiently resolve conflicts has been demonstrated many times in the experimental economics literature. Recent experiments (Forsythe, Palfrey, and Plott, 1982; and Plott and Sunder, 1982) have demonstrated that markets can also *disseminate* information efficiently. In this paper we address the more complicated and subtle issue of information *aggregation* when different traders have diverse information about an underlying state of nature. The situation is one in which no trader knows the state of nature but if traders pool their information, the state can be identified with certainty. Subject to the usual caveats about side-payments, the pooling of information would improve the welfare of all. Rational expectations models suggest that markets might be used to accomplish this result even though traders are unable to

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communicate information directly and even though traders have no obvious incentive unilaterally to reveal what they know. The experiments reported below explore the possibility.

Previous experiments have demonstrated the power of the rational expectations (RE) model, so we began with the working (null) hypothesis that with replication the predictions of the rational expectations model would be reasonably accurate. The first experiments (Series A) led us to reject this idea and forced us to proceed on the opposite presumption that aggregation as suggested by the model does not occur at all. With this perspective a second set of experimental markets (Series B) in which a complete set of state-contingent securities were traded was designed. The information structure was exactly the same as it was in Series A. Our discovery that this second series of markets behaves substantially as predicted by the RE model led us to design a third series (Series C) of single compound security markets in which payoffs of a security in a state were identical across all traders. Again, the same information structure was retained. The fact that both the second and the third series perform as forecast by the RE model leads us to suspect that the existence of instruments which enable traders to link the actions of others to a source of motivation is important to the information aggregation function of markets.

In the next section the experimental design, parameters, and procedures are introduced. The third section outlines a rational expectations model and two competing models which will help us organize the data. The data from all series are presented in the fourth section and analyzed in terms of the major predictions of the models about prices, allocations, profits, and efficiency. It also contains a discussion of aspects of behavior which may help in the development of a fully appropriate model. A fifth section contains a discussion of several parameters which may vary across experiments and our attempts to explain why the complete markets for state contingent securities seem better able to aggregate diverse information. The final section is a summary of conclusions.

2. MARKET DESIGN

A total of eleven markets (plus one pilot) were studied. Nine of the markets (1, 2, 3, and 6 through 11) involved a single asset. Six of these markets had diverse dividends (1, 2, 3, 6, 10, 11) and are labelled as Series A. The other three markets had uniform dividends (7, 8, 9) and are referenced as Series C. The other two markets (4 and 5) had a complete set of state-contingent claims during the first nine periods (labelled 4-CC and 5-CC) followed by several periods in which only a single compound security could be traded (labelled 4-S and 5-S). The contingent claims portions of these markets are referenced as Series B and the single security portions are grouped in Series A. The numerical indexing of the markets reflects the sequence in which the markets were conducted and to some extent the experience of subjects, but for purposes of analysis the markets will be rearranged as Series A, B, and C.

Each market was conducted for several periods and in each period securities with one-period lives were traded. Each security paid a single dividend to the holder at the end of the period. These dividends differed across traders (except in markets 7, 8, and 9) and depended upon the state of nature. The differences in dividends and in expectations about the underlying state of nature led to the existence of gains from trade similar to those induced by the differences in attitudes towards risk, wealth, and/or portfolio positions. The markets were organized as oral double auctions. Subjects were graduate and undergraduate students at three universities. Experience varied across markets as shown in Table I.

2.1. *Preferences and Assets*

Instructions, procedures for training subjects, the method of inducing preferences, and other details of experimental procedure were like those used in Plott and Sunder (1982). Trader, i, was assigned a dollar redemption function of the form:

$$R_i^t = \gamma_i \left[a_i + \sum_\alpha d_{\alpha i}(\theta_t) x_{\alpha i}^t + \sum_s p_s^{it} - \sum_p p_p^{it} + C_i^t \right],$$

$$a_i < 0, d_{\alpha i}(\theta_t) > 0, \gamma_i > 0, x_{\alpha i}^t \geqslant 0$$

where $i \in \mathscr{I}$, the set of traders, $\alpha \in \mathscr{A}$, the set of types of securities, $\theta \in \Theta$, the set of states of nature, R_i^t are dollar earnings of trader i in period t, $x_{\alpha i}^t$ are units of security of type α held by trader i at the end of period t (end of period short sales were prohibited so $x_{\alpha i}^t \geqslant 0$), and they are equal to the initial endowment of securities plus purchases less sales in period t, $d_{\alpha i}(\theta_t)$ is the dividend rate of type α security in francs for trader i expressed as a function of the state of nature θ, $\Sigma_s p_s^{it}$ is revenue from sales of securities during period t, $\Sigma_p p_p^{it}$ is cost of securities purchased during period t, C_i^t is initial endowment of cash in francs, a_i^t is fixed cost in francs (in all experiments we chose $a_i^t = -C_i^t$, so the entire working capital was taken away in term of fixed cost at the end of each period), and γ_i is the conversion rate of francs (experimental currency) into U.S. dollars.

Traders who have positive utility for money would like R_i^t as large as possible. Derived demand induces values on securities which, in turn, can be used as parameters in the models of market behavior.

Constraints on decisions of traders were as follows. At the beginning of each period each trader was given an initial endowment of working capital (C_i^t) which was sufficiently large never to be binding. Each trader was also given an initial endowment of securities (x_α) of each type α. Short positions were permissible (in markets 4 though 11 but not in markets, 1, 2, or 3) during a trading period, but no one was allowed to remain short at the end of the period.[2] Thus the supply of each type of security was fixed at $\Sigma_i x_{\alpha i}^t$.

[2] A penalty of 300 francs plus the highest transaction price during the period was imposed for each short unit. Only once (market 4, period 9) did a trader end a period in a net short position.

TABLE I

Design of Markets

Markets	Series	Location[a] & Subject Experience	Trader Type	Number of Traders	Initial Endowment: Certificates	Initial Endowment: Francs	Fixed Cost (Francs)	Dollar per Franc	Dividends x	Dividends y	Dividends z	Probabilities x	Probabilities y	Probabilities z	Expected Dividends: No Information	Expected Dividends: Not x	Expected Dividends: Not y	Expected Dividends: Not z
1	A	UC	I	4	2	10,000	10,000	0.003	70	160	300	0.35	0.20	0.45	191.5	257	199	103
		(inexperienced)	II	4	2	10,000	10,000	0.003	230	90	60				125.5	69	134	179
2	A	UC	I	4	2	10,000	10,000	0 003	100	330	190	0.35	0.45	0 20	221.5	287	133	229
		(experienced in market 1 or pilot)	II	4	2	10,000	10,000	0.003	260	90	120				155.5	99	209	164
3	A	CIT	I	4	2	10,000	10,000	0.003	70	160	300	0.35	0.20	0 45	191.5	257	199	103
		(inexperienced)	II	4	2	10,000	10,000	0.003	230	90	60				125 5	69	134	179
4		CIT	I	4	2	10,000	10,000	0.003	70	130	300	0.35	0.20	0 45	185.5	248	199	92
(contingent claims		(inexperienced)	II	4	2	10,000	10,000	0.003	230	90	60				125 5	69	134	179
periods 1–9)	B		III	4	2	10,000	10,000	0 003	100	160	200				157 0	188	156	122
(single security periods 10–13)	A																	
5		CIT	I	4	2(4)[b]	15,000	15,000	0.0025	140	260	600	1/3	1/3	1/3	333	430	370	200
(contingent claims		(experienced in	II	4	2(4)[b]	15,000	15,000	0.0025	460	180	120				253	150	290	320
periods 1–9)	B	market 3 or 4)	III	4	2(4)[b]	15,000	15,000	0 0025	200	320	400				307	360	300	260
(single security periods 10–16)	A																	
6	A	CIT	I	4	4	16,000	16,000	0.00125	50	240	590	1/3	1/3	1/3	293	415	320	145
		(experienced in	II	4	4	16,000	16,000	0.00125	170	450	110				243	280	140	310
		market 3 or 4)	III	4	4	16,000	16,000	0.00125	310	190	390				297	290	350	250
7	C	IIM (inexperienced)	I	12	4	25,000	25,000	0.0015[c]	50	240	490	1/3	1/3	1/3	260	365	270	145
8	C	IIM (experienced in market 7)	I	12	2	25,000	25,000	0.0015[c]	125	375	525	1/3	1/3	1/3	342	450	325	250
9	C	CIT (inexperienced)	I	12	4	25,000	25,000	0.015	50	240	490	0 35	0.45	0.20	223 5	317	210	157
10	A	CIT	I	4	4	16,000	16,000	0.00125	240	50	590	1/3	1/3	1/3	293	320	415	145
		(experienced in	II	4	4	16,000	16,000	0 00125	450	170	110				243	140	280	310
		market 9)	III	4	4	16,000	16,000	0.00125	190	310	390				297	350	290	250
11	A	IIM	I	4	2	16,000	16,000	0.00125[c]	50	240	590	1/3	1/3	1/3	293	415	320	145
		(experienced in	II	4	2	16,000	16,000	0.00125[c]	170	450	110				243	280	140	310
		market 7 & 8)	III	4	2	16,000	16,000	0.00125[c]	310	190	390				297	290	350	250

[a] UC is University of Chicago CIT is California Institute of Technology IIM is Indian Institute of Management
[b] 2 in complete markets (periods 1–9), 4 in single-security markets (periods 10–16)
[c] Rupee per franc for markets 7, 8, and 11

2.2. *Information*

The information structure of the markets was the same across all markets. Traders were publicly told that the selection of the state each period depended upon a draw from a bingo cage and they were trained through preliminary draws to guest the events which were to have led to various states of nature (see Plott and Sunder (1982) for procedures and instructions).[3]

No subject knew the dividends of any other subject. The number of informed traders and the type of information were both public. The method of distributing information (based on a random number table) was public.

In all cases there were three states x, y, and $z(\Theta = \{x, y, z\})$. As outlined above we postulate that a probability distribution $P(\theta), \theta \in \{x, y, z\}$ represents the beliefs of all traders about the probability of the occurrence of each state in any period. At the beginning of the period the state was drawn. Information given to traders was as follows: if the state was, say, x, then half of the traders were told that the state was not y and the other half were told that the state was not z. Furthermore, all traders knew that the identity of the traders who received each clue was determined according to a random number table. That is, probability that any given trader receives the clue "not y," given that the state is x, is one-half, etc.

