

Experimental Asset Markets: A Survey

Shyam Sunder

Capital or asset markets are distinguished from other markets by the informational role of prices and by the duality of the traders' role: each trader may buy and sell asset(s) in exchange for money or some other numeraire commodity.* Although prices in other markets may inform the participants in the sense of making them aware of their opportunity sets, prices in capital markets inform the traders substantively as determinants of their endogenously formed demand and supply. Asymmetry of information among the traders is an essential ingredient for prices to have an informational role, and I use this as the defining characteristic of capital or asset markets research covered in this review.

Information dissemination and aggregation *can* occur, but does not occur under all conditions. When it does occur, it is rarely instantaneous or perfect. Although such lags and imperfections often annoy the theorists, they can be surprisingly small when we consider the complexity of task facing the traders, and the documented limitations of human information processing (see Camerer, chapter 8 in this volume). These lags and imperfections also provide a more convincing basis for noisy rational expectations models than the exogenous noises (e.g., supply noise) artificially introduced in the theoretical models to construct such equilibria. While theoretical models focus on transaction price as the vehicle for information transmission in markets, experiments reveal the presence and importance of other parallel channels of communication such as bids, offers, identity of traders and timing, and so on. Experiments have also made it possible to develop more refined theories of the precise role of various vehicles (such as arbitrage and logical inference) in information transmission in markets.

The first asset market experiments were not conducted until the early 1980s. They have, however, already yielded a number of key results. The Hayekian hypothesis about the importance of the informational role of prices in markets has received consistent support. Dissemination of information, from informed to the uninformed, and aggregation of individual traders' diverse bits of information through the market process alone have been shown to be concrete, verifiable phenomena, bringing abstract theory into empirical domain.

As the experimental camera focused on information processing in asset mar-

warts. This finer grain portrait of asset markets confirms the rough outline of the extant theory but is considerably more complex, providing guidance and challenges for further theoretical investigation of the role of information in markets.

Perhaps the most important finding to emerge from a decade of experimentation is that statistical efficiency of a market *does not* imply that it is allocatively or informationally efficient. In econometric studies of field data from asset markets, absence of profitable filter rules or other arbitrage opportunities is assumed to imply informational efficiency of the market. Experiments have shown that markets we know to be informationally inefficient can be quite efficient by these statistical criteria.

The first section of this chapter reviews evidence on informational efficiency of markets. The second section concerns the behavior of markets for derivative claims (e.g., futures, options, and contingent claims) and their effect on the market for the primary asset. The third section focuses on bubbles and false equilibria—a topic for which laboratory modeling is especially useful because it is difficult to address with field data. The fourth section concerns learning in competitive markets. The fifth section compares econometric analyses of data from the field and the data gathered in the laboratory, and the sixth section addresses several investment and public policy issues to which these results are pertinent. The seventh section discusses laboratory modeling of asset markets, followed by a summary and some concluding remarks in the eighth section.

I. Informational Efficiency of Markets

Informational efficiency of capital markets is a central theme in modern finance. Empirical observations about the brownian motion-like statistical properties of prices were made by Bachelier (1900), Kendall (1953), Roberts (1959), Alexander (1961), Cootner (1964), Fama (1965), and others. Samuelson (1965) applied the no-arbitrage condition to prove that properly anticipated prices must behave like a random walk. The logic of arbitrage suggests that when the informed traders move to take advantage of their information, the price will move by an amount and in the direction that eliminates this advantage. Neutral observers of such a market would observe an association between the unanticipated information obtained by the informed traders and the consequent movement of market prices.

Knowledge of this association would enable even the uninformed traders to infer from an observed price increase that some traders in the market have favorable information about the asset. Lucas (1972) used this inverse inference from observed price to the state of nature in rational expectations environments (see Muth 1961) where the price is the consequence of optimal actions of traders. Information is not wasted; in equilibrium, price summarizes and reveals (i.e., is a sufficient statistic for) all the relevant information in possession of all the traders (see Hayek 1945; Grossman 1976). The idea that prices in stock markets promptly and unbiasedly (though not precisely) adjust to reflect information came to be labeled as the efficient market theory (see Fama 1970).

A. Field Data from Financial Markets

Price data gathered from stock and commodity exchanges provided the initial impetus for development of the random walk theory and made it possible for researchers to test this statistical theory. Several difficult problems arose in testing the efficient market theory with field data. Strictly speaking, empirical testing of the theory requires that the observed prices be compared against the correct theoretical prices after taking into account the prevalent information conditions that produce the observed prices. It is difficult for a researcher to know these private information conditions in markets in which thousands of traders participate. Even if these private information conditions were somehow known, how could one determine the correct theoretical stock price of, say, General Motors on June 1, 1993, to serve as a benchmark of comparison to evaluate the efficiency of prices observed in the market?

Empirical testing of market efficiency therefore centered on *changes* in stock prices associated with private or public events that become observable to the researcher. If it is known a priori that an event represents “good news” for the stockholders of a firm and the price of its stock is found to increase upon its occurrence, one could conclude that the market price adjusts to reflect the information represented by that event. In spite of supportive results from a large number of such studies (and many ambiguous or contradictory results; see Fama 1990, for a recent survey) this incremental approach could not erase the suspicion that even if the market is efficient in small changes, it may yet be grossly mispriced in the large. Further, efficiency of price *changes* does not rule out the inefficiency of price levels.

The general principle that it is possible for market prices to reflect information so the uninformed traders are able to act as if they are informed cannot be conclusively tested with the field data. There are two major obstacles to such field testing: prices change due to information arrival as well as other events, and identification of the informed traders in the field is no mean task. Rational expectations equilibrium models, on the other hand, have merely shown the feasibility of the principle. Since the analytical models used to characterize the equilibrium are concerned with the end point of the process of equilibration, and not with the process itself, existence of the equilibrium provides no guarantee that it would be reached. Further, the analytical models, typically stripped of institutional details, do not tell us much about the market structure and environment in which this general principle may hold.

B. Designing Experimental Asset Markets

Experimental studies of informational efficiency of asset markets can be divided into three groups. The first group of studies focuses on dissemination of information from a group of identically informed insiders to a group of identically uninformed traders. The second set of studies is concerned with the more difficult task of market aggregation of diverse information in possession of individual traders

and the dissemination of this information across all traders. The third group of studies endogenizes the production of information and focus on simultaneous equilibrium in both the asset and the information markets. Details of designing asset markets can be found in Sunder (1991) and Friedman and Sunder (1994).

Endogenous modification of demand and supply based on within-market experience and learning is a key feature of asset market studies. The stage for the experimental examination of this phenomenon was set by three prior studies of learning *across* markets. Miller, Plott, and Smith (1977) and Plott and Uhl (1981) examined formation of derived demand by introducing arbitrage opportunities across markets. Forsythe, Palfrey, and Plott (1982) allowed each participant to be a buyer as well as a seller in the same market, thus creating opportunities for derived demand as well as supply.

The upper panel of Figure 6.1 reproduces figure 2 of Forsythe, Palfrey, and Plott's (1982) paper that reports the result of their first market labeled "Experiment 1." The market consisted of eight consecutive trials, labeled "Years" 1 through 8, each consisting of two periods, A and B. Certificates traded in these markets had no uncertainty of dividends and, therefore, no chance for information asymmetry across traders. This study focused on determining whether, over replication of trials, learning of equilibrium in period 2 market seeps back into period 1 market and alters the behavior of that market from naive to perfect foresight equilibrium.

Each trader in these markets was given an endowment of two identical assets and an interest-free loan of cash (to serve as working capital) at the beginning of each trial. Each asset paid a dividend to its holder at the end of period A as well as period B. Dividends were private and different across three classes of traders, creating gains from trade. For example in Market 1, period A and B dividends were 300 and 50 for type I traders, 50 and 300 for type II traders, and 150 and 250 for type III traders. The horizontal lines for period B indicate the unique equilibrium price of 300. For period A, the broken horizontal line indicates the naive equilibrium price of 400. However, the perfect foresight equilibrium price for period A, based on the knowledge of the market value of assets in period B, is higher by 200; the solid horizontal line indicates this perfect foresight equilibrium price of 600. Each dot represents an observed transaction for one asset in chronological order. The average of transaction prices for each period is shown at the bottom.

This experiment revealed that the initial behavior of the market in period A is well described by the naive equilibrium (400 in the top panel of Figure 6.1). However, over repeated trials under a stationary environment, convergence toward the perfect foresight equilibrium (600 in top panel of Figure 6.1) takes place, as more and more of the traders learn to exploit the market opportunities available to them in period B, and to appreciate the implications of this opportunity for their strategy in period A. Frank (1988) repeated the Forsythe, Palfrey, and Plott (1982) experiment on economics undergraduates using computer (instead of oral) double auction by adding once-for-all shifts as well as trended shifts in economic

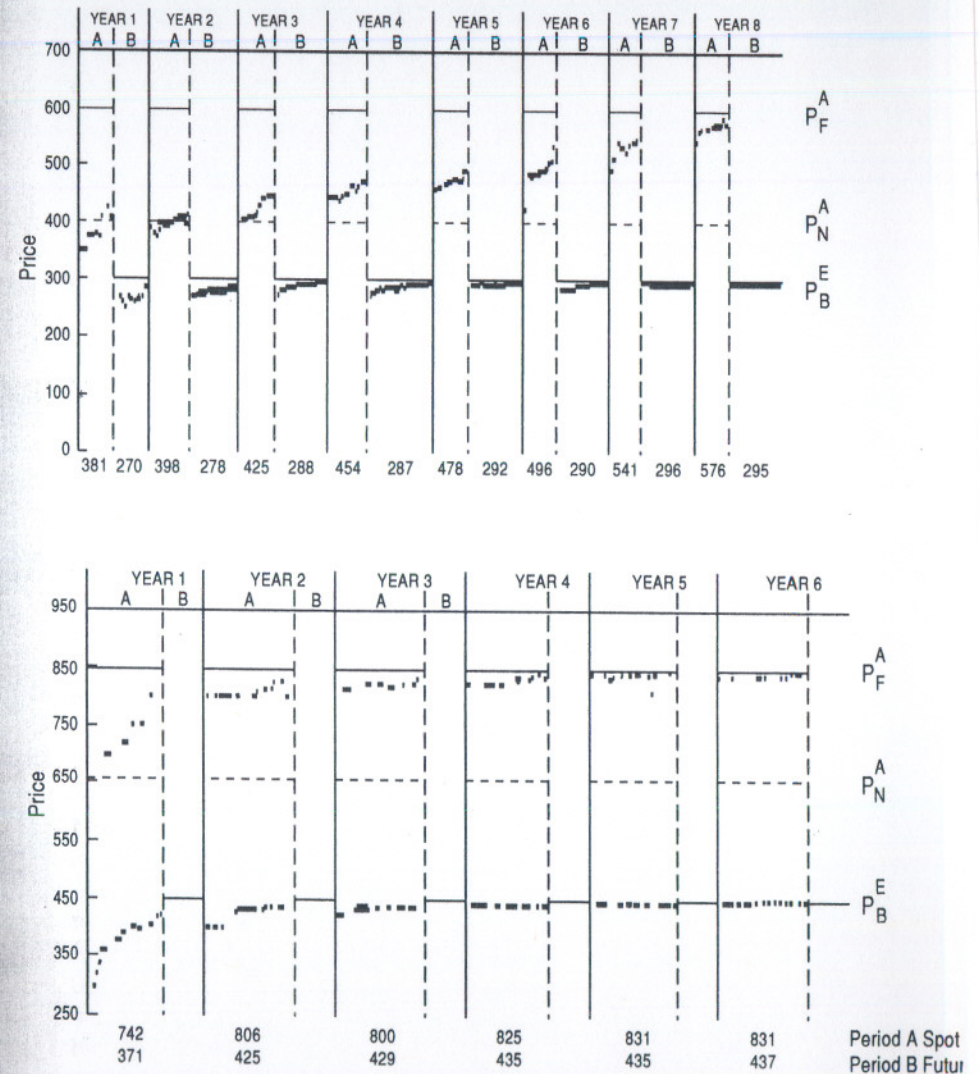


Figure 6.1. Transmission of information across markets. Top: sequence of contract and average prices for Experiment 1. Bottom: sequence for Experiment 5. Source: Forsythe, Palfrey, and Plott 1982, figures 2 and 6.

fundamentals. The perfect foresight model "does a remarkably good job of predicting where these markets will go," even though the explanatory power is diminished somewhat in shifting environments.

Dissemination of information from period B to period A markets created derived demand and supply in period A and set the stage for experimental examination of endogenous creation of demand and supply due to information aggregation and dissemination *within* markets.

C. Dissemination of Information

Plott and Sunder (1982) designed a market in which traders could trade units of a single-period asset, one unit at a time, in a double auction. The market had three types of traders, and for each type of trader the dividend could take one of two possible values, depending on the exogenously realized state of the world with known probabilities (see Table 6.1). In effect, they simplified Forsythe, Palfrey, and Plott's (1982) assets from two to one period and added uncertainty to dividends. Information about the realized state of the world was given to six traders (two of each dividend type), while the other six traders (two of each type) remained uninformed. The fact that half of the traders in the market had the information was common knowledge, but the identity of the informed traders remained private. Dividends and probabilities were chosen so the price and allocation predictions of the rational expectations and prior information competitive equilibria were distinct in one of the two states of the world.

For example when state Y was realized, informed traders of type I, II, and III knew that their dividend from holding the asset in that period would be 100, 150, and 175, respectively. Traders who do not learn the state might attribute a value of 220, 210, or 155 to the asset, depending on whether they are of type I, II, or III (see the last column of Table 6.1), if we assume that they are risk neutral. Supply of assets is limited to the aggregate initial endowment of 24 (2 for each of the twelve traders). The large working capital loan to traders means that each type of trader has a large flat demand for the asset at a price equal to its value to him or her. The market supply and demand configuration is shown in Figure 6.2. The competitive equilibrium price is the maximum of the six individual values listed above, which is 220. Since the uninformed traders of type I value the asset the most, they are the predicted holders of the asset under the prior information equilibrium.

The rational expectations model, on the other hand, suggests that this prior information equilibrium will not be sustained. The uninformed traders of type I, who pay a price as high as 220 with the expectation of receiving a dividend of 400 with 40 percent chance, soon discover that they never receive the high dividend. Whenever state X is realized, informed traders of type I pay more than 220 and shut the uninformed traders of type I out of the market. On the other hand, whenever an uninformed trader of type I is able to buy the assets at or below 220, the dividend turns out to be only 100 in state Y. If the uninformed traders refuse to be fooled all the time and learn from the market behavior whether the state is X or Y, the price under state Y would be the maximum of 100, 150, and 175, which is 175. Thus in rational expectations equilibrium, price in state Y is 175 and the assets will be held by type III traders. Furthermore, since those who are initially uninformed learn the state from observing the market behavior, type III holders will include such traders along with those who are initially informed. This market was designed so the prior information and rational expectations equilibrium price and allocation predictions under state Y were distinct. The empirical question is

Table 6.1. Parameters and Equilibria for a Simple Asset Market

	Dividends in States of the World		Expected Dividend
	State X Probability = 0.4	State Y Probability = 0.6	
<i>Trader type</i>			
I	400	100	220
II	300	150	210
III	125	175	155
<i>RE equilibrium</i>			
Price	400	175	
Asset holders	Trader type I	Trader type III	
<i>PI equilibrium</i>			
Price	400	220	
Asset holders	Trader type I, informed	Trader type I, uninformed	

Source: Extracted from Plott and Sunder (1982, tables 2 and 3).

whether these (or some other) equilibria will organize the data. Existence of the theoretical equilibria provide no assurance that such equilibria will be attained under any specific trading mechanisms.

Plott and Sunder (1982) found that, given experience with replications, the behavior of these markets converges to close proximity of the predictions of the rational expectations theory that assumes that traders are able to infer the state of the world from the observed market phenomena.

Figure 6.3 plots the individual transaction prices of the twelve periods of this market in chronological order. The rational expectations price (400 for state X, 175 for state Y) is shown in solid horizontal line, while the prior information price for state Y is shown in a broken horizontal line (prior information price for state X is 400). The first two periods of the session were procedural warm ups when no information was distributed to the traders. In X-state periods (4, 7, and 9) price converged close to 400, the common prediction of both models. In Y-state periods (3, 5, 6, 8, and 10) prices converged close to the rational expectations prediction of 175 instead of the prior information prediction of 220. End-of-period asset holdings shown at the top of Figure 6.3 show that Y-state asset allocations were more consistent with the prior information predictions in early periods; however, as traders gained experience, asset allocations became more consistent with the predictions of the rational expectations model. In period 3, eighteen of twenty-four units of assets were allocated to type I traders as predicted by the prior

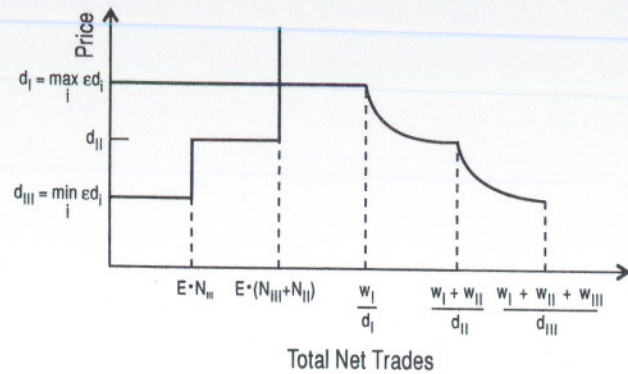


Figure 6.2. Market supply and demand functions. W_i = initial working capital of investors of type i ; N_i = number of agents in the market of dividend type i ; E = initial endowment of securities per agent; d_i = dividend of agents of dividend type i ; ϵ = mathematical expectation with respect to the prior probability distribution of the states of nature. Source: Plott and Sunder 1982, figure 1.

