

India Studies in Business and Economics

S. Mahendra Dev  
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# Development in India

Micro and Macro Perspectives

**EXTRAS ONLINE**

 Springer

# Chapter 10

## Experimental Exploration into Macro Economics

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### 10.1 Economics as an Experimental Science

The use of experimental methods to explore our understanding of economics is only a little over half-a-century old. Its use in macro economics originated more recently. While applications of this method to various aspects of economics have expanded rapidly, much remains to be done on its usefulness, linkages, and acceptability. I address some of these issues at the outset, before delving into what we have learned.

Classical uses of experiments were confined to natural sciences such as physics, chemistry, and aspects of biology where the objects of experimentation are either inanimate, or cannot reasonably be expected to change their behavior in response to experimental treatments. This invariance makes it possible for natural scientists to identify laws of nature that retain their validity and predictive power across time and space. Universality of their laws earns for science and scientists high prestige that social sciences covet, and try to emulate.

Experimental method is valued for enabling investigators to gain manipulative control over conditions or treatments under which observations are gathered. Invariance of underlying laws, combined with careful design of treatments, allow investigators to infer regularities in observations. When independently replicated with sufficient and convincing frequency, and logically linked to related phenomena, these regularities are characterized as laws by virtue of their high predictive power and contribution to better understanding.

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Presented at the Silver Jubilee International Conference at the Indira Gandhi Institute of Development Studies, Mumbai, December 1–3, 2012. Revised February 1, 2013. I thank Qin Tan for her assistance.

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© Springer India 2016  
S.M. Dev and P.G. Babu (eds.), *Development in India*,  
India Studies in Business and Economics, DOI 10.1007/978-81-322-2541-6\_10

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Social sciences, too, seek to identify observational regularities which can be called laws on the basis of their power to explain and predict. Their observational base had long been confined to domains which are outside the investigators' manipulative control—often referred to as field data from 'naturally occurring' phenomena. There were three reasons for this restraint.

First, unlike in the natural sciences, the objects of observation and analysis in the social sciences are sentient beings—ourselves. Human consciousness, including self-consciousness, means that we tend to learn, change behavior with time and experience, and are likely not only to become aware of the treatments to which we are being subjected, but also to have the capacity to expect, anticipate, and react willfully to such treatments.<sup>1</sup> Such reactions can make the investigator a part of the phenomenon he/she is trying to investigate. Under such conditions, identifying universal laws of behavior, or even delineating the boundaries of any local regularity we may come upon, is a far more challenging task than what the natural scientists face.

Second, the human tendency to learn and adapt their behavior challenges the robustness of the validity of any laws relative to their discovery. If discovered "laws" in social sciences induce those who learn of the discoveries to adapt their behavior to this knowledge, they may no longer remain valid. This endogeneity risks rendering any discovered regularities into transient facts, instead of steady state functional relationships that constitute the essence of what we can call a science.

Third, many social phenomena such as legislation, macro economic policy, and race relations, remain well-beyond manipulative control of investigators because such manipulation is infeasible, carries unacceptable risk of undesirable consequences, or is simply unethical. However, this second difficulty is shared with some natural sciences, of which astronomy, geology, and meteorology are well-known examples.

All these three difficulties of extending the use of experimental method to social sciences have been at least partially addressed in the recent decades with the development of experimental methods to address economic questions. The first two can be addressed by constraining the focus of experimental investigations to properties of economic institutions. Institutional properties are, at least potentially, more stable and less subject to the abovementioned endogeneity problems associated with adaptation of human behavior to anticipations of experimental treatments and to the knowledge of institutional properties. Further, it can be argued that it is useful to make at least an approximate distinction between psychology as the study

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<sup>1</sup>I do not address the deeper philosophical issue of whether human free will, and the idea of replicable laws of individual behavior, are irreconcilable with each other. Major aspects of experimental economics that I shall mention here are confined to regularities in the outcomes of social institutions (e.g., markets) that constrain the behavior of individuals who interact with one another. Even if populated with individuals whose free will cannot be captured in identifiable laws of behavior, it is entirely possible for social institutions to exhibit regular and replicable properties. It is an issue I return to in sections on the role of optimization and markets as artifacts.

of individual behavior and economics and sociology as the study of aggregate level outcomes that result from individual behavior but may have distinct properties of their own. In this paper, I use this criterion to distinguish experimental economics from studies of individual behavior by economists, often referred to as behavioral economics, and confine my remarks to the former.

Smith (1962) found that the outcomes of markets with a mere dozen or so student traders are surprisingly close to the predictions of equilibrium derived from assuming perfect competition among optimizing atomistic traders. This discovery enabled economists to have greater faith that markets with a bare handful of traders in laboratory settings can yield useful approximations and insights into the behavior of much larger markets which would be essentially infeasible to replicate in laboratory. The problem of addressing macro economic questions in small-scale laboratory settings has been eased by the development of microeconomic foundations of macro economic phenomena (Lucas 1972; Barro 1997). As with laboratory work in all fields, experimental economics results also must pass a skeptical external validity check; credibility of inferences must remain a matter of judgment by the disciplinary community.

In Sect. 10.2, I take a sample of some experimental economics results over the recent decades, with additional attention to macro economic experiments. Since the literature has grown rapidly to become quite large, this cannot be a review, only an appetizer. Excellent collections of reviews of various aspects of experimental economics are available elsewhere and I shall not try to duplicate them (e.g., Kagel and Roth's Handbook of Experimental Economics (1995), and a second edition expected).

## 10.2 What Have We Learned?

### 10.2.1 *Properties of Competitive Markets*

Smith (1962) conducted a simple laboratory experiment with 22 students in his class divided equally into buyers and sellers. Each buyer received a card with a number indicating the value of one unit of the good to him if he could buy it in the market. Each seller also received a card indicating the cost of producing one unit of the good to him if he could sell it in the market. All the buyers and sellers were free to independently propose bid and offer prices in a double auction and accept any prices they found attractive to close a transaction. He labeled this form of market organization "double auction."

He found that with a mere 11 traders on each side (hardly atomistic competition of economic theory), there was a "strong tendencies for a supply and demand competitive equilibrium (*as judged by transaction prices, trading volume, and allocative efficiency*) to be attained as long as one is able to prohibit collusion and to maintain absolute publicity of all bids, offers, and transactions" (see Fig. 10.1, reproducing Smith's Chart 1, p. 134).

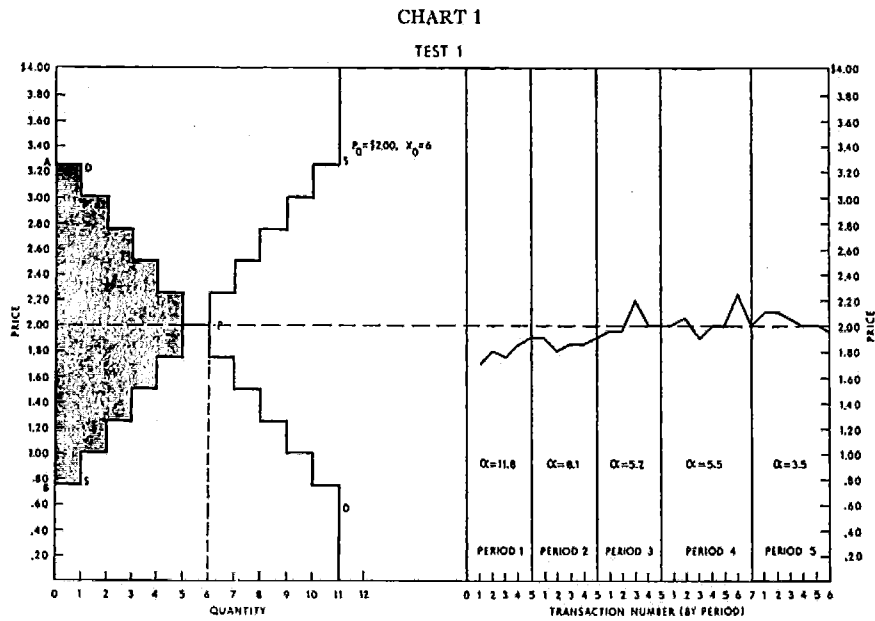


Fig. 10.1 Competitive equilibrium: price and volume (Source Chart 1 on page 113 in Smith 1962)

In retrospect, this correspondence between economic theory and observation may appear obvious. However, since observation of markets does not tell us if their observed behavior is in competitive equilibrium, until 1962 there was little observational support for this concept at the foundation of economics. Smith's experiment provided convincing and robust evidence that the concept *can* work, but needs time for adjustment. Subsequent work (Karim and Sunder 1996) has also revealed situations in which equilibrium predictions may not be supported, especially when there are multiple applicable equilibria.

