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Distinguished Guest Lecture

Markets as Information Gathering Tools

Charles R. Plott*

The academic literature, Wall Street commentary, and even daily news reporting reflect a belief that markets can anticipate events. The current movements in the stock market are interpreted as reflecting the likelihood that the Federal Reserve System will change interest rates. Futures markets are interpreted as reflecting the best estimates of things to come. Movements in individual stock prices are thought to anticipate earnings reports or the probability of a merger or buyout. If we want to know about future weather in the South, we should study the orange juice futures. The academic journals are filled with the concept of rational expectations in which current prices are supposed to reflect the sum of all knowledge in the system. Prices, according to this theory, are a statistic that indicates the aggregation of information about underlying states of the economy. Those who are ''outsiders'' to the information in the system become ''insiders'' by simply observing the economic activity.

While such beliefs are pervasive, there is a need to pause and ask ourselves what it means for markets to have such capacities. First, it means that markets can find the solution to a complex set of equations that are part of the knowledge of no one. Second, it means that while finding this solution, it can collect information that is dispersed across the economy, aggregate it like a statistician, and publish the findings in the form of the prices.

Why do the commonly held notions imply such complexity? According to received theory, an economy is best described as a large set of nonlinear, simultaneous equations. Equilibrium is just a solution to the set, the ''zeros'' so to speak. Of course, no one knows what these equations are since the information that forms the equations is typically known only to the individual agents in the economy. Thus, the information about the equations is not in one head, but there is even more information that must be collected. Each individual has private information about the world around him. Expectations based on this private information are sufficient for decisions so long as such expectations are not inconsistent with other information reflected in the behavior of the economy, such as prices. If prices or other variables contain additional

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information, the behavior of the individual will change, pushing the system to a different form of equilibrium. Equilibration will not occur until all information is comfortably incorporated in the publicly observable variables. When the additional information property is added, the computation is challenging indeed. Even if the equations were known to individuals, finding a solution (in finite time) might be very challenging to even the most numerically inclined applied mathematician.

On the surface, the idea that markets can perform such aggregation seems to be false. It seems to be beyond human capacities. One is tempted to dismiss the theory immediately, without further thought. However, such dismissal would be premature. The capacities to infer underlying information from the behavior of others is so commonplace that we hardly notice the complex process that is taking place. When searching for a restaurant in an unfamiliar area, people typically look to see where many others are eating. If one stands and looks into a store window, those passing on the sidewalk will frequently pause to look also. When judging the quality of movies, both the number of favorable reviews as well as the reported ticket sales figure into an otherwise uninformed decision. The odds at horse races or the Las Vegas point spreads on ball games are frequently good predictors of winners. In fact, when these variables are used in models, they leave very little for other variables to explain. The odds and point spreads are not made by a single mind but instead are the product of many interdependent minds competing for an advantage. These examples illustrate the ability of humans to infer subtle information from systemic properties and suggest that such inferences might be commonplace. In fact, it might not be limited to humans, as will be the testimony of any fisherman who uses the movements of birds to locate fish.

The theory goes much further than the casual observations of the examples and makes rather precise, quantitative claims that are in need of investigation. That issue forms the topic of this talk. Can markets perform the tasks as advertised? Can markets find the zeros? If so, how do they do it? Can markets collect and aggregate information? If markets can do these things, what might be the uses? After all, the capacity to harness such powerful tendencies might be something of value. In addition to these topics there is another issue, which is the substance of the talk. How can we answer the above questions? The answer to the substantive issue is the use of laboratory experimental methods.

In posing the topics, a perspective is in order. The question is whether markets can do it at all, as opposed to whether they can always do it. Are such properties within the capacities of humans and organized markets? We want to establish only the possibility, a proof of principle. Whether markets can always do it and/or the full range of capacities to do it is far beyond the scope of what is known.

1. Systems of Equations

Can Markets Solve Them?

Two examples will be explored. Consider first a simple case, which turns out to not be simple at all: a laboratory setting in which each individual is given a ‘‘redemption value’’ and a time interval in which that redemption value is valid. The redemption value is of the form $R_i(x_i, T)$, where x_i is the quantity of some specific commodity purchased, T is a time interval, and $R_i(.,.)$ is the amount that the subject can collect from the experimenter from holdings of an amount x_i. Literally, the subject buys units in the market and resells them to the experimenter at prices reflected in the function $R_i(x_i, T)$ as long as the subject resells in the time interval T. Thus, the income to the subject from purchases in the quantity x is

$$R_i(x_i, T) - [\text{cost of purchases of } x_i], \tag{1}$$

where the cost of purchases of x_i is the sum of the prices paid for the units that make the total quantity x_i.