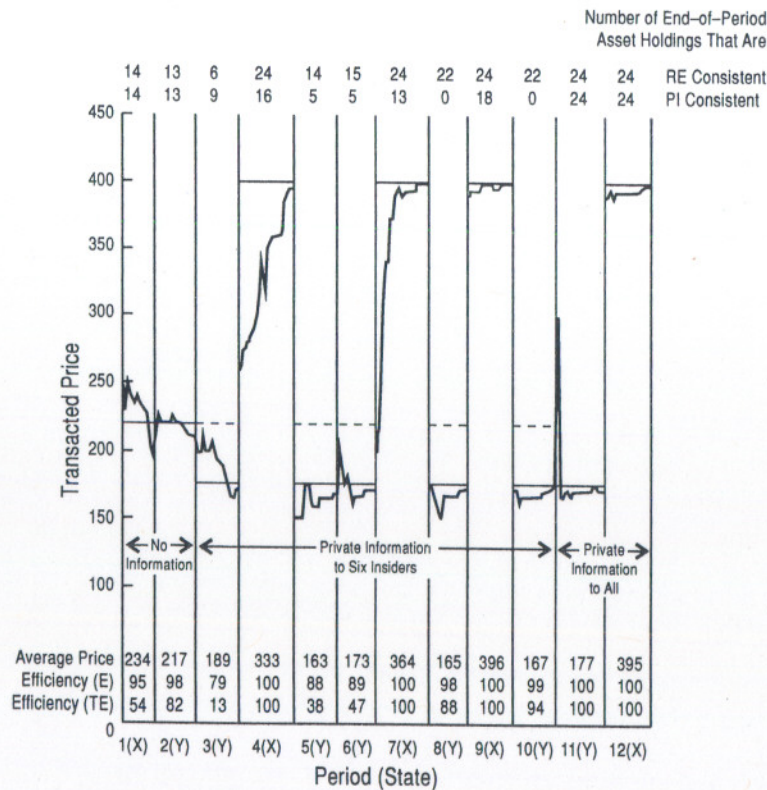


Figure 6.3. Dissemination of information in an asset market. Source: Plott and Sunder 1982, figure 4.

Table 6.2. Direction of Asset Transfers When the Rational Expectations and Prior Information Models Made Contradictory Predictions

	Period and State							
	3	4	5	6	7	8	9	10
	Y	X	Y	Y	X	Y	X	Y
Certificates sold per uninformed agent when RE model predicts sales and PI model predicts purchases (agent types I and II)	-2.5		-0.5	-0.25		2		2
Certificates bought per informed agent when RE model predicts purchases and PI model predicts sales (agent type III)	-1.5		0.5	1.5		5		4.5

Source: Extracted from table 15 of the working version of Plott and Sunder (1982). Note: Positive numbers are consistent with RE predictions.

information model; only six were allocated to type III traders according to the prediction of the RE model. By period 10, only two assets were allocated to type I while twenty-two were in the hands of type III traders.

Finally, it is the behavior of the uninformed traders of type I and type III under state Y that is critical in distinguishing between the rational expectations and prior information models. The rational expectations model predicts that uninformed traders of types I and II will learn from the market and thus refuse to buy at 175 assets that have a prior information expected value of 220 or 210 for them. It also predicts that the uninformed traders of type III will learn from the market and be willing to pay prices as high as 175 for assets that have a prior information expected value of only 155 in Y periods. Row 1 of Table 6.2 shows that the uninformed agent of types I and II started out buying assets in period 3, gradually decreased their buying in periods 5 and 6 and then sold all their assets (2 per trader) in periods 8 and 9. Row 2 shows that the uninformed agents of type III started out selling an average of 1.5 assets per trader in period 3 and started buying beginning period 5. In periods 8 and 10, these initially uninformed traders became so confident of the information they had learned from observing the market that they bought, on average, more assets per capita than the informed traders of type III did.

Experience with replications is necessary, and instantaneous convergence to equilibrium is not observed. Of course, Smith (1962) discovered that convergence to equilibrium needs replication even in the simpler environments of his early experiments (spot markets for non-durables without uncertainty in private costs or values). It would have been surprising if more experience were not needed for convergence to rational expectations equilibrium in environments where subjects face state uncertainty and have so much more learning to do. Once the traders

have been exposed to the range of exchange possibilities available to them, the market can disseminate information about the realized state of the world for a particular period in a surprisingly economical fashion—by the first few bids and asks.

The approximate nature of convergence is the second important qualification to these results. Again, even in the simpler environments of Smith's (1962) experiments, convergence to equilibrium was noisy and approximate. Increased complexity is accompanied by increased noise.

However, establishing the empirical existence of such a market does not establish that all, or even most, market structures and environments converge to rational expectations equilibrium upon replication. A number of studies have explored the boundaries of the market structures and environments in which such results hold. In their fifth market, Plott and Sunder (1982) added a third state of nature to their two-state design discussed above, without noticeably delaying or weakening the convergence of prices, allocations, and efficiency to the rational expectation predictions. Banks' (1985) experiments also used three-state assets and yielded comparable results.

Only a few experiments with assets with four or more discrete states, or a continuum of states, have been attempted in the laboratory so far. As the number of states is increased, it takes more periods of trading to experience and learn the market consequences of each state. Moreover, as the number of states increase, the average distance between the equilibrium prices of any pair of states decreases. For any given level of price noise, traders are less certain of the state-price correspondence they may conjecture on the basis of their observations. Increase in the number of states to be learned and the crowding of equilibrium prices should delay and dilute the convergence to rational expectations equilibria. In an alternative treatment, Plott and Sunder (1982) introduced eleven subjective states of nature by distributing to the insiders an imperfect signal about which of the two possible states of nature prevailed.¹ The eleven periods of replication in this experiment proved to be insufficient for the traders to disentangle the equilibria for each of the eleven signals. Given the inherent noise levels, such a market may not reach rational expectations equilibrium even after a few dozen repetitions. If eleven discrete states are too many, what is likely to happen in a continuum of states? Similar caution is appropriate in interpreting theoretical and experimental results obtained from stationary environments to naturally occurring markets where conditions relevant to their equilibrium behavior are subject to continual change. The boundaries of the applicability of rational expectations models in such markets need further exploration.

Copeland and Friedman (1987) experimented with sequential distribution of information among traders. They divided each five-minute period into four equal segments of seventy-five seconds each. A randomly chosen subset of traders received information at the end of the first, second, and the third time segment, respectively. Once informed, a trader knew for sure which of the two possible states of nature had occurred in that period. Copeland's (1975) and Jennings, Fellingham, and Starks' (1981) models, based on the assumption that traders do

not learn about the state of nature from observing the market phenomena, predict that trading volume under sequential arrival of information would be higher than under simultaneous arrival of information. Instead, the actual trading volume was significantly higher in markets where information was given to traders simultaneously. Sequential arrival of information presents the uninformed with a choice between trading against possibly better-informed opponents, or simply refusing to trade for a few minutes until information arrives. Reluctance to trade against better-informed opponents is also reflected in their analysis of bid-ask spreads. Wider bid-ask spreads were observed in early periods, in early parts of periods, and in seconds immediately following the arrival of information. In these markets, every trader knew that he or she would receive perfect information about the state of nature no less than seventy-five seconds before the end of the trading period. One interpretation of these results is that it is not necessarily advantageous to trade early in a period before the information arrives. This interpretation is also supported by Frank's (1988) and Friedman's (1993a) subsequent experiments where traders preferred to transact in the later part of a trading period.

How widely must the distribution of information be to ensure its dissemination in the market? This is a question about measurement of a market parameter, and parameters measured in the laboratory cannot easily, or meaningfully, be translated to the field environments. It is more useful to ask the qualitative question: does the increase in the number of insiders increase the speed or precision of information dissemination in the market?

Plott and Sunder (1982) kept the number as well as the identity of the informed traders fixed at six out of a total of twelve. Sunder (1992) observed information dissemination when as few as one out of twelve traders was informed. However, dissemination with one, two, or even three informed traders cannot be relied upon; such informationally-thin markets are prone to serious malfunctioning, especially when traders have some confidence in their ability to extract information from the market phenomena.² Von Borries and Friedman (1989) compared the performance of a two-state, single-period, eight-trader asset market in which the number of the informed was fixed at four, against the performance of a similar market in which the number of the informed traders was randomly chosen each period to be either one or zero. The identity of the informed trader, when there was one, also was randomly chosen each period. Information is disseminated in the market with four informed traders, but not in the second market. This result suggests that as the market becomes thinner in information, dissemination of information becomes more chancy. Watts (1993) examined Plott and Sunder's (1982) markets by making the presence of informed traders a random variable; there was 50–50 chance that zero or six out of twelve traders in the market had received perfect information about the realized state of the world before the market opened for trading. Her results confirmed that the uncertainty about the presence of informed traders in the market weakens the reliability and precision of rational expectations predictions, especially in the state corresponding to the lower price.

Is it possible to detect the presence of insiders in a market by applying statisti-

cal techniques to data collected in the laboratory? Lundholm (1986) compared Plott and Sunder's (1982) data for initial periods when no trader was informed against later periods in which 50 percent of the traders were informed and reached an affirmative conclusion. Markets with asymmetric information have a higher volume, and this volume is attributable to activities of the insiders. In markets with asymmetric information, a price change is more likely to be followed by another of the same sign. He developed a logistic response model that could predict the presence of insiders in a market with about 75 percent accuracy. Whether these results would hold in data obtained from markets in which the existence of informed traders is *not* common knowledge is an open question. Camerer and Weigelt's (1990a, 1990b) experiments (discussed in the section on bubbles and false equilibria) suggest that it takes many replications to learn to recognize the presence or absence of information from market characteristics.

The number of insiders in these experiments was relatively large, and the number as well as the identity of insiders was exogenously determined. Once these variables are endogenized (in experiments reported in the section on costly information) it may be more difficult to detect the presence of insiders. Further, the uninformed would like to learn not only whether, and how many, insiders are present, but also what the insiders know about the state of nature.

Few researchers have explored the possibility of drawing *ex post* statistical inference from experimental data gathered by other researchers. Such techniques are frequently applied to data gathered from stock and commodity exchanges, and their application in the laboratory would be an illuminating linkage between these two types of empirical research. It is interesting that Lundholm's own analysis was motivated by Morse's (1980) efforts to use field data to test his own model about the effect of the presence of insiders on market behavior. Lundholm recognized that, in spite of other advantages of using the field data, Morse's tests were deficient in one critical respect—unobservability of the presence of insiders, the treatment variable. The laboratory allows exact measurement of the treatment variable.

D. Aggregation of Information

The studies reviewed above demonstrate that it is possible for markets to disseminate information from perfectly informed insiders to the uninformed. Is it also possible for a market to perform the more subtle and difficult task of aggregating the less-than-perfect, diverse information in possession of individual traders, and disseminating it to all traders? If this were to happen, such a market would function as if every individual trader has access to all the information in possession of all the individuals. Hayek's (1945) critique of central planning suggested that he believed that markets are able to accomplish this feat. Grossman (1981) proved that such information aggregation would lead to allocations that cannot be Pareto dominated by a planner who had access to all of the economy's information. Do there exist markets that will aggregate and disseminate private information in possession of egoistic individuals?

Plott and Sunder (1988) modeled information aggregation in the laboratory by using three discrete dividend states. Traders were endowed with two or more units each of a single-period asset. The dividends of this asset depended on which one of the three possible states of nature with known probabilities (X, Y, or Z), was realized in that period. Every trader received diverse, but imperfect information about the state of nature before trading by a oral double auction began: if the realized state was X, one half of the participating traders, randomly chosen, were privately informed that the state was "not Y," while the others were similarly informed "not Z." This system of distributing information was common knowledge among the traders. Dividends and probabilities were chosen so the equilibrium predictions of the rational expectations model were distinct from the predictions of the prior information or Walrasian equilibrium in which traders extracted no information about the state of nature from observing the market.

This experiment consisted of three series of markets. In series A, consisting of five market sessions, a single-period, three-state asset was traded among traders who received diverse information about the realized state of the world and received different dividends from the same asset depending on the class of traders they belonged to. These markets did not converge to rational expectations equilibrium. Two markets of series B were created by unbundling the single asset of series A markets so traders could trade a complete set of three different state-contingent claims. Three markets of series C were created by modifying series A design so all traders belonged to the same dividend class. Series B and series C markets converged to rational expectations equilibrium.

When dividends varied across traders, the markets could not aggregate information by trading the single, three-state asset described above. In such environments, the task of extracting information about the realized state of nature from others' bids and asks is more complicated. Plott and Sunder (1988) experimented with two alternative treatments. In one treatment (series C), dividends of all traders were made identical. With the common knowledge of identical dividends, traders were able to interpret others' bids and asks in an unambiguous manner and extract information to revise their own beliefs about the realized state of nature.

In the second treatment (series B), they replaced the market for a single three-state asset by a simultaneous market for three single-state-contingent assets. X-contingent asset paid dividend x_i to trader i if state X was realized and trader i held the asset at the end of trading. Y-contingent and Z-contingent assets were similarly defined.

For example, Table 6.3 shows that X-contingent asset paid dividends of 70, 230, and 100 to traders of type I, II, and III, respectively, if state X was realized and nothing otherwise. Under state X, two traders of each type knew that the state was "not Y" while two traders of each type knew that it was "not Z." Thus, there was no aggregate uncertainty. Rational expectations equilibrium aggregates the diverse information available to individuals and yields prices of 230, 0, and 0 for X-, Y-, and Z-contingent assets respectively in state X. Prior information equilibrium, on the other hand, assumes that no aggregation of information occurs. This market, with simultaneous trading in three different assets, is considerably more

Table 6.3. Parameters and Equilibria for a Complete Market

	X-Asset			Y-Asset			Z-Asset		
	Dividend in State			Dividend in State			Dividend in State		
	X	Y	Z	X	Y	Z	X	Y	Z
<i>Trader type and number</i>									
I (4)	70	0	0	0	130	0	0	0	300
II (4)	230	0	0	0	90	0	0	0	60
III (4)	100	0	0	0	160	0	0	0	200
<i>RE equilibrium</i>									
State	X	Y	Z	X	Y	Z	X	Y	Z
Price	230	0	0	0	160	0	0	0	300
Asset holders (trader type)	II	—	—	—	III	—	—	—	I
<i>PI equilibrium</i>									
State	X	Y	Z	X	Y	Z	X	Y	Z
Price	146	146	101	58	58	49	169	208	208
Asset holders (trader type with information)	II (not Z)	II (not Z)	II (not Y)	III (not Z)	III (not Z)	III (not Y)	I (not Y)	I (not Y)	I (not X)

Source: Extracted from Plott and Sunder (1988, tables 1 and 2).

Note: Prob (X) = Prob (Y) = Prob (Z) = 1/3.

complex than single asset markets. Yet, as can be seen from Figure 6.4, it was able to aggregate information. Transaction prices for X-, Y-, and Z-contingent assets in periods 1–9 are plotted against time in three panels of Figure 6.4. Each dot represents one transaction. When two consecutive transactions occur in the same market, the two dots representing these transactions are joined by a line. The realized state of nature for each period is shown at the bottom. In each panel, a solid horizontal line indicates the price prediction of the rational expectations equilibrium (e.g., 0 for X- and Y- and 300 for Z-contingent markets in period 1). Average transaction price for each market and overall allocative efficiency is shown at the top by period. Within a few periods, all three asset prices, as well as allocations (not shown here) converge close to the predictions of the rational expectations equilibrium.

Periods 10–13 in Figure 6.4 show that, when the three state-contingent assets of periods 1–9 were bundled together and traded as single assets, the market was unable to aggregate information. By experimenting with several other markets, Plott and Sunder (1988) found that a market that trades a single three-state asset is unable to aggregate information when dividends vary across traders.

These experiments are a good example of potential for productive interplay

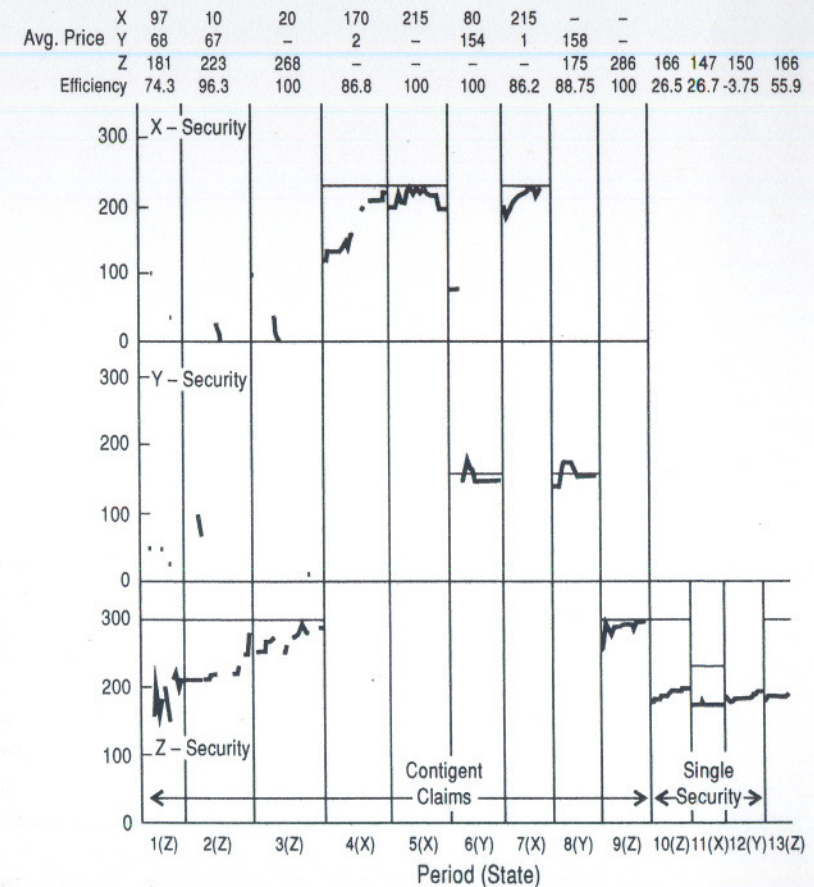


Figure 6.4. Aggregation and dissemination of information in complete markets with state-contingent securities. Source: Plott and Sunder 1988, figure 4.

between theory and experimental data. The first three markets of the experiment were motivated by a curiosity to find out if the ability of double auctions to disseminate information, documented in Plott and Sunder's (1982) experiment, extends to aggregation of diverse information. In order to test the information aggregation hypothesis, the market for a single two-state asset used in Plott and Sunder (1982) was modified to a single three-state asset market. When this market failed to aggregate information, the authors searched for explanations of this failure. They realized that this market was incomplete (because a single asset cannot span the three-state space). The rational expectations equilibrium in both complete as well as incomplete markets would be identical, and there had been no theoretical work to suggest either that incomplete markets would have difficulty in arriving at this equilibrium or that a more complete set of trading instruments would facilitate information aggregation and efficiency. Yet, in observing the process of trading in incomplete markets and the difficulty traders had in extract-

ing information from market data, it became clear that expanding the message set available to traders (i.e., prices of different assets in this case) until it spanned the state space may enable traders to distinguish the realized state from other states on the basis of observable market data. This conjecture led to the design and testing of a second set of markets (series B) in which a complete state-spanning set of assets was traded. The conjecture turned out to be correct, and markets of this series aggregated information. The experimental work now needs to be followed by theoretical analyses of conditions that promote informational efficiency (see section on learning sequences for further discussion).

