Chapter 40

MARKETS AND INFORMATION AGGREGATION MECHANISMS

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The awareness that markets can be created specifically to aggregate information has roots in a long history of experimental economics research. Plott and Sunder (1982, 1988) made three central discoveries. The first is that markets can aggregate information when individuals have diverse preferences. The second is that the ability of markets to do so is related to the underlying architectures and instruments that exist in the market. If markets do not consist of a complete set of Arrow–Debreu, state contingent commodities, the aggregation might not occur. The third discovery is that if the preferences are homogeneous then markets can perform the task even if the instruments do not consist of a full set of state contingent commodities. An impressive literature has developed since (Copeland and Friedman, 1987, 1991, 1992; Forsythe and Lundholm, 1990; Friedman, 1993; Sunder, 1992, 1995; Nöth and Weber, 1996; Plott, 2000).

While this literature establishes the ability of markets to carry information from insiders to outsiders, it is also known that markets can make mistakes (Camerer and Weigelt, 1991). Furthermore the large literature on the winner's curse demonstrates that the logical possibility of conditioning on the information of others does not evolve naturally from strategic behaviors alone. Indeed, Kagel and Levine (1986) and Guarnaschelli et al. (2003) demonstrate that the existence and magnitude of a winner's curse are closely related to market architectures. Sealed bid processes, for example, and perhaps call markets in general, will not be an effective architecture for information aggregation, while the double auction is an effective architecture. The same message is found in the cascade literature, initiated by Anderson and Holt (1997). The information that becomes integrated into the pattern of social decisions is heavily influenced by incentives and procedures. Indeed the incentives and procedures such as majority rule can increase the information aggregation capacities of sequential observations and incentives to conform can destroy the capacity (Hung and Plott, 2001). The cause of mistakes systematically made by agents, the detectability of mistakes and the relationship between market architectures, market instruments and the information transmission process contains huge categories of unexplored issues.

The data reported here fill a gap in the literature. Roughly speaking, the literature suggests that markets with instruments consisting of a full set of Arrow–Debreu securities and organized as continuous, multiple unit double auctions have the capacity to collect and aggregate information. The ability to perform the function is related to replication

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of experiences similar to the convergence exhibited by all experimental markets. However, these suggestions are drawn from experiments with only a small number of states, a small number of traders and private information that contained "strong" signals. Such features of earlier experiments were dictated by the limitations of experimental technology but with the development of the Marketscape programs in the 1990s, much larger experiments became possible.

The experiments reported here were used as a test of the robustness of the earlier results referenced above. The purpose was to make sure that the lessons of the early experiments generalized to a more complex world that had features of the field exercise that was to be undertaken.

Figure 1 illustrates the information structure and the instruments created in the market. The experiment proceeds in a series of periods or "days." The economy consists of 10 states. A state is randomly drawn at the beginning of each period with all states are equally likely. The state drawn is unknown to subjects but each individual is given an independently drawn signal dependent on the state. The signal given to an individual consists of three draws with replacement from a distribution with the correct state having a probability of one fourth of being drawn and each of the other states having a probability of one of twelve. So, an individual with three draws of the same state has a posterior probability of 0.75 of knowing the state. If the individual has two draws the same then the probabilities are 0.45, 0.15 and 0.05 for the three types of states represented. If the individual gets three separate states drawn then the probabilities are 0.188 and 0.063 for those represented and those not represented, respectively.

Thus, each individual has very little information about the state. Even an individual with all three draws the same has a .25 chance of being wrong. However, if there are many individuals and if the draws of all individuals are pooled together then an application of Bayes Law to the pooled samples will give the true state with near certainty. Thus, the experimental environment is one in which each individual knows "very little" but "collectively" they know a lot. If the markets collect and reveal all information that is known to all individuals then the true state should be revealed in the prices with almost certainty. That is, the true state should be revealed with almost certainty if the principles of rational expectations information aggregation are in operation.

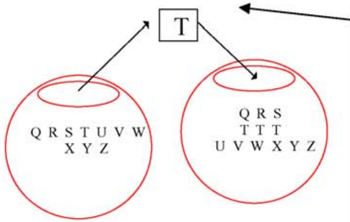
The instruments are Arrow–Debreu securities. Each state is represented by a security that pays \$2.00 if the state occurs and \$0 otherwise. Each agent is given an initial endowment consisting of a portfolio of 10 of each type of securities. By holding the full portfolio and making no trades at all, the portfolio would pay \$20, which would allow the individual to repay the \$10–\$15 loan for the period. The rational expectations, fully revealing competitive equilibrium is for the price of the security representing the true state to be near \$2.00 and the price of securities representing all other states to be near \$0.