Although it was not a Walrasian tâtonnement process, shifts in demand and supply changed the market outcomes after a short erratic transient phase (see Fig. 10.2, reproducing Smith's Chart 5). Prices, allocation of surplus, and the direction of convergence of prices towards equilibrium are driven by the equilibrium levels of consumer and producer surplus (see Fig. 10.3, reproducing Smith's Charts 4 and 7).

Smith also reported that markets in which both buyers and sellers actively propose prices exhibit a stronger tendency towards equilibrium than markets in which only one of the two sides proposes prices. The price adjustment process appears to be driven by the size of rents, and not by Walras' suggestion of excess demand and supply.

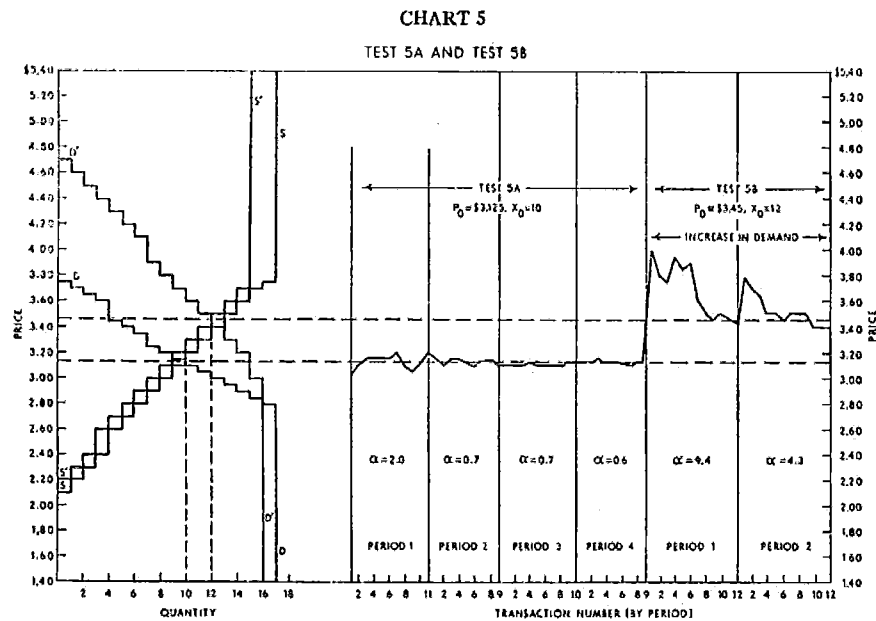
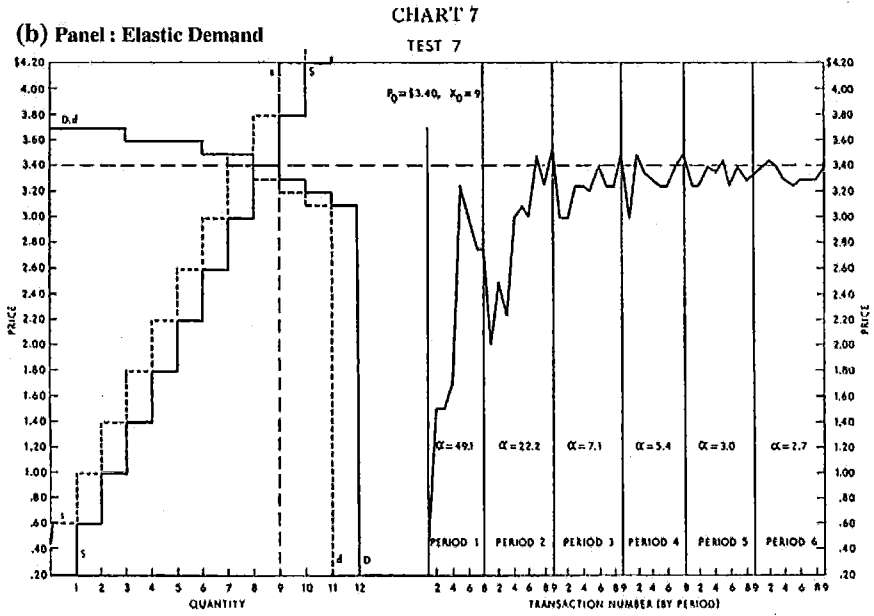
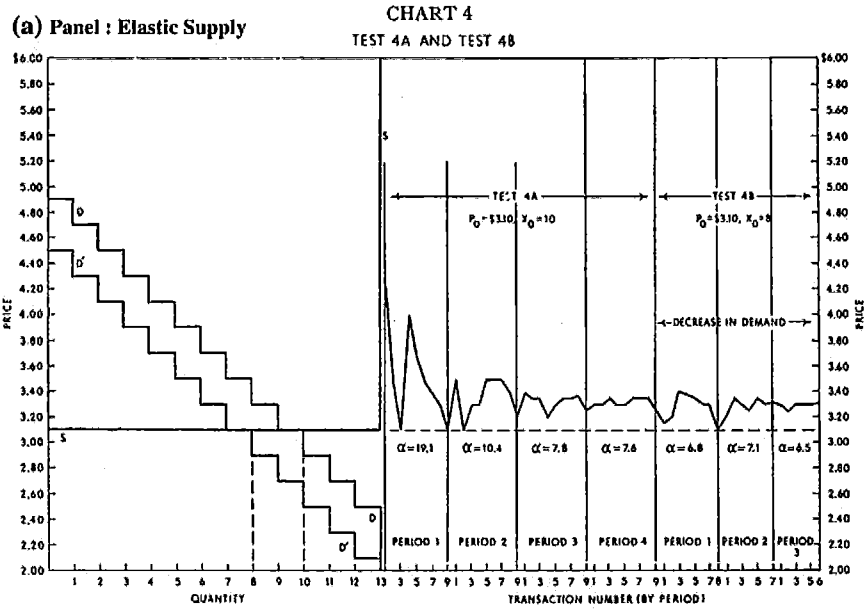


Fig. 10.2 Competitive equilibrium: shift in demand and supply (Source Chart 5, p. 121 of Smith 1962)

### 10.2.2 Rational Expectations Equilibria in Asset Markets

As with properties of competitive equilibria (and their dependence on the organization of market institutions), it is difficult to examine the information processing properties of asset markets from field data because we hardly ever know what information various traders have. Without this knowledge, we do not know the equilibrium predictions under alternative theories of information dissemination; and without this knowledge, there is no benchmark against which the observations can be compared and inferences drawn. Control of market and information parameters in laboratory experiments allows us to gain insights into information dissemination properties of markets. I consider a few examples.

Twenty years later, Plott and Sunder (1982) asked if markets can disseminate information from those who know to those who don't. A satisfactory answer to this question could not be established from analysis of field data because we don't know which investors have what information. Plott and Sunder (1982) used a simple experiment with a market for a single-period two-state ( $X$  and  $Y$ ) security to address the question. Table 10.1 shows the known probability of each state. The market was populated with four traders each of the three types for a total of 12 traders. Type I received dividend of 400 in State  $X$  and 100 in State  $Y$  while the other two types received dividends of 300–150 and 125–175 respectively. Each trader was endowed with two securities and 10,000 in "cash" at the beginning of each period. The last



**Fig. 10.3** Competitive equilibrium: price convergence path and division of surplus (Source Charts 4, p. 119 and 7, p. 123 of Smith 1962)

**Table 10.1** Information dissemination equilibria in a simple asset market

Trader type	State X Prob. = 0.4	State Y Prob. = 0.6	Expected dividend
I	400	100	220
II	300	150	210
III	125	175	155
Prior information eq. price Asset holder	400 Trader type I Informed	220 Trader type I Uninformed	220 Trader type I
Rational expectations eq. price Asset holder	400 Trader type I	175 Trader type III	

(Source Plott and Sunder 1982)

column of Table 10.1 shows the expected dividends from the security for each of the three types of traders, when they do not know whether State X or Y is realized. The expected values are calculated from the probabilities of the two states (0.4 for X and 0.6 for Y) given to the subjects at the outset.