Besides empirical demonstration that aggregation of diverse information can take place through certain market processes, Plott and Sunder (1988) yielded a second important result about the relationship between statistical and allocative efficiency of a market. All eight single-security, heterogenous-preference markets failed to aggregate information. In other words, all these markets were allocatively and informationally quite inefficient; the potential gains from trading actually exploited in these markets varied from a minimum of 8 percent to a maximum of 78 percent. However, in spite of this gross informational inefficiency, the price data revealed no obvious opportunities that could be exploited advantageously by the traders. Application of hypothetical filter trading rules to the price data generated from these experiments revealed that such rules are dominated by a naive buy-and-hold strategy. Had these data been generated in the field, we may well have concluded, on the basis of such statistical tests, that these markets are efficient. But, possessing the knowledge of information and dividend conditions, the experimenter *knows* that these markets are, allocatively and informationally, quite inefficient. Statistical efficiency of markets and lack of arbitrage opportunities would appear to be a necessary condition for informational efficiency; it is not sufficient.

Forsythe and Lundholm (1990) conducted detailed experiments to search for conditions that would allow information aggregation in incomplete markets in spite of heterogeneous preferences. They observed aggregation of information when the entire table of dividends was common knowledge among traders and the subjects were given additional sessions of trading experience. On the other hand, O'Brien and Srivastava (1991b) showed that even with uniform, common-knowledge dividends (across traders), addition of sufficient complexity (e.g., multiple, multiperiod assets, correlation of dividends across assets and across periods, absence of common knowledge about distribution of information) can render aggregation of information difficult or unlikely. Which of these market characteristics are crucial to its information aggregation ability remains to be explored.

O'Brien (1990) examined the effect of withholding the ex post revelation of the state of nature on market behavior. Instead of announcing the realized state of nature at the end of each period, he withheld the announcement until the end of the last period of the market. Withholding this information prevented a market that could otherwise aggregate information from doing so. Ex post revelation of the state would allow individual traders to recursively modify their rules of infer-

ence about the state of nature from observation of the market. The results suggest that such recursive modification is crucial to convergence of markets to rational expectations equilibrium. When states of nature are not revealed—and it is not unusual to have years of delays in markets for corporate equity—one must be careful in interpreting the behavior of natural markets in terms of rational expectation models.

Kruse and Sunder (1988) and Eberwein (1990) are experimenting with the common knowledge of information distribution as a treatment variable. Plott and Sunder (1982) suggest that the behavior of markets with asymmetric information may be sensitive to common knowledge conditions. Ang and Schwarz (1985) report an experiment in which common knowledge about information distribution is manipulated. Since their manipulations were conducted sequentially over various subsets of periods in a single market session, more detailed work is needed to obtain definitive results. The Kruse and Sunder design seeks to compare the performance of markets in which absence of information is common knowledge against markets in which it is not. This research design differs from Camerer and Weigelt's (1990b) in which the number of informed traders is randomly set to zero or six each period; when information is absent, this absence is not common knowledge. Experimental designs described in this paragraph seem to push experimental complexity close to its limits, yielding only a few noisy observations from a large amount of time and money spent on experimentation.

Results of these experiments suggest that aggregation of information in markets depends on features of markets—rules, information distribution, common knowledge, experience of traders, number, nature and relationship of assets traded, etc. Specific empirical relationships between these features and the performance characteristics of markets identified in these experiments may help incorporate such features into analytical models of markets. Some markets aggregate information, all of them do not. The difficult work lies ahead in establishing more precise understanding of factors that facilitate or retard information aggregation.

E. Market for Information

Studies of information aggregation and dissemination in markets revealed that it is unrealistic to expect this process to be complete or instantaneous, even in simple laboratory settings. Even in the absence of exogenous noise, laboratory prices are necessarily noisy, relative to the predictions of formal models. If markets instantaneously and completely reveal information produced or purchased by the informed at positive cost, there would be no incentives to produce information. How do we reconcile costly information production with the revelation of information in markets?

Noisy rational expectations models addressed this problem by deriving equilibria in which asset markets reveal some information, but noise disguises just the right amount of information to allow the informed traders to recover the cost of information (see Grossman and Stiglitz 1980; Hellwig 1980; and Verrecchia 1982). Sunder (1992) allowed traders in his single-period, two-state asset market

to buy perfect information about the realized state of nature before trading opened in the asset market.³ The informed traders' gross profits exceeded the gross profits of the uninformed. However, when the cost of information was netted out, these profits were statistically indistinguishable. Noisy revelation of information in asset market was just enough to compensate the informed for the cost of buying information.

Two sets of markets in Sunder (1992) provide insights into the equilibrating process. When information was auctioned off to the four (out of twelve) highest bidders in a uniform price sealed bid auction (at the fifth highest bid price), the price of information was relatively high in the early periods (see Figure 6.5, top of the upper panel). However, with a few periods of experience, traders learned to infer the state of nature from market observations in the asset market (Figure 6.5, bottom of the upper panel), and they lowered the amounts they were willing to pay for information, creating a steep fall in the price of information. In later periods of these experiments, the price of information was just enough to be recovered from small deviations between the transaction and full revelation rational expectations equilibrium prices in the asset market.

In a second set of markets, the price of information was fixed and each trader had to choose each period if she wished to be informed about the state of nature by paying this price. The number of buyers of information did not stabilize (see Figure 6.5, upper part of the bottom panel). All traders in this market are in an essentially symmetric position and the double auction does not allow them a mechanism to coordinate or communicate their information-buying decisions. The result was that the number of informed traders varies widely over a range. When many traders buy information, information is promptly revealed through the prices (see Figure 6.5, lower part of the bottom panel), depriving the buyers of information of the opportunity to recover their information costs. In other periods, when only a few buy information, the market occasionally fails to reveal information, allowing the informed to reap large profits. On the average across many periods, however, the net profits of the informed and the uninformed tend towards equality.

Copeland and Friedman (1991, 1992) examined the behavior of asset markets with sequential arrival of information, with the provision of costly purchase of information early in each period. In the simplest cell of their four-cell experimental design, they obtained results similar to those reported by Sunder (1992) in simpler environments.⁴ When they used more complex settings, revelation of information in asset markets becomes less than complete, allowing higher gross profits for the buyers of information and higher price of information. Von Borries and Friedman (1989) used an environment similar to Copeland and Friedman's (1992) with uncertain presence of a single informed trader who received information at zero cost. In the absence of common knowledge about distribution of information, the asset markets are not able to reveal information when the monopolist insider is present, allowing the insider to earn large net profits. It is likely that the price of the right to be the monopolist insider would have reduced his net profits to the level of the other traders if the right to be the insider had been

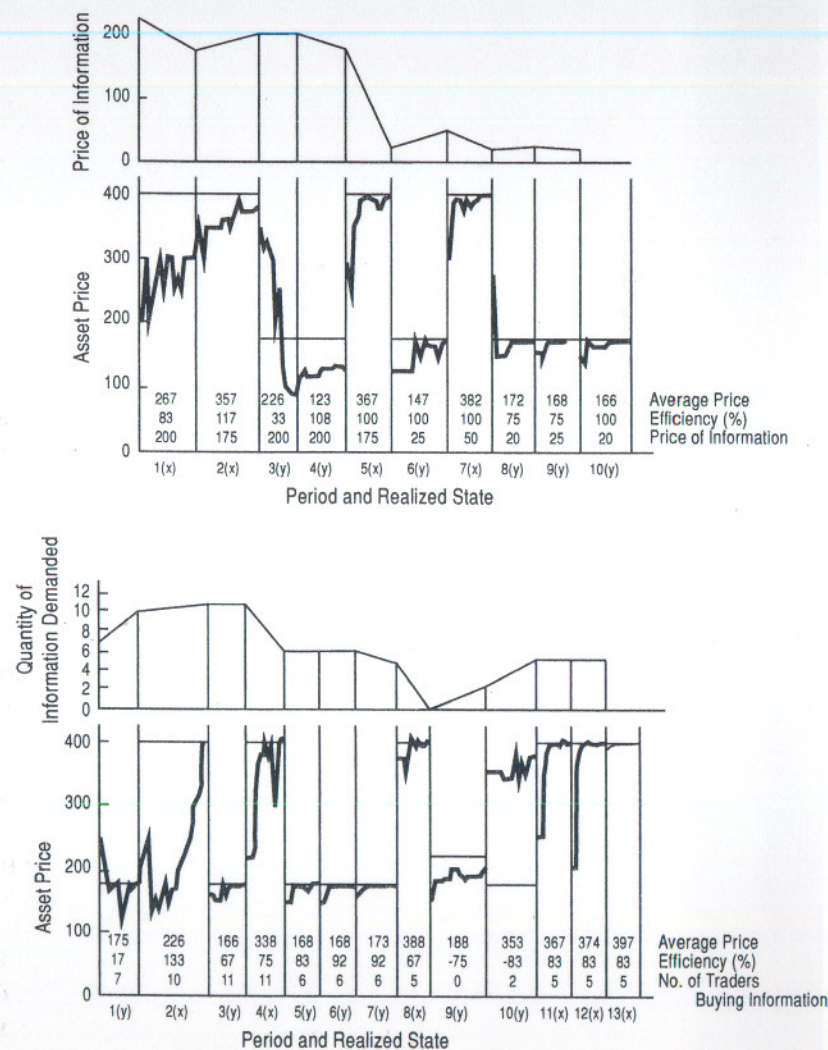


Figure 6.5. Asset and information market equilibria with costly information. Top: information price and asset price for market 1. Bottom: information demand and asset price for market 2. Information prices are for sealed-bid auction with fixed supply; asset prices are for double oral auction; information demand is the number of traders who bought information at a price fixed by the experimenters. Source: Redrawn from Sunder (1992, figures 1 and 2).

auctioned off. As long as entry into the information market remains free, the behavior of asset and information markets is consistent with the theory. Theoretical models of noisy rational expectations equilibrium use exogenous sources of noise (e.g., supply noise in Grossman and Stiglitz [1980]). King (1987) modelled his experimental markets with such exogenous supply noise. However, it is clear, from the data gathered to date, that noise is an inherent characteristic of experi-

mental markets. It is also inherent in natural markets (see Black 1986). Analytical models started out using exogenous noise arising out of state uncertainty to construct equilibria. I hope that someday these models will develop to incorporate endogenous noise arising out of *behavioral* uncertainty instead. Since the behavioral noise is ever present, indeed inherent, in laboratory and field markets, the advantage of incorporating exogenous, state-of-nature noise into laboratory experiments is unclear.

II. Futures and State-Contingent Claims

What is the effect of a market for futures contracts or state-contingent claims on the behavior of the primary market? Forsythe, Palfrey, and Plott (1982, 1984) examined the markets for a two-period asset (without uncertainty) and found that when the first period spot market was supplemented with a futures market for period two delivery, convergence to equilibrium was speeded up. Theirs was the first laboratory evidence to provide qualitative support to Hicks' (1939), Danthine's (1978) and Grossman's (1977) idea that futures markets help disseminate the private information about the future plans and price expectations of various agents in an economy, thus increasing the informational and allocative efficiency of the spot market.

While there was no payoff uncertainty in the Forsythe, Palfrey, and Plott experiments, perfect foresight equilibrium in the first period of the asset life could not be reached until the traders learned the equilibrium price in the second (and the last) period of the asset life. Even with subjects who had participated in previous asset double auctions, it took eight replications for the transaction prices in the first period to enter the neighborhood of the perfect foresight equilibrium prediction (see top panel of Figure 6.1). Then they added a period A futures market for period B delivery. The bottom panel of Figure 6.1 shows the transaction price data from this session. The higher set of dots represent transactions in period A spot market while the lower set of dots represent transactions that occurred in period A for a futures contract for period B delivery. Introduction of futures trading had two effects. First, as indicated by the absence of any dots in period B in the lower panel of Figure 6.1, spot market trading in period B dried up completely. Second, the period A spot price converged close to the perfect foresight equilibrium level of 845 by the end of the first trial itself (instead of the eighth trial in the upper panel). Existence of the side-by-side futures and asset markets made it easier for each trader to estimate the perfect foresight value of the asset.

Forsythe, Palfrey, and Plott (1984) reported that the variance of spot prices increases in the presence of futures markets. This result is consistent with the notion that futures prices enable more information to be promptly incorporated into prices, and greater volatility of spot prices in the presence of futures is simply reflective of this faster adjustment process. Like cholesterol, there seems to be good and bad volatility—good if it is caused by more precise tracking of rational expectations equilibrium and bad if it arises for any other reason.⁵ They also

found that the allocative efficiency of the market is higher with futures markets than without.

Friedman, Harrison, and Salmon (1983) extended the Forsythe, Palfrey, and Plott (1982, 1984) experiments by adding a third period to the life of their assets. Subject experience and existence of a futures market in the first and the second period for the third period delivery were the two treatment variables in their experiment. They confirmed that the presence of a futures market speeds up convergence to perfect foresight equilibrium price. However, contrary to prior results, they also found that the presence of a futures market reduces allocative efficiency as well as price volatility in the spot market.⁶ The authors attribute the lower efficiency of their futures markets to aberrant behavior of a single trader (out of a total of nine). Addition of a third period to asset lives made these markets considerably more complex, and the reported results are based on six sessions of only three to five replications of three period cycles. With computerized auctions, it should be possible to run many more replications. Resolution of these paradoxical results remains open.

In their second study, Friedman, Harrison, and Salmon (1984) added state uncertainty by using two-state, three-period assets and introduced information asymmetry by giving perfect information about the realized state of nature to three traders (one of each dividend type). In Figure 6.6, x 's in the upper panel show that the transaction prices in a spot market without concurrent futures markets have difficulty converging to the perfect foresight equilibrium prices corresponding to the realized state (shown by solid horizontal lines). Introduction of futures trading in periods A and B (for period C delivery) promoted dissemination of information given to insiders. This can be seen in the lower panel of Figure 6.6 where spot market transaction prices (x 's) in periods A and B are closer to their respective perfect foresight equilibrium prices (indicated by solid horizontal lines) in the presence of futures transactions (indicated by o 's). Consistent with their previous paper, they could not find evidence that the futures markets induce higher allocative efficiency in spot markets. The presence of futures markets stabilizes transaction prices (lower coefficient of variation), especially in the presence of event uncertainty. This finding is consistent with some, but not all of the field studies of price volatility reviewed by Cox (1976). For example, Working (1960) and Gray (1977) in onion futures, Tomek (1971) in wheat futures, and Powers (1970) in pork belly futures found that price volatility is lower in the presence of concurrent futures markets in the field. On the other hand, on the basis of laboratory experiments, Forsythe, Palfrey, and Plott (1984) reached the opposite conclusions on price stability as well as efficiency and gave some plausible reasons why such might be the case.

In summary, experimental studies agree on the positive effects futures trading has on speeding the convergence of price to an informationally efficient equilibrium and do not support Svensson's (1976) predictions to the contrary about price. On price stability and allocative efficiency, the laboratory results seem to be no more consistent than the field studies so far.

Three other derivative securities—state-contingent options, call options, and



Figure 6.6. Effect of futures trading on asset markets. Top: Experiment 1. Bottom: Experiment 2. Source: Friedman, Harrison and Salmon 1984, figures 5 and 6, enhanced for clarity of exposition.

put options—have been examined for their effect on market behavior in laboratory settings. Derivative securities expand traders' message space and render the market less incomplete. Plott and Sunder (1988) found that when they introduced Arrow-Debreu state-contingent options, information and allocational efficiency of markets increased dramatically (see Figure 6.3 and its discussion in the section on information aggregation above). Kluger and Wyatt (1990) introduced a call option to a two-state, single-period asset environment and found that the presence of call options in the market speeded up the convergence of price to the informa-

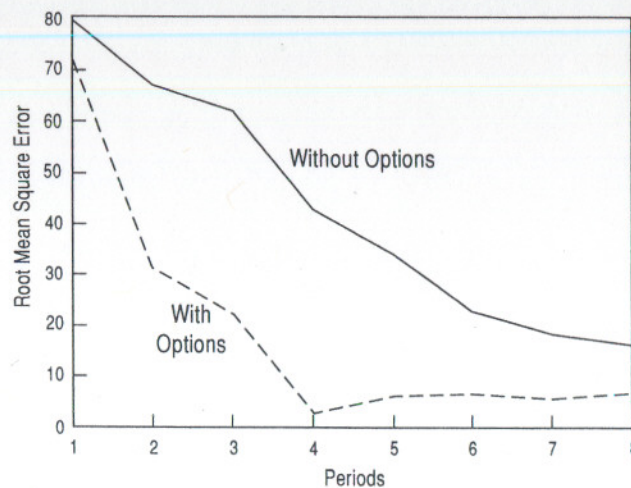


Figure 6.7. Mean squared error of asset prices with and without options traded. Source: Drawn by the author on the basis of data from Kluger and Wyatt (1990, appendix A).

tionally efficient equilibrium level (see Figure 6.7). Allocative efficiency of these markets also increased.