Figure 2 contains typical time paths from a single period of the ten markets when the agents in the markets have had some experience. Opening prices exhibit considerable variance with some prices being much too high, often due to computer entry errors but sometimes due to agents who had strong signals. All prices tend to drop and as the clus-

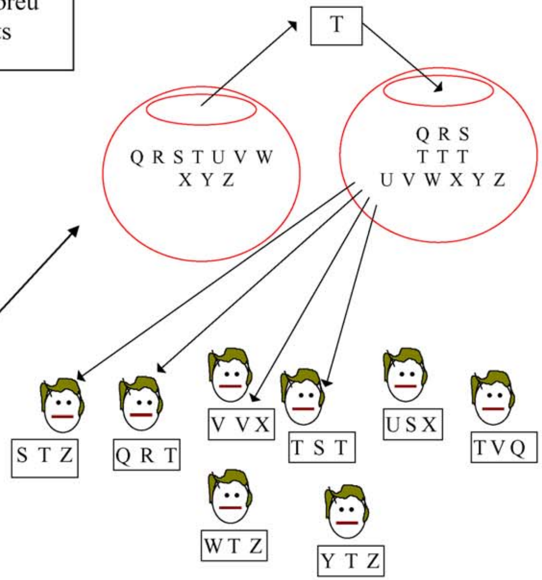
Arrow Debreu Instruments

EACH STATE HAS ITS OWN CERTIFICATE
IT PAYS IF THAT STATE OCCURS AND NOTHING
OTHERWISE

Type Cert	State Q	State R	State S	State T	State U	State V	State W	State X	State Y	State Z
Q-cert	$ 2.00	0	0	0	0	0	0	0	0	0
R-cert	0	$ 2.00	0	0	0	0	0	0	0	0
S-cert	0	0	$ 2.00	0	0	0	0	0	0	0
T-cert	0	0	0	$ 2.00	0	0	0	0	0	0
U-cert	0	0	0	0	$ 2.00	0	0	0	0	0
V-cert	0	0	0	0	0	$ 2.00	0	0	0	0
W-cert	0	0	0	0	0	0	$ 2.00	0	0	0
X-cert	0	0	0	0	0	0	0	$ 2.00	0	0
Y-cert	0	0	0	0	0	0	0	0	$ 2.00	0
Z-cert	0	0	0	0	0	0	0	0	0	$ 2.00



Nature draws a state and a probability distribution condition on nature's draw is created.



Signals are randomly determined from the distribution conditional on nature's draw and the signals are distributed to individuals as their private information about the state. Notice that each individual has very little private information about the state but collectively, the pooled information is substantial because of the independence of the private signals.

Figure 1. Market instruments correspond to states. States are randomly drawn and randomly generated private information is distributed to subjects.

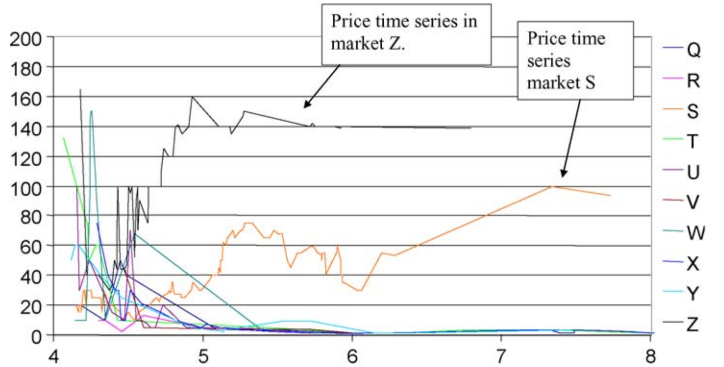


Figure 2. Given the aggregate of all private signals the probability of state z is .99. Market Z is shown in black. Arrow–Debreu markets are able to collect and publish information distributed over many agents: the market of the actual state emerges quickly with highest prices.

ter of prices drop and occasionally a price will move upward only to be competed back down. Eventually one price begins to emerge and move upward steadily and when this takes place it is almost always the market of the true state. In Figure 2 this is the Z market. State Z has a .99 chance of being the true state according to the pooled information that was sent privately to all agents. In the figure a second market, S, begins to emerge with a higher price. While the price of Z and the price of S sum to near the 200, the sum is not perfect and certainly the price of S is too high given the information in the system. In the sense of these time series, one can say that the markets managed to aggregate the information and make it available for all. The aggregation is not perfect but it is useful.