When subjects do not know which state is realized (no information condition), if they are risk-neutral, they should value the security at its expected dividends given in the last column of Table 10.1. The equilibrium price of the security would be 220 (equal to the maximum of the three expected values 220, 210 and 155) and Type I traders should buy all the securities at this price from the other traders.

Suppose the realized state is X and two traders of each type are informed at the beginning of the period that the state is X, and the other two are not. The informed traders know that the value of the dividend from the security (if they decide to hold it) is given in Column X, while the uninformed traders (assuming they are risk-neutral) would value the securities at the expected values given in the last column of the table. The equilibrium price would be the maximum of these six numbers which is 400, and Type I informed traders would tend to buy the security at that price. If the realized state were Y instead, by a similar argument, the equilibrium price would be 220, the maximum of the six numbers in the Y and the expected value columns, and the Type I uninformed traders should buy the security at that price. This equilibrium is labeled Prior Information (PI) equilibrium because it assumes that the traders rely entirely on the information they receive at the beginning of the period, and do not learn any additional information about the realized state from their participation in the market.

PI equilibrium is problematic because it assumes that traders do not learn from their failures. Whenever Type I uninformed traders pay a price of 220 to buy a security, they will discover that the state turns out to be Y with a dividend of only 100, leaving them with a loss. They are willing to pay a price of 220 only because they believe that they have a 40 % chance of getting a dividend of 400 under state X. But whenever state X occurs, the informed traders outbid the uninformed by their willingness to pay up to 400 for the security. Thus, the uninformed are able to buy



the security only under state  $Y$  when it pays a mere 100 in dividend, which is not worth paying a price of 220. If we assume that one cannot fool even some of the people all the time, these traders should learn not to buy the securities at that price, and such learning makes the PI equilibrium unworkable.

Under the rational expectations (RE) or efficient market equilibrium, information about the state would be disseminated from the informed to the uninformed traders through the market process. Under this assumption, in State  $X$ , all traders would know or learn that the state is  $X$ ; this will yield an equilibrium price of 400 which is the maximum of the three dividends in the column for State  $X$ , and all traders of Type I would buy the securities from the others. Similarly, in State  $Y$ , the equilibrium price would be 175 which is the maximum of the three dividends in the column for State  $Y$ , and all traders of Type III would buy the securities.

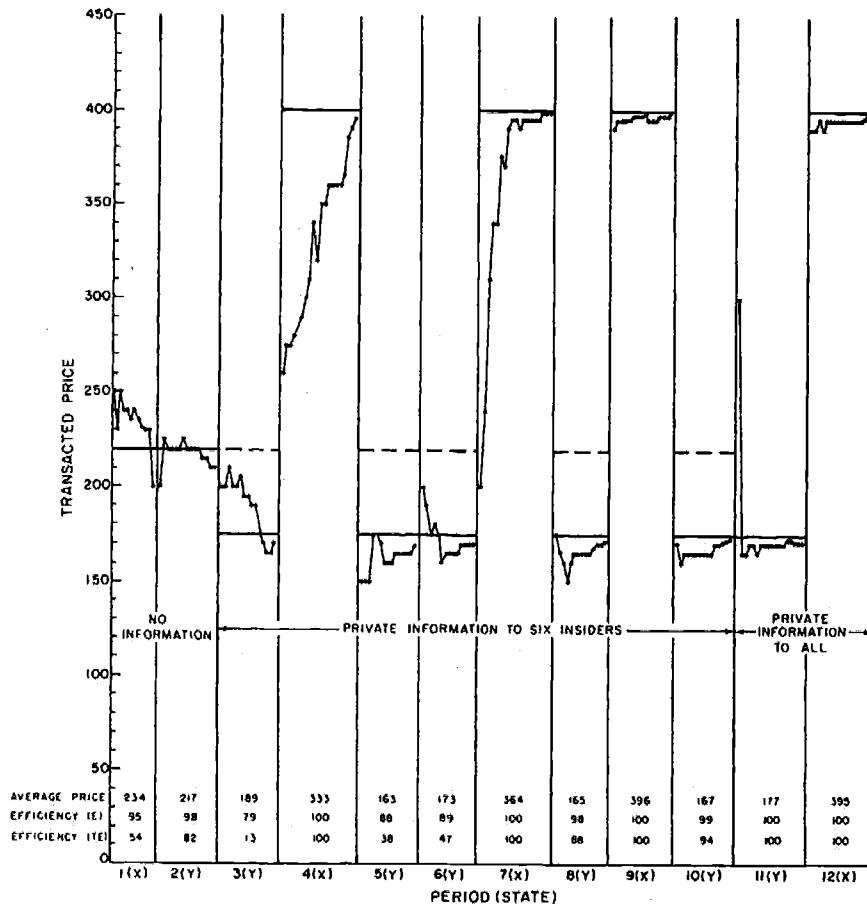
This market was designed so the PI and the RE equilibrium theories yielded mutually distinct predictions of the market outcomes in prices and allocations. The ability of the two theories to predict the behavior of markets can be assessed based on market observations.

Figure 10.4 shows the results for one of these markets. In Periods 1 and 2, traders were not given any information and the observed prices were located in the vicinity of the no information prediction of 220. In Period 3, State  $Y$  was realized, and one-half of the traders in each of the three classes were informed of State  $Y$  while the other half remained uninformed. The observed prices were much closer to the RE prediction of 175 than to the PI prediction of 220. Similar results were repeated in the other four periods (5, 6, 8 and 10) when State  $Y$  was realized. The observed allocative efficiency (shown in numbers above the  $x$ -axis), as well as prices, are much closer to the predictions of the RE model (100 %) than PI model. Although both models predicted a price of 400, observed asset allocations were closer to the predictions of the RE than the PI equilibrium. This experiment provided the first direct empirical evidence that markets can disseminate information from the informed to the uninformed through the process of trading alone, without an exchange of verbal communication. Such markets can achieve high levels of efficiency by transferring securities to the hands of those who value them most.

While this experiment demonstrated that these markets can disseminate information from the informed to the uninformed, the exact process through which markets do so remained unclear—a topic to which I return later.

### ***10.2.3 Information Aggregation in Markets***

Evidence on the ability of markets to disseminate information led to a more ambitious experiment: Can markets behave as if diverse information in the hands of traders be aggregated so all information is in the hands of all? To address this question, Plott and Sunder (1988) designed a market with three states of the world ( $X$ ,  $Y$ , and  $Z$ ). When the realized state was, say,  $X$ , they informed some traders that it was “not  $Y$ ” and informed the others that it was “not  $Z$ .” Do markets aggregate the



**Fig. 10.4** Dissemination of insider information in rational expectations equilibrium (Source Fig. 4, p. 680 of Plott and Sunder 1982)

diverse information in the hands of individual traders and behave as if everyone learns that the realized state is  $X$  in such a case?

They found that in markets with a complete set of Arrow-Debreu state-contingent securities such aggregation and dissemination of diverse information can take place, and markets can achieve high levels of information and allocative efficiency (see Fig. 10.5). Three panels of this figure for the first 9 periods show transaction prices in the each of the three markets for state-contingent securities—i.e., contingent on state  $X$ ,  $Y$ , and  $Z$  respectively. In the first three periods, state  $Z$  was realized and one-half of the subjects were informed that the realized state was not  $X$  while the other half learned that it was not  $Z$ . As seen in the figure, trading in the market for  $X$ - and  $Y$ -contingent securities was thin, and their prices converged near zero. Most of the trading volume occurred in the market for  $Z$ -contingent security, and its price climbed near the RE equilibrium level of 300.