Kluger and Wyatt (1990) also used the observed option and asset prices to estimate the implied volatility of asset prices and compared these estimates to the volatility of full information aggregation asset prices. The results suggest that traders used option prices to estimate the variability of asset prices across states. O'Brien and Srivastava are currently experimenting with call and put options in two-period, three-state asset markets with diverse information. The laboratory evidence to date lends support to the idea that the presence of option type derivative securities increases the informational efficiency of asset markets. The theory (see Ross 1976), the field data (see Manaster and Rendleman 1982; Jennings and Starks 1986), and the laboratory evidence seem to converge to the same conclusion.

III. Bubbles and False Equilibria

Can market value of assets become unhinged from its "fundamentals" and become dependent solely on free-floating expectations? Is Keynes's (1936, 156) oft-quoted description of stock markets accurate?

Or, to change the metaphor slightly, professional investment may be likened to those newspaper competitions in which the competitors have to pick out the six prettiest faces from a hundred photographs, the prize being awarded to the competitor whose choice most nearly corresponds to the average preferences of the competitors as a whole; so that each competitor has to pick,

not those faces which he himself finds the prettiest, but those which he thinks likeliest to catch the fancy of the other competitors, all of whom are looking at the problem from the same point of view. It is not the case of choosing those which, to the best of one's judgment, are really the prettiest, nor even those which the average opinion genuinely thinks the prettiest. We have reached the third degree where we devote our intelligences to anticipating what average opinion expects the average opinion to be. And there are some, I believe, who practice the fourth, fifth and higher degrees.

Of course, if each competitor believed his own opinion to be the best estimate of the opinion of the others, the outcome of the competition will not come unhinged from the fundamentals—in this case, the personal opinions of the individual competitors. Answers to questions about the existence and formation of bubbles and false equilibria depend on how people form their beliefs and expectations.

In a world of uncertainty, “fundamentals” get replaced by expectations about the fundamentals. Mutual dependence of current prices and current expectations about the future yields two types of bubble theories. First, deviation of asset price from its intrinsic value can be compounded over time in rational expectations equilibrium to form a bubble (see Tirole 1982). When individuals have finite decision horizons and markets are incomplete, one cannot guarantee that asset prices will not create such a bubble. Second, “sunspot” equilibria arise when agents form certain arbitrary beliefs that alter the fundamentals of the economy in such a way that such beliefs become self-fulfilling (see Evans 1989).

Formal models either rely on a consistency condition such as rational expectations or use Bayesian revision with some ad hoc prior and likelihood function, or use some ad hoc adaptive process. Given the key role of assumptions about belief formation in economics, surprisingly little work has been done in modeling and testing the theories of belief formation within environments where market discipline prevails. It is difficult to gather reliable data on beliefs and expectations from the field. It is almost never possible to rule out the chance that the apparent generation and bursting of bubbles in the field data is due to some information unknown to the researchers.⁷ Laboratory testing of bubbles phenomena has the advantage that the researcher has access to and control of the information structure of such markets. Consequently, experimental methods are now being applied to study bubbles.

Many interesting experiments on formation of expectations have concerned inflation. Daniels and Plott (1988), Lim, Prescott, and Sunder (1994), Marimon and Sunder (1993, 1994), Marimon, Spear, and Sunder (1993), and McCabe (1989) are examples of this work. However, the substantive matter of these papers will take us on a digression from asset markets, the main concerns of this review. Jack Ochs's “Coordination Problems” in this volume reviews this literature. I shall therefore limit attention on the study of bubbles and false equilibria in asset markets.⁸

Sunder (1992) reported observations of false equilibria in markets for single-

period, two-state assets with insider information (see period 10 in lower panel of Figure 6.4). Each trader had to decide each period whether to buy perfect information about the state at a fixed price (see the section on market for information above for further details of the design). In early periods of these markets, six or more out of twelve traders chose to pay the price of being informed, and the asset markets converged to rational expectations equilibrium revealing the state of nature to those who did not buy information. As the advantages of free riding became apparent, the number of traders willing to pay the fixed price of information dropped. False equilibria were observed only in the later periods of markets when at least one trader was informed, the number but not the identity of the informed traders was common knowledge, short sale restrictions were in place, and no more than one trader was informed on the buyer side of the market. By later periods, most, if not all, traders had acquired some confidence in their ability to infer the state of nature from observing the market. Common knowledge about the positive number of informed traders gave them reason to think that the market does have the information about the state. The short sale restriction prevented the informed traders on the sell side of the asset market from exploiting their information to the fullest extent, thus preventing its revelation through the price. The information monopolist on the buy side of the asset market had the ability to maintain a false equilibrium at a low price without fear of competition from other informed buyers.⁹ The combination of these circumstances created opportunities for false equilibria to develop in five (out of twenty-one) periods; such equilibria were actually observed in three periods.

Theoretical predictions about such false equilibria were made by Beja (1976), Grossman (1976) and Milgrom (1981). When traders know the state-price correspondence and have reasons to believe that the market provides them with information better than their own private information, they may have reasons to discard their private information and rely entirely on the market to inform them. Under these circumstances, market variables can become self-fulfilling, and any price from the state-price correspondence is sustainable. False equilibrium is observed when price is sustained at a level that does not correspond to the realized state of nature. These conditions seem to have been approximated in some periods of Sunder's (1992) markets described above.

Having discovered that inferring state from price can sometimes lead them astray, traders may be less confident in repeating such behavior in subsequent periods. Verifying if, and when, this higher order of learning takes place will take even longer and require more experiments and replications. Virtually all stories of stock manipulation depend, at least in part, on the willingness and tendency of some traders to infer the state of nature from observable market actions of others, while the manipulators exploit this tendency by also engaging in non-observable actions at the same time.¹⁰

Short sale restriction is an exogenously imposed rule of the market. Removal of short sale restriction permits informed traders to exploit their information to the maximum possible extent until price adjusts to eliminate such opportunity to

profit. It is therefore possible that false equilibria could be eliminated simply by removing the short sale restriction. The rationale for imposing the short sale restrictions in laboratory economies is essentially the same as in the stock exchanges—to reduce the chances of bankruptcy among traders. If short sale restriction turns out to be the cause of such inefficient equilibria, it would be the collective price paid by the market participants to reduce the welfare losses associated with the possibility and actual occurrences of bankruptcy.

Camerer and Weigelt (1990b) searched for false equilibria (which they refer to as “mirages”) in markets similar to Sunder’s (1992). During each period the number of informed traders was chosen to be either zero or six (out of twelve). However, unlike Sunder (1992), the number of informed traders in their experiments was not announced. The absence of knowledge about the number of informed traders in any given period created a possibility that some traders may incorrectly believe that the information is present. Such beliefs may induce actions that help bring the observed market variables close to equilibrium values for one of the two states of nature. They reported observing four false equilibria out of a possible forty-seven periods when the number of informed traders was zero.

For example, consider the transaction price data for period 6 in Figure 6.8. The three types of horizontal lines mark the three different types of equilibrium price predictions for the information conditions prevailing in the respective periods. The price of individual transactions is plotted on the vertical scale against transaction sequence number on the horizontal scale. The period number is followed by a code for information condition and the mean of transaction prices for the period. Code W (warmup) means that the state was not determined; X(Y) means that half the traders in the market were informed that X(Y) dividend will be paid while the other half were uninformed about the state; N means that no trader knew the state, though this lack of information was not common knowledge.

In period 6, code N indicates that nobody knew the state of the world. The no-information equilibrium price of 265 is shown by a horizontal line. Had the information condition been X or Y, rational expectations equilibrium price would have been 375 or 175, respectively. As can be seen from Figure 6.8, the market opened with a transaction at 350 and closed at 365 with a maximum price of 370. It is clear from transaction prices (as well as from asset allocations not shown here) that in period 6 the traders behaved as if they were virtually certain that this was an X period, even though, in fact, nobody had any information. A few temporary “mirages” that did not last for a whole period were also observed. Several other periods in Figure 6.8 indicate prices far in excess of the equilibrium level; these were not classified as mirages because the asset allocations did not match with the rational expectations equilibrium allocations for the observed price. Watts (1993) independently conducted experiments with a similar research design and observed only one period of false equilibrium out of a possible thirty-one.

There is an important difference between the false equilibria reported by Sunder and by Camerer and Weigelt. In the former, false equilibria occurred in the

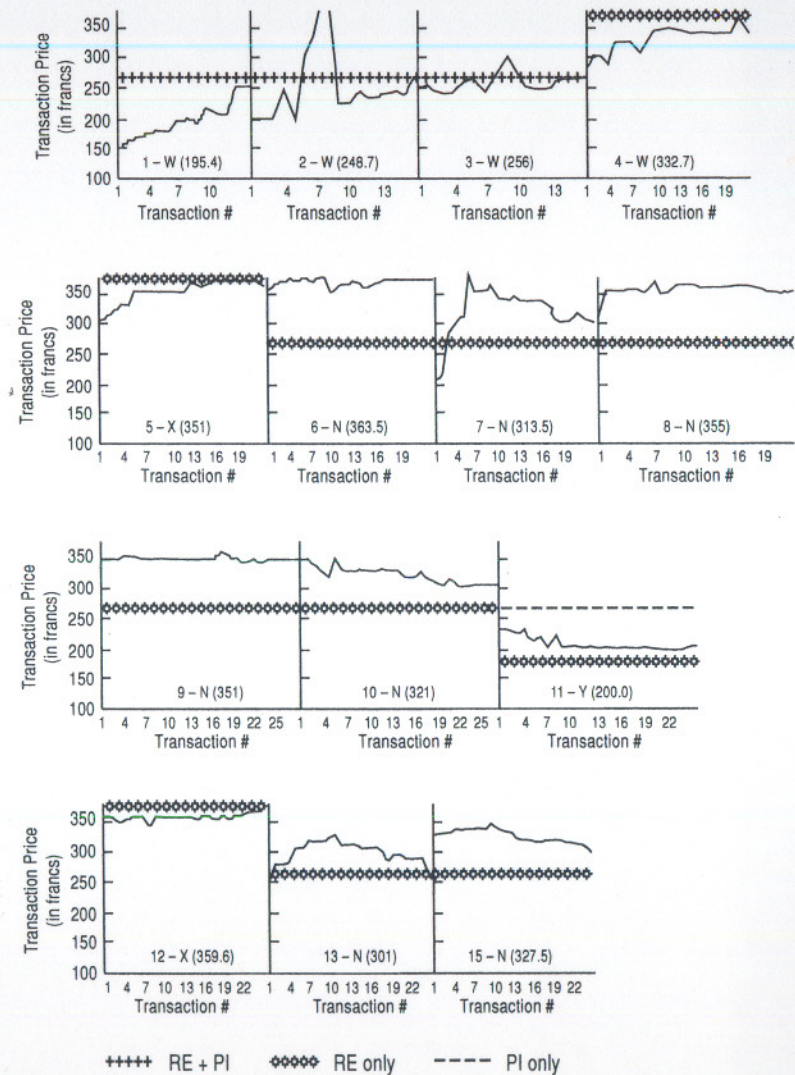


Figure 6.8. Formation of an information mirage in a market: time series of transaction prices. Source: Camerer and Weigelt 1990, figure 2.

second half of the experiments after the traders had learned the state-price correspondence and had discovered that they could free ride on market information as long as they knew that other trader(s) in the market were informed. After the first half a dozen or so periods, convergence of the asset market to rational expectations equilibrium became plainly obvious to many traders. Establishment of rational expectations equilibrium in the asset market led more and more traders to realize that they did not have to buy information in order to become

informed. When enough traders dropped their demand for information, false equilibria arose.

On the other hand, with the number of informed traders being either zero or six, Camerer and Weigelt report more rapid trading with fewer unaccepted bids/offers when insiders are present. They observed false equilibria in periods that constitute the second third of their markets because, they explain, by then the traders had learned the state-price correspondence, but had not yet learned to distinguish between the presence or absence of informed traders on the basis of the pace of trading. It is possible to attribute these false equilibria to traders' overreaction to the similarity of the first few trades of a period to trades in the preceding period in which insiders happened to be present.¹¹ Once the traders learned to discriminate by the pace of trading, false equilibria ceased to occur. These explanations from both papers are essentially *ex post*, and need to be verified by more detailed investigation. The question about whether the behavior observed in these experiments represents the end point of the learning process in these environments remains open.

The most surprising results to date have been reported by Smith, Suchanek, and Williams (1988) using a double auction market for a fifteen-period asset which paid a dividend, either zero or x_1 , x_2 , or x_3 , each with probability 0.25, at the end of each period. For risk-neutral traders, the asset had an expected value of $15 \sum x_i/4$ in the first period, and this value declined by $\sum x_i/4$ each period. The values of x_i were the same for all traders, and the structure, including zero redemption value of the asset at the end of the fifteenth period, was common knowledge. Risk neutral traders with rational beliefs, and common knowledge of rational beliefs, would have no reason to trade in this environment.

Yet, they observed vigorous trading in their twenty-eight markets, as well as a persistent tendency of prices to rise from a low level in the first few periods (relative to the expected value of the remaining dividends) to an inexplicable high level in the middle before collapsing towards the end (see Figure 6.9). This tendency to engage in trading and to transact the asset at bubble prices was attenuated by trader experience. Since this market had no information asymmetries, the results are difficult to explain. Perhaps traders start the markets with quite diverse home-grown expectations which are not immediately homogenized by the experimenter's instructions. Common knowledge may not be easily imparted. It is also possible that individual traders have very different ways of adapting their beliefs to market observations, and the model they use to adapt their own beliefs is not necessarily consistent with the model used to adapt their beliefs about others' beliefs. Thus, a trader who believes that a "greater fool" would buy the asset at an even higher price in the future, may buy it now at a price that exceeds its fundamental value.

King et al. (1990) conducted further experiments to determine if the frequency or size of bubbles might be reduced by short selling, availability of credit to buy assets on margin, brokerage fees, limits on price changes, subjects familiar with the results of prior bubble experiments, and subjects drawn from the world of business. Their results, discussed in more detail in the section on public

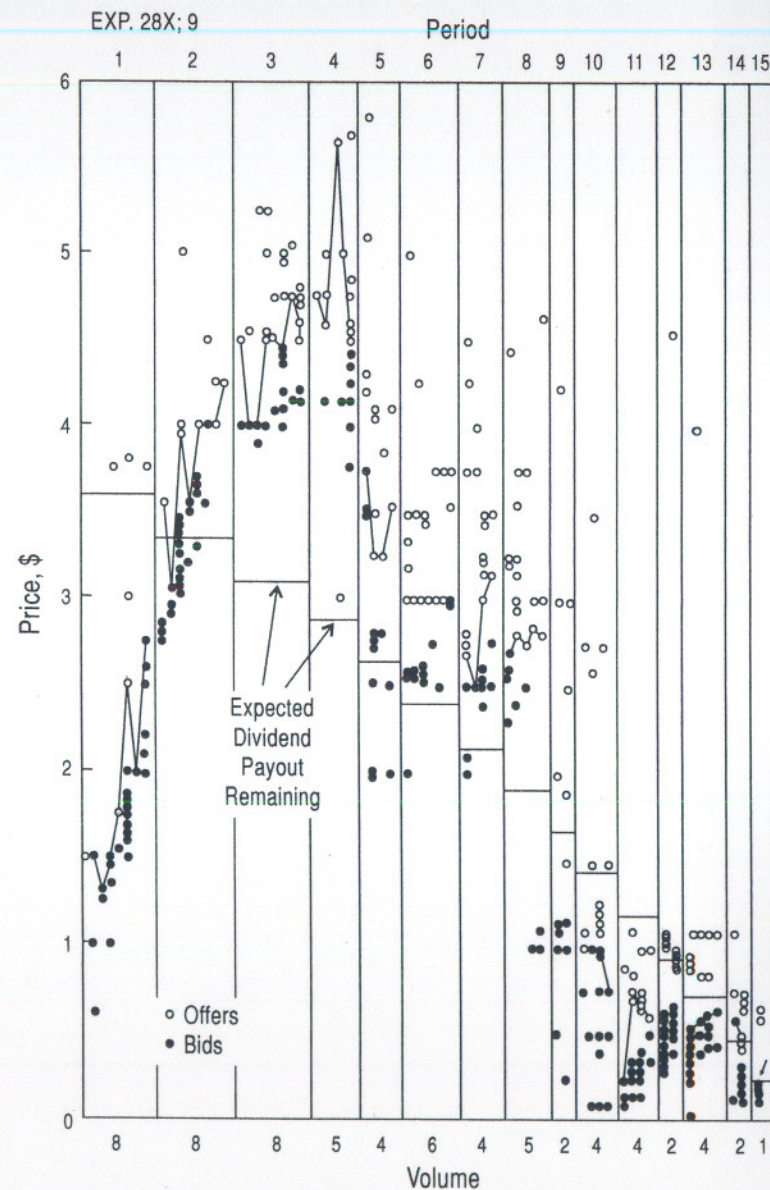


Figure 6.9. Formation and bursting of a bubble. *Source:* Smith, Suchanek, and Williams 1988, figure 9.

policy, suggest that none of these treatments have any significant impact on the occurrence of bubbles. Of all the factors they tested, repeat experience in trading in this specific environment is the only one that reduces bubbles. Porter and Smith (1989) found that neither the elimination of dividend uncertainty nor the introduction of futures markets eliminates price bubbles in this setting; existence of futures markets does reduce the amplitude of the bubble significantly. Given Porter and Smith's result, it is not surprising that, when King (1990) sold perfect information about the dividend to three or four of the nine traders in his markets, it had little effect on the incidence of bubbles.

Current work to generate a consistent explanation of Smith, Suchanek, and Williams' (1988) results focuses on careful examination of instructions, increasing the depth of markets, and making subjects responsible for paying any losses they may incur out of their pockets, and introduction of cross-market arbitrage opportunities. At the time of this review, lack of repeat experience alone seems to be the simplest and most likely explanation of Smith, Suchanek, and Williams' results. Few asset markets with uncertainty get close to equilibrium in less than four or five replications or trials. In case of a single-period asset, each period is a trial. However, for a fifteen-period asset, one cycle of 15 periods is a single trial, two cycles are two trials, and so on. Since a single experimental session may have time enough for only one trial of a fifteen-period asset, several sessions are needed to impart the same level of experience to subjects as could be imparted in a few periods of a single-period asset market. If this explanation holds up, the Smith, Suchanek, and Williams results may not turn out to be so surprising after all.