2.3. *Parameters*

The parameters for each experiment are contained in Table I. In the first three markets traders were partitioned into two types (designated I and II) according to dividend payoffs and, in 4, 5, 6, 10, and 11, three types (designated I, II, and III). In all these markets there were four traders of each type. Thus in each of the first three markets there were eight traders and in all other markets there were twelve. In markets 7, 8, and 9 there was only one type of trader but there were twelve traders of this type. Each period each trader had an initial endowment of two securities except in markets 5-S, 6, and 9 where each trader had four. The initial cash endowments given to traders each period, the fixed cost, and dollar/franc (or rupee/franc) exchange rate, are all listed in the table. The initial endowment and therefore the total supply of securities was doubled from market 3 to see if volume of trading is a critical variable in convergence.

The structure of dividends differed between the contingent claims and the single security organizations. The dividend paid at the end of a period on a single security depended on the state of nature for that period and the type of trader holding the security. For example, in period 10 of market 4 in which only a single security exists, a security held by, say, a type II trader yielded a dividend of 230

[3] In fact, the state in all markets was picked from a predetermined sequence of draws made in advance of the experiment. Draws from the bingo cage were conducted each period and the proportions of states were the same as the stated probabilities but the announced states were those of the predetermined sequence. We have no evidence which leads us to suspect that subjects disbelieved the mechanism.

francs if the state was x, 90 francs if the state was y, and 60 francs if the state was z. The dividend returns to other types can also be read from Table I.

The contingent claims markets had three different securities. For convenience the securities were called x, y, and z, i.e., $\mathscr{Q} = \{x, y, z\}$. The x securities yielded a positive dividend if x occurred and zero otherwise. The y security yielded a positive dividend if y occurred and zero otherwise, etc. For example, reading from Table I, dividends for a type II trader during period 1 of market 4-CC were the following: $(d_{xi}(x) = 230, d_{xi}(y) = 0, d_{xi}(z) = 0)$; $(d_{yi}(x) = 0, d_{yi}(y) = 90, d_{yi}(z) = 0)$; $(d_{zi}(x) = 0, d_{zi}(y) = 0, d_{zi}(z) = 60)$. A portfolio of one of each type of security is equivalent to a portfolio of one security in the single security markets. The dividend structure for all other traders can be determined similarly from Table I.

3. COMPETING MODELS OF SECURITY BEHAVIOR

Three models are examined as candidate explanations of the behavior of security markets. The project was motivated by the fully revealing rational expectations equilibrium (RE) in which beliefs are endogenously developed. The two other models, the prior information equilibrium (PI) and maximin (MM), utilize exogenously formed beliefs and both are known from other experiments (Plott and Sunder, 1982) to be less reliable than RE. They are used here as benchmarks against which to evaluate RE. In addition, both models could be used as starting points in dynamic models of formation of rational expectations; so both are of independent interest.

3.1. *Rational Expectations* (*RE*)

The central principle of this model is the fully revealing rational expectations hypothesis (RE): all traders choose in equilibrium as if they are aware of the pooled information of all traders in the system regarding the underlying state. This principle is supplemented with the standard principles of demand and supply as applied to competitive markets.

Under these assumptions an RE equilibrium can be derived for the markets described in the section above. In all states the pooled information will identify the state with certainty (half of the traders can eliminate one of three states with certainty and the other half can eliminate another). Under competitive conditions demands are perfectly elastic at the dividend rate (assuming no transaction cost). The supply is fixed.

The price and allocation predictions of this model for each market are listed in Table II in rows marked RE. In any given state the equilibrium price is the highest dividend in that state and the securities are held by the traders who have that high dividend potential. In market 1, for example, the rational expectations model predicts a price of 230 francs when the state is x and it also predicts that all securities will be held by type II traders. In market 4-CC the rational expectations model predicts, when the state is x, that the price of the x, y, and z

TABLE II

PRICE AND ALLOCATION PREDICTIONS

Market	Model	Price: No Information	Price: Diverse Information about the State x	y	z	Type of Trader Purchasing Assets: No Information	Type of Trader: Diverse Information about the State x	y	z
1 and 3	RE	191.5	230	160	300	I	II	I	I
(single security)	PI	191.5	199	257	257	I	I(not y)	I(not x)	II(not x)
	MM	70	90	160	160	I	II(not z)	I(not x)	I(not x)
2	RE	221.5	260	330	190	I	II	I	I
(single security)	PI	221.5	229	287	287	I	I(not z)	I(not x)	I(not x)
	MM	100	120	190	190	I	II(not y)	I(not x)	I(not x)
4-CC	RE								
(contingent claims)	x-certificate	80.5	230	0	0	II	II	—	—
	y-certificate	32	0	160	0	III	—	III	—
	z-certificate	135	0	0	300	I	—	—	I
	PI								
	x-certificate	80.5	146	146	101	II	II(not z)	II(not z)	II(not y)
	y-certificate	32	58	58	49	III	III(not z)	III(not z)	III(not x)
	z-certificate	135	169	208	208	I	I(not y)	I(not x)	I(not x)
	MM								
	x-certificate	0	0	0	0				
	y-certificate	0	0	0	0	no predictions about allocations			
	z-certificate	0	0	0	0				
4-S	RE	185.5	230	160	300	I	II	III	I
(single security)	PI	185.5	199	248	248	I	I(not y)	I(not x)	I(not x)
	MM	100	100	160	160	III	III	III(not x)	III(not x)

5-CC (contingent claims)	RE								
	x-certificate	153	460	0	0	II	II	—	—
	y-certificate	107	0	320	0	III	—	III	—
	z-certificate	200	0	0	600	I	—	—	I
	PI								
	x-certificate	153	230	230	230	II	II	II(not z)	II(not y)
	y-certificate	107	160	160	160	III	III(not z)	III	III(not z)
	z-certificate	200	300	300	300	I	I(not y)	I(not x)	I
	MM								
	x-certificate	0	0	0	0	no prediction about allocations			
	y-certificate	0	0	0	0				
	z-certificate	0	0	0	0				
5-S (single security)	RE	333	460	320	600	I	II	III	I
	PI	333	370	430	430	I	I(not y)	I(not x)	I(not x)
	MM	200	200	320	320	III	III	III(not x)	III(not x)
6 and 11 (single security)	RE	297	310	450	490	III	III	II	I
	PI	297	350	415	415	III	III(not y)	I(not x)	I(not x)
	MM	190	310	240	310	III	III(not y)	I(not x)	III(not y)
7 (uniform dividends single security)	RE	260	50	240	590	← all (no trade) →			
	PI	260	270	365	365	all (no trade)	not y	not x	not x
	MM	50	50	240	240	← all (no trade) →		not x	not x
8 (uniform dividends single security)	RE	342	125	375	525	← all (no trade) →			
	PI	342	325	450	450	all (no trade)	not y	not x	not x
	MM	125	125	375	375	← all (no trade) →		not x	not x
9 (uniform dividends single security)	RE	223.5	50	240	490	← all (no trade) →			
	PI	223.5	210	317	317	all (no trade)	not y	not x	not x
	MM	50	50	240	240	← all (no trade) →		not x	not x
10 (single security)	RE	297	450	310	590	III	II	III	I
	PI	297	415	350	415	III	I(not y)	III(not x)	I(not y)
	MM	190	240	310	310	III	I(not y)	III(not x)	III(not x)

securities well be 230, 0, and 0, respectively. All of the x securities would, according to this model, be held by type II traders and there should be no trades in the other two securities.[4] In market 7, with all traders having identical dividends, RE implies prices of 50, 240, and 490 in states x, y, and z, respectively and no trading, leaving final allocations of securities the same as the initial endowments.

3.2. *Prior Information (PI)*

The prior information model is based on three principles of individual action. The first is that traders apply Bayes law to the problem of ascertaining the likelihood of a state after having received their private prior information. The second principle is that traders act on the probability so derived. The third principle is that actions are taken in accord with the expected utility hypothesis. (Here we make a further and stronger assumption that traders are risk neutral.) The law of supply and demand is then applied. Aside from the parametric structure the model is that developed by Lintner (1969) and applied to the U.S. securities market.

For our experimental markets these axioms imply that the price of an asset will be equal to the expected value to the trader whose prior information about the state leads to the highest expected value across all traders. The model predicts that these highest expected value traders will hold all of the securities. These predictions for each period and each state are listed in Table II on rows labelled PI.

3.3. *Maximin (MM)*

The maximin model replaces the hypothesis regarding expectations formation of PI with the hypothesis that traders act only on certainty.[5] This means that traders will not purchase a security unless the price is below the minimum they could possibly receive given their prior information. Thus the trader with the maximum (across all traders) of minimum (across all states) dividend will purchase the security and the competitive market hypothesis implies that the price will be equal to this dividend. The predictions of this model are listed in Table II on rows labelled MM.

4. RESULTS

Prices of the completed transactions in the relevant experimental markets are plotted chronologically in Figures 1 through 11. Horizontal lines in these figures

[4] Since the RE equilibrium price of y and z securities under state x is zero, the model actually makes no predictions about allocations. If we assume that the investors will not incur the pecuniary or psychological costs of conducting a transaction without expectation of gain from it, the zero trade prediction follows. Some evidence on reluctance of investors to enter trades which have zero expected benefit is available in the experimental literature (Plott and Smith, 1978).

[5] One could interpret this as an alternative to the expected utility hypothesis as opposed to a difference in belief structures between the models.