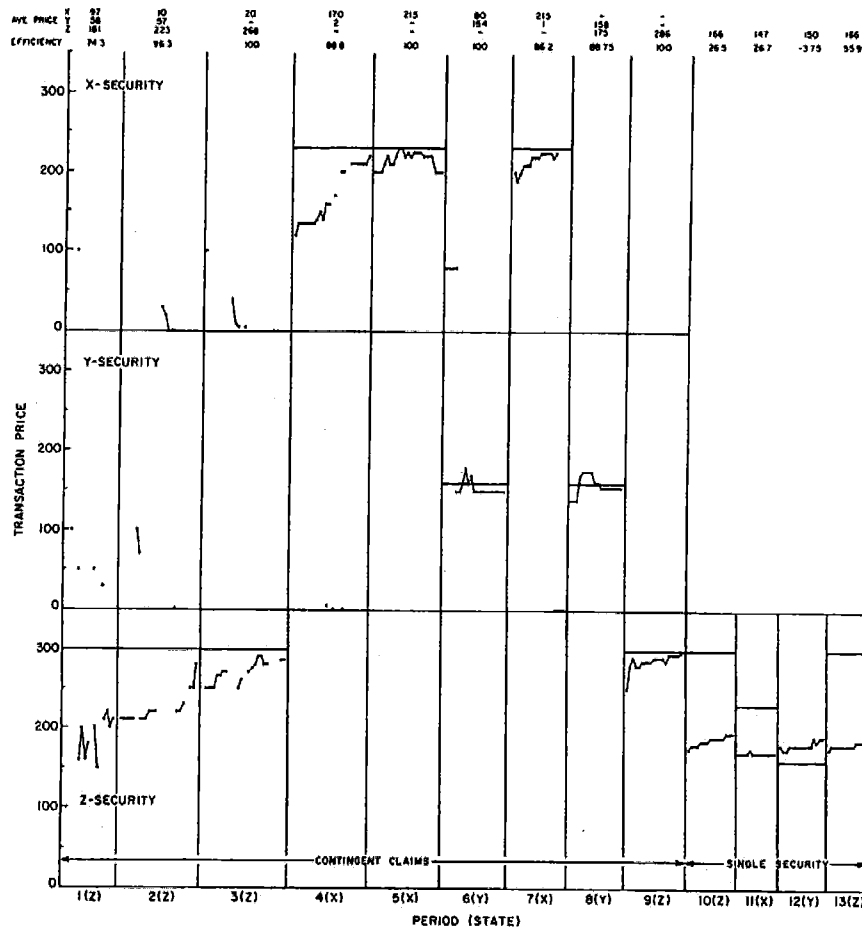


Fig. 10.5 Aggregation of diverse information in complete markets (Source Fig. 5, p. 1098 of Plott and Sunder 1988)

In periods 6 and 8 when the realized state was *Y*, prices of *X*- and *Z*-contingent securities were zero or non-existent, and the price of *Y*-contingent security converged near its RE equilibrium level. Analogous results can be seen in periods 4, 5, and 7 when the realized state was *X*.

The experiment also showed that when investors have homogenous preferences (which make it easier for traders to infer information from the actions of others), market is able to aggregate the diverse information. However, when markets have heterogeneous preferences and are incomplete (see periods 10–13 in Fig. 10.5) such aggregation does not occur.

Just because markets can aggregate and disseminate information does not mean that all markets do so under all conditions. Experiments show that market conditions must allow investors the opportunity to learn information from what they can

observe. Even in these simple experimental markets, these conditions are not always satisfied for various reasons (e.g., too many states, too few observations and repetitions to facilitate learning). For example, in the information aggregation experiment mentioned above, a complete market for three Arrow-Debreu securities is efficient, but an incomplete market for a single security is not.

Even in the best of circumstances, equilibrium outcomes are not achieved instantaneously. Markets tend toward efficiency, but cannot achieve it immediately. It takes time for investors to observe, form conjectures, test them, modify their strategies, etc. With repetition, investors get better at learning, but when the environment, including the behavior of other investors, changes continually, the learning process and the market may never reach a stationary point.

### 10.2.4 Cost of Information

If markets are efficient in the sense of aggregating and disseminating information across traders, who would pay for costly research? Grossman and Stiglitz (1980) and others have pointed out this problem. Experiments have helped us understand what actually goes on (Sunder 1992), and allowed us to better address this conundrum of the efficient market theory: finite rate of learning makes it possible to support costly research, even in markets which tend toward efficient outcomes. Enough people would conduct costly research so the average returns to research equal the average cost. As shown in Panel a of Fig. 10.6, the demand function for information tended to shift to the left from an initially higher level to a lower level,

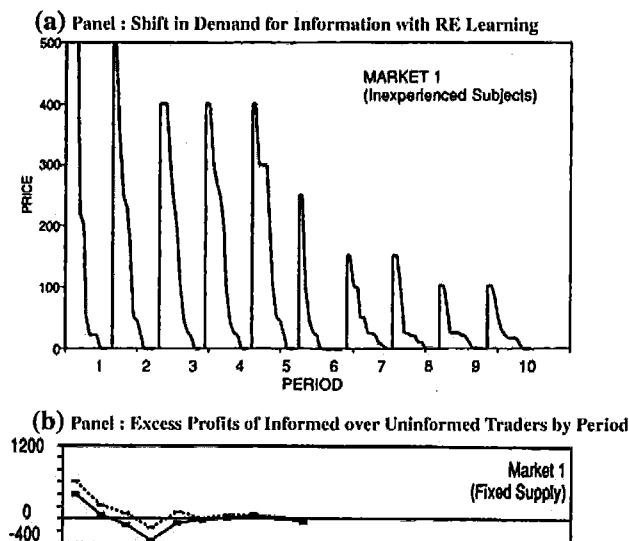


Fig. 10.6 Market for information (Source Fig. 8, p. 680 and Fig. 11, p. 687 of Sunder 1992)

as the traders learn to read the information from the asset market. Panel b charts the difference between average profits of traders who invest in information and those who do not (gross in broken line, net in firm line). In early periods, both the people who invest in information have higher gross as well as net profits. However, as traders learn to read information from the asset market, their demand for information and therefore the price of information (the distance between gross and net profits) drops, and the absolute level of excess profits converges near zero. Research users have higher gross profits, but their net profits are the same as the profits of the others. As investors learn (in a fixed environment), their value of information decreases because they can ride free on others' information, and the market price of information drops. If the supply of information can be maintained at the lower price, the price drops to a level sustainable by learning frictions. If the supply of information also falls with its price, we get a noisy equilibrium.<sup>2</sup>

### ***10.2.5 Price Indeterminacy and Bubbles***

Under what conditions do prices become indeterminate and possibly form bubbles has been a major issue in literature on asset markets as well as their regulation. An experiment by Hirota and Sunder (2007) explores the proposition that the fundamental economic model of valuation (discounted cash flow or DCF) is difficult, even impossible, to apply in markets populated by short term traders, and such markets give rise to price indeterminacy and bubbles.

When a security matures beyond the investment horizon of an investor, his personal estimate of DCF includes the sale price at his personal investment horizon. His estimate of the sale price depends on his estimate of other investors' expectations of DCF beyond that investor's own personal horizon. In a market populated with short-term traders, applying the DCF model of valuation involves backward induction from the maturity of the security through the expectations and valuations of the "generations" of investors between the present and the date of maturity. DCF valuation model makes heroic assumptions about the common knowledge necessary to do backward induction. Even if investors are rational and make no mistakes, it is unlikely that they can have the common knowledge necessary for the price to be equal to the fundamental valuation in a market populated by limited horizon investors. Bubbles and price indeterminacies arise, even with rational investors who make no errors, if they cannot backward induct the DCF through these multiple high orders of expectations of future cash flows.

In their eleven experimental sessions, Hirota and Sunder found that bubbles do not arise when the markets are populated with investors who have long-term investment horizons (see Fig. 10.7), but consistently arise when markets are populated with short-term investors (see Fig. 10.8). In each figure, the fundamental

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<sup>2</sup>See Sunder (1995) for further results.