Figure 3 contains the results of an experiment with over 60 subjects for a number of periods. Subjects were located remotely, participating through the continuous Marketscape exchange over the Internet. Before a period opened, each subject received private information about the state as described above. They were given the initial endowment portfolio for the period, a loan of working capital, the results of any previous period states, and their own earnings. The figure contains the results of eight periods. The time sequence for each market is shown in the figure.

As can be seen, during the prices when the first period opens reveal very little. Almost all prices are roughly at the same level. However, even in the early periods a trained eye can detect the proper state by the behavior of the prices. Not shown in the figure are the bids and asks, which are known to be important carriers of information in addition to prices. By about the fourth period the price of the correct state emerges very quickly in the period and moves to near the rational expectations level. The prices of all other states fall toward zero. By the final periods the information becomes aggregated quickly in the prices and even those with no information at all can infer what others know from the behavior of the markets.

While experiments demonstrate that properly designed markets have the capacity to collect, aggregate and publish information the experiments also demonstrate that there

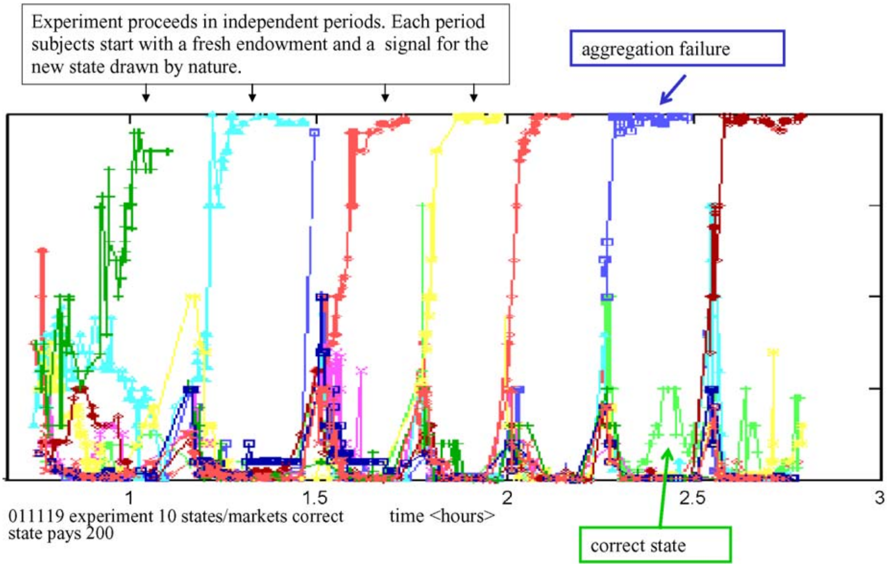


Figure 3. The time series for each trade in each market is contained in the figure. Each market is represented by a different color.

are limitations. Bubbles can be observed in experiments in which the wrong market emerges with a high price and strongly signals the wrong state. This can be seen in period six in which the wrong state emerges. However, it must be added that such events are rare, given strong underlying information and they are reduced with experience. It is also important to note that the market itself suggests that a bubble might be present and does so through the high prices that emerge for the X state shown in green.

1. Are The Lessons From The Simple Cases Useful?

The experimental work demonstrates that markets have the capacity to collect information through a process of equilibration and that fact suggests the feasibility of creating a system of markets that have only a purpose of gathering information. The laboratory work suggests that theory and experiments can be turned to the design and implementation of *Information Aggregation Mechanisms*.

The issue of whether or not laboratory methods are useful can now be brought into view. The idea of an information aggregation mechanism as a product of institutional design is a direct product of experimental work. Background laboratory work established the two important legs for an application.[1] First, the laboratory work established

[1] Considerable thought has been devoted to the methodology of using experiments in policy contexts. The concepts of "proof of principle" and "design consistency" are introduced by Plott (1994).

a "proof of principle" in the sense that when tested under laboratory conditions it performed as predicted. Second, the experiments established "design consistency" in the sense that the mechanism performed as it did for understandable reasons. The success of the mechanism has a theoretical underpinning and thus the success does not appear to be some sort of accident or accidental choice of parameters.