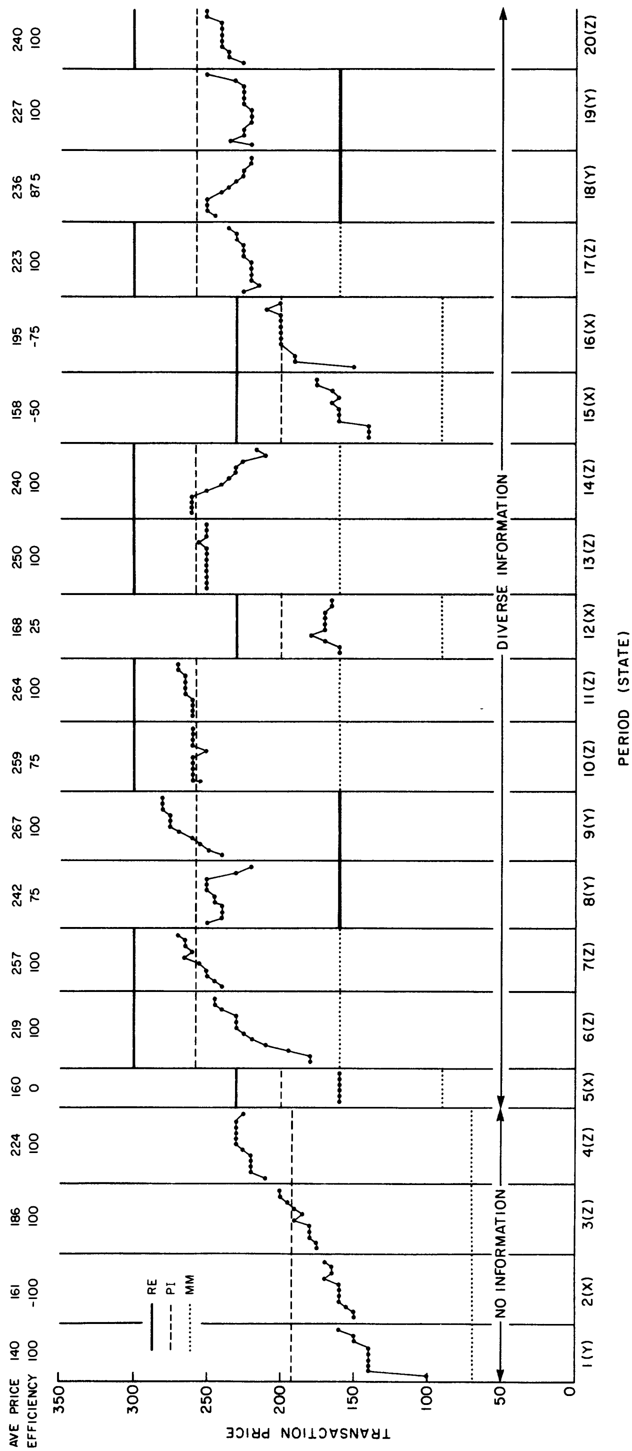

FIGURE 1.—Market 1 transaction prices.

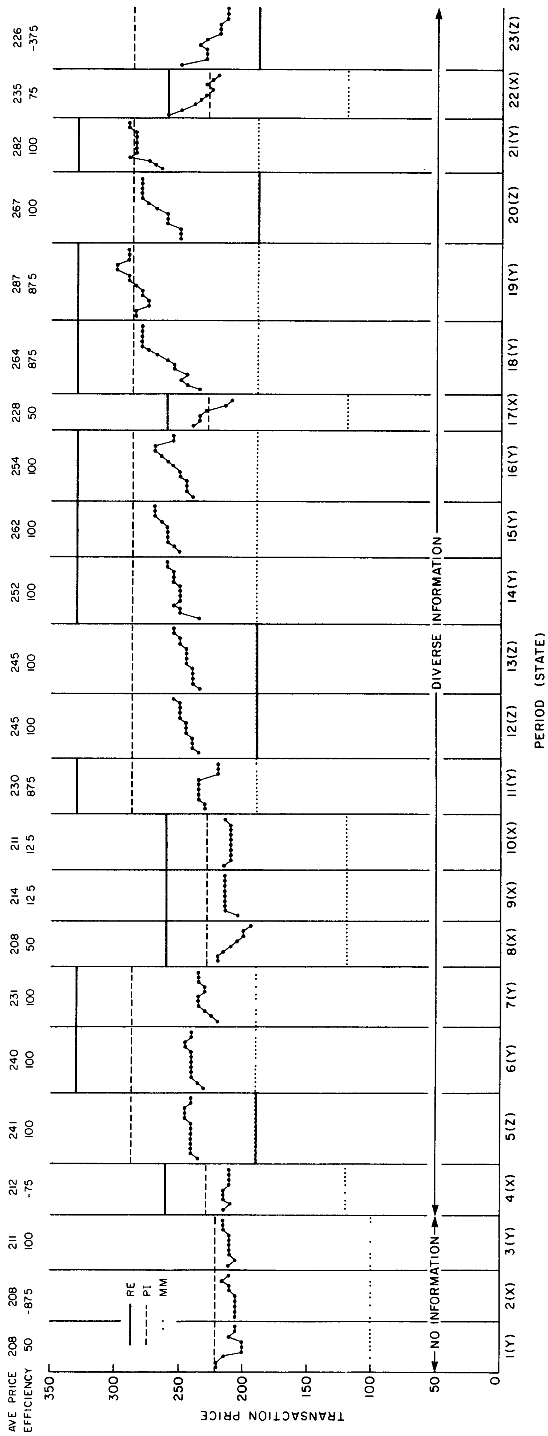

FIGURE 2.—Market 2 transaction prices.

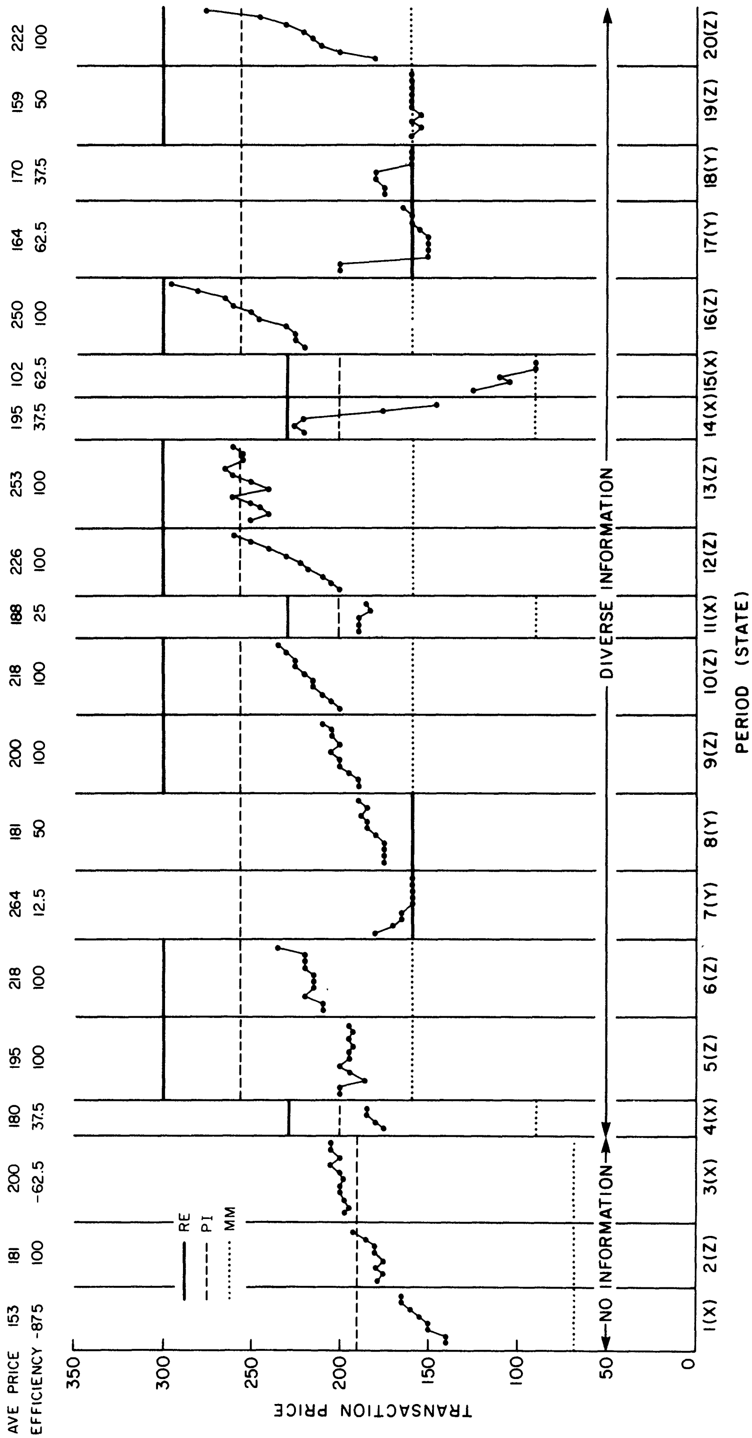

FIGURE 3.—Market 3 transaction prices.