If prices were fixed at some level P, then the theory of consumer choice asserts that each individual, i, will attempt to solve the equation:

$$\partial R_i(x_i, T)/\partial x_i - P = 0. \tag{2}$$

When inverted, Equation 2 yields the equation

$$x_i = D_i(P, T). \tag{3}$$

Sellers in the market can buy from the experimenter according to a cost function $C_j(y_j, T)$, where the individual is j and the number of units purchased from the experimenter during the time interval T is y_j. The income from the experiment is

$$[\text{Revenue from sales of } y_j] - C_j(y_j, T). \tag{4}$$

If prices are fixed at P, then Equation 4 becomes

$$Py_j - C_j(y_j, T) \tag{5}$$

and according to theory, the individual solves the equation

$$P - \partial C_j(y_j, T)/\partial y_j = 0, \tag{6}$$

producing supply functions of the form

$$y_j = S(P, T). \tag{7}$$

The law of supply and demand represents another equation of the form

$$\sum_i x_i - \sum_j y_j = 0. \tag{8}$$

Notice the complexity of this model. If there are n people, then Equations 3, 7, and 8 represent $n + 1$ equations, without considering the complexity introduced by the variable T. The equations are nonlinear, and no one in the system knows them all. Indeed, no one in the system knows more than one of them. Furthermore, the solution is found under most unusual circumstances because typically there is no single price in a market. There are many prices because of the nature of bids, asks, and contracts.

Can markets solve such a complex system? Figure 1 illustrates the fact that the answer is ‘‘yes.’’ In the market represented in the figure, there were 87 people, approximately half of whom were buyers and half sellers. Shown there is the time series from a market created much like the one described above, only the time, T, is more complicated.[1] It is also more complicated

[1] In this market, the incentive functions ‘‘overlapped’’ in the sense that the time periods of incentives overlapped. For example, the T for one group of subjects was from, say, 1:00 to 2:00, with a new set of incentives arriving at 2:00 and lasting for an hour. The T for another group started at, say, 1:30 and was good to 2:30, and so on.

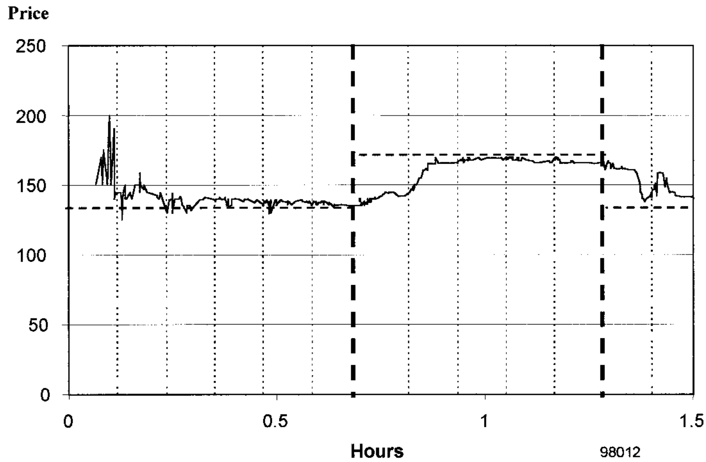

Figure 1. Price Convergence to the Equilibrium of the Competitive Model

because these people could speculate. They could buy and resell for a profit; thus, the nature of the interactions is extremely complex, suggesting that there are many more equations needed to solve the system than the 88 suggested by theory. Yet, as can be seen in the figure, the price-time path converges to the competitive equilibrium, the dotted line. When the competitive equilibrium is shifted, the markets adjust to the new equilibrium. By observing the time series alone, one knows the solution to this complex set of equations even without going through the complex set of computations.

To those who have observed this phenomena demonstrated many times in experimental markets, the discussion above is not particularly surprising. For those who have not, a natural suspicion is that the ability of markets to perform this complex function is somehow related to the fact that only one market is in operation and that the major interdependencies that might exist in an economy would change the result. It is well known that when time is involved and the commodity traded has the form of an asset, bubbles can occur (Smith, Suchanek, and Williams 1988; King et al. 1993; Van Boening, Williams, and LeMaster 1993; Porter and Smith 1994, 1995; Fisher and Kelly 2000; Lei, Noussair, and Plott, in press). The surprising thing is that when the economy is complicated in the natural way, the result remains the same. The economy can still ‘‘compute’’ the equilibrium (Goodfellow and Plott 1990; Sunder 1992, 1995; Noussair, Plott, and Riezman 1995, 1997; Lian and Plott 1998).

As an example, consider a general equilibrium experiment conducted over the Internet. The experiment includes resources, X and Y, that were supplied with disutility (such as labor), production functions that used the two inputs in a nonlinear way to produce an output, Z. The demand for Z and final consumption depended on the income of the buyer from resource sales. Notice that since production functions were used, the underlying marginal cost of supply depended on the ability of the system to achieve a least-cost combination of resources by every producer. Thus, output cost became a variable to be determined by the market. The system was closed with the introduction of a fiat money and by making consumers of Z and suppliers of resources X and Y the same agent. Thus, in order to get fiat money to buy, the subjects had to supply a resource and sell it. The resource could be supplied only at a ‘‘disutility’’ cost to the subject represented by U.S. dollars. It was sold for fiat, which was then used to buy the output