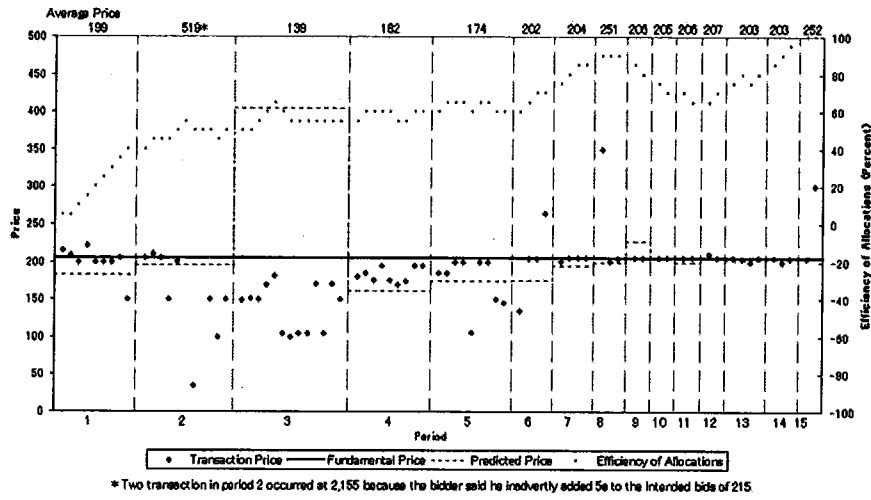


Fig. 10.7 Absence of price indeterminacy with long-term investors (Source Fig. 2, p. 1888 of Hirota and Sunder 2007) (Color figure online)

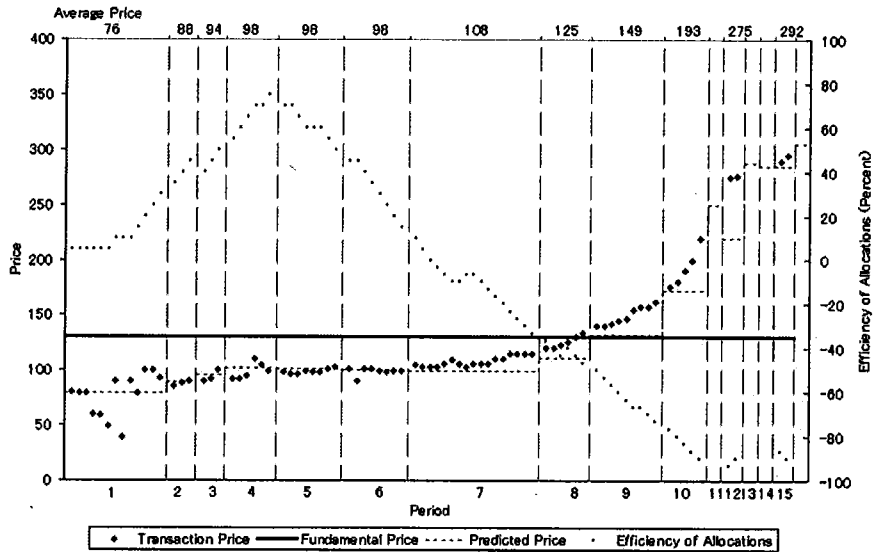


Fig. 10.8 Indeterminacy of prices with short-term traders (Source Fig. 9, p. 1892 of Hirota and Sunder 2007) (Color figure online)

value of the security is shown in red line, and the price of individual transactions in diamond markers. Allocative efficiency of the market after each transaction is shown in smaller dots, and dashed lines show the average prediction of transaction prices obtained at the beginning of the respective periods. Not surprisingly, the

pricing of new technology, high growth, and high risk equities are more susceptible to bubbles. In such circumstances, if we do not have common knowledge of higher order beliefs, testing theories of valuation becomes problematic.

### 10.2.6 Equilibrium Selection in Presence of Multiplicity

When two or more equilibria are mathematically possible, human experiments can help choose the more plausible subset among them. For example, overlapping generations (OLG) model of fiat money yields an infinity of competitive equilibrium solutions, only one of which is stationary. In addition, there is a range of strategic (for small number of agents) stationary equilibria—all mathematically possible. Which of these are better at organizing data obtained from economies populated with human agents?

Lim et al. (1994) was the first attempt to resolve this question experimentally. Experimental economies reported in this paper involved a sequence of overlapping generations of three or four individuals; each individual lived for two periods. In their “young” age individuals were endowed with “chips” that could be traded for fiat money with the individuals of the old generation. In their old age, individuals could exchange their units of fiat money for the consumption good. Results of the experiments exhibited support for the stationary solution (see Fig. 10.9). The results were robust to two designs of exchange institutions (double oral auction and supply schedule auction) and to two different endogenous ways of converting money into “chips” at the end of the game.

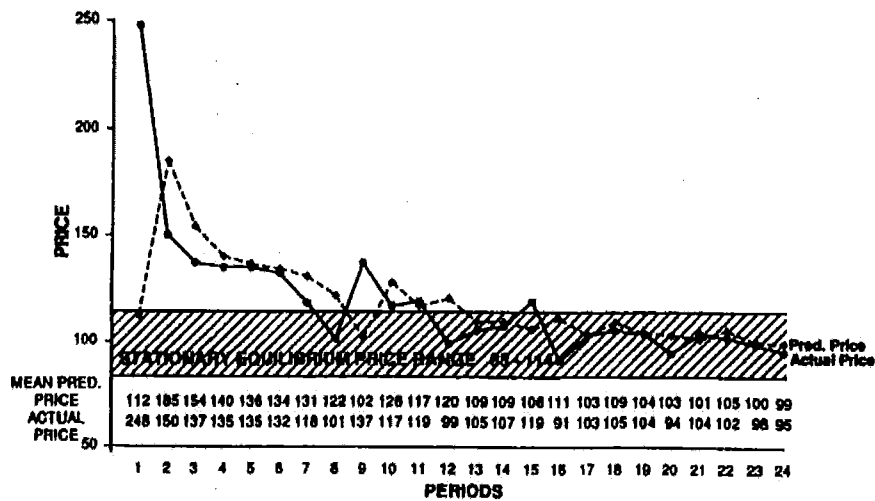


Fig. 10.9 Price of money in an overlapping generations economy (Source Fig. 4, p. 266 of Lim et al. 1994)

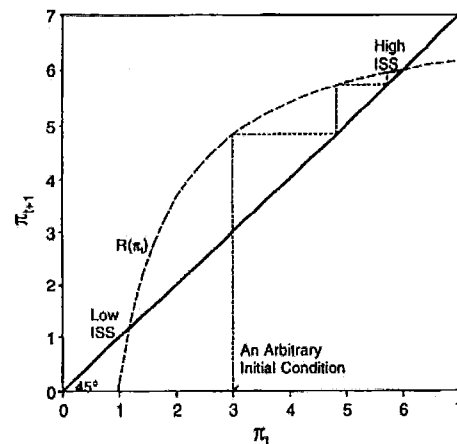
The substantive finding of the experiment was that the stationary solutions to the overlapping generations model of fiat money form the domain of attraction for the behavior of these experimental economies. Since the initial price in all experimental economies deviated significantly from the stationary solutions, there was every chance for these economies to follow one or more of the continuum of non-stationary paths. The fact that all experimental economies stabilized close to the range of stationary solutions suggests that stationary solutions are better descriptors of the behavior of such economies.

Lim, Prescott and Sunder (LPS) used two different techniques of bringing laboratory experiments of indefinitely lived economies to an end. Converting the end-of-the-game money balances into goods at (1) price observed in the last period and at (2) price forecast made during the last period, seem to be satisfactorily neutral devices for terminating such economies. Both methods worked well.