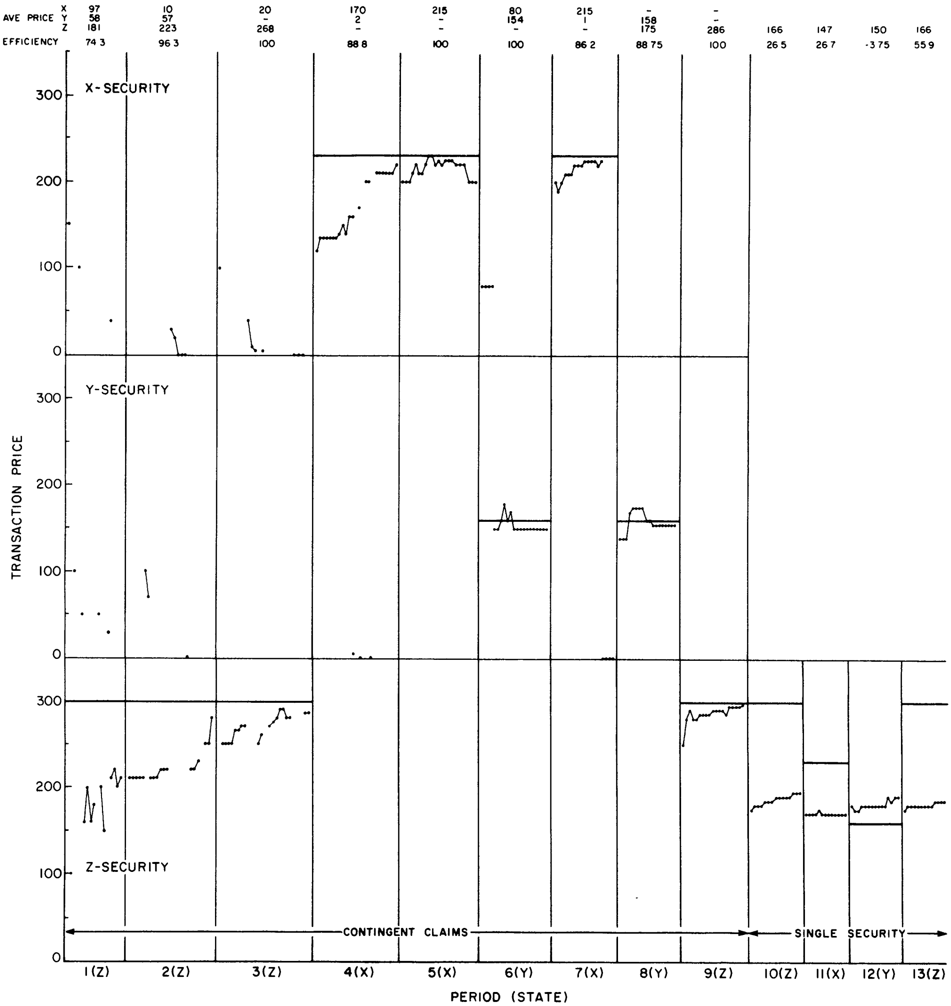

FIGURE 4.—Market 4-CC and 4-S transaction prices.

indicate the predictions of the three models described above which can be compared to the actual results. Average transaction prices are also shown for each period.

The conclusions developed below can be seen in the data presented in the figures. Market behavior relative to the predictions of the three models differs substantially depending upon treatment variables. The behaviors of the single security markets with diverse preferences (Series A) are only partially captured by the rational expectations model. A good example is market 10 in Figure 10. The early period prices are close to the MM predictions. Prices drift upward and remain about the same regardless of the state. If the markets are complete as in Series B or if preferences are identical (Series C), the rational expectations model

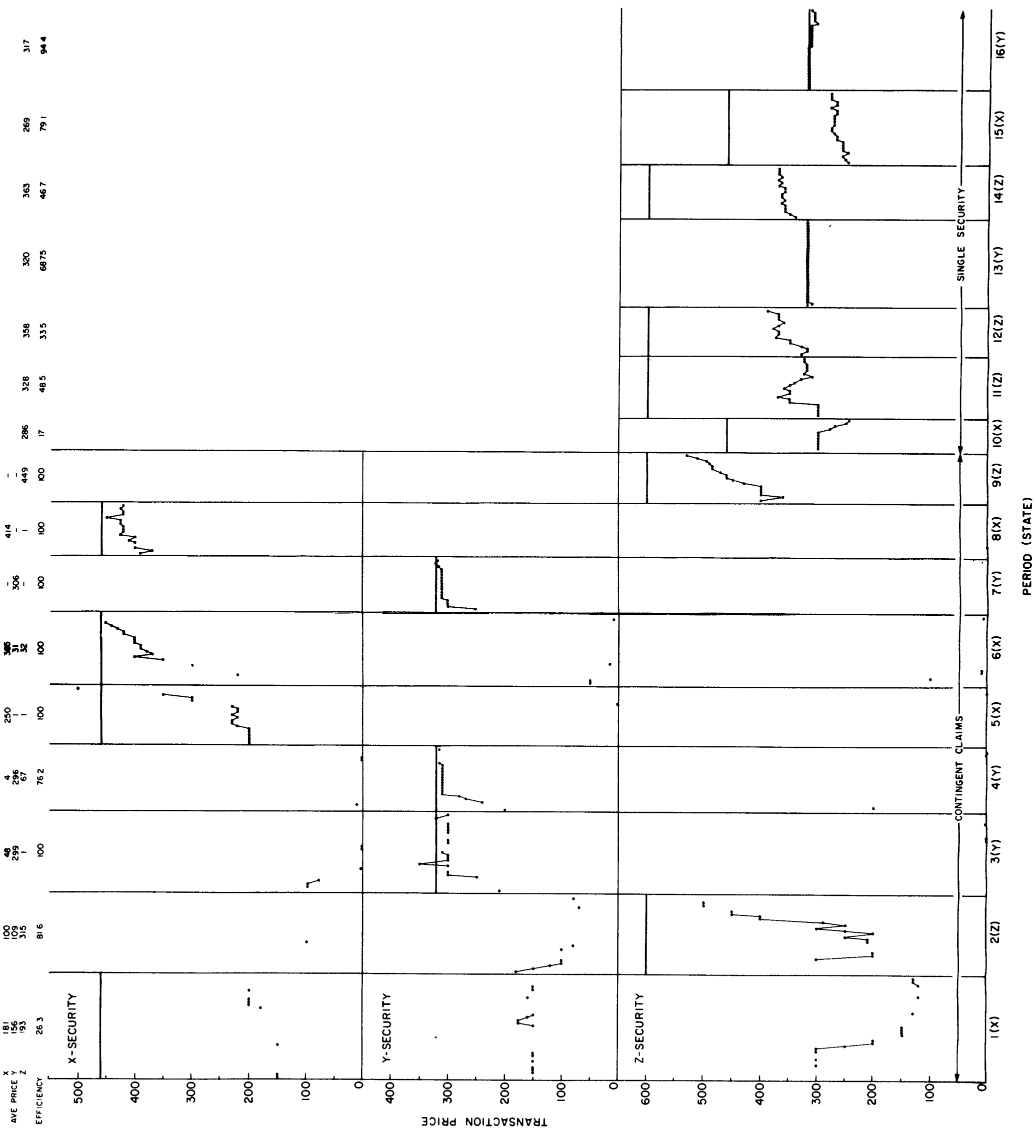

FIGURE 5.—Market 5-CC and 5-S transaction prices.

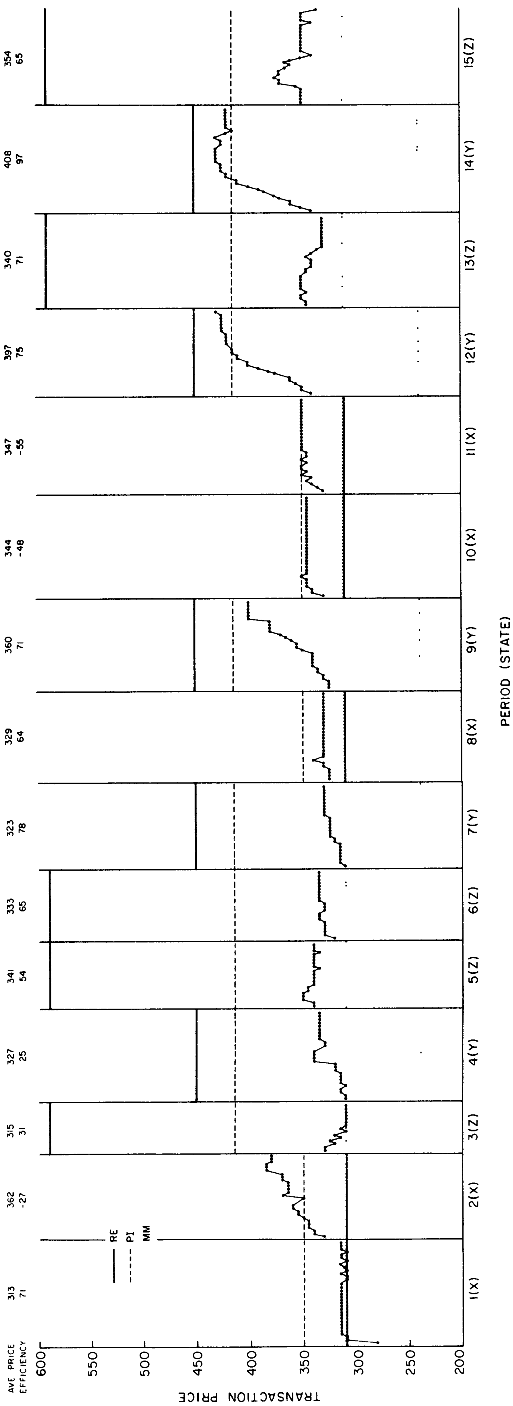

FIGURE 6.—Market 6 transaction prices.

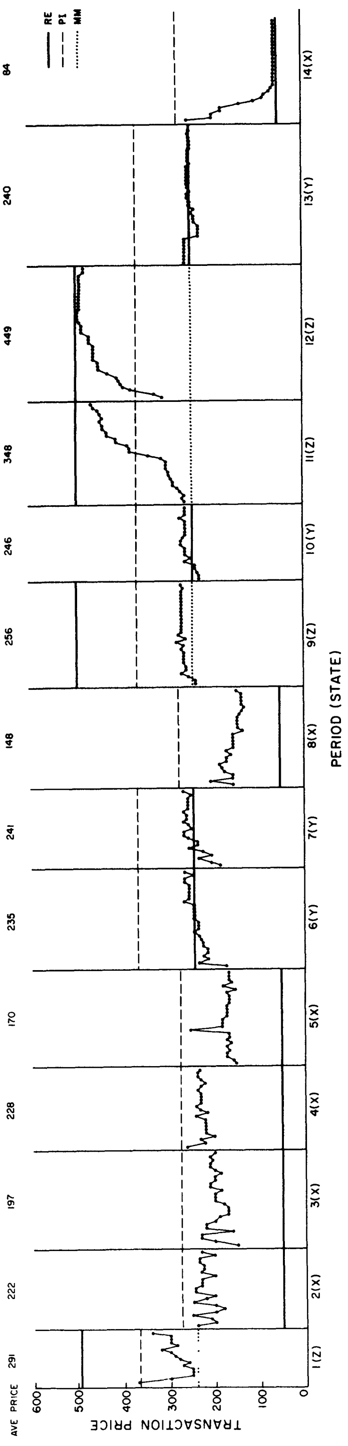

FIGURE 7.—Market 7 transaction prices.