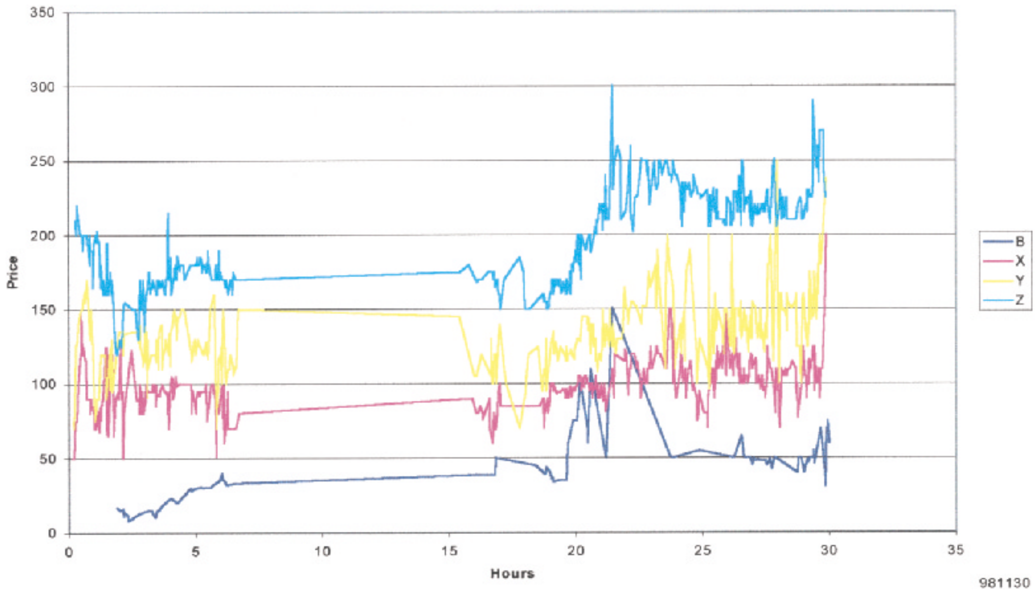

Figure 2. Relative Prices Converge to the Predictions of the General Competitive Equilibrium Model

Z, which could be ''consumed'' to gain utility represented by a sale to the experimenter for U.S. dollars. Of course, at the close of the experiment, fiat would be worthless. To overcome this, the experimenter opened the markets again, after the close of the experiment, and sold the outputs valued by subjects at the franc prices that had existed some periods in the past before the end of the experiment was announced.

Since the economy was cash in advance, cash flow presented possible problems. To overcome this, a type of ''bond'' was introduced. Each bond was worth a 50-50 chance at $0.50 or nothing after the experiment was over. Bonds were bought and sold for fiat. Thus, if fiat cash balances were too large, bonds could be purchased as a store of wealth. If cash balances were too low, bonds could be sold to get the fiat needed for trading.

In order to illustrate the technical features of these experiments, the parameters are listed in a footnote,[2] and the data are shown in Figure 2. As can be seen in the figure, the data have substantial variance, which is probably related to the relatively thin markets and the long time of the experiment. Nevertheless, the means of prices are close to the competitive equilibrium, which is really remarkable given that the supply depends on the optimal combination of resources and equilibrium input prices.[3] The rapid increase in prices exhibited near the middle of

[2] Utility functions of the two different types of agents are of the form: $100Z - 9X - 2X^2 - 32Y - 5/2Y^2$; $100Z - 9X - 2X^2 - 30Y - 5/2Y^2$. Of course, Z is the consumption good, and X and Y are the resources that are supplied causing disutility to the supplier. Production functions of the two different types of producing agents were of the form $Z = 2X^{1/2}Y^{1/3}$; $Z = 2.3X^{1/3}\,Y^{1/2}$. Producers also had a utility from consuming X and Y such that they would want to buy one unit of Y for consumption purposes at competitive equilibrium prices and spend the rest of their profits on the consumption of X. Each agent had an initial endowment of 300 francs (fiat) cash and also 10 bonds, each of which represented a lottery with a 50-50 chance between 50 cents or nothing.

[3] If the estimates of the price of X near the end of the experiment are on the order of 115, then the price of Y, which is 1.3 times the price of X in the competitive equilibrium, should be about 150. The price of Z is 1.9 times the price of X in the competitive equilibrium, so the price of Z should be about 218. A reasonable representation of the data is that

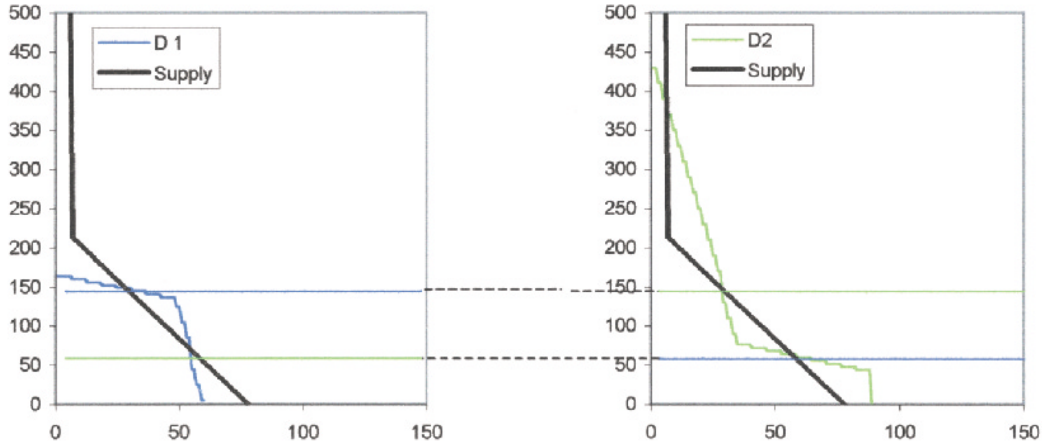

Figure 3. Backward Bending Supply with Two Demand Configurations Used to Separate Theories of Stability