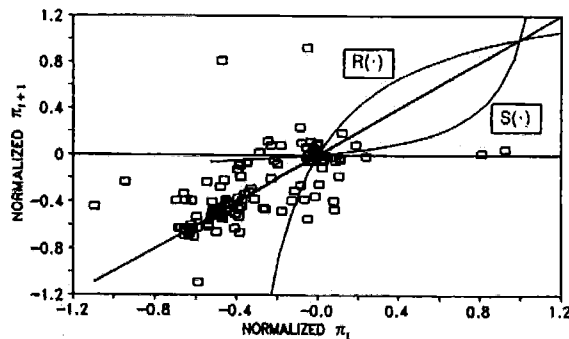
### 10.2.7 Fiat Money and Monetary Policy

LPS experiment opened the way to use OLG economies in laboratory to explore consequences of monetary policy by comparing theoretical predictions of various models with empirical observations. Marimon and Sunder (1993) modified the LPS economy so the government financed a fixed real deficit through seigniorage. The economy had two stationary RE equilibria (labeled Low Inflation Stationary State or LISS and High Inflation Stationary State or HISS, respectively in Fig. 10.10) and a continuum of non-stationary RE equilibria paths. Although both stationary equilibria are consistent with RE, LISS is unstable under rational and stable under adaptive expectation. On the other hand, HISS is stable under rational and unstable under adaptive expectations.

**Fig. 10.10** Rational expectations equilibria in fixed real deficit OLG economy (Source Fig. 1, p. 1079 of Marimon and Sunder 1993)







**Fig. 10.11** Normalized observations from multiple laboratory economies with fixed real deficit in relation to the two RE stationary equilibria (Source Fig. 2, p. 142 of Marimon and Sunder 1994)

Results from several such experimental economies are combined (after being normalized) in Fig. 10.11. We do not observe any non-stationary RE paths. Observed paths tend to converge close to, or somewhat below, the low inflation stationary state (LISS in the middle of the figure) and not near HISS (in the upper right corner of the figure). The adaptive learning hypothesis is consistent with the data in selecting the LISS RE equilibrium as a long-run stationary equilibrium. Nevertheless, simple adaptive learning models do not capture the market uncertainty or the downward (lower left) biases observed in the data.

Marimon and Sunder (1994) proceeded to design, conduct, analyze, and compare experimental versions of monetary overlapping generations economies under four alternative policy regimes: (1) constant real deficit financed through seigniorage in Marimon and Sunder (1993) described above; (2) real deficit adapted each period to try to achieve a given inflation rate; (3) pre-announced changes in real deficit levels; and (4) economies with no theoretical stationary competitive equilibrium.

Figure 10.12 shows that adaptive and realized paths of inflation for four separate experimental economies in which the real deficit was adjusted each period to target a fixed rate of inflation (50, 55, 200 and 200 % per period respectively). While the realized paths are in the approximate neighborhood of the target levels, there is considerable variance between the two. There is no significant evidence that these economies adjust to pre-announced changes in real deficit before the change is actually implemented (Marimon and Sunder 1994, Figs. 8, 9 and 10, not reproduced here).

In their next paper, Marimon and Sunder (1995) designed and explored the behavior of experimental overlapping generations economies in which the government follows a simple rule (instead of discretion) as suggested by Friedman (1948, 1960). Government either finances a fixed real deficit through seigniorage or allows money supply to grow at a predetermined rate. The experiment was designed to study the conjecture that a "simple" rule, such as a constant growth of the money

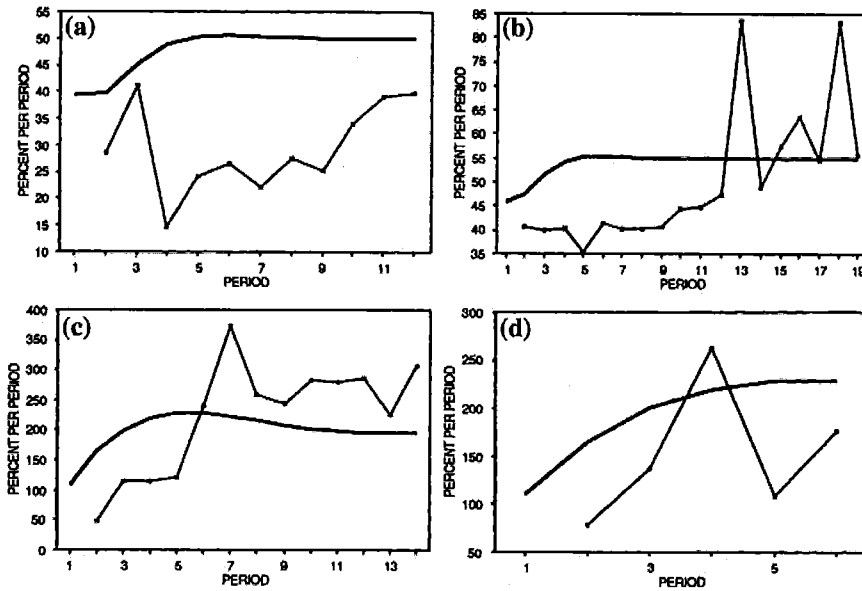
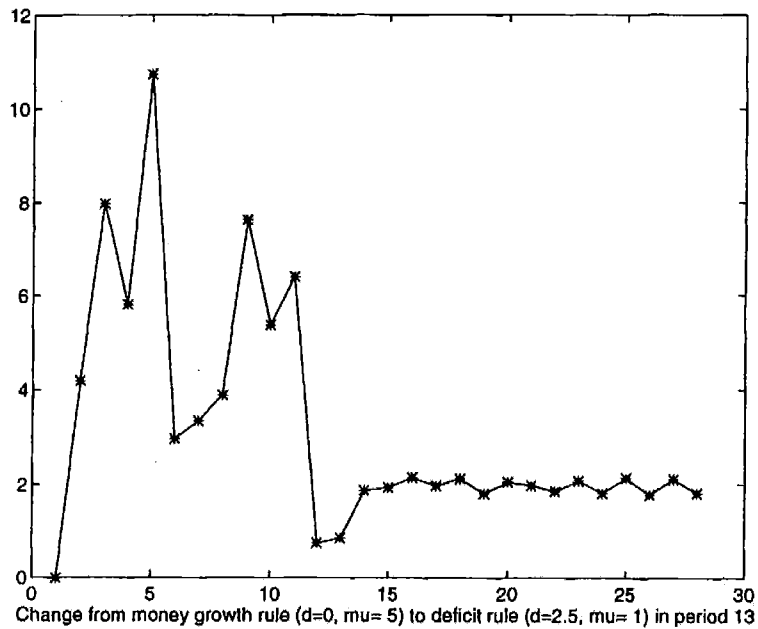


Fig. 10.12 Adapting real deficit to target a given rate of inflation (Source Fig. 5, p. 147 of Marimon and Sunder 1994)

supply, can help coordinate agents' beliefs and help stabilize the economy. The experimental data provided weak evidence for such a conjecture. For example, in Fig. 10.13, during the first twelve periods, the economy operated under a fixed money growth rule, and switched to fixed deficit rule from period thirteen onwards. The change in stability of the economy is clearly visible in the data. However, this change is not obviously attributable to the change in the rule itself because the stability parameter (contraction factor) of the economy changed from 1.58 in the first 12 periods to 0.63 in the subsequent periods. From this (as well as other experimental economies not shown here) it is clear that it is the reduction in the contraction factor of the economy that stabilizes it. The underlying stability parameters of the economy provide a better explanation of observed price volatility than differences in the policy do.

### 10.2.8 From Research to Policy

The experimental economies studied here are far from capturing the complexity of any historical economy. The experimental environment is simple (one good and one asset), and the subjects have little opportunity to communicate through news media and other channels routinely available in historical societies. As in other experimental economies, individual behavior is far from perfect. It appears a long leap of



**Fig. 10.13** Inflation under fixed money growth and fixed real deficit rules (*Source* Fig. 10, p. 142 of Marimon and Sunder 1995)

faith to draw inferences from simple laboratory experiments, and to apply them meaningfully to monetary policy for managing complex economies. Similarly, theoretical models are gross simplifications, and one cannot be confident that their deductions can be used as the basis for monetary policy in more complex situations.

Fortunately, even with the small number of agents in the cohort, the aggregate can smooth out some, but not all, individual errors and eccentricities. One naturally wonders how useful such experimental data can be as a benchmark to improve our understanding of historical economies. One way of answering this question is to see if the laboratory data share some interesting common features with historical economies.