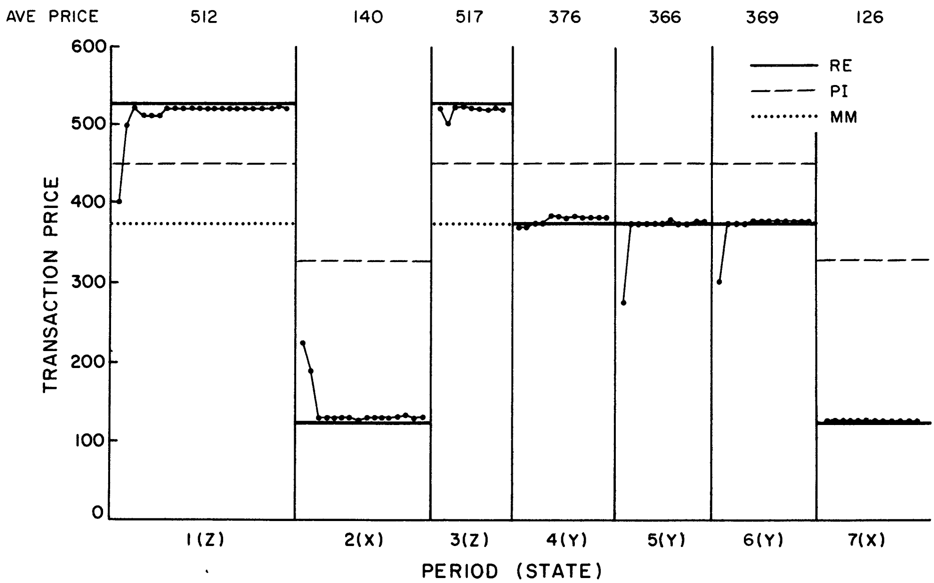

FIGURE 8.—Market 8 transaction prices.

provides a reasonably accurate summary of market behavior. Market 4-CC in Figure 4 is one of the two contingent claims markets. Notice that after the initial period or two the market corresponding to the realized state is near the RE price and the other two "not-state" markets have prices near zero. With uniform dividend, market 7 is slower to attain RE prices but by period 11 they are being attained and in the other two uniform dividend markets, 8 and 9, the RE levels are attained very quickly.

The discussion of results is divided into six subsections. Subsection 4.1 contains analysis relative to the equilibrium predictions of the three competing models. All models predict prices, allocations, and profits. Subsection 4.2 addresses the central issue of information aggregation as reflected in market efficiency. In a third subsection, 4.3, the dynamics of the possible equilibrating process receive some attention and 4.4 extends the investigation of dynamics to the bids and offers in the contingent claims markets. Subsection 4.5 analyzes the data relative to the fair game hypothesis of security markets. The sixth subsection, 4.6, addresses the possible effects of many variables which changed across the markets. Though these variables are not central to the major thesis of this study, we analyze them in search for institutional variables that may assist in aggregation of information. We have labelled as conjectures those results which are either suggested by the data or are based on very little data. In either case more data are needed for testing these conjectures.

4.1. *Equilibrium Behavior*

Earlier experiments have demonstrated that replication of periods is necessary for the data to approach the levels predicted by static equilibrium models.

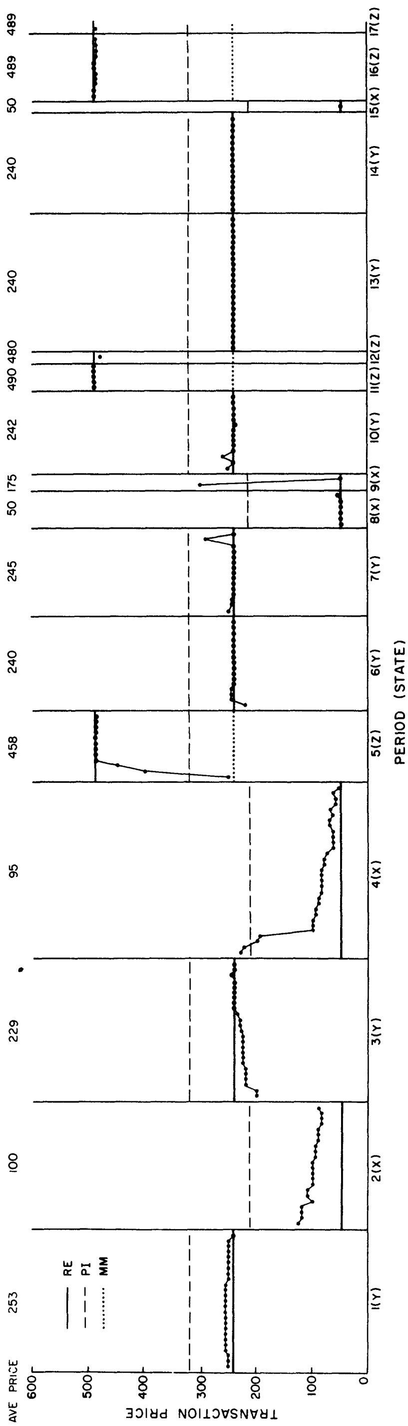

FIGURE 9.—Market 9 transaction prices.

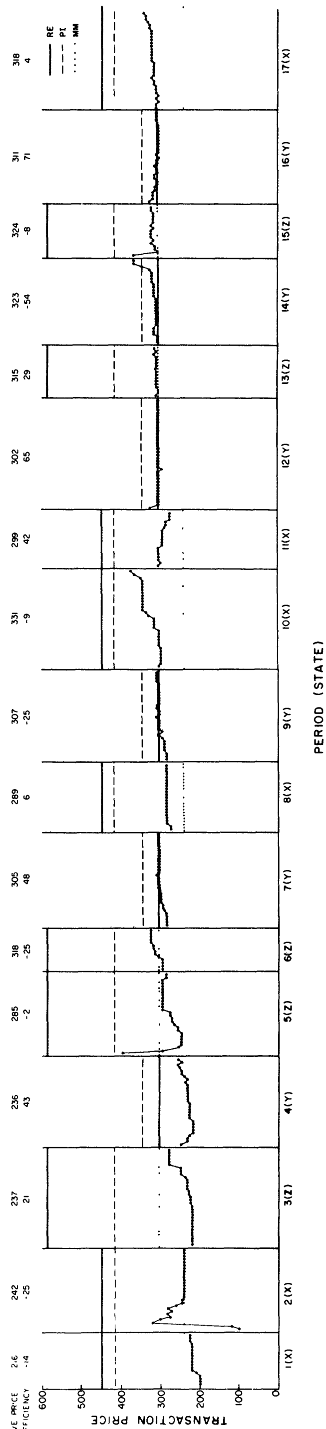

FIGURE 10.—Market 10 transaction prices.

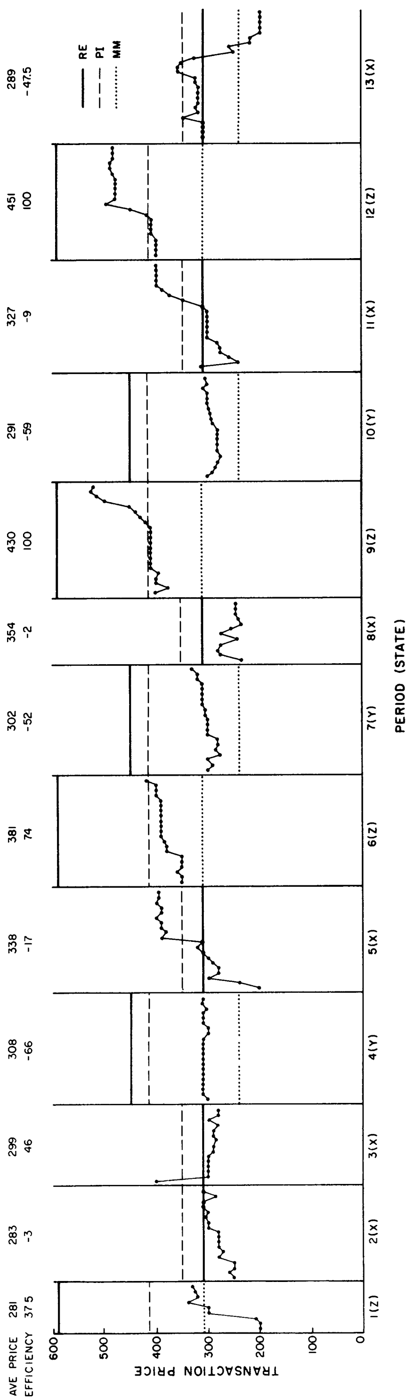

FIGURE 11.—Market 11 transaction prices.

Accordingly, only the last occurrence of each for the three states in each experimental market has been used to evaluate the possible equilibrium behavior.[6] The question about increased model accuracy upon even more replications remains open.

Conclusion 1 (Price Level). In single security markets with diverse preferences (Series A) the price predictions of the rational expectations model do not perform well relative to the performance of the price predictions of PI or MM. Neither PI nor MM is distinguished as an overall "best model."

Table III provides the supporting statistics. Three measurement criteria are presented. For Series A the mean absolute deviations of actual prices (during the last occurrence of each of the three states in each market) from the price predictions of the PI model are less than those for either of the other models. The RE model is significantly worse than PI on this criterion since its predictions have a lower mean absolute deviation than PI in only one of the eight relevant experiments and the predictions of the RE model are marginally worse than MM. If log odds are used, RE is significantly worse than both PI and MM since the data are never the most likely under RE. The third measure is the percent of price changes in the direction of the predicted price. With this measure MM is significantly worse than RE while PI is marginally better than RE. In summary, RE is worse than PI, and has mixed results with respect to MM.

Conclusion 2 (Price Level). In markets with a complete set of state contingent securities (Series B) and in markets with a single security with uniform dividends (Series C) the RE model price predictions outperform both PI and MM. Furthermore the RE model is more accurate in Series B and C than it is in Series A.