Camerer and Weigelt (1990a) experimented with an indefinitely-lived asset that had probability 0.15 of being extinguished at the end of any period. The dividends were diverse across subject and were privately and perfectly known to them. Since the probability of extinguishment is analytically equivalent to a discount rate on an infinitely lived asset, they examined such markets for occurrences of bubbles. In eleven out of twelve markets, bubbles failed to materialize, and subjects in the twelfth market had participated in an experiment in which price inflation had been exogenously induced. Camerer and Weigelt's experiment failed to support the bubbles observed in Smith et al.'s fifteen-period asset markets. Given indefinite life of asset in Camerer and Weigelt's experiment, one might have expected a greater chance of generating bubbles. This difference between the two experiments remains to be explained.

Perhaps a useful distinction can be drawn between the sources of bubbles and the false equilibria. The false equilibria arise when some traders *incorrectly* believe that the state of nature is, say, X , when in fact it is Y (as in Sunder 1984, 1992) or when it is, in fact, unknown (as in Camerer and Weigelt 1985). The bubbles, on the other hand, arise when some traders believe that other traders, for whatever reasons, would be willing to pay more than the asset was worth and decide to pay a high price themselves in the hope of extracting some capital gains. In bubbles experiments, there is market or strategic uncertainty, even though there is no state uncertainty.

IV. Learning and Dynamics

How is information aggregated and disseminated in asset markets? In these markets, traders must not only learn about the trading opportunities made available to them by the market, but they must also infer the state of the world from market data. In simpler commodity double auctions only the first of these two issues is present. In spite of some progress, (Wilson 1982; Friedman 1984; Easley and Ledyard 1986; and Gode and Sunder 1993a, 1993b, 1994), convergence in these simple double auctions is not well understood. Dynamics of information aggregation and dissemination is even more complex because the knowledge of trading opportunities affects prices, prices are used to infer the state, and this inference about the state itself affects the prices and alters the trading opportunities.

A. Adjustment Path

It is not clear that an obvious learning sequence exists to disseminate and aggregate information in asset markets. Jordan (1983) and Kobayashi (1977) examined a model of tâtonnement adjustment in which agents first use their private information to express their demands and supplies, so the market converges to a temporary private information equilibrium. The knowledge of this temporary equilibrium is included in the traders' information set that determines their demands in the next iteration of tatonnement. These iterations continue until no trader chooses to revise her demand. This process generally converges to rational expectations equilibrium. This iterative tatonnement imposes a synchronized sequence of alternate steps of generating market data from information sets and generating information sets from market data across all traders. Nontatonnement processes such as double auctions have no mechanism for enforcing such a synchronized sequence *within* a trading period. Whether convergence would actually occur in such processes is a matter for empirical observation and more detailed modeling of dynamics.

Experimental studies reveal that learning of rational expectations equilibrium does not always occur successfully in double auctions. Plott and Sunder (1982, 1988), Forsythe and Lundholm (1990), and O'Brien and Srivastava (1991b, 1991c) show some evidence that, as suggested by Jordan and Kobayashi models, private information equilibrium provides a better description of data from early periods of an auction; the performance of rational expectations equilibrium as a description of data improves in later periods, even when it fails to dominate the prior information equilibrium. However, this process does not capture many observed aspects of information aggregation.

B. Variables That Transmit Information

Several attempts have been made to form and test conjectures about the nature of the learning process in asset markets on the basis of experimental data. Though formal models of equilibrium rely largely, if not exclusively, on price as

the vehicle for transmission of information in markets, traders also observe many other variables such as bids, asks, identity of traders, timing, intensity and volume of bids, asks, and transactions. In oral auctions, eye contact, voice, laughter or side remarks provide additional vehicles for communication. It is not unusual to observe that, after some experience with replications, the very first transaction of a period occurs at a price close to the rational expectations equilibrium and away from the prior information equilibrium (see, for example, period 8 in Figure 6.3). On the basis of such observations, it is easy to reject the proposition that transaction prices are the sole vehicles for transmission of information in markets. Unaccepted bids and offers that precede the transactions play an important role.

DeJong et al. (1991) conducted a computerized replication of two of Plott and Sunder's (1982) oral double auctions by restricting the information available to each trader. These traders could only learn, in real time, the current bid, the current ask, and the price of their own transactions; the computer masked the price of others' transactions, and the identities of traders associated with bids, asks, or transactions. These markets did disseminate information from the insiders to the uninformed and converged to rational expectations equilibrium, though the speed of dissemination indicated by the extra profits was slower. Bids, asks, trader's own transaction prices and their timing seem sufficient for information dissemination. In the context of a double auction, it is difficult to see how the information available to the traders could be cut any further.

The identity of traders is salient in oral auctions but not in computer auctions. Plott and Sunder (1982) used a fixed set of insiders across all periods of each market and conjectured that the ability of the uninformed to identify the informed traders might be important. A questionnaire survey of the traders failed to support this conjecture. Banks (1985) also conjectured that the fixed identity of the insiders might be a key to rational expectations convergence, possibly by making it easier for their identity to be revealed. However, the performance of his markets in which the identity of the informed was changed each period was substantially unchanged. Identification of the insiders does not appear to be a necessary condition for rational expectations convergence. Whether such identification facilitates convergence remains unverified.

The availability of various market variables and the timing of their availability to various market participants are important features of the rules of most markets. For example, information on the outstanding bids and asks in the specialist's book in the New York Stock Exchange is not available to people who are not on the Exchange floor. In addition, a specialist may hold working orders from traders that may not be entered in the book at all, and revealed selectively to traders on the floor at the specialist's discretion. Communication among traders in computerized trading systems is both limited and more detailed, as compared to the information available in oral auctions. Designing the rules of an asset market may be facilitated by better understanding the role of each element of communication among traders.

C. Learning Sequences

At least two kinds of learning are identifiable in asset markets: (1) about the realized state of the world, and (2) about the state-equilibrium correspondence. At the beginning of the first period of a market, the uninformed agents do not know the state of the world for that period, and due to heterogeneity of preferences or dividends that are private, no agent knows what the price would be under any given state. Formal models of learning in markets usually focus on learning about the state. However, learning about the state cannot occur unless traders learn the equilibrium price and net trade correspondence associated with each state. Applied to experimental markets, this reasoning suggests that traders must first learn about prices associated with various states before they can hope to infer the state from prices.

Profit data can be used to distinguish these two types of learning in a market. Given the flat demand and vertical supply in the Plott and Sunder (1982) markets (see Figure 6.2), transactions at equilibrium price award the entire surplus to the equilibrium sellers and none to the equilibrium buyers. Transactions at equilibrium price distribute the total payoff equally among equilibrium buyers and sellers. If information is evenly distributed among the equilibrium buyers and sellers, equality of payoffs earned by the two groups of traders indicates that the equilibrium price correspondence has been revealed to the traders and understood by them.

Even if the equilibrium price correspondence were known to all traders, uninformed traders may fail to arrive at the correct inference about the realized state for a particular period and, therefore, receive a smaller payoff than the informed traders. Equality of payoff between informed and the uninformed traders is, therefore, an indication of learning about the state.

Plott and Sunder (1982) used convergence of equilibrium buyers' and sellers' profits as a measure of learning the price for a given state, and convergence of the period profits of the informed and the uninformed traders as a measure of learning the state given the market price. Figure 6.10 shows the ratio of profits of equilibrium buyers/sellers and of informed/uninformed traders for the market shown in Figure 6.3. By these measures, it appears that these two kinds of learning occur simultaneously, not sequentially as suggested by comparative static models. However, since profit data are measured by period, they do not rule out the possibility that sequential learning occurs *within* the trading periods.

Forsythe, Palfrey, and Plott (1982) noted that in their markets for two-period assets, convergence to equilibrium in period B *preceded* the convergence in period A in the sense that it took fewer replications (see upper panel of Figure 6.1). This "swingback" phenomenon suggests that learning in markets is sequential. Since all the data needed to arrive at perfect foresight equilibrium in period B was immediately available to the traders, period B markets converged early. Perfect foresight demands, supplies, and, therefore, the equilibrium for period A depended on the knowledge of period B market value of the asset. Equilibrium in

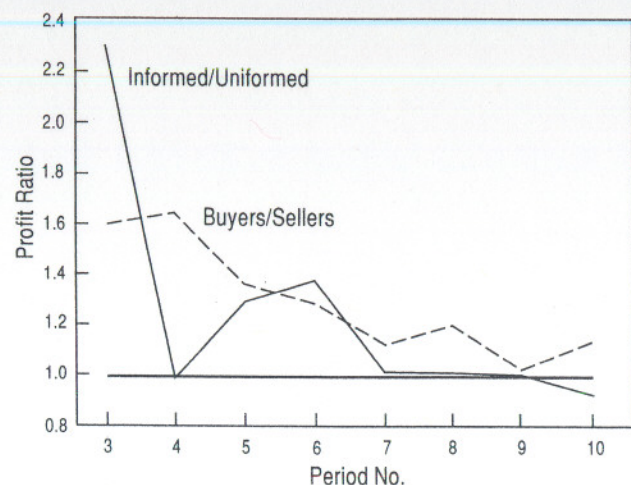


Figure 6.10. Ratio of profits of buyers/sellers and Ratio of profits of informed/uniformed.
 Source: Drawn by the author on the basis of data given in the working paper version of Plott and Sunder (1982).

period A, therefore, followed the period B equilibrium. Introduction of period A futures market for period B delivery speeded up the process by speeding up the availability of information about period B equilibrium. In any case, perfect foresight, when it is observed in market behavior, must be *acquired* through historical observation and experience.

Anderson, Johnston, Walker, and Williams (1991) examined computerized markets for three-period assets similar to the oral markets of Friedman, Harrison and Salmon (1983) and found that the convergence to perfect foresight equilibrium takes place only after the subjects acquire a great deal of experience:

Although it is not clear how these very subtle institutional and procedural differences can explain the behavior discrepancy between our experiments and the two reported by FHS, it is clear that there is more driving these markets than is captured by either the simple perfect foresight or prior information models. Our interpretation is that trading based on capital gains expectations is quite common. This is most readily apparent when we observe prices in excess of the PF equilibrium prediction in the first year of trading. It is unclear why subjects have such expectations in the absence of prior relevant market information. Speculative trading at prices well above a level supported by an asset's intrinsic dividend value is, however, quite consistent with results reported by Smith, Suchanek and Williams (1988) in PLATO double auction asset markets with a 15-period time horizon. The repetitive stationarity of market years appears to be a critical factor leading to the deterioration of these expectations. In the experiments using experienced subjects, the improvement in the predictive ability of the PF model is at least in part due to subjects "learning" to have common expectations that are supported by the exogenous dividend structure.

Bronfman (1990) estimated the decision functions of traders by replicating Smith, Suchanek, and Williams (1988) experiments modified to yield one-period-ahead price forecasts from each trader. She concludes that the trader behavior of the type reported by Smith, Suchanek, and Williams is more consistent with their extrapolating market trends than with their use of intrinsic values. Following intraperiod price movements as trends explains an important part of the data gathered in these experiments. Obviously intrinsic values must play a role too, especially in the behavior of experienced traders. This role has not been isolated in Bronfman's study.

D. Aggregate Uncertainty

Dynamics of information aggregation seem to be affected by aggregate uncertainty and the number of trades. There are empirical suggestions in several studies that the observed behavior of asset markets corresponds more closely to equilibrium predictions when there is no aggregate uncertainty in the market about the state of the world (Plott and Sunder 1982; O'Brien and Srivastava 1991b). Lundholm (1991) subjected this proposition to formal tests. He modified Plott and Sunder's (1988) asset market design (single, three-state asset with single period life, identical dividends across all traders; see the section on aggregation of information above) by adding a fourth state and by making dividends common knowledge among the traders. In markets *without* aggregate uncertainty, he distributed imperfect information signals to individuals in such a way as to eliminate aggregate uncertainty. For example, when state X was realized, one third of the traders in the market learned that the state was "not Y," another third learned that it was "not Z" and "not W," respectively. The markets *with* aggregate uncertainty were created by withholding one of the three "not" signals from the traders. He found that efficiency of asset markets increases when aggregate uncertainty is eliminated. He also found that, contrary to general belief, an increase in the number of traders does not necessarily increase the speed or precision of information aggregation. Both these effects are consistent with individual differences in risk attitudes and information processing. These individual differences become more important in the presence of aggregate uncertainty. As the number of traders increases, so does the range between the extremes, making it more difficult for traders to draw consistent inferences from observed data.

E. Role of Arbitrage

The preceding discussion suggests that dissemination of information in asset markets is a complex process involving many observables and trader inferences. As a first cut, it is useful to find out how much of the information dissemination or aggregation can be understood in terms of arbitrage behavior alone, that is, by traders' attempts to make profits on the basis of the private information in their possession without exposing themselves to any risk.

For example, consider series B markets reported by Plott and Sunder (1988) (see the section on information aggregation above) in which a complete set of single-state-contingent claims are traded in an environment with no aggregate uncertainty. Since every trader was given information to rule out one of the three possible states of nature, competition in the markets for claims corresponding to the two "not states" drove the prices of these claims to zero; any price other than zero would have offered opportunity for riskless arbitrage to more than one trader. Once these prices went to zero, rational expectations equilibrium in the market for claim corresponding to the realized state could be arrived at by either the arbitrage argument, or by simple inference of the third state when the remaining two have been ruled out on the basis of the market phenomena observable to all. Such opportunities were not available to traders in the incomplete markets (e.g., the last four periods in Figure 6.4) when a single compound asset was traded; these markets failed to aggregate information.

O'Brien and Srivastava (1991c) developed a formal theory using the arbitrage arguments. They identify a set of "separating portfolios" whose price must go to zero, based on private information of traders, if the markets in which they trade are free of arbitrage, liquid, and perfectly competitive. Complete markets always have sufficient number of separating portfolios, so the full exploitation of arbitrage opportunities in these markets implies full aggregation of information. However, full aggregation of information does not always require the markets to be complete in the traditional sense of that term; O'Brien and Srivastava define "informationally complete" markets that have enough separating portfolios to ensure that the absence of unexploited arbitrage opportunities implies information aggregation. They suggest that even redundant securities can play a useful role in information aggregation.

This theory only says that if an informationally complete market is perfectly liquid and if traders do not leave any arbitrage opportunities unexploited, then the market must be at rational expectations equilibrium. Whether a market that is designed to be informationally complete is actually observed to be liquid and arbitrage free depends on the depth of competition, trading institution, trader incentives, and their behavioral characteristics. O'Brien and Srivastava present empirical evidence from 16-trader double auction markets that (1) zero arbitrage and liquidity (and therefore information aggregation) are observed, but not always; (2) competition reduces arbitrage; and (3) availability of separating portfolios facilitates information aggregation. These empirical results are consistent with the results reported in Plott and Sunder (1988).

F. Generation of Bids and Asks

In their "bubble" experiments, Smith, Suchanek, and Williams (1988) show that price change from period t to $t + 1$ follows excess number of bids over offers (or offers over bids) in period t . They suggest that the large number of unaccepted bids in period t generate the capital gain expectation in period $t + 1$. Why excess bids or offers arise in the first place remains open.

O'Brien and Srivastava (1991b) proposed a simple rule for constructing a range for bids and asks submitted by individual traders based on the prior information in their possession at the beginning of the period and the price of completed transactions since the beginning of the period. After n transactions have been completed in a period at prices p_1, p_2, \dots, p_n , range for the next bid is given by

$$p_{n+1}^b < \text{Min} \{ (n p_n^b + p_n) / (n + 1), \text{Max dividend} \},$$

where p_0^b is the bidder's expected dividend given his initial information at the beginning of the period. The ask range for offers is analogously defined as

$$p_{n+1}^a > \text{Max} \{ (n p_n^a + p_n) / (n + 1), \text{Min dividend} \},$$

where p_0^a is the asker's expected dividend given his initial information. They reported that only some 5 to 18% of actual bids and asks fell outside these ranges. This explanatory power is high, especially when one notes that these ranges are constructed after each transaction without any strategic considerations. On the other hand, these ranges are open on the safe side (low bids and high offers) and cannot be violated in that direction.

This brief review suggests that the experimental literature on asset markets has so far been focused on discovering conditions under which market data may or may not be well described by various static models of equilibrium. Explorations of learning and dynamics has been carried out mostly as an afterthought. Experiments have, however, produced valuable data to support efforts for building dynamic theories.

V. Econometric Comparisons of Field and Laboratory Data

A. Variance Bound Tests

LeRoy and Porter (1981) argued that if securities are efficiently priced in a market, variance of security prices should not exceed the variance of the discounted present value of dividends. Shiller (1981) has shown that the variance of realized stock prices significantly exceeds the variance of discounted present value of dividends *actually realized* in the subsequent years. Since researchers have no way of knowing the ex ante distribution of future dividends, or discount rates, field tests of this idea must necessarily be based on some assumption about this distribution (e.g., it is identical to the realized distribution in the subsequent periods).

This difficulty of testing the theory on field data has given rise to a lengthy and inconclusive debate (see Camerer 1989). Those who believe in market rationality claim that their null hypothesis remains to be rejected, while others claim that the null hypothesis of excess volatility stands (see Marsh and Merton 1986; Shiller 1986). In laboratory environments, ex ante distribution of dividends is known to the researcher, making it possible to conduct more powerful tests of the excess

volatility hypothesis. O'Brien and Srivastava (1991b) have reported some preliminary tests of this type on laboratory data on two-period securities. But they did not utilize the fact that ex ante distribution of dividends is known in laboratory data. Variance bound tests that utilize this advantage of laboratory data on long-lived assets should make a useful contribution to this open debate.