The top left panel of Fig. 10.14 (taken from Marimon and Sunder 1995) plots the annual Consumer Price Index inflation rate against the rate of growth of money for the U.S. economy for 1959–88. The top right panel shows the same data when the same data is smoothed (using  $\beta = 0.95$  in Lucas (1980) procedure), along with a  $45^\circ$  line superimposed on the smoothed data. The bottom left panel of Fig. 10.14 shows money growth and inflation data from six experimental economies in a similar chart. The right bottom panel shows the same experimental data when it is smoothed using the same Lucas procedure.

Our experimental economies, based on a deterministic OLG model, give a sharp picture of the quantity theory. Both the U.S. as well as the experimental raw data on money growth and inflation are quite scattered in the left panel. However, when

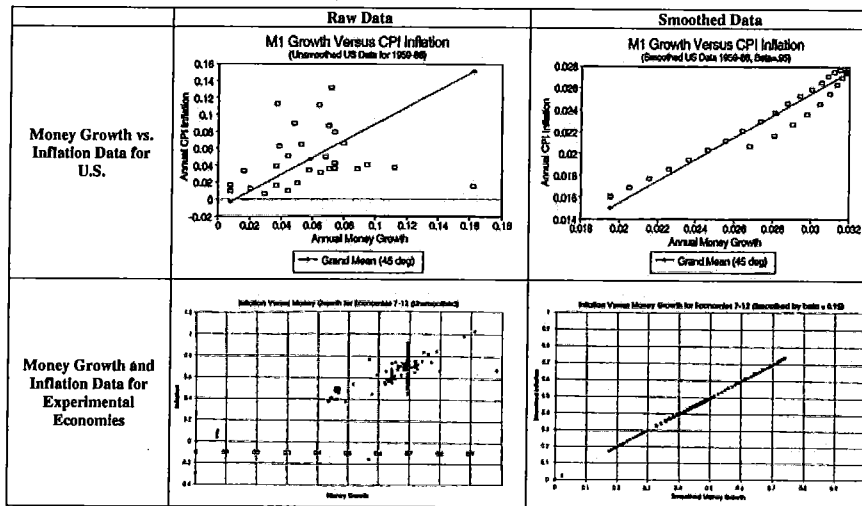


Fig. 10.14 Comparing raw and smoothed M1-growth versus inflation data for US and experimental economies (Source Figs. 11–14, pp. 144–147 in Marimon and Sunder 1995)

properly (time) averaged in the two right panels, the rates of inflation and money-growth become virtually identical. To an econometrician’s eye, the U.S. data and our experimental data might not be qualitatively different. Nevertheless, we know that behind the experimental data there are some clear predictions about which stationary equilibrium is more likely to have been selected and generated the data. It is the low inflation stationary state (or classical equilibrium in which higher deficit is associated with higher equilibrium rate of inflation), and not the high inflation stationary state (in which higher deficit is associated with lower equilibrium rate of inflation). It does not seem unreasonable to infer that, there is a good chance that the historical data from the U.S. economy was also generated by the classical equilibrium.

### 10.2.9 Sunspot Equilibria

In dynamic models of economies, indeterminacies frequently manifest themselves as so-called “sunspot” equilibria. In these equilibria, the expectation that extrinsic random events matter becomes self-fulfilling, and causes extrinsic uncertainty to have real allocative effects. While there is a large theoretical literature on when sunspots may matter (see, e.g., Shell 1977; Cass and Shell 1983), empirical evidence that expectationally driven randomness is at work in real-world markets has been scarce. For example, econometric estimates of stock price volatility exceed the predictions of economic theory (see Shiller 1981). However, marshaling

econometric evidence to support or reject the hypothesis that stock price changes (or any other prices) are driven by extrinsic noise is difficult for two reasons. First, since equilibria are defined in terms of subjective expectations, inherent unobservability of expectations in natural settings makes it difficult to construct convincing tests of theory. For example, years after Shiller's first paper on the subject, a hot debate continues on the validity of the evidence on "excess" stock price volatility (Kleidon 1986). Second even if the fact of excess volatility were indisputably established, demonstrating that it is caused by extrinsic uncertainty is yet another challenge. Indeed, from an econometric perspective, the problem of demonstrating a sunspot effect is enormous. Since it requires identifying the extrinsic random variable driving the process and demonstrating that it is in fact the cause of the observed volatility.

Marimon et al. (1993) study the existence and robustness of expectationally driven price volatility in experimental overlapping generation economies. In their theoretical model there exist "pure sunspot" equilibria which can be "learned" if agents use some adaptive learning rules. Figure 10.15 (reproduced from Marimon et al.'s Fig. 3) shows five such economies of varying lengths. All (except Economy 5<sup>3</sup>) start with some 10 or more periods when the economy is subjected to an alternating binary extrinsic shock, and the subjects have the opportunity to empirically associate this shock with an observable signal—i.e., a "sunspot." When this extrinsic shock is in fact withdrawn without withdrawing the associated signal, two different equilibria arise. One is a stationary equilibrium based on the expectation of no extrinsic shock, shown by a firm horizontal line in the charts. The second is a sunspot equilibrium in which the expectation of oscillating prices between high and low levels in alternate periods becomes self-fulfilling, as shown by a broken horizontal line in the charts. The data show the existence of expectationally driven cycles, but only after subjects have been exposed to a sequence of real shocks and "learned" a real cycle.

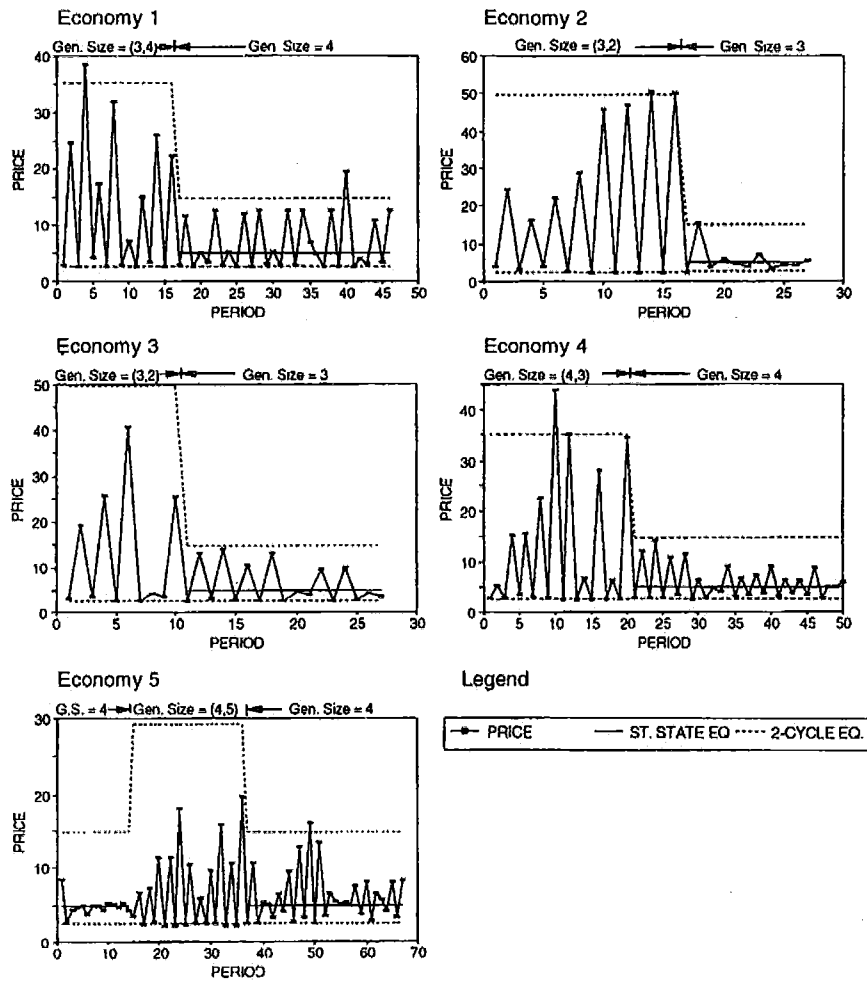
To our knowledge, Marimon et al. provided the first experimental data that has some bearing on the existence of expectationally driven cycles and found that if agents expect sunspots to matter, they can matter (although we cannot assess how persistent they can be). Further, the evidence on price volatility under sunspot equilibrium was found to be path-dependent.