the experiment is the result of an unexpected increase in the money supply. The money supply was increased by the experimenter through an application of the experimental version of open market operations in which the experimenter bought heavily in the bond market using a reserve of fiat and thereby increasing the amount of fiat in circulation.

Thus, we see here that markets can find the solution to an extremely complex set of equations. The solution is not as accurate as a mathematical derivation from theory, but the approximate accuracy is striking. Depending on how one counts, with the 32 subjects, standard theory amounts to over 100 equations that must be solved. As an exercise, the interested reader should try to solve them.

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the price of X near the end of the experiment is 115, the price of Y is somewhere over 130, and the price of Z seems to be in the 210–220 range. The price of bonds is one-half the price of X in the competitive equilibrium. Of course, absolute prices are not predictable given the current development of the theory of general equilibrium. The money supply was doubled at about 18 to 19 hours into the experiment. It is easy to see that the system responded, but whether velocity of circulation is constant and the price levels will double as a result remains an open question.

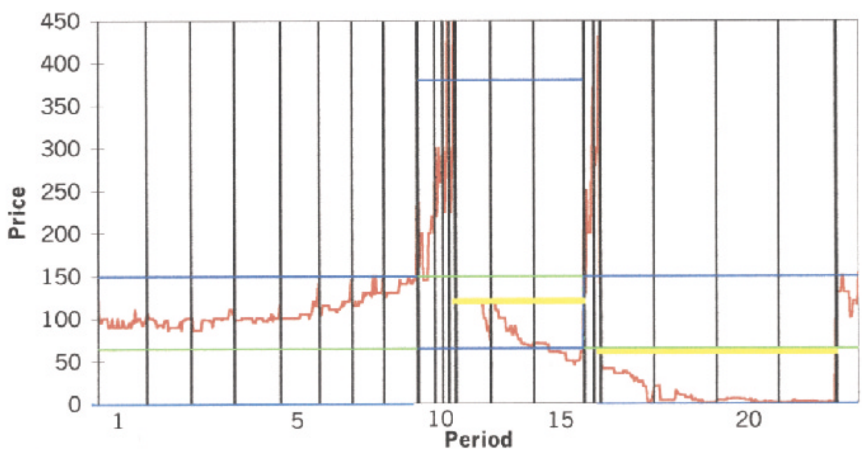

Figure 4. Price Convergence to the Walrasian Stable Equilibrium (blue) as Opposed to the Marshallian Stable Equilibrium (green) With and Without Price Ceilings (yellow)

What Is the Process? Can Markets Find All the Solutions?

How does the market find a solution to such a complex problem? What happens if multiple solutions exist? Complex systems of nonlinear equations can have multiple solutions. If many solutions exist to the market equations, does the method of solution allow it to find all of them?

While the exact method by which information gets into the market is unknown, it is clear that ‘‘local’’ activities are important (Friedman 1991; Cason and Friedman 1993, 1996; Easley and Ledyard 1993; Gode and Sunder 1993, 1997; Gjerstad and Dickhaut 1995; Turocy and Plott 1996; Jamison and Plott 1997; Brewer et al. 1999). Markets have a tendency to converge and the nature of the convergence process is heavily influenced by the conditions of demand and supply near the neighborhood of the price and allocation. The clearest view of this phenomena comes from experiments that deal with the possibility that markets can exhibit properties of stability and instability.

Figure 3 illustrates stability and instability in the case of a backward-bending supply of a resource, which could be interpreted as the backward-bending supply of labor. Shown on the left are the demand and supply parameters under the assumption of competitive markets. By changing the shape of the demand curve from D_1 to D_2, the stability properties of an equilibrium can be changed from stable to unstable. When the demand is D_1, points A and B are stable and unstable, respectively. When the demand is D_2, points A and B are unstable and stable, respectively. The shift from one demand to the other during an experiment is part of the experimental design. The blue lines are stable according to the Walrasian model of dynamic adjustments, and the green lines are the unstable equilibria according to that theory.[4] By allowing the markets to adjust under conditions of multiple equilibria, the experiments explore whether the markets will adjust to an unstable equilibrium, and by making an equilibrium unstable after the market has adjusted, the experiment determines the nature of the adjustment laws.

The data from the experiment presented in Figure 4 are typical of patterns of results in general (Plott 2000). As can be seen, the data first converge to a stable equilibrium. When the equilibrium becomes unstable because of a demand shift, the data quickly move away from the equilibrium toward a stable equilibrium. A price ceiling imposed just below the unstable equilibrium, without changing the demand or supply, results in prices that fall to the stable equilibrium below. Thus, even when the data are forced to be near the unstable equilibrium, the market moves away. If an equilibrium is unstable, it will not be ‘‘found’’ by the market.