B. Arbitrage Relationships

In a great deal of efficient markets literature in finance, it has been held that the absence of arbitrage opportunities in the market implies that the price reflects all information available to the market participants. If the price at any time does not reflect the information, the argument goes, it would be possible for traders to make money through riskless arbitrage until the no-arbitrage condition holds. An important contribution of experimental work to finance has been a demonstration that the absence of arbitrage opportunities in a market *does not* imply informational efficiency.

Plott and Sunder (1982) subjected their transaction price data to three kinds of statistical tests—mechanical filter tests, serial correlation of log price changes, and frequency distribution of log price changes. All tests were applied to within-period transaction data. They found that certain statistical characteristics of field data are shared with the data generated in laboratory.

Tests on transaction price data from stock exchanges suggest that it is difficult to devise mechanical trading rules that consistently yield abnormally high returns (see Alexander 1964; Fama and Blume 1966). Plott and Sunder (1982) compared the performance of three trading rules: (1) Buy and hold: buy one certificate at the opening transaction price of each period and liquidate at the closing transaction price of the period; (2) Trend filter: Observe transaction price trend from opening to 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 the closing transaction price; (3) y -unit filter: If the transaction price goes up by y or more units, buy if necessary to hold one certificate until the price goes down by y or more units, at which time sell if necessary to maintain a short position of one certificate until the price goes up again by y or more units; liquidate at closing price. Three different filter sizes ($y = 1, 5, \text{ and } 25$) were used in these tests.¹²

For the single-period security used in these markets, equilibrium return over time is zero. However, the naive buy-and-hold strategy yields a positive return in early periods that declines to zero as the asset markets converge to rational expectations equilibrium. Trend, one franc, and five franc filters perform almost as well as the naive buy-and-hold strategy, and the twenty-five franc filter performs worse. However, all returns approach zero as the market converges to rational expectations equilibrium. Trading strategy based on the knowledge of the rational expectations equilibrium price yields positive returns.

Plott and Sunder (1982) found that the first order serial correlation of log price relatives $\log(P/P_{t-1})$ is insignificantly different from zero. The magnitude of serial correlation does not seem to be affected by the presence of disequilibrium

trades. All these tests suggest that serial dependence in price changes in data gathered from stock exchanges are shared by laboratory data for asset markets that converge to rational expectations equilibrium.

Plott and Sunder (1988) reported a surprising result when they applied similar filter tests to examine the transaction prices from series A markets that failed to converge to rational expectations equilibrium.¹³ They found that the filter rules fail to generate abnormal profits, even though we know that these markets failed to aggregate information and did not converge to rational expectations equilibrium. Even more important, a trading strategy based on full knowledge of rational expectations equilibrium price, when applied ex post to the data generated in the laboratory, fails to beat the naive buy and hold strategy. This paradoxical result obtains because these markets consistently failed to converge to rational expectations price. Trading on the assumption that the price will reach the rational expectations level is not profitable if the price never gets there. The data from series B and C markets (that converged to rational expectations equilibrium) also did not permit filter rules to earn abnormal returns, but yielded superior returns to strategies based on the knowledge of rational expectations equilibrium price. These results led them to conclude that statistical independence of security price changes or absence of arbitrage opportunities in the market is not a sufficient condition for informational efficiency of the markets that generate such data.

These results and conclusions about the lack of one-to-one mapping between absence of arbitrage profits and informational efficiency of asset markets were confirmed and strengthened by O'Brien and Srivastava (1991b) who applied three separate statistical tests to their data. First, they applied ex post filter tests to bids and asks available in the market (instead of applying them to transaction prices actually observed). Mechanical trading rules could not make money in these informationally inefficient markets. Second, they applied Dickey and Fuller's (1981) unit root test to their price series obtained from markets that failed to aggregate information. They could not reject the unit root hypothesis in informationally inefficient markets. Third, they showed that in one of their multisecurity markets, there existed a portfolio whose value in periods 1 and 2 would differ by a constant amount, independent of information about the realized state of the world. They presented evidence that these riskless arbitrage relationships held reasonably well in their data, even though the asset markets did not always aggregate information.

Empirical foundations of efficient market theory were built on the assumption that statistical testing of price data from markets would reveal any inefficiencies. Validity of this assumption has gone largely unchallenged; since we do not know the equilibrium price in a naturally occurring market at any given time, no serious challenge based on data gathered from the field was possible. With all their other limitations, laboratory markets allow the economist to gather data with the knowledge of equilibrium price under various theories and make comparisons that are impossible to make with the field data. Now that such comparisons are possible and being made, serious doubts have arisen about the assumed equation between statistical efficiency and informational or allocative efficiency of markets.

VI. Investment and Public Policy

When proposals are made to effect changes in existing trading mechanisms or to introduce new mechanisms, government and private policymakers must assess their possible consequences. Novelty of proposals precludes the use of historical data as a basis of forming an opinion in most cases. Market microstructure literature has developed in recent years to use analytical techniques to address such questions (see Gorman 1976; Mendelson 1982; Ho and Stoll 1983; Glosten and Milgrom 1983; Amihud et al. 1985; Kyle 1985; Cohen et al. 1986; Schwartz 1988, for examples). However, as games of incomplete information, even simple trading mechanisms are extraordinarily complex to analyze. Study of alternative designs and performance characteristics of trading institutions is a promising niche for experimental economics in finance. Experimental studies have revealed several results that are important not only for investment policy but also for the design of trading mechanisms, and the manner in which they are regulated. A few studies on these lines are reviewed below.

A. Trading Suspensions and Price Change Limits

Coursey and Dyl (1990) explored the effects of trading suspension and price change limits on price, volume, and efficiency of two-state asset markets similar to those used by Plott and Sunder (1982). After allowing normal trading for five periods, they suspended trading for the next five periods after shifting the probabilities of the two states by a degree unknown to the traders. During trading suspension, traders continued to observe the realized state and receive the resulting dividends. In Figure 6.11, period-wise median of transaction prices has been plotted. Results of the first market, which had no trading suspension, are shown by a solid line. In contrast, results for the market with trading suspension are shown with a dotted line. Both can be compared against the equilibrium benchmarks before and after the change in probabilities shown in a solid horizontal line. When trading resumed after suspension, transaction prices in these markets moved toward the new equilibrium level. However, adjustment of prices in markets without trading suspension was faster and more precise. Higher allocative efficiency was achieved in markets without trading suspension. Since the trading process itself is a part of the mechanism by which prices adjust to information, trading suspension does not promote such adjustment. Trading suspensions are often defended on the basis of their distributive consequences, to reduce the informational disadvantage of those who do not actively participate in the trading mechanism. This aspect of the consequences of trading suspensions remains to be explored.

Coursey and Dyl (1990) also examined the effect of imposing limits on the amount by which price could change in any single trading period. Again, they found that the imposition of a limit of 4 percent on the magnitude of price change

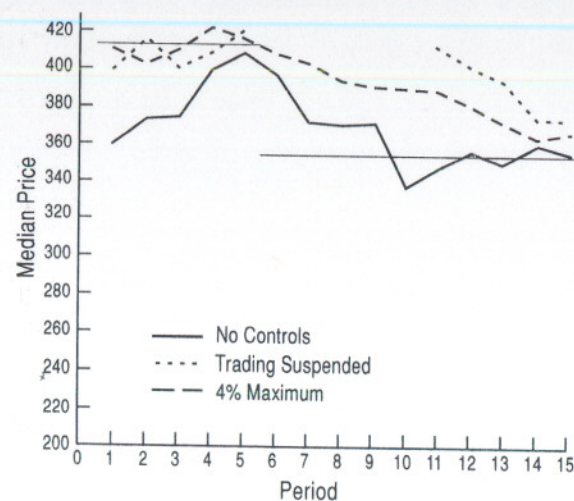


Figure 6.11. Effect of price change limits and trading suspensions in markets. Source: Coursey and Dyl 1990, figure 1.

from one period to the next slows down the process of adjustment of prices to information (unknown change in probabilities associated with dividends discussed in the previous paragraph) and reduces allocative efficiency (see dashed line in Figure 6.11). Other features of environments that may create demand for such limits (bankruptcy and default by margin traders, preferential access to information among geographically distributed traders) were absent in their research design and remain to be investigated.

B. Double Auction versus Call Market

Friedman (1993a) compared the performance of continuous double auction market and call market for Copeland and Friedman's (1993a) asset markets with uncertain dividends and asymmetric information. In a continuous double auction, a transaction is completed when an outstanding bid or ask is accepted by another trader; each period therefore consists of multiple bids, asks, and transactions, typically at different prices. In a call market, bids and asks are accumulated until some predetermined condition is fulfilled and the maximum possible number of transactions are simultaneously cleared at a single price per clearing.

Friedman (1993a) found that trading volume is higher in double auction, perhaps because the double auction allows each trader to be a gross buyer as well as a gross seller in the same period. Friedman (1993a) used three measures of efficiency to compare double auction and call markets. Actual transaction prices in a call market are closer (in root mean squared deviations) to the rational expectations price, than in a double auction. Call markets generate narrower bid/ask spreads, and their allocative efficiency is indistinguishable from the allocative efficiency of double auctions. Since most of the past work in asset markets has been done using only double auctions, these results may come as a surprise to

some experimentalists. Narrower bid/ask spreads of call markets are also inconsistent with the theoretical predictions of the Ho, Schwartz, and Whitcomb (1985) model.

Liu (1992) repeated Plott and Sunder (1988) experiments with computerized continuous and call auctions. She found that continuous double auctions are more efficient when all traders are endowed with diverse information; however, call auctions dominate when uninformed traders are present in the market along with diversely informed insiders. Van Boening et al. (1992) repeated Smith, Sucharek, and Williams' (1988) experiment in closed-book call markets and found little change in results. Williams and Walker (1993) conducted one open-book call market with 300 subjects, again with similar results. This line of research holds promise for further interesting results. While call markets may discover the equilibrium price more precisely, continuous double auctions may have the advantage of faster (albeit less precise) discovery of price during the inter-call periods when the call market leaves the price undefined.

C. Specialist Privileges and Book Display

Friedman (1993b) experimented with a variety of special privileges granted to one or more traders in double auctions or call markets. All privileges bring significant extra profits to their beneficiaries. The privileges tested in double auctions included (a) earlier receipt of order flow information, (b) ability to arbitrage crossing bids and asks submitted by the traders who receive order flow information with a time delay,¹⁴ and (c) ability to submit bids and asks while other traders are restricted to accept others' bids or offers. Allocative efficiency of the market as a whole increases slightly under (a) and (b) but declines under (c). In call markets, (a) last mover and (b) order flow access privileges are both modestly profitable and neither impairs allocative efficiency of the market. He also found that where timely order flow information was distributed to *all* traders in a call market; allocative efficiency of the market declined, probably due to strategic bidding behavior.

D. Control of Speculative Bubbles

King et al. (1990) examined the effect of several institutional factors on the propensity of the market to generate price bubbles in an environment that is known to generate bubbles. Nine to twelve traders have the opportunity to buy or sell a fifteen-period asset in each period of its life. The asset yields to its holder a dividend of 0, 8, 28, or 60¢ with equal probability each period. Equilibrium price of the asset starts at \$3.60 in the first period and declines each period in steps of \$0.24 to \$0.24 in the last period. Equilibrium trading volume is zero; all dividend information is common knowledge and there are no gains from trading. Yet this environment generates bubbles in the middle third of the trading periods (see discussion of Smith et al. [1988] in the section on bubbles above).

It might be argued that bubbles are created by over-optimistic traders, and

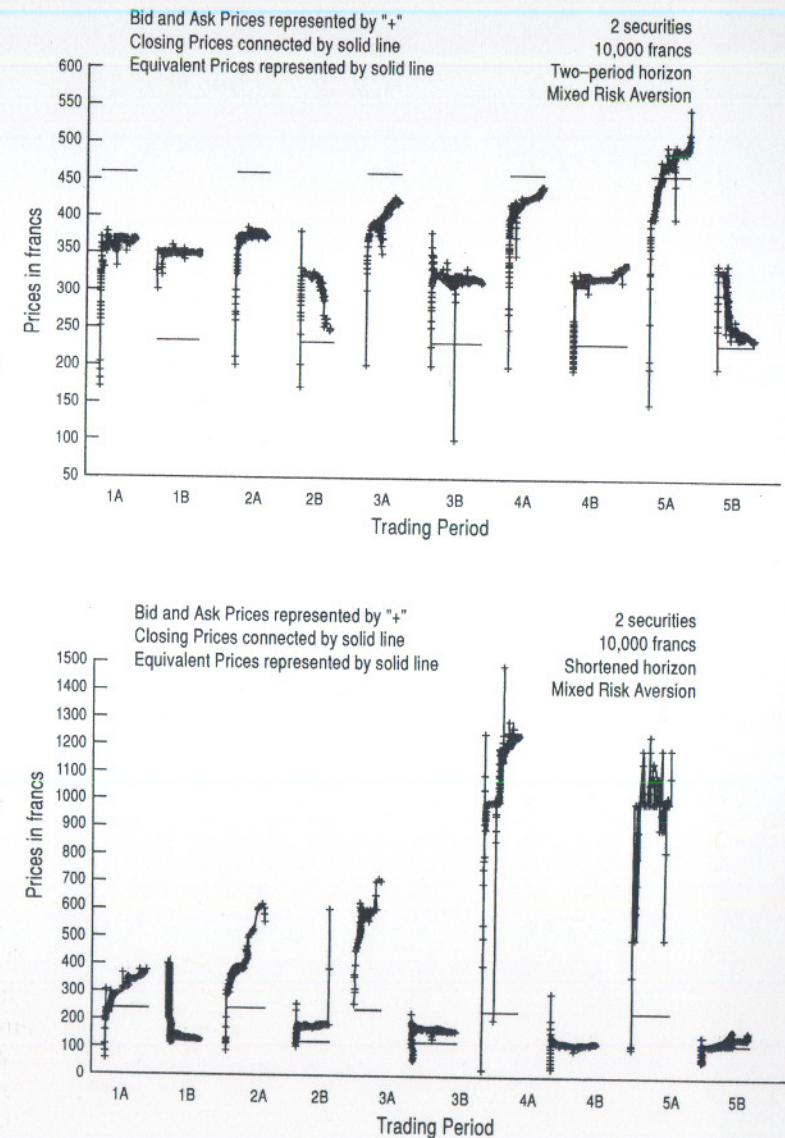


Figure 6.12. Bid, ask, close and equilibrium prices. *Source:* Ang and Schwarz 1992, figures 3 and 4.

introducing an opportunity to short sell would allow the better-informed traders to make money at the expense of the over-optimistic traders, and thus discipline them. Such disciplining won't occur if there were no traders who are better informed or willing to subject themselves to the higher risks of short sales.¹⁵ Further, depending on the timing of the short sale and cover trading, it is plausible that a scramble to cover at the last moment may create its own bubble.

Allowing traders to sell short (up to two units beyond their initial endowment

of two units each) does not reduce the number of periods for which bubbles last, nor does it cut the size of bubbles. Trading volume is increased even higher, further away from the equilibrium level of zero. Neither this evidence nor the evidence presented by Kluger and Wyatt (1991) or Rietz (1991) supports the widely-held idea that introducing opportunity to sell short reduces the incidence of bubbles in asset markets. The opportunity to buy on margin is conjectured to reduce formation of bubbles. King et al.'s experimental data does not support the idea that opportunity to buy on margin reduces bubbles. On the contrary, the size of bubbles in markets with inexperienced margin traders is even larger. Simultaneous introduction of margin buying and short sale opportunities seems to have no significant effect on the incidence of bubbles.

Transaction costs discourage trading and presumably work against the incidence of bubbles. However, when King et al. (1990) introduced significant transaction costs to their design, this treatment also had little effect.

Ang and Schwarz (1992) examined the conditions that may promote or inhibit formation of bubbles in asset markets. In their experiment, they modified the Forsythe, Palfrey, and Plott (1982) market for two-period assets (see the discussion of designing experimental asset markets above). They replaced certain dividends by uncertain dividends that depended on which of the two possible states of nature was realized in each period, and rotated the dividend types of individual subjects after each two-period trial. Their two-period asset life, being much shorter than the fifteen-period asset life in Smith, Suchanek, and Williams' (1988) and related experiments, allowed them to conduct five trials in each experimental session (versus only one in Smith, Suchanek, and Williams). Diversity of dividends and gains from trading meant that the traders had to learn the equilibrium prices from the market, even though their design had no information asymmetries like those used in Plott and Sunder (1982).

The upper panel of Figure 6.12 shows the bid/ask/transaction prices for the five two-period trials of one of their baseline markets (market 3). The horizontal lines show the risk neutral perfect foresight equilibria. By comparing these results with the upper panel of Figure 6.1, it is easily seen that the uncertainties introduced by randomness of dividends caused the convergence to perfect foresight equilibrium in their baseline markets to be slower and less precise than in Forsythe, Palfrey, and Plott (1982). The same is true relative to the results reported by Frank (1988).

Ang and Schwarz (1992) subjected their baseline design described above to three different treatments in three additional sets of sessions. In the first set, they offered significantly large additional bonus payments to subjects based on relative ranking of the sum of net change in their cash position plus the market value of their asset portfolio at the end of period A trading. This treatment was designed to shorten the investment horizon of traders along the lines of portfolio managers in the investment world. As can be seen in the lower panel of Figure 6.12, introduction of this extra incentive launched a wild bubble in period A that increased progressively over the five trials, even though period B prices converged close to risk neutral equilibrium. The size of such bubbles was only partially restrained when subjects were asked to play with twenty dollars of their own money. Will-

ingness to play with their own money raises the possibility that these subjects might be more risk-loving, or at least less risk averse, than others.

Ang and Schwarz (1992) conjectured that such bubbles may arise from the imbalance between buying and selling powers of subjects in laboratory experiments. Such imbalance is represented in the real world by short-sale restrictions and high costs, as well as by availability of credit to leverage long positions. In their second treatment, they modified their baseline design to equate the buying and selling power by increasing the asset endowment of traders and reducing the cash endowment until it is approximately equal to the market value of assets. In addition, they retained the short-term horizon bonus of the first treatment described above. In spite of this bonus, bubbles disappeared, and the asset was traded at a discount from risk neutral equilibrium in period A.