Experimentalists in Hewlett Packard Corporation were aware of the potential value of developing and deploying an Information Aggregation Mechanism. They decided that a field test would be appropriate and management was approached accordingly (Chen and Plott, 2000). Criteria for finding the appropriate problem were closely linked to the properties that existed in successful laboratory experiments. (i) The state of nature should be objective and not too far in the future, reflecting the fact that participant experience might be necessary for mechanism success. (ii) The state forecasted should be replicable in the sense that the same type of forecast should be undertaken repeatedly with the same participants. (iii) Those participating in the forecast should possess information that can be aggregated. The Information Aggregation Mechanism involves information collection and aggregation but not information creation. If no information existed to be collected, then there would be no reason to think that the forecast would be successful. (iv) The participants should have no interest that depended on the outcome of the exercise. The incentives should be to make money and not to manipulate the prediction.

The applied problem chosen for field tests was related to sales forecasting. In the context of the application, the company would like to obtain information about the sales of a particular piece of equipment a few months in the future. For purposes of the example used for this discussion the equipment will be called "Low" and the month for which sales were to be forecast was September. The month in which the markets operated was June. The possible sales were divided into ten intervals such as 0000–1500; 1501–1600; 1601–1700; etc. up to 2301-more. From the point of view of the theory and the market instruments, these intervals can be identified as the "states of nature" but of course that language was not used in the field. Thus, the mechanism was based on ten securities. Each state of nature was associated with a specific security and the associated security was given the name of the state. So, there was a security called, SEP-LOW-0000–1500 and one called SEP-LOW-1501–1600, etc. After the actual sales for the month of September were to become known the security associated with the state would pay a dollar per share to the holder. Those securities associated with all other states would pay zero. Thus, the situation is exactly a full set of Arrow–Debreu securities as described in the experiment above. Figure 4 contains the list.

Each of the individuals identified for the exercise was given a portfolio of approximately 20 shares of each security and some trading cash. The initial portfolio was designed with variations across subjects so as to promote trading. The timing of the markets, special screens, special training and online help were developed. Links to the company database were provided for those who wanted to study such data that the company had for processing and applications for forecasting. The time line of the exercise

SEPTEMBER SALES OF "LOW"

Markets (Open 1st week of July)	000 1500	1501 1600	1601 1700	1701 1800	1801 1900	1901 2000	2001 2100	2101 2200	2201 2300	2301 MORE
SEP-LOW-0000-1500	$1.00	0	0	0	0	0	0	0	0	0
SEP-LOW-1501-1600	0	$1.00	0	0	0	0	0	0	0	0
SEP-LOW-1601-1700	0	0	$1.00	0	0	0	0	0	0	0
SEP-LOW-1701-1800	0	0	0	$1.00	0	0	0	0	0	0
SEP-LOW-1801-1900	0	0	0	0	$1.00	0	0	0	0	0
SEP-LOW-1901- 2000	0	0	0	0	0	$1.00	0	0	0	0
SEP-LOW-2001- 2100	0	0	0	0	0	0	$1.00	0	0	0
SEP-LOW-2101- 2200	0	0	0	0	0	0	0	$1.00	0	0
SEP-LOW-2201-2300	0	0	0	0	0	0	0	0	$1.00	0
SEP-LOW-2301- MORE	0	0	0	0	0	0	0	0	0	$1.00