The experiments tell us that the answer to the first question of how the markets solve the equation is related to the adjustment process. The method of solution is hidden in some complex process of dynamic adjustments. Can the market find all the solutions? The answer to this second question is ‘‘no,’’ markets cannot find all the solutions. This process of adjustments is such that some equilibria are unstable and thus will never be approached or found. Market forces will not lead to a configuration of prices and allocations that exist at an unstable equilibrium.

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[4] Two theories have been prominent in the literature over the last century. One was developed by Walras, and the other was developed by Marshall. Under certain conditions, the two theories are diametrically opposed. As it turns out, which theory is correct depends on the underlying economy and the reason for the ‘‘perverse’’-shaped curves. Walrasian stability is appropriate in the case of income effects, but Marshallian stability is appropriate in the case of externalities (Plott and Smith 1999).

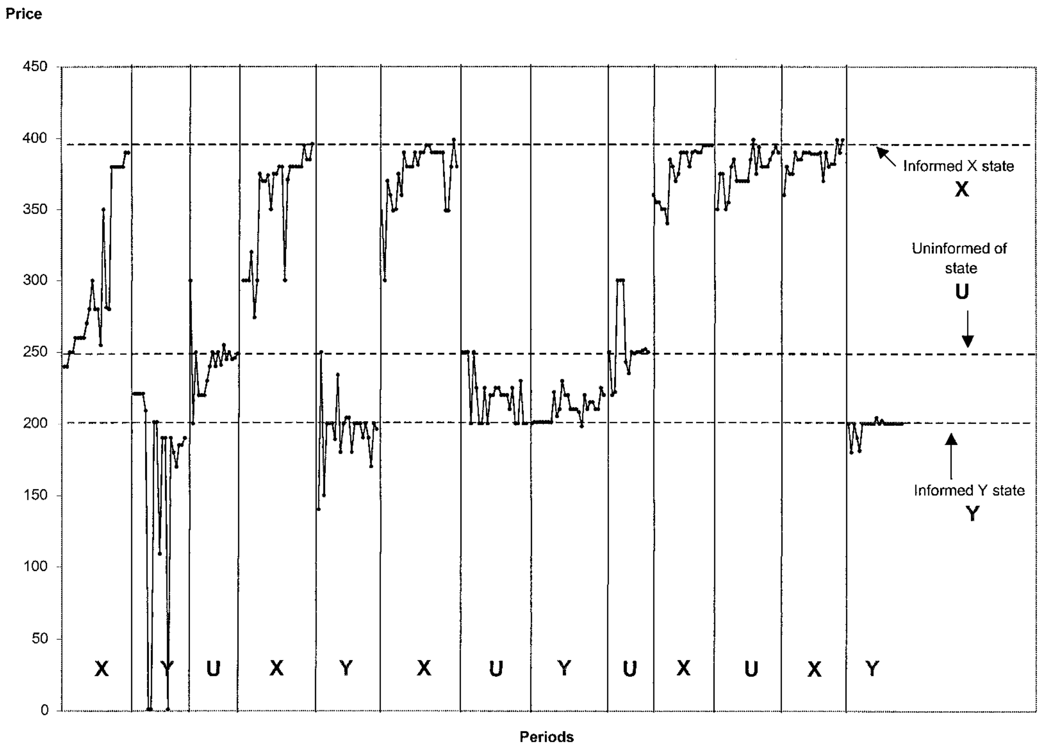


Figure 5. The Information of Insiders is Revealed in the Prices of One Period Assets: If Insiders Exist They Know the State but the Existence of Insiders is Uncertain

2. Information Aggregation

Can Markets Collect and Broadcast Information?

Figure 5 can be used to address this question. The experiment is a replication of a design found in Camerer and Weigelt (1991). Consider an economy in which there is a single asset that pays according to which of two states that nature has chosen. All agents are endowed with units, and the economy proceeds in a series of days, or ''periods,'' in which each agent is endowed with a number of one-period securities. Information about the state may be distributed and trade takes place, and after the period ends the state of nature is announced, the dividend is paid, and the securities are discarded. The dividends are 200 if the state is Y and 400 if the state is X with probabilities 0.75 and 0.25, respectively.

Before the trading begins, inside information is distributed. Each agent receives a slip of paper that is either blank or contains the true state. A 50-50 random event determines whether insiders will exist. If insiders do not exist, then the papers distributed to all agents are blank. If the random event designates that insiders will exist, then a small number of agents are given accurate information about the state. Thus, if there are insiders, the insiders themselves know that insiders exist, and they know the state, but those who are not insiders do not know whether insiders exist. If there are no insiders, then no one knows whether insiders exist.

A theoretical exercise will help explain the ideas. If the state is X, and if everyone knows that the state is X, then the price of the security will be 400. If the state is Y and if everyone knows that the state is Y, then the price of the security will be 200. If there are no insiders and if everyone knows that there are no insiders, then the price of the security will be the expected value of 250, neglecting any discount for risk aversion.