In their third treatment, Ang and Schwarz (1992) used Jackson Personality Inventory (1976) and Jackson, Houraney, and Vidmar (1972) tests to pre-screen subjects who were more averse to monetary risk (conservatives) from those who were less averse (speculators). They compared separate baseline sessions of conservatives and speculators against their performance when short-term horizon bonus was introduced. In baseline experiments, speculators traded in period A at a smaller discount than the conservatives did. Introduction of a short-term horizon bonus created a period A bubble in the speculator markets but not in the conservative market.

On the basis of these experiments, Ang and Schwarz (1992) conclude that short-term decision horizons of traders, market power imbalance in favor of buyers, and presence of traders who are inclined to take monetary risks promote formation of bubbles in asset markets. Removal of the short-term bonuses and the market power imbalance seems to be sufficient to eliminate them. They suggest that modifying regulatory environment so buyers as well as sellers face similar costs in implementing their ideas will reduce unnecessary volatility.

Rietz (1991) designed an experiment to test general equilibrium predictions for two-asset market in which each asset pays a simple dividend contingent on one of the two states with known probabilities. Aggregate payoff is identical across the states and all subjects can always eliminate their risk entirely, yielding an equilibrium price ratio of two assets equal to their ratio of the probabilities of states in which they yield a dividend. No-arbitrage restrictions give precise predictions about absolute prices, their sum, and asset allocations. The main advantage of this design is that in spite of aggregate uncertainty, absolute price levels—and, therefore, price bubbles—are well defined without need to specify traders' attitudes toward risk.

Rietz (1991) found that, on average, trading does facilitate risk sharing to the extent of about 60 percent of ideal, and relative price ratio generally corresponds to the ratio of the corresponding probabilities. However, absolute asset prices, and their sum, consistently exceed the predictions to form bubbles. These single-period asset market bubbles are persistent and cannot be explained if all subjects are expected utility maximizers. Bubbles create arbitrage opportunities that are seldom exploited, even after they are explained and pointed out to subjects. The

author explains the results in terms of decision regret. However, as Ang and Schwarz's (1992) and O'Brien and Srivastava's (1991a) experiments suggest, understanding and exploiting arbitrage trading opportunities may not come naturally from one or two sessions of trading experience.

E. Bid-Ask Spread

In theoretical models, bid-ask spread is shown to be increasing in uncertainty (Copeland and Galai 1983) and decreasing in trading volume (Glosten and Harris 1988). Both these hypotheses have been subjected to laboratory tests.

Copeland and Friedman (1987) compared the behavior of bid-ask spreads across periods, within periods, and across the moment of information arrival. They found that (1) the bid-ask spread narrows in later periods as subjects gain experience, (2) spreads narrow in the later part of trading periods as more traders receive information and prices converge to equilibrium, and (3) spreads widen immediately upon distribution of new information to subsets of traders creating information asymmetry. Overall, they concluded that their data support a positive relationship between uncertainty and bid-ask spreads.

Campbell et al. (1991) examined the effect of increasing uncertainty about the equilibrium price in perishable goods double auctions by adding a different random number to individual supply and demand schedules for each trading period. They found that, compared to markets in which supply and demand conditions remained stationary over periods, randomness increased the bid-ask spread.

O'Brien and Srivastava (1991b) compared the bid-ask spreads across the two period lives of their securities in which traders faced greater uncertainty in period 1 than in period 2. They found the spreads to be greater and, therefore, consistent with the uncertainty hypothesis. Bid-ask spreads are also found to be positively correlated with the mean absolute deviation of transaction prices from rational expectations equilibrium. Given the greater complexity of information structure, period 1 markets have greater difficulty in converging to rational expectations equilibrium, leaving the traders less certain about the state. They found no correlation between trading volume and bid-ask spread.

F. Off-Floor and Block Trading

In their experiment cited above, Campbell et al. (1991) also introduced the opportunity to conduct off-floor trades (that did not show as public data to the other traders) and block trades (three units or more per transaction, as compared to one unit per transaction for other traders). They observed a greater off-floor volume in markets that also exhibited wider bid-ask spreads, probably because of greater uncertainty in the environment. Introduction of opportunity to transact in blocks also caused off-floor trading to increase. Since most off-floor trades took place within the bid-ask spread, their data support "the hypothesis that a motive for such trades is to split privately the gain represented by the bid-ask spread without revealing publicly a willingness to make price concessions" (1).

VII. Laboratory Modeling of Asset Markets

In designing a laboratory economy, it is tempting to make it as similar as possible to the naturally occurring empirical phenomenon that the experimentalist wishes to explore. On the other hand, the experimentalist is attracted to making the laboratory economy resemble the formal or informal *models* of that phenomena. Reproducing the field environment inside the lab, or implementing the exact details of a formal model of that phenomena, is difficult, often impossible. Moreover, increasing the resemblance of the laboratory economy to the formal model may make it less similar to the field environment, and vice versa. What should an experimentalist do? Should he try to get as close to one, or the other, or should he try to strike a balance between the two? If so, how?

Let us consider the purpose and usefulness of modeling, the relationship between a phenomenon of substantive interest and its models, and the relationship among various models of the same phenomena. If realism were to be the dominant criterion for judging a model, each phenomena would be its own best model. There is only one real thing. The New York Stock Exchange is its own best model. Yet we *build* models. The Stock Exchange has been modeled in reporters' language, in regulators' rules, in statisticians' numbers, in mathematicians' equations, in artists' canvas and paint, in architects' drawings, in masons' bricks and stone, in scientists' computer programs, in photographers' film and video, and in economists' laboratories. Why do we build these models of the Exchange that we know do not capture all the reality of this complex entity? Why do we use so many different media for making "important" models of the real thing?

The demand for models arises from the finiteness of our own capacity either to perceive or to comprehend all aspects of the infinitely complex reality. A few sentences on the evening television news, a few columns in the morning newspaper, or an equation or a graph in a book of economics abstract the infinite details of the day's events into a comprehensible model of these events. Mapping from reality to model is not necessarily unique, even for a given modeling medium. For any given purpose, we choose or build a model that serves us satisfactorily.

The value of a model is judged by how well it captures the chosen aspect of the reality *and* by how completely it discards all other aspects of reality as unwanted details. Its value lies in simplicity, not in complexity. What is an essential factor in a model built for one purpose, is unessential detail in another model of the same reality.

The choice of the modeling medium depends on what aspect of the reality is considered essential to the purpose of building the model. Different media are able to capture different aspects of the reality well. Mathematics and laboratory are two of the media used in economics, just as paint and marble are two of the media used by artists to model a person. While paint on canvas can capture the color better, marble has the advantage of capturing the space. While a sculptor may use a painting or photograph for help or inspiration, her art will still be seen in relation to its principal subject.

Similarly, mathematics and a laboratory populated by human subjects have different advantages, and disadvantages, in modeling different aspects of economic reality. While laboratory modeling is often assisted, even inspired by the great deal of mathematical models already available, evaluating laboratory work in terms of its fidelity to the mathematical model is just as sterile as evaluating a sculpture in relation to a photograph. Laboratory work can and does yield insights into economic phenomena that cannot be obtained analytically. The reverse is also true. Potential to yield such insights is a suitable evaluation criterion.

Limitations of each modeling medium force the development of standard operating procedures or routine assumptions in each field. This is certainly true of formal analytical modeling and laboratory modeling in economics. Identification of these limitations becomes especially important when one takes an analytical model and "tests" it with data in the laboratory or field. It is essential that the experimentalist, in seeking guidance from an analytical model, separate methodological conveniences from the essential aspects of the economic field environment that he wishes to explore, and discard the former before setting out to construct the laboratory model.

Laboratory modeling of asset markets differs from equity and commodity futures markets in the field in three important respects. First, most laboratory markets use one- or two-period assets, and re-endow the traders at the end of each one or two-period cycle. This design enables subjects to learn through repetition over periods; it also reduces, without eliminating, the possibility of developing speculative bubbles in asset markets. Second, the traders are typically divided into two or more types of investors, and a different set of dividend values is assigned to each type of trader in order to create gains from trading under perfect information and to make it possible to define and measure allocative efficiency of these markets in a meaningful way.

Heterogenous redemption values have a natural interpretation in commodity spot markets; a car manufacturer may get a different value from a sheet of steel than a furniture manufacturer does. In laboratory models of asset markets this heterogeneity is frequently justified by the possibility of different tax rates, consumption patterns, or attitudes toward risk for different traders. However, a great deal of trading in capital markets is driven by differences in the traders' beliefs and information about the investment and production processes that underlie the capital markets. After all, the allocative efficiency of capital markets can only be judged relative to the allocation of capital among competing investments. Assignment of heterogenous dividends to traders in laboratory asset markets is a convenient modeling technique that encapsulates the traders' beliefs and information about this investment and production process.

The third, and perhaps the most important, abstraction in laboratory models of capital markets is the use of a small number of discrete states of the world to create uncertain environments. A small number of discrete states permit the traders to observe and learn the state-price correspondence within some ten or twenty replications of a typical laboratory session. Learning this correspondence for a

larger number of discrete states, or for a continuum of states, may require more experience than is possible within the laboratory environment. This abstraction raises some thorny problems about some generalizations.

Unlike commodity markets where each trader is assigned the role of a buyer or a seller, asset markets permit traders to transact in both directions. Three implications follow from the duality of traders' role. First, traders' profits include capital gains and losses in addition to the usual margin on the units sold (relative to their cost) and on the units bought (relative to their redemption value, usually labeled "dividends" in asset markets). Second, the opportunity to speculate is accompanied by the possibility of bankruptcy, creating the problem of enforceable and credible payoffs to the participating subjects. Third, unless the costs, redemption values, or information are varied across traders, these markets have no gains from trading and their allocative efficiency is undefined.

VIII. Concluding Remarks

What has been learned from the experimental work with asset markets?

First, dissemination and aggregation of information through the trading mechanism alone (as opposed to conversations among traders, or news) is possible. Rational expectations equilibrium, requiring the seemingly impossible bootstrap operation of learning from one's own creation, is an observable, reproducible phenomena of regular empirical characteristics. One may still argue that such phenomena cannot occur in a specific market environment, but it is no longer possible to dispute its existence in general.

Second, it is no longer defensible to argue that rational expectations can be achieved instantaneously, or precisely, or without replication. Nor is it defensible to argue that such equilibria are achieved in all market environments.

Third, the absence of arbitrage opportunities in the market is not a *sufficient* condition for informational or allocative efficiency of a market. From the predicate—if a market were not allocatively and informationally efficient, some participant would have incentive to exploit this inefficiency—one cannot deduce that all markets must be efficient. A trader may have the information and the incentives but not the means of doing so. Conditions under which the rational expectations bootstrap works remain to be fully understood. Dimensionality of market signals in relation to the size of the state space, ex post observability of realized states, and stationarity of the market environment seem to be important features that promote efficiency.

Fourth, formation of individual expectations and beliefs in economically rich environments of asset markets is a complex, diverse, perhaps even unstable, phenomenon. Statistical laws that may capture the important systematic features of expectation formation in market settings remain to be identified.

Finally, the experimental method has already been shown to be a valuable tool that helps refine our understanding of asset markets. Using this tool in judicious

conjunction with theoretical analysis and field data will yield insights into poorly understood aspects of asset market behavior such as formation of bubbles, stability of markets, impact of insider trading, and of alternative regulatory policies and trading institutions.

Notes

*Comments from Colin Camerer, Robyn Dawes, John Kagel, Alvin Roth, Vernon L. Smith, Charles R. Plott, Brian Kluger, Edward Dyl, Dan Friedman, Ron King, and Russ Lundholm on earlier versions of this chapter are gratefully acknowledged. Financial support for this research was provided by Margaret and Richard M. Cyert Family Funds and by the National Science Foundation under Contract SES-8912552.

1. If the realized state was X (prior probability 1/3), the subjects saw a string of ten binary digits drawn with replacement from an urn which contained 4 zeros and 1 one. If the realization was Y (prior probability 2/3), the string of ten binary digits was drawn from an urn containing 3 zeros and 2 ones. Thus, the string presented to subjects could contain anywhere from 0 to 11 ones, yielding eleven distinct Bayesian posterior probabilities of X ranging from .90 (for 0 ones) to 0.0005 (for 10 ones), and eleven distinct rational expectations equilibrium prices ranging from 262 to 350. Also see Liu (1992).
2. I return to this topic in the section on bubbles and false equilibria.
3. The design of asset markets used in this experiment was identical to the Plott and Sunder (1982) design described in the section on information dissemination and Table 6.1. Plott and Sunder (1982) gave information about the realized state of the world to some traders for free before trading opened in the asset market; in contrast, Sunder (1992) sold this information to traders. In the first set of markets, the four highest bidders bought information at the fifth highest bid price through a sealed bid auction. In the second set of markets, all those who wished to could buy information a price announced in advance by the experimenter.
4. Copeland and Friedman's experiment was subdivided into four equal subperiods of 60 seconds each. Under "Simultaneous" treatment, all traders received information simultaneously at the beginning of one of the subperiods; under "Sequential" treatment, different traders received information at the beginning of different subperiods. All traders in a market were divided into three groups of "clones." Under "Homogenous" treatment, the realized state of the world for each period (i.e., the good/bad dividend payout from the asset) was identical across the three groups; under "Heterogenous" treatment, the dividend payout for each group was independent of the other groups. Thus, they used a 2 × 2 experimental design (*Sim* vs. *Seq* and *Hom* vs. *Het*). The first cell of this design (the *Sim/Hom* treatment) is the simple design comparable to Sunder's (1992). The other three cells represent more complex settings.
5. Ang and Schwarz (1985, 840) also reached a similar conclusion on the basis of their laboratory experiment: "Thus, the role of speculators may not be entirely dysfunctional, nor is greater price volatility necessarily harmful."
6. Since allocative efficiency of a market depends not on price but on the identity of the buyers and sellers, faster convergence to perfect foresight equilibrium price is not necessarily inconsistent with reduced efficiency.
7. See Flood and Garber (1980), Hamilton and Whiteman (1988), and Flood and Hoderick (1990).
8. See Camerer (1989) for a survey of bubbles and fads literature, as well as its relationship with some of the early experimental work. Also, the Spring 1990 (Vol. 4, No. 2) issue of the *Journal of Economic Perspectives* carried a symposium on bubbles, including a brief overview by Joseph G. Stiglitz.
9. Given the finite number of traders in the market, this information monopolist (unlike Kyle's

1985) had no incentive to reveal the information through his trading activity by the end of the period.

10. See Friedman (1984, 64) for the famous anecdote concerning stock manipulation in London by Nathan Rothschild at the time of the Battle of Waterloo.
11. See Duh and Sunder (1986, 1994), Camerer (1990), and Anderson and Sunder (1995) for a discussion of the use of representativeness heuristic in experimental markets.
12. As is the practice with applications of filter rules in research studies with field data, Plott and Sunder (1982) also applied the filter tests to the data ex post. Buying and selling (including short selling) is assumed to have no effect on the market. Thus, the fact that taking short positions is constrained under rules of the market does not preclude researchers from testing the filter rules that generate short sales.
13. See the section on aggregation of information above for description of markets in series A, B, and C.
14. When traders do not have up-to-the-second information on the inside spread, the specialist may receive a bid that exceeds the inside ask or an ask that is below the inside bid.
15. The short sellers were required to cover their shorts before the end of the last period of the asset life, and failure to cover carried a substantial fine.

Bibliography

- Alexander, Sidney. S. 1961. Price movements in speculative markets: Trends or random walks. *Industrial Management Review* 2:7-26.
- . 1964. Price movements in speculative markets: Trends or random walks, no. 2. *Industrial Management Review* 5:25-46.
- Amihud, Y., Thomas S. Y. Ho, and Robert A. Schwartz, editors. 1985. *Market making and the changing structure of the securities industry*. New York: Lexington Books.
- Anderson, Matthew J., and Shyam Sunder. 1995. Professional Traders as Intuitive Bayesians. *Organizational Behavior and Human Development Processes* (forthcoming).
- Anderson, Scott, David Johnston, James Walker, and Arlington Williams. 1991. The efficiency of experimental asset markets: Empirical robustness and subject sophistication. In *Research in experimental economics*, vol. 4, Mark Isaac, editor, Greenwich, Conn.: JAI Press. 107-90.
- Ang, James S., and Thomas Schwarz. 1985. Risk aversion and information structure: An experimental study of price volatility in the security markets. *Journal of Finance* 40:824-44.
- . 1992. The formation and control of asset bubbles: An experimental study. Working paper. Southern Illinois University and Florida State University. November.
- Bachelier, M. L. 1900. *Theorie de la speculation*. Paris: Gauthier-Villars.
- Banks, Jeffrey S. 1985. Price-conveyed information versus observed insider behavior: A note on rational expectations convergence. *Journal of Political Economy* 93:807-15.
- Beja, A. 1976. The limited information efficiency of market processes. Working paper. University of California.
- Black, Fischer. 1986. Noise. *Journal of Finance* 41 (July): 529-43.
- Bronfman, Corinne. 1990. Expectation formation and price fluctuations in laboratory asset markets. Working paper. University of Arizona. June.
- Camerer, Colin. 1989. Bubbles and fads in asset prices. *Journal of Economic Surveys* 3:3-41.
- . 1990. Do markets correct biases in probability judgment? Evidence from market experiments. In *Advances in behavioral economics*, vol. 2, John Kagel and L. Green, editors, Norwood, N.J.: Ablex. 126-172.
- Camerer, Colin, and Keith Weigelt. 1985. Non-price information in the rational expectations of asset traders: Some experimental results. Working paper. University of Pennsylvania.
- . 1990a. Bubbles and convergence in experimental markets for infinitely-lived assets. Working paper. University of Pennsylvania.