Again, Table III contains the relevant measures. In the last periods of the contingent claims markets (Series B) and in the last periods of the uniform dividends markets (Series C) the price predictions of the RE model are significantly better than both PI and MM on two criteria (mean absolute deviation of price and log odds) and marginally better on the third criterion (percent of converging price changes). The RE model is unambiguously the best.

The second part of the conclusion establishes the accuracy of the RE model in a sort of absolute sense by comparing its accuracy to the case in which it was performing badly relative to other models. The mean absolute deviations from the RE model in all markets in Series B and C, with the exception of market 5-CC, are less than all markets in Series A, and in 5-CC the mean absolute deviation is better than all Series A markets except markets 1 and 2. Log odds are always better in Series B and C than in Series A. Percent of convergent price changes gives a less clear picture.

Each model predicts a transfer of securities from some traders to others depending upon traders' dividends and the pattern of private information. The allocations predictions of the three models are in Table II. Notice that the traders

[6] Rational expectations can be seen either as a static theory of markets (e.g., in the efficient market literature in finance) or as an end-point of a dynamic path of adjustment. Our previous work favors the second interpretation. We use the second interpretation here by restricting analysis to the last period data and thus giving the RE model its "best shot."

TABLE III

COMPARISON OF ACTUAL PRICES TO PRICES PREDICTED BY THREE MODELS AT THE END OF EACH MARKET[a]

Market Experiments		Criteria								
		Mean Absolute Deviation			Log Odds under Normality			Percentage of Convergent Price Changes		
Series	Number	PI	RE	MM	PI	RE	MM	PI	RE	MM
	1	18	54	84	−55	−284	−455	82	71	18
	2	26	36	81	−85	−102	−373	69	57	62
	3	75	72	28	−146	−86	−17	50	50	50
A	4-S	54	67	38	−2482	−7482	−5757	70	63	30
	5-S	94	144	38	−4719	−4509	−344	57	57	37
	6	27	105	83	−251	−3429	−652	61	54	37
	10	76	134	32	−1175	−2715	−547	57	66	45
	11	77	114	79	−511	−853	−160	56	61	39
Summary Statistics, Series A										
Wilcoxon Signed Rank Sum Test T^+		35	27		31	31		25	33	
Level of Significance		.008(PI)	.125(MM)		.039(PI)	.039(MM)		.191(PI)	.02(RE)	
B	4-CC	82	13	220	−493	−33	−3853	35	65	35
	5-CC	159	71	389	−580	−72	−2801	25	75	25
	7	133	27	83	−1530	−59	−189	28	81	57
C	8	186	5	50	−281	−17	−1016	79	46	54
	9	136	0	83	−1	−1	−1	–	–	–
Summary Statistics, Series B and C										
Wilcoxon Signed Rank Sum Test T^+		15	15		10	10		8	9	
Level of Significance		.031(RE)	.031(RE)		.062(RE)	.062(RE)		.188(RE)	.125(RE)	

[a] The model favored by the data in each paired comparison is shown in parentheses. The level of significance is the probability of incorrectly rejecting the null hypothesis that both models predict equally well.

TABLE IV

COMPARISON OF ACTUAL ALLOCATIONS WITH THE ALLOCATIONS PREDICTED BY THREE MODELS. CRITERION: PERCENT OF PREDICTED FLOW OF SECURITIES THAT ACTUALLY OCCURRED AT THE END OF EACH MARKET[a]

Market Experiments		Models		
Series	Number	PI	RE	MM
A	1	86	42	50
	2	19	46	47
	3	28	67	39
	4-S	17	17	5
	5-S	−8	59	18
	6	12	42	−2
	10	7	21	11
	11	−7	10	−7
Summary Statistics for Series A: Wilcoxon Signed Rank Sum Text T^+		PI vs. RE: 22		RE vs. MM: 33
Level of Significance		PI vs. RE: .109(RE)		RE vs. MM: .020(RE)
B	4-CC	26	90	No Prediction
	5-CC	29	100	No Prediction
C	7	18	No Prediction	48
	8	0	No Prediction	4
	9	18	No Prediction	25
Summary Statistics for Series B and C: Wilcoxon Signed Rank Sum Test T^+		PI vs. RE: 13		RE vs. MM: 9
Level of Significance		PI vs. RE: .048(RE)		RE vs. MM: .100(RE)

[a] The model favored by the data in each paired comparison is shown in parentheses. The level of significance is the probability of incorrectly rejecting the null hypothesis that both models predict equally well.

predicted to hold the securities by one model sometimes have a nonempty intersection with those predicted to hold by another model. On occasion the predictions by one are a subset of the predictions of another. In order to avoid some of the inherent problems associated with evaluating such models we chose to use the security transfers predicted by the models as opposed to the final holdings alone. Table IV reports the ratio:

$$\frac{\sum_{j \in C_m}(x_j - \bar{x}_j)}{\sum_{j \in C_m}(x_j^m - \bar{x}_j)} \times 100,$$

where C_m is the set of traders who are predicted by model m to hold the securities in equilibrium, x_i^m is the predicted holding of trader i, and x_i are as defined in Section 2.2 with the α and t suppressed. The measures are taken for the final occurrence of each state.

Conclusion 3 (Allocation Predictions). In all series, allocations aggregated over the final occurrence of each state are more accurately predicted by the RE model than either the PI or MM. The RE model is more accurate in Series B (the RE makes no predictions in Series C) than it is in Series A.

Only in market 1 (Series A) is the prediction of the RE model substantially dominated by either of the other two and in this case it is dominated by both. In market 2 the RE model is dominated by only MM and then only by 1 percent, and in 4-S it is tied for first with PI, but in all others it is the best. Rank sum tests indicate significantly better performance for RE than MM (at $\alpha = .02$) and marginally better than PI (at $\alpha = .109$). In Series B the RE model accounts for 90 to 100 percent of the security transfers. These predictions of the RE model are so accurate that it seems safe to conclude its superiority is not due to chance. In the contingent claims markets the MM model predicts zero price for all securities so traders would be indifferent about holdings. Consequently we indicate no predictions for the model.

In Series C in which all traders have the same preference the price should equal the state dividend according to the RE model and all traders should be indifferent between holding and not holding. Of the two remaining models MM seems marginally better. If, however, a slight transaction cost exists the RE model predicts zero trades. As can be seen in Figures 8 and 9 the value is lower in the later periods.

TABLE V

COMPARISON OF ACTUAL DISTRIBUTION OF PROFITS TO DISTRIBUTION PREDICTED BY THE THREE MODELS. CRITERION: SQUARED SUM OF DEVIATION FROM THE MEAN ACROSS INVESTORS AT THE END OF EACH MARKET[a]
(in thousands)

Market Experiments		Models		
Series	Number	PI	RE	MM
	1	37	132	277
	2	140	29	125
	3	124	37	217
A	4-S	181	65	76
	5-S	3101	564	962
	6	3049	2356	2877
	10	2033	954	622
	11	1007	551	593
Summary Statistics for Series A		PI ↔ RE	RE ↔ MM	
Wilcoxon Signed Rank Sum Text T^+		34	30	
Level of Significance		.012(RE)	.055(RE)	
B	4-CC	907	6	242
	5-CC	2320	86	516
	7	387	47	340
C	8	70	0	313
	9	328	0	333
Summary Statistics for Series B and C		PI ↔ RE	RE ↔ MM	
Wilcoxon Signed Rank Sum Test T^+		15	15	
Level of Significance		.031(RE)	.031(RE)	

[a] The model favored by the data in each paired comparison is shown in parentheses. The level of significance is the probability of incorrectly rejecting the null hypothesis that both models predict equally well.

Predictions of the distributions of profits across individual traders for each model are obtained by assuming that the predicted holders of securities buy up all securities at the predicted equilibrium price. Applied to the final occurrence of each state in each experiment, the sums of the square deviations from the mean are in Table V.

Conclusion 4 (Profit Distribution). In all series the RE model is a significantly better predictor of the distribution of profits than either the PI model or the MM model.

In every market except 1, in which the PI model was the best, and 10, in which the MM model was best, the error of the RE model is less than the error of either competitor. In Series B the error is very low and in Series C the error of the RE model is near zero. Order statistics applied to the ranking of models can be used to significantly reject both PI and MM in favor of RE.

4.2. *Efficiency and Information Aggregation*

Efficiency, as the term is applied here, is at 100 percent in a given period if and only if the total earnings of all traders are the maximum possible given the particular state that occurred in that period. For example, in market 3, all securities should be held by type II traders during periods in which the state was x because during these periods, type II traders receive larger dividends than type I. In market 4-CC, during periods when, say, state y occurred, type III traders should hold the y securities. In this way the total earning over all traders is maximized. For convenience the measure is truncated at no-trade earnings. That is, efficiency is zero if dividends paid equal the payment that would occur if no trades took place. Efficiencies are presented in Table VI.

Conclusion 5. Efficiencies in the single security market are low relative to the nondiverse information experiments (Plott and Sunder, 1982) and relative to the contingent claims markets.

Parametrically these markets are similar to those studied by Plott and Sunder (1982). The major difference is that in the 1982 study information aggregation was not necessary as the state was known with certainty by some traders. After a few periods those markets operated at near 100 percent efficiency for all states. On the other hand the efficiency of Series A markets averages only 47 percent. Interestingly enough, the efficiency of single security markets is lower (markets 4-S, 5-S, 10, 11) when the experience of traders is greater. Series B markets, with a complete set of contingent claims, have substantially higher (around 90 percent) efficiency levels.

Different models sometimes predict different levels of efficiency so efficiency can be used as a measure of model accuracy. Table VII contains the mean square errors for all models in all markets. Only Series A is useful because for Series B, PI and RE have identical predictions while MM makes no predictions.

Conclusion 6. The rational expectations model is the least accurate predictor for the efficiency of Series A markets.

The rank test leads directly to a rejection of the RE model when compared to either PI or MM.