The time series of prices of an experiment are shown in Figure 5. As can be seen, the prices typically adjust rapidly to the equilibrium price as if everyone knew whether there are insiders and as if everyone knew the state. That is, in period 1 there are insiders who know that the state is X and the prices adjust to near 400. In period 2 there are insiders who know that the state is Y and the prices adjust to near 200. In period 3 there are no insiders and no one knows that there are no insiders. The price adjusts to near 250. A major exception is period 11, which will be discussed later.

Is the information aggregated? The answer to that can be tested by the reader. If you are able to determine the state by looking at the time series and without looking at the key at the bottom of the figure, then the answer to the question is ''yes.'' The reader is not an insider, yet from observing the data, knowledge of the state emerges.

Can the market be wrong? Period 11 is of special interest because it is an instance in which the market clearly came to the wrong answer. The market suggests that an insider exists who knows that the state is the high-dividend state, but in reality there were no insiders at all. Had the situation of no insiders been public information, then the price would have been 250. Thus, markets have the capacity to collect information and publish it, but that capacity is not perfect. The market can make mistakes. Camerer and Weigelt (1991) call such mistakes ''mirages.''

Can Markets Aggregate Information?

The result above demonstrates that markets can collect information and publish it but can make mistakes. That leaves open the question of whether markets can perform the additional function of aggregating information and whether the capacity of markets to perform this function can be improved. The issue has received some attention in the literature. The original discovery is found in Plott and Sunder (1982, 1988), and an impressive literature has developed since (Copeland and Friedman 1987, 1991, 1992; Forsythe and Lundholm 1990; Sunder 1992, 1995; Nöth and Weber 1996). It is known that certain circumstances will not result in success (Kagel and Levin 1986; Dyer, Kagel, and Levin 1989; Lind and Plott 1991; Anderson and Holt 1997). The answer to both questions is ''yes,'' as the following experiments will demonstrate.

Consider the following experiment. The economy consists of 10 states, and each individual has only a small amount of private information about the true state. However, because of the large number of agents, each with independently drawn information, much information exists in the system. While each individual knows very little, the ''market knows'' the state with almost certainty. The question to be posed is whether the information will become aggregated when individuals compete in a complete set of state-contingent commodities. This will test the robustness of the result originally reported by Plott and Sunder (1988), in which a complete set of markets successfully aggregated information when a single market could not.

The experiments are developed as follows. The markets were conducted on the Marketscape software with subjects located at home, in their dorm rooms, or in one of the local laboratories. The possible states of nature are labeled by 10 letters of the alphabet. For each of these letters a certificate with a one period life is created. That is, there is a Q certificate traded in the Q market, an R certificate traded in the R market, and so on. The certificate that corresponds to

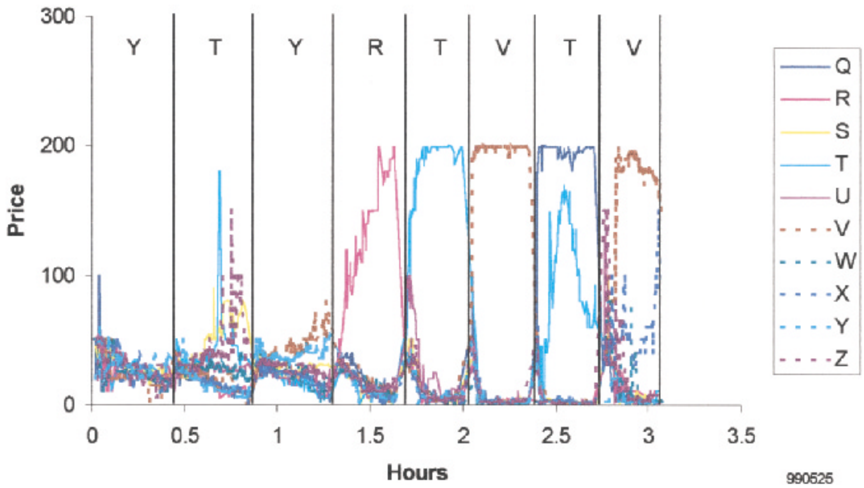


Figure 6. Arrow Debreu Markets Collect and Publish Information Distributed Over Many Agents: The Market of the Actual State Emerges Quickly with the Highest Price

the letter chosen as the state pays a 200 dividend, and all other certificates pay nothing. Each individual is given an initial endowment of 10 certificates to create a 10-dimensional exchange economy. Endowments are refreshed, and a new drawing of a state occurs each period. Thus, if the state is known, the certificate corresponding to the state has a competitive equilibrium price of 200, and all others have a competitive equilibrium price of 0.