- Camerer, Colin, and Keith Weigelt. 1990b. Information mirages in experimental asset markets. Working paper. University of Pennsylvania.
- Campbell, Joseph, Shawn LaMaster, Vernon L. Smith, and Mark Van Boening. 1991. Off-floor trading, disintegration, and the bid-ask spread in experimental markets. Forthcoming in *Journal of Business*.
- Cohen, Kalman J., Steven F. Maier, Robert A. Schwartz, and David K. Whitcomb. 1986. *The microstructure of securities markets*. Englewood Cliffs, N.J.: Prentice-Hall.
- Cootner, Paul A., editor. 1964. *The random character of stock market prices*. Cambridge, Mass.: MIT Press.
- Copeland, Thomas E. 1975. A model of asset trading under sequential information arrival. *Journal of Finance* 30:1149-68.
- Copeland, Thomas E. and Daniel Friedman. 1987. The effect of sequential information arrival on asset prices: An experimental study. *Journal of Finance* 42:763-98.
- . 1991. Partial revelation of information in experimental asset markets. *Journal of Finance* 46:265-81.
- . 1992. The market value of information: Some experimental results. *Journal of Business* 65:241-66.
- Copeland, Thomas E., and Dan Galai. 1983. Information effects of the bid-ask spread. *Journal of Finance* 38:1457-69.
- Coursey, Don L., and Edward A. Dyl. 1990. Price limits, trading suspensions, and the adjustment of prices to new information. *Review of Futures Markets* 9:343-60.
- Cox, C. C. 1976. Futures trading and market information. *Journal of Political Economy* 84:1215-37.
- Daniels, Brian P. and Charles R. Plott. 1988. Inflation and expectations in experimental markets. Working paper. California Institute of Technology.
- Danthine, Jean-Pierre. 1978. Information, futures prices, and stabilizing speculation. *Journal of Economic Theory* 17:79-98.
- DeJong, D., R. Forsythe, R. Lundholm, and S. Watts. 1991. Do prices convey information: Further experimental evidence. In *Research in experimental economics*, Mark Isaac, editor, Greenwich, Conn. JAI Press.
- Dickey, D. A., and W. A. Fuller. 1981. Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica* 49:1057-71.
- Duh, Rong Ruey, and Shyam Sunder. 1986. Incentives, learning, and processing of information in a market environment: An examination of the base-rate fallacy. In *Laboratory market research*, Shane Moriarty, editor, University of Oklahoma, Center for Economic and Management Research.
- Duh, Rong-Ruey, and Shyam Sunder. 1994. El agente económico como un Bayesiano intuitivo: Evidencia experimental (Economic agents as intuitive bayesians: Experimental evidence). *Cuadernos Economicos De ICE* 54 (1993-1992): 101-28.
- Easley, David, and John O. Ledyard. 1992. Theories of price formation and exchange in oral auctions. In *The double auction market: Institutions, theories, and evidence*, D. Friedman and J. Rust, editors, Santa Fe Institute Series in the Sciences of the Complexity, Proceedings vol. XV, New York: Addison-Wesley.
- Eberwein, Curtis J. 1990. Information aggregation under differing information structures: Some preliminary results. Working paper. University of Pittsburgh.
- Evans, G. W. 1989. On the fragility of sunspots and bubbles. *Journal of Monetary Economics* 23:297-317.
- Fama, Eugene F. 1965. The behavior of stock market prices. *Journal of Business* 38:34-105.
- . 1970. Efficient capital markets: A review of theory and empirical work. *Journal of Finance* 25:383-417.
- . 1990. Efficient capital markets: II. CRSP Working paper 303. University of Chicago. December.
- Fama, E. F., and Marshall E. Blume. 1966. Filter rules and stock-market trading. *Journal of Business* 39:226-41.

- Flood, Robert P., and Peter M. Garber. 1980. Market fundamentals versus price-level bubbles: The first tests. *Journal of Political Economy* 88:745-70.
- Flood, Robert P., and Robert J. Hoderick. 1990. On testing for speculative bubbles. *Journal of Economic Perspectives* 4:85-101.
- Forsythe, Robert, and Russell Lundholm, 1990. Information aggregation in an experimental market. *Econometrica* 58:309-47.
- Forsythe, Robert, Thomas R. Palfrey, and Charles R. Plott. 1982. Asset valuation in an experimental market. *Econometrica* 50:537-68.
- . 1984. Futures markets and informational efficiency: A laboratory examination. *Journal of Finance* 39:955-81.
- Frank, Murray. 1988. Asset trading in computerized experimental markets. Working paper. University of British Columbia. June.
- Friedman, Daniel. 1984. On the efficiency of experimental double auction markets. *American Economic Review* 74:60-72.
- . 1993a. How trading institutions affect financial market performance: Some laboratory evidence. Forthcoming in *Economic Inquiry*.
- . 1993b. Privileged Traders and asset market efficiency: A laboratory study. Forthcoming in *Journal Financial & Quantitative Analysis*.
- Friedman, Daniel, Glenn Harrison, and J. Salmon. 1983. Informational role of futures markets and learning behavior—Some experimental evidence. In *Futures markets—modelling, managing and monitoring futures trading*, M. E. Streit, editor, Oxford: Basil Blackwell.
- . 1984. The informational efficiency of experimental asset markets. *Journal of Political Economy* 92:349-408.
- Friedman, Daniel, and Shyam Sunder. 1994. *Experimental methods: A primer for Economists*. Cambridge, U.K., and New York: Cambridge University Press.
- Glosten, L., and L. Harris. 1988. Estimating the components of the bid-ask spread. *Journal of Financial Economics* 21:123-42.
- Glosten, Lawrence, and Paul Milgrom. 1983. Bid, ask and transaction prices in a specialist market with heterogeneously informed traders. *Journal of Financial Economics* 9:71-100.
- Gode, Dhananjay K., and Shyam Sunder. 1993a. Lower bounds for efficiency of surplus extraction in double auctions. In *The double auction market: Institutions, theories, and evidence*, D. Friedman and J. Rust, editors, Santa Fe Institute Series in the Sciences of the Complexity, Proceedings vol. 15, New York: Addison-Wesley. 199-219.
- . 1993b. Allocative efficiency of markets with zero intelligence traders: Markets as a partial substitute for individual rationality. *Journal of Political Economy* 101:119-37.
- . 1994. Human and artificially intelligent traders in a double auction market: Experimental evidence. In *Computational organization theory*, Kathleen Carley and Michael Prietula, editors, Hillsdale, N.J.: Lawrence Erlbaum Associates. 241-62.
- Gorman, Mark B. 1976. Market microstructure. *Journal of Financial Economics* 3 (June).
- Gray, Roger W. 1977. Onions revisited. *Journal of Farm Economics* 65:273-76.
- Grossman, S. J. 1976. On the efficiency of competitive stock markets where traders have diverse information. *Journal of Finance* 31:573-85.
- . 1977. The existence of futures markets, noisy rational expectations, and informational externalities. *Review of Economic Studies* 44:431-49.
- . 1981. An introduction to the theory of rational expectations under asymmetric information. *Review of Economic Studies* 48:541-59.
- Grossman, S., and J. Stiglitz. 1980. On the impossibility of informationally efficient markets. *American Economic Review* 70:393-408.
- Hamilton, James D., and Charles H. Whiteman. 1988. The observable implications of self-fulfilling expectations. *Journal of Monetary Economics* 16:353-74.
- Hayek, F. A. 1945. The use of knowledge in society. *American Economic Review* 35:519-30.
- Hellwig, M. F. 1980. On the aggregation of information in competitive markets. *Journal of Economic Theory* 22:477-98.
- Hicks, John R. 1939. *Value and capital*. Oxford: Oxford University Press.

- Ho, Thomas S. Y., and Hans Stoll. 1983. The dynamics of dealers markets under competition. *Journal of Finance* 38:1053-74.
- Ho, Thomas S. Y., Robert A. Schwartz, and David K. Whitcomb. 1985. The trading decision and market clearing under transaction price uncertainty. *Journal of Finance* 40:21-42.
- Jackson, Douglas. 1976. *Jackson personality inventory manual*. Goshen, N.Y.: Research Psychologists Press.
- Jackson, Douglas, D. Hourney, and N. Vidmar. 1972. A four-dimensional interpretation of risk taking. *Journal of Personality* 40:433-501.
- Jennings, R., John Fellingham, and L. Starks. 1981. An equilibrium model of asset trading with sequential information arrival. *Journal of Finance* 36:143-161.
- Jennings, R., and L. Starks. 1986. Earnings announcements, stock price adjustment, and the existence of option markets. *Journal of Finance* 41:107-25.
- Jordan, James S. 1982. A dynamic model of expectations equilibrium. *Journal of Economic Theory* 28:235-54.
- Kendall, M. G. 1953. The analysis of economic time series—Part I: Prices. *Journal of the Royal Statistical Society (Series A)* 96:11-25.
- Keynes, John Maynard. 1936. *The general theory of employment, interest and money*. New York: Harcourt Brace.
- King, Ronald R. 1987. Noisy rational expectations equilibrium in experimental markets. Working paper. Washington University. October.
- . 1990. Private information acquisition in experimental markets prone to bubble and crash. Working paper. Washington University.
- King, Ronald R., Vernon L. Smith, Arlington W. Williams, and Mark Van Boening. 1990. The robustness of bubbles and crashes in experimental stock markets. Forthcoming in *Journal of Economic Behavior and Organization*.
- Kluger, Brian D., and Steve B. Wyatt. 1990. Options and efficiency: Some experimental evidence. Working paper. University of Cincinnati.
- . 1991. Noise and the information aggregation process. Working paper. University of Cincinnati. December.
- Kobayashi, Takao. 1977. A convergence theorem of rational expectations equilibrium with price information. Working paper No. 79, IMSSS. Stanford University.
- Kruse, Jamie, and Shyam Sunder. 1988. Common knowledge and information dissemination. Carnegie Mellon University.
- Kyle, Albert. 1985. Continuous auctions and insider trading. *Econometrica* 1315-35.
- LeRoy, Stephen F., and R. Porter. 1981. The present value relation: Tests based on implied variance bounds. *Econometrica* 49:555-74.
- Lim, Suk S., Edward C. Prescott, and Shyam Sunder. 1994. Stationary solution to the overlapping generations model of fiat money: Experimental evidence. *Empirical Economics* 19 (No. 2):255-77.
- Liu, Yu-Jane. 1992. Auction mechanisms and information structure: An experimental study of information aggregation in security markets. Mimeo. National Chung Cheng University (Taiwan).
- Lundholm, Russell J. 1986. Information asymmetry and capital market behavior: Some evidence from a laboratory market setting. In *Laboratory Market Research*, Shane Moriarty, editor, Norman, Okla.: University of Oklahoma Press.
- . 1991. What affects the efficiency of the market? Some answers from the laboratory. *The Accounting Review* 66:486-515.
- Lucas, Robert E. 1972. Expectations and the neutrality of money. *Journal of Economic Theory* 4:103-24.
- Manaster, S., and R. Rendleman. 1982. Option prices as predictors of equilibrium stock prices. *Journal of Finance* 37:1043-57.
- Marimon, Ramon, Stephen E. Spear, and Shyam Sunder. 1993. Expectationally-driven market volatility: An experimental study. *Journal of Economic Theory* 61 (No. 1): 74-103.

- Marimon, Ramon, and Shyam Sunder. 1993. Indeterminacy of equilibria in a hyperinflationary world: Experimental evidence. *Econometrica* 61 (No. 5): 1073-1108.
- . 1994. Expectations and learning under alternative monetary regimes: An experimental approach. *Economic Theory* 4:131-62.
- Marsh, Terry A., and Robert C. Merton. 1986. Dividend variability and variance bounds tests for rationality of stock market prices. *American Economic Review* 76:483-98.
- McCabe, Kevin A. 1989. Fiat money as a store of value in an experimental trading game. *Journal of Economic Behavior and Organization* 12:215-31.
- Mendelson, Haim. 1982. Market behavior in a clearing house. *Econometrica* 50:1505-24.
- Milgrom, Paul. 1981. Rational expectations, information acquisition, and competitive bidding. *Econometrica* 49:921-44.
- Miller, R. M., Charles R. Plott, and Vernon L. Smith. 1977. Intertemporal competitive equilibrium: An empirical study of speculation. *Quarterly Journal of Economics* 91:599-624.
- Morse, Dale. 1980. Asymmetrical information in security markets and trading volume. *Journal of Finance and Quantitative Analysis* 15:1129-48.
- Muth, John. 1961. Rational expectations and the theory of price movements. *Econometrica* 29:315-35.
- O'Brien, John. 1990. The formation of expectations and periodic ex post reporting: An experimental study. Working paper. Carnegie Mellon University.
- O'Brien, John, and Sanjay Srivastava. 1991a. Liquidity and persistence of Arbitrage in experimental options markets. In *The double auction market: Institutions, theories, and evidence*, D. Friedman and J. Rust, editors, Santa Fe Institute Series in the Sciences of the Complexity, Proceedings Vol. XV New York: Addison-Wesley.
- . 1991b. Dynamic stock markets with multiple assets: An experimental analysis. *Journal of Finance* 46:1811-38.
- . 1991c. Arbitrage and informational efficiency: Theory and experimental evidence. Working paper. Carnegie Mellon University. March.
- Plott, Charles R., and Shyam Sunder. 1982. Efficiency of experimental security markets with insider information: An application of rational-expectations models. *Journal of Political Economy* 90:663-98.
- . 1988. Rational expectations and the aggregation of diverse information in laboratory security markets. *Econometrica* 56:1085-1118.
- Plott, Charles R., and Jonathan T. Uhl. 1981. Competitive equilibrium with middlemen: An empirical study. *Southern Economic Journal* 47:1063-71.
- Porter, David, and Vernon L. Smith. 1989. Stock market bubbles in the laboratory. Working paper. University of Arizona.
- Powers, Mark J. 1970. Does futures trading reduce fluctuations in the cash markets? *American Economic Review* 60:460-64.
- Rietz, Thomas A. 1991. Arbitrage, asset prices and risk allocation in experimental markets. Working papers. Northwestern University. November.
- Roberts, Harry V. 1959. Stock market patterns and financial analysis: Methodological suggestions. *Journal of Finance* 14:1-10.
- Ross, Stephen. 1976. Options and efficiency. *Quarterly Journal of Economics* 90:75-89.
- Samuelson, Paul A. 1965. Proof that properly anticipated prices fluctuate randomly. *Industrial Management Review* 6:41-50.
- Schwartz, Robert A. 1988. *Equity markets: Structure, trading and performance*. New York: Harper & Row.
- Shiller, Robert. 1981. Do stock prices move too much to be justified by subsequent changes in dividends? *American Economic Review* 71:421-36.
- . 1986. Comments on Miller and on Kleidon. *Journal of Business* 59:S501-S505.
- Smith, Vernon L. 1962. An experimental study of competitive market behavior. *Journal of Political Economy* 70:111-37.

- Smith, Vernon L., Gerry L. Suchanek, and Arlington W. Williams. 1988. Bubbles, crashes, and endogenous expectations in experimental spot asset markets. *Econometrica* 56(6):1119–52.
- Sunder, Shyam. 1984. Rational expectations equilibrium in asset markets with costly information. Working paper. University of Minnesota.
- . 1991. An introduction to design, planning and conduct of asset market experiments. Working paper, Carnegie Mellon University, February 1991.
- . 1992. Market for information: Experimental evidence. *Econometrica* 60:667–95.
- Svensson, L.E.O. 1976. Sequences of Temporary Equilibria, Stationary Point Expectations, and Pareto Efficiency. *Journal of Economic Theory* 13:169–83.
- Tirole, Jean. 1982. On the possibility of speculation under rational expectations. *Econometrica* 50:1163–81.
- Tomek, William G. 1971. A note on historical wheat prices and futures trading. *Food Research Institute Studies* 10:109–13.
- Van Boening, Mark, Arlington W. Williams, and Shawn LaMaster. 1992. Price bubbles and crashes in experimental call markets. Working paper. Indiana University.
- Verrecchia, Robert. 1982. Information acquisition in a noisy rational expectations economy. *Econometrica* 50:1415–30.
- Von Borries, Alexander, and Daniel Friedman. 1989. Monopolist insiders in computerized asset markets: A note on some experimental results. Working paper. University of California at Santa Cruz.
- Watts, Susan. 1993. Private information, prices, asset allocation and profits: Further experimental evidence. In *Research in experimental economics*, vol. 5, Mark Isaac, editor, Greenwich, Conn.: JAI Press.
- Williams, Arlington W., and James M. Walker. 1993. Computerized laboratory exercises for microeconomic education: Three applications motivated by the methodology of experimental economics. Forthcoming in *The Journal of Economic Education*.
- Wilson, Robert. 1982. Double auctions. Unpublished manuscript. Stanford University.
- Working, Holbrook. 1960. Price effects of futures trading. *Food Research Institute Studies* 1:3–31.

Auctions: A Survey of Experimental Research

John H. Kagel

Introduction

Auctions are of considerable practical as well as theoretical importance. In practical terms, the value of goods exchanged each year by auctions is huge. In theoretical terms, auctions play a prominent role in the theory of exchange as they remain one of the simplest and most familiar means of price determination in the absence of intermediate market makers. In addition, auctions serve as valuable illustrations of games of incomplete information as bidders' private information is the main factor affecting strategic behavior (Wilson 1992).

In organizing this survey I have relied heavily on Wilson's (1992) and McAfee and McMillan's (1987a) surveys of auction theory. That is, I have chosen to review series of auction experiments that deal with theoretical issues, along with follow-on experiments designed to sort out between competing explanations of the behavior observed. This serves to circumscribe greatly the literature reviewed.

There are two main strands to the literature: private value auctions, where bidders know the value of the item to themselves with certainty, and common value auctions, where the value of the item is the same to everyone, but different bidders have different information about the underlying value. This review is almost exclusively concerned with one-sided auctions, auctions in which there are many buyers and one seller or many sellers and one buyer. Two-sided auctions with many sellers and many buyers are not nearly as well understood theoretically and for this reason have not received the same kind of attention in terms of theory testing as one-sided auctions. (However, see Holt, chapter 5, and Sunder, chapter 6, for the many uses of two-sided auctions in industrial organization experiments and asset market experiments, respectively.)

Part I reviews private value auction experiments. The experimental procedures employed are characterized in section I.A. Section I.B focuses on the Revenue-Equivalence Theorem: In auctions with independently distributed private values,