We have no measure of the degree to which information was successfully aggregated in these markets. However, information aggregation is related to efficiency even though the precise relationship is unclear. If information is perfectly aggregated, then an application of supply and demand suggests that the markets should operate at 100 percent efficiency. Those traders who have the highest dividends should acquire the security. If information fails to be aggregated, then resources should be allocated according to the prior information model in which each trader is risk neutral and acts on privately received information alone.

Conclusion 7. Information aggregation occurred in all markets in which the measurement can be made, except one. Furthermore, aggregation improved with replication of periods.

The data are in Table VIII. Of the fifty-two periods in which the measurement can be made, all were positive except four. Three of the four periods of negative aggregation occurred in market 11 in which aggregation never occurred. A test on the changes in the aggregation index indicates that twenty out of thirty-two changes in aggregation index upon repetition of a state within the same market converged towards 100 percent. The probability of chance is 0.107.

Unfortunately this aggregation measure cannot be applied to either Series B or C because those who would hold the securities on the basis of private information form a subset of those who would hold after full aggregation. The price behavior in the Series B and C markets suggests that the information in both series was almost perfectly aggregated. Otherwise, without aggregation, price would not have been so close to the rational expectations prices. Nevertheless, given our definitions and parameters, we are unable to provide an elegant demonstration of the degree of aggregation under the alternative institutional regimes.

4.3. *Initial Periods*: *Some Price Dynamics*

A study of the dynamics of these markets is obviously of highest priority. Unfortunately progress in impeded by two factors. First, the convergence behavior of even the simplest markets with no information aggregation is not well understood in spite of substantial progress (Easley and Ledyard (1986), Friedman (1984), Wilson (1982)). Secondly, the dynamic theory of information aggregation is similarly underdeveloped.

A natural empirical approach is to inquire if convergence toward equilibrium is occurring across periods similar to the convergence commonly observed in simple markets. This question is also suggested by a model developed by James Jordan (1982). He studies a model of tâtonnement adjustment in which agents first use private information to express demands during intital iterations but use the information implicit in those iterations in formulating expressed demands in later iterations. In his model, prices first converge to PI equilibria as temporary equilibria which provide sufficient information to permit the ultimate convergence to the REE.

TABLE VI
EFFICIENCY[a]

Market Experiment Series	Market Experiment Number	Period 1	2	3	4	5	6	7	8	9	10	11
A	1	*y* 100	*x* −100	*z* 100	*z* 100	*x* 0	*z* 100	*z* 100	*y* 75	*y* 100	*z* 75	*z* 100
	2	*y* 50	*x* −87.5	*y* 100	*x* −75	*z* 100	*y* 100	*y* 100	*x* 50	*x* 12.5	*x* 12.5	*y* 87.5
	3	*x* −87.5	*z* 100	*x* −62.5	*x* 37.5	*z* 100	*z* 100	*y* 12.5	*y* 50	*z* 100	*z* 100	*x* 25
	4-S										*z* 26.5	*x* 26.7
	5-S										*x* 17	*z* 48.5
	6	*x* 71	*x* −27	*z* 31	*y* 25	*z* 54	*z* 65	*y* 78	*x* 64	*y* 71	*x* −48	*x* −55
	10	*x* −14	*x* −25	*z* 21	*y* 43	*z* −2	*z* −25	*y* 48	*x* 6	*y* −25	*x* −9	*x* 42
	11	*z* 37.5	*x* −3	*x* 46	*y* −66	*x* −17	*z* 74	*y* −52	*x* −2	*z* 100	*y* −59	*x* −9
B	4-CC	*z* 74.3	*z* 96.3	*z* 100	*x* 88.8	*x* 100	*y* 100	*x* 86.2	*y* 88.75	*z* 100		
	5-CC	*x* 26.3	*z* 81.6	*y* 100	*y* 76.2	*x* 100	*x* 100	*y* 100	*x* 100	*z* 100		
C	7, 8, 9	Efficiency of uniform dividend markets is undefined.										

[a] $\text{Efficiency} = \dfrac{\text{Actual Dividends Paid} - \text{Zero-Trade Dividends}}{\text{RE Dividends} - \text{Zero-Trade Dividends}}$.

In our markets the PI equilibria contain sufficient information to reveal the state to half of the agents of each type. Once half of each type is informed, the REE is the only supportable equilibrium. A natural question then is whether prices evolve along a Jordan path from the PI to the REE. Clearly the Jordan model suggests that the evolution takes place within a period. However, empirical adjustments to equilibria are observed occurring across periods with bid/asks, etc., within periods providing additional information not captured by standard models.[7] The question about dynamics is formalized by Conjecture 1.

Conjecture 1. The markets adjust across periods (along a Jordan path) with the first occurrences of a state near the PI equilibrium and the last occurrence of a state near the REE.

The measures of model accuracy that were made for the final periods and are reported in Table III were also made for the initial periods. At the beginning

[7] Table of supporting data available from the authors.

Period													
12	13	14	15	16	17	18	19	20	21	22	23	Mean	Median
x 25	*z* 100	*z* 100	*x* −50	*x* −75	*z* 100	*y* 87.5	*y* 100	*z* 100				69	100.0
z 100	*z* 100	*y* 100	*y* 100	*y* 100	*x* 50	*y* 87.5	*y* 87.5	*z* 100	*y* 100	*x* 75	*z* −37.5	73	93.7
z 100	*z* 100	*x* 37.5	*x* 62.5	*z* 100	*y* 62.5	*y* 37.5	*z* 50	*z* 100				78	62.5
y −3.75	*z* 55.9											33	26.6
z 33.5	*y* 68.75	*z* 46.7	*x* 79.1	*y* 94.4								49	48.5
y 75	*z* 71	*y* 97	*z* 65									46	65.0
y 65	*z* 29	*y* −54	*z* −8	*y* 71	*x* 4							8	6.0
z 100	*x* −47.5											18	−3.0
												93	96.3
												87	100.0

periods in series A the RE model is the worst of the three models and the PI model is marginally the best. However, if the difference between the measured error of a model in the first period and the measured error of the model in the last period is considered, the RE model clearly shows the greatest improvement. In this weak sense we find support for the conjecture. Of course, the fact that an RE was not achieved at the end of the series is an important fact that suggests that the conjecture might not capture the essential elements of the dynamics.

The pooled data from Series B and C only yield some weak support for the conjecture. During the first periods the performance of the PI model is closer to the RE model than it was at the end periods, and in Series C the performance of the MM model was closer to the RE at the beginning than it was at the end. The fact that the RE model receives competition from these alternate models during the early stages but not at the end generates enough support for the spirit of the conjecture to justify further study in future experiments.

TABLE VII

ABSOLUTE DIFFERENCE BETWEEN THE EFFICIENCY PREDICTED BY EACH MODEL AND THE OBSERVED EFFICIENCY AT THE END OF EACH MARKET[a]

Market Experiments		Models		
Series	Number	PI	RE	MM
	1	9	58	58
	2	46	21	21
	3	25	42	42
A	4-S	74	74	22
	5-S	14	27	24
	6	19	64	10
	10	33	78	4
	11	61	106	32
Summary Statistics for Series A		↑ PI vs. RE ↑		↑ RE vs. MM ↑
Wilcoxon Signed Rank Sum Test T^+		25		15
Level of Significance		.039(PI)		.031(MM)
B	4-CC	8	8	—
	5-CC	0	0	—
	7	Efficiency of uniform dividend markets is undefined.		
C	8			

[a] The model favored by the data in each paired comparison is shown in parentheses. The level of significance is the probability of incorrectly rejecting the null hypothesis that both models predict equally well.

4.4. *Contingent Claims Price Dynamics and the Role of Bids*

In contingent claims markets with the diverse information structure traders who know, say, that state x has not occurred, know not only that the value of x-contingent security is zero to them, but they also know that its value is zero to all those who acquire this information. Making an offer to sell a security contingent upon the state that a trader knows has not occurred is a no-loss proposition if the trader expects the price to move toward zero. Buying any security on initial information involves some risk. It is reasonable to hypothesize that the first market action will be an offer (to sell) by a trader who knows the security is worth nothing.

Hypothesis 1. The opening action in a market period is an offer to sell a contingent claim corresponding to one of the two states that has not occurred and is made by a trader who has prior information that the corresponding state has not occurred.

Under the null hypothesis the opening action could occur in any of the three contingent claims markets, could be a bid or an offer, and could be made by any trader with the exception that the traders informed "not x" will not bid for x-contingent security and similarly for the other states. Thus, there is a two-out-of-ten or 20 percent probability that the events in Hypothesis 1 will occur by random chance. The event occurred in 12 of the 18 opportunities. The null hypothesis is rejected in favor of Hypothesis 1 at $\alpha = .0000$.

If the substance of Hypothesis 1 is true, then opening offers made in a contingent claims market corresponding to a state that has not occurred can, by a

TABLE VIII

AGGREGATION INDEX[a]

Market Experiment Series	Number	Period 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Median	Convergent Changes Within State
A	1					x 69	z —	z —	y 93	y 100	z —	z —	x 77	z —	z —	x 54	x 46	z —	y 97	y 100	z —				87	3 out of 5
	2				x 4	z —	y 100	y 100	x 73	x 52	x 52	y 90	z —	z —	y 100	y 100	y 100	x 73	y 90	y 90	z —	y 100	x 86	z —	90	5 out of 8
	3				x 81	z —	z —	y 76	y 86	z —	z —	x 77	z —	z —	x 81	x 88	z —	y 90	y 83	z —	z —				82	4 out of 6
	4-S										z —	x 56	y −15	z —											20	—
	5-S										x 30	z —	z —	y 65	z —	x 87	y 94								76	2 out of 2
	6	x —	x —	z —	y 44	z —	z —	y 83	x —	y 78	x —	x —	y 81	z —	y 98	z —									81	3 out of 4
	10	x 15	x 7	z —	y —	z —	z —	y —	x 30	y —	x 19	x 57	y —	z —	y —	z —	y —	x 29	y						24	2 out of 5
	11	z —	x —	x —	y −24	x —	z —	y −13	x —	z —	y −19	x —	z —	x —											−19	1 out of 2
B	4A 4B	Aggregation Index is undefined for complete markets.																								20 out of 32 $\alpha = 0.107$
C	7 8 9	Aggregation Index is undefined for uniform dividend markets.																								