The experiments proceed in a series of independent periods, and before each period the subjects are given private information about the state in the upcoming period. No communication or sharing of private information is allowed.[5] Trading takes place in the context of much individual uncertainty as each person gets very little information—a sample of three independent draws from a distribution in which the true state is drawn with probability 0.25 and each of the nine others with a probability 1⁄12. For example, if the sample for a subject contains three different states, each of those three states has a posterior probability of .188, and all others have a posterior probability of about 0.06. If the signal is ''strong,'' with the same state drawn all three times, then the subject could associate the state with a 0.75 probability.[6]

The pattern of results can be most easily understood from the example of one experiment. The time series of prices for each market are shown in Figure 6. This experiment operated with approximately 90 subjects. Thus, even though each individual had very little information, the ''market,'' consisting of the aggregate of about 270 observations, three from each of 90 people, had a great deal of information. In other words, the market ''knew'' the state with near certainty.

As can be seen in Figure 6, the information aggregation occurs. According to the information aggregation hypothesis of rational expectations, the prices should reflect all available

[5] Methods for controlling such communications and checking for violations are part of the research.

[6] The experimenter chose one of the 10 letters at random as the state of nature. Given the state, a distribution of letters was created with the state having a probability of ¼ and each of the other nine states a probability 1⁄12. Each subject was then given a sample of three independent draws from this second distribution. If the sample contains three separate letters, the probability of the state given the sample is 0.188 for each letter in the sample and .063 for each letter not in the sample. If one letter is drawn twice, its probability goes up to 0.45 as opposed to 0.15 for the other drawn letter and 0.05 for each letter not drawn. If one letter is drawn three times, the probability that letter is the state is 0.75 as opposed to 0.028 for each of the others.

information, so the price of certificate corresponding to the state should be near 200 and the price of all others near 0. In the first two periods, it is difficult to determine from the figure whether the market of the true state is emerging with a higher price than the other markets. However, by period 3 the correct market begins to emerge very early, and in periods 4, 5, and 6 the market with the correct state emerges strongly after only a few trades. An exciting event occurs in period 7, when the market that approaches 200 very early is actually the wrong state. However, the market itself seems to broadcast that something is wrong because a second market (the correct state) also emerges with a high price. Of course, with two states with high prices, substantial arbitrage possibilities existed, but these were not immediately competed away. In the final period, a wrong market also emerges early, but it is ‘‘beat down,’’ and the true state becomes identified.

3. Do Such Theories and Experiments Have Uses?

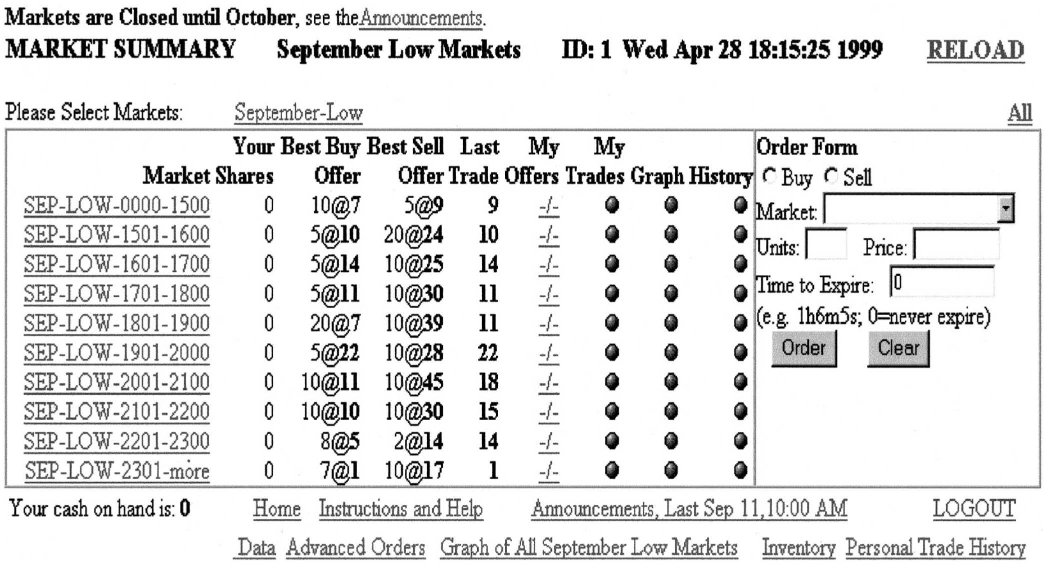
If markets have the power to collect and to aggregate information, then harnessing that power could be valuable. Explorations of the possibilities have resulted in the creation of special markets or processes that have no use other than as *information aggregation* devices. Indeed, if the principles of economics are reliable, then such exercises in invention should be possible.

Consider the following problem. A company wants to know the level of sales in some product some months in the future. It feels that the best information regarding the state of the market resides dispersed as opinions, hunches, and beliefs in its sales force. It is the sales force that meets the customers and has the most recent experience regarding demand. While any particular salesperson might have very little information, the collection of salespeople might have considerable knowledge. However, it must be collected and organized. If collected and organized, it might become enhanced by the process because an individual salesperson might want to reevaluate private information in the light of the opinions of others.

Figure 7 reproduces the screen from a test of information aggregation that took place inside a business a few years ago. The issue was whether a market mechanism could be used to collect and aggregate information that was thought to be held remotely as intuitions and hunches by individuals scattered across the organization.