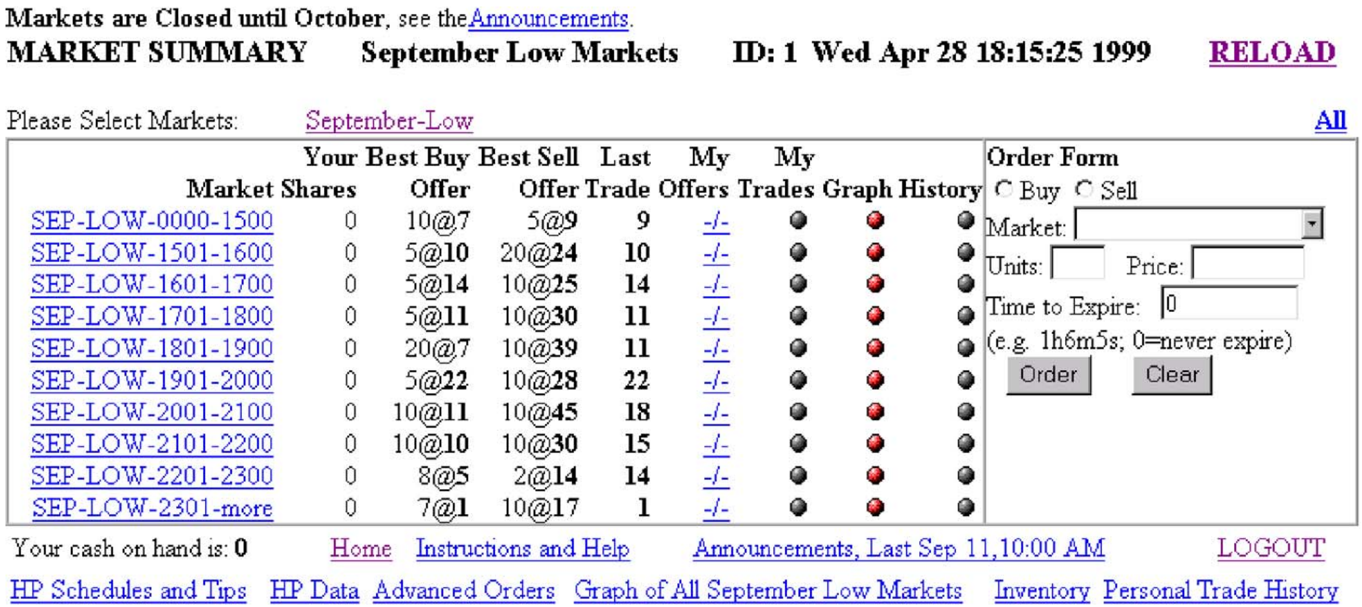
Figure 4. Information aggregation markets for probable September sales of equipment called “low.”

had to be consistent with the potential use of the data. In fact the exercise involved several different forecasts over a period of time.

Figure 5 contains the closing display on the software that participants used for trading. The prices listed there were part of the ingredients for the September-Low predictions. For each market the bid (best buy offer), ask (best sell offer) and the price of the last transaction in that market are displayed. For example, in the SEP-LOW-1601–1700 market the bid was 14 cents each for up to 5 units, the ask was 25 cents each for up to 10 units and the last trade was at 14 cents.

Since the security representing the correct state pays 100 cents. All prices should be between 0 and 100 and so prices can be interpreted as probabilities. In particular one can interpret the 14 cent price that existed in the SEP-LOW-1601–1700 markets as a “market belief” that with probability .14 the sales in September will be in the interval 1601–1700. With such an interpretation the mode of the predicted sales occurs at SEP-LOW-1901–2000 at a probability of .22. The distribution itself is skewed to the states higher than the mode. Thus, one could predict the most likely state, which would be the security with the highest closing price. Of course there are many other statistics that can be used, and the Information Aggregation Mechanism produces additional data such as the time series of trades, bids and asks, as well as the trading patterns of individual participants, all of which can be used as the basis for forecasts.

The mechanism has performed well inside Hewlett Packard Corporation with a total of twelve predictions. The predictions from the mechanism have been better than the official forecasts in all but two occasions. The complexity of field applications should not be minimized. There are many differences between the laboratory environment and



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**	-/-			

Order Form
Buy Sell
Market:
Units: Price:
Time to Expire: 0
(e.g. 1h6m5s; 0=never expire)
Order Clear

Your cash on hand is: **0** Home Instructions and Help Announcements, Last Sep 11,10:00 AM LOGOUT

HP Schedules and Tips HP Data Advanced Orders Graph of All September Low Markets Inventory Personal Trade History

Figure 5. Markets are closed until October, see the announcements.

the field environment. In the laboratory it was known that information exists to be collected. That is not the case in the field. In the laboratory, information is known to be independently distributed and there is a value to collection and aggregation. That is not known about the field. In the laboratory, the time, attention, and training of the subjects is controlled. Certainly that is not the case in the field. In the laboratory the subjects have no incentive to manipulate the outcome, but in the field they might. Thus, by no means does success in the laboratory guarantee success in the field.

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