[a] $\text{Aggregation Index} = \dfrac{\text{Actual Dividends Paid} - \text{Dividends under PI Allocation}}{\text{Dividends under RE Allocation} - \text{Dividends under PI Allocation}}$.

Note that the Aggregation Index is undefined whenever RE and PI allocations are identical. This is always the case for the uniform dividends and contingent claims markets and is true for at least one of the three states in the other markets.

process of elimination, inform half the traders which state has occurred. Such newly informed traders will wish to buy the corresponding contingent security. Thus, the opening action in the contingent claims market corresponding to the realized state should be a bid (to buy).

Hypothesis 2: The first action in the "state" market is a bid (to buy).

Because the first action can be either a bid or an offer, probability that the first action in this market will be a bid by random chance is 50 percent. Again, the data rejected the null in favor of Hypothesis 2 at $\alpha = .001$.

Assume that state x has occurred and the first action is an offer to sell the y-contingent security. If this offer is interpreted by traders whose private information is "not z" to mean that the state is not y either, they would know that the state is x and will therefore be inclined to buy the x-contingent security. This reasoning leads to the third hypothesis about the behavior of bids and offers:

Hypothesis 3: When the first action in the "state" market is preceded by action in only one of the two "not" markets, this first action (a bid by Hypothesis 2) will be by a trader whose private information is that the state corresponding to the second of the two "not" markets has not occurred.

Because this action could be taken by traders with either of the two pieces of information and the number of traders with each piece of information is equal, the condition in Hypothesis 3 will be fulfilled by random chance 50 percent of the time. The null cannot be rejected by the data in favor of Hypothesis 3 ($\alpha = .23$).

4.5. *Fair Game Tests*

In the single security markets of Series A, the trading occurred at prices far from the RE equilibrium prices. However, such trading did not offer traders opportunity to make profits by using mechanical filter trading rules.[8] The behavior of these markets is similar to the New York Stock Exchange in that it is difficult to discover mechanical trading rules that statistically beat the naive buy-and-hold strategy. In addition, in the single security markets of series A, a rule based on perfect knowledge of the RE equilibrium price in these markets does not beat the naive strategy. Markets in Series A are fair games but these markets are not near RE equilibrium.

[8] *Buy-and-Hold*: buy one certificate at opening transaction price of each period; liquidate at closing transaction price of each period.

Trend Filter: observe transaction price trend from opening to the current price; if positive, buy if necessary to hold one certificate; if negative, sell if necessary to maintain a short position of one certificate. Liquidate at closing transaction price.

y-Franc Filter: if transaction price goes up by y or more francs, buy if necessary to hold one certificate until the price goes down by y or more francs at which time sell, if necessary to maintain a short position of one certificate until the price goes up again by y or more francs. Liquidate at closing price.

The filter rules were tested for values of y equal to 1, 5, and 25 francs respectively. None of the four filters (these three and the trend filter) yielded higher profits than the buy-and-hold rule for a majority of markets.

Markets in Series B and C converge to near the rational expectations prices. Buy and hold beats the filter rules in Series B and C but it is not as good as knowledge of the RE equilibrium price. We can make the following conclusion:

Conclusion 8. The fair game property of security markets is a necessary but not a sufficient condition for the existence of RE prices.

4.6. *Other Variables*

The first few markets of Series A yielded a negative result on the ability of markets to aggregate information. The changes in variables in later markets represent probes of the possibility that some aspects of the structure of the markets or the procedures might be responsible for the negative results. The variables we perturbed were: (1) prior experience of subjects with RE phenomenon, (2) number of traders, and (3) volume of trading per person. Analysis of data led us to the following ex post conjectures about what additional experiments will show.

Conjecture 2. Prior experience of traders with the RE phenomenon is not a sufficient condition for the single security market to arrive at the RE equilibrium.

Conjecture 3. The increase in the number of trader types does not improve the RE formation process.

Conjecture 4. Volume increases do not facilitate RE price formation.

Collinearity of the three treatment variables would have to be handled more carefully, especially if the effect of experience, number of investor types, and volume on efficiency of these markets were positive. Given the lack of detectable effect of all of them on efficiency, our conjectures merely suggest that these treatment variables are unlikely to be of independent significance.

5. WHY DO THE CONTINGENT CLAIMS MARKETS AGGREGATE INFORMATION BETTER?

The title of this section states the overriding question that has emerged from the research. Three different types of explanations have occurred to us.

The first potential explanation is that the single security markets are slow to adjust and that, given more time, these markets too will behave as predicted by the RE model. Indeed data exist that suggest the single security markets might ultimately attain a rational expectations equilibrium. In markets 3 the price in state z seems to be separating in spite of the remarkable counter-example provided by period 19 (see Figure 3). In markets 6 and 1 the price in state y appears to be separating near the end of these experiments. In market 11 the x state appears to be separated. But of course these signs that a willing eye can extract from the data must be considered with the seventeen periods of market 10 where there seem to be no signs of separation.

A second explanation rests on a comparison of the "size" of the message space. The message space of the contingent claims markets is larger than the message space of the single security markets in the sense that three sets of bids/offers/prices are available to the traders in the former. The larger message space, according to this view, allows traders to establish a one-to-one message-state correspondence. The problem with the idea is Series C, for which the size of the message space was identical to that of Series A. Series C performed substantially in accord with the RE models whereas Series A did not. If message space size alone was the problem with Series A, it should have surfaced also with Series C.

The third explanation rests with the type of information implicit in the structure of the contingent claims used in these markets. A security paid a positive dividend only if a state occurred and paid zero otherwise; so strategic considerations aside, the purchase or sale of a security could be directly interpreted as a belief about the occurrence of a particular state. Thus traders in the contingent claims markets had a "natural" knowledge about the preferences of other traders that was not present in the single security markets.

The same type of information probably existed in the uniform dividend series C. If traders began with a presumption that other preferences are similar to their own, their initial assessment of others is correct in these markets. The knowledge bases of actions can then be inferred.

This idea, that one key to market performance is a knowledge of others' preferences, is further supported by the analysis of bids discussed above. Traders seemed to use their knowledge of others' preferences in determining their own actions. The offer to sell the x security, for example, at the opening of a market seemed to be interpreted as a signal that the seller knew the state was not x. If, for example, the contingent claims were replaced by a "spanning" set of compound securities that were not "Arrow-Debreu" securities, then such an inference could not necessarily be made. On our belief about the behavior of these markets, information would not become perfectly aggregated with such a "spanning" set of securities.

These three ideas exhaust our current thinking on the subject. We are of the opinion that the key to understanding these markets rests in part with traders' beliefs of other traders' preferences. Some sort of knowledge of others' preferences appears to be a necessary condition for aggregation of diverse information. However, our own understanding of the issue is so incomplete that we cannot even provide a precise conjecture.

6. CONCLUSIONS

The results have both positive and negative elements. On the positive side, experiments in the contingent claims markets (Series B) and in the uniform dividends markets (Series C) demonstrate that markets can aggregate diverse information in a manner consistent with rational expectations models. The markets in Series B and C are perhaps the very first demonstration that markets can simultaneously perform the independent functions of information aggregation, information dissemination, and conflict resolution.

The negative results are of two forms. First as demonstrated by the markets in Series A, not all markets can be depended upon to behave in accord with the rational expectations model. The second negative result is that fair game tests used to check for efficient market behavior are not reliable indicators about when a market is operating efficiently. The markets in Series A were "fair games." That is, filter rules for potentially profitable trades worked no better than "buy and hold," so the tests indicated that the markets were efficient. However, these markets were not operating efficiently in a rational expectations sense. Markets that are "fair games" are not necessarily efficient.

A comparison of the single security markets in Series A with the contingent claims markets of Series B that had substantially the same economic parameters demonstrates the importance of market institutions and instruments. The introduction of a complete set of Arrow-Debreu securities transformed a market that was operating inefficiently into a market that rapidly achieved a rational expectations equilibrium.

Exactly why the contingent claims instruments produced such a dramatic effect is an open question. Series C demonstrates that a single security will perform according to the RE model if all traders have similar preferences. An analysis of the bids in the contingent claims markets suggests that traders used implicit information about others' preferences. These two series together suggest that some knowledge about other traders' preferences may be a necessary condition for the operation of rational expectations principles in markets.

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APPENDIX

Markets were conducted in four steps: (1) training with the mechanism used to draw states of nature; (2) training with the mechanism to distribute diverse information; (3) explanation of procedures and rules of the market; and (4) conduct of markets for several periods.

Step 1 of the procedure has been described in Plott and Sunder (1982, p. 693). The only change was from two to three states of the world.

In order to train subjects with the mechanism to distribute diverse information in the second step of the experiment, the experimenter drew a ball from the bingo cage, recorded the state drawn, consulted the master clue sheet, and called out the row and column numbers of the cell on the subjects' clue sheet that contained each subject's clue.

In advance of the experiment, a complete list of all possible ways of dividing a group of an even number of investors into two equal groups (for $n = 12$, this number is $(1/2)^n C_{n/2} = 462$) was prepared. These combinations were randomly ordered. One combination beginning from the top of this list was used each period to distribute information among the investors and none were repeated because the number of periods in any one experiment never exceeded 23. A coin toss determined the distribution of information about the unrealized states between the two groups. A separate clue sheet was designed for each investor along with a master clue sheet for the experimenter.

CLUE SHEET

	Columns					
	1	2	3	4	5	6
1	not y	not x	not z	not y	not x	not z
2	not x	not y	not x	not z	not z	not y

After determining the realized state, the experimenter called out the row and column number of the clue sheet which contained the private information of each investor. This method provided quick, confidential, and open means of communicating diverse information to all market participants.

Training with this clue sheet was continued for eight to ten draws until all subjects were familiar with the mechanism. A show of hands after each draw of the training session revealed that the state was known to the group and that the information was randomly distributed.

Steps 3 and 4 also were essentially similar to those described as Steps 2 and 3 respectively in Plott and Sunder (1982) with appropriate modifications to the instructions in order to incorporate diverse information and contingent claims when necessary.

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