Ten markets were created and operated only within the company using electronic markets created within the Caltech Laboratory for Experimental Economics and Political Science. The markets were labeled SEP-LOW-000-1500, SEP-LOW-1501-1600, SEP-LOW-1601-1700, and so on. If the upcoming September sales of the item were to fall in the interval 0–1500, then the market with that label would pay $1.00 per share to the owner of the shares, and all other markets would pay nothing. If the upcoming September sales of the item were to fall in the interval 1501–1600, then the market with that label would pay $1.00 per share to the owner of the shares, and all other markets would pay nothing and so on. As can be seen, the structure of this market system is exactly the same as that represented in Figure 6, only the states of nature are different, the subjects are different, and the time scale is different.

Each person who was allowed to participate was given an endowment of approximately 20 shares in each of the markets. The markets were open for several days, during which participants could buy and sell shares reflecting their beliefs about what the likely level of sales might be. The question posed was whether the market prices would reflect the relative probabilities of the actual sales.



Markets are Closed until October, see the Announcements.

MARKET SUMMARY September Low Markets ID: 1 Wed Apr 28 18:15:25 1999 RELOAD

Please Select Markets: September-Low All

Market	Your Shares	Best Buy Offer	Best Sell Offer	Last Trade	My Offers	My Trades	Graph	History
SEP-LOW-0000-1500	0	10@7	5@9	9	-/-	●	●	●
SEP-LOW-1501-1600	0	5@10	20@24	10	-/-	●	●	●
SEP-LOW-1601-1700	0	5@14	10@25	14	-/-	●	●	●
SEP-LOW-1701-1800	0	5@11	10@30	11	-/-	●	●	●
SEP-LOW-1801-1900	0	20@7	10@39	11	-/-	●	●	●
SEP-LOW-1901-2000	0	5@22	10@28	22	-/-	●	●	●
SEP-LOW-2001-2100	0	10@11	10@45	18	-/-	●	●	●
SEP-LOW-2101-2200	0	10@10	10@30	15	-/-	●	●	●
SEP-LOW-2201-2300	0	8@5	2@14	14	-/-	●	●	●
SEP-LOW-2301-more	0	7@1	10@17	1	-/-	●	●	●

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(e.g. 1h6m5s; 0=never expire)
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Your cash on hand is: **0** Home Instructions and Help Announcements, Last Sep 11,10:00 AM LOGOUT

Data Advanced Orders Graph of All September Low Markets Inventory Personal Trade History

Figure 7. Arrow Debreu Markets Used to Collect Information Distributed Within a Business Enterprise

Figure 7 reflects the state of the system at the end of all trading sessions. For each market, the bid, ask, and last trade are shown. Links to take the traders to history are there, as is the bid form. Since the prices must range from 0 to 100, they can be interpreted as probabilities. Thus, the price of 9 in the market SEP-LOW-000-1500 can be interpreted as the ‘‘market belief’’ that the probability is 0.09 that the September sales will be in the range 0–1500. With the interpretation of prices as probabilities, the modal state is 1901–2100 with a probability of 0.22, and the distribution seems to be skewed upward from there.

How does this particular information aggregation mechanism perform? The exercise was conducted 16 times inside the company, and the mean state was never further from the actual sales than was the official prediction and was significantly closer in all but one. All indications are that this type of mechanism works in practice.

4. Concluding Remarks

In essence, this talk is really two talks. One is the topic, and another deals with substance. The topic of the talk posed questions about the capacity of markets to gather information distributed across a system in the form of beliefs, hunches, and opinions; aggregate the information like a statistician; and then publish it for all to see. Stated in that form, it is a rather challenging task. The answer to the questions is ‘‘yes,’’ markets really can perform such tasks.

The substance of the talk dealt with a deeper question about how one would know the answer to the questions posed by the topic. The tools were experiments that exposed the principles involved and provided the machinery needed to develop judgments about how robust the phenomena might be. Experiments tell us that the ability of markets to perform the task of information aggregation is closely related to the dynamics that take place in market adjustments. Furthermore, that dynamic is itself closely related to the way that markets are organized and the instruments that exist in the markets for trading. Some modes of organization and some instruments do not lead to reliable information, while others clearly do a better job. While we do not have a complete theory for explaining what we see, we do have very powerful models that are helpful and suggestive.

The combination of theory and experiments lead naturally to a new class of issue to challenge the profession. Can we design competitive-type processes for the explicit purpose of collecting information? These can be called information aggregation mechanisms. Once designed, can they be tested in the laboratory? Can they be deployed under field conditions? Do they work once deployed?

The answer to all the questions is ‘‘yes.’’ Examples of explicit designs and experimental tests are given in the body of the talk, but more evidence exists. Experiments exist with types of information aggregation mechanisms that are not directly market processes (Plott, Wit, and Yang 1997). There are also information aggregation mechanisms that have been implemented without direct testing but that have an amazing ability to perform (Forsythe et al. 1992; Berg, Forsythe, and Rietz 1996; Forsythe, Rietz, and Ross 1999). Given the complexity of the task, the progress is impressive. It is hoped that as the profession realizes the power that it has in theory and the ability of experiments to help refine that theory as needed for field implementation, we will see even more progress.

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