### ***10.2.10 Default Penalty as an Equilibrium Selection Mechanism***

When a production-and-exchange economy has multiple equilibria, default and bankruptcy laws are required to prevent strategic default. These accounting,

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<sup>3</sup>Unlike the other four economies with two phases, Economy 5 has three phases: no extrinsic shock, extrinsic shock, and no-extrinsic shock again.



**Fig. 10.15** Behavior of five overlapping generations economies with sunspot equilibria (Source Fig. 3 p. 89 in Marimon et al. 1993)

bankruptcy and possibly other aspects of social mechanisms also play an important role in resolving the otherwise mathematically intractable challenges associated with multiplicity of equilibria in such economies. Huber et al. (2011a, 2012) report experimental evidence on the effectiveness of this approach in resolving multiplicity (Fig. 10.16). As can be seen in Fig. 10.17 (reproduced from HSS 2012, Fig. 2) choice of a penalty can direct the economy to any of the chosen equilibria from the three that exist.

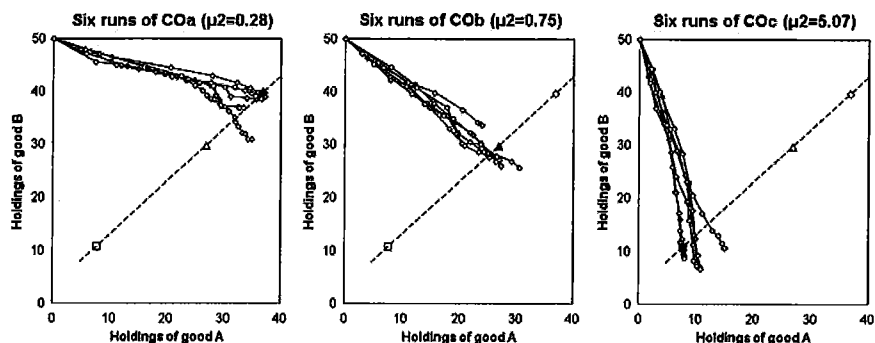


Fig. 10.16 Equilibrium selection by choice of bankruptcy/default penalty ( $\mu$  = default penalty parameter) (Source Huber et al. 2012, Fig. 2)

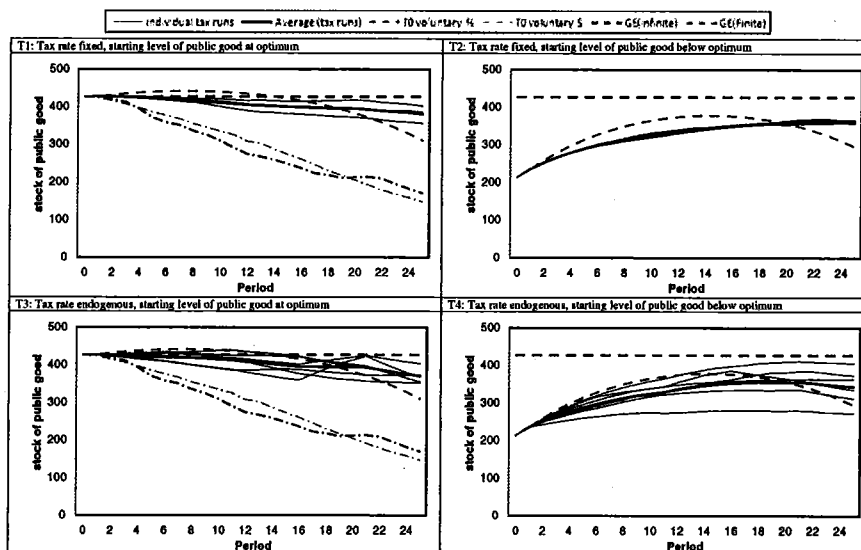


Fig. 10.17 Paths of the stock of public good under democratically determined rate of taxation

### 10.2.11 Financing Public Goods Through Democratic Taxation

Ways of financing production of public goods have attracted much interest (Huber et al. 2010). Game theoretic models suggest that egoistic individuals have little reason to finance production of public goods through individual voluntary anonymous contributions. Laboratory public good experiments tend initially to yield

average contributions around 50 % of the collective optimum, gradually declining towards 5–20 % range. Although the averages rarely drop below 5 %, many individuals free ride by making no contributions.

Huber et al. (2011a) conducted laboratory experiments to explore the suitability of setting taxes through democratic voting to finance provision of public goods. In these laboratory economies building and maintenance of a depreciating public good is financed either by voluntary contributions or by taxes. The results (see Fig. 10.17 from their Fig. 1) show that the experimental economies sustained public goods at 80–90 % of the infinite horizon but considerably more than the finite horizon optimum. Payoff efficiency is around 90 %. This contrasts with rapid decline in the provision of public goods under voluntary anonymous contributions. When subjects can vote to choose between a system of voluntary contributions or taxation (with rate determined as the median of individual proposals) 19 out of 20 voting decisions favored taxation.

The results of the experiment suggest that the important social problem of financing public goods can be, indeed has been, addressed by societies through significant reliance on the institution of taxes set either by the ruler or by democratic vote. Dependence on individual voluntary anonymous contributions among large groups may be too unreliable a basis for providing services essential to their productivity, even survival. Voluntary contribution mechanisms have the inherent appeal of being decentralized, and thus insulated from tyranny. Taxation, representing centralized power and a centralized enforcement mechanism, has historical associations with tyrannical oppression. Democratic government and taxation based on popular voting attempts to balance the consequences of centralization. Our experimental results suggest that such a reasonable balance is achievable for financing of public goods and services through democratic mechanisms.

### *10.2.12 Role of Optimization in Economics*

Adam Smith (1776) wrote:

It is not from the benevolence of the butcher, the brewer, or the baker that we expect our dinner, but from their regard to their own interest. We address ourselves, not to their humanity, but to their self-love, and never talk to them of our own necessities, but of their advantages. (I.2.17)

Over the intervening centuries, economics has developed the concept of competitive equilibrium that, under various assumptions such as convexity of preferences and maximizing agents, is Pareto efficient. Derivation of equilibrium in economies populated by agents who optimize some well-ordered function such as profit or utility is a central feature of economics. The normal modeling technique is to ascribe sophisticated computational abilities to a representative agent to solve for equilibrium (Muth 1961).



At least since Newell and Simon (1972), the plausibility of intuitive optimization by human agents, with their limited cognitive faculties, has come under question. They proposed a descriptive model of human behavior of bounded rationality in which agents seek satisficing instead of maximization by using a means-end heuristic. Selten (1999) has pursued the bounded rationality in game-theoretic domains. Where does the conflict between the maximization assumption, that underlies much of today's economic theory, and limited cognition and rationality documented by Simon and his followers leave us? Fortunately, a promising way out of this conflict is suggested by three works: Becker (1962), Smith (1962), and Gode and Sunder (1993).

Becker (1962) showed that price changes alter the opportunity set of consumers in such a way that even if they choose randomly from their opportunity sets, the expected demand function is downward sloping. Assumption of utility maximization is not necessary to generate a downward sloping demand function; random choice from budget constrained opportunity sets is sufficient.

As discussed earlier in Sect. 10.2.1, Smith (1962) showed that profit motivated student traders in a double auction market structure generate market outcomes close to competitive equilibrium even when most of the assumptions used to derive the equilibrium (e.g., perfect competition, information, Walrasian tâtonnement, etc.) do not hold.

Gode and Sunder (1993) compared the behavior of simple markets (similar to Vernon Smith's discussed earlier) populated by profit-motivated human traders with the behavior of the same markets when they are populated by very simple trading algorithms (computer programs), labeled zero-intelligence or ZI traders with and without budget constraints. Figure 10.18 (reproduced from Gode and Sunder, Fig. 1) shows the demand, supply, equilibrium price, and transaction price paths under the three different treatments. The bottom panel shows the outcomes from human traders, similar to Smith's results. The top panel shows the outcomes from unconstrained algorithmic traders who submitted uniformly distributed random numbers over 0–200 range as bids and asks. The middle panel shows the outcomes from budget-constrained ZI traders who bid and asked uniformly distributed random numbers in ranges where they will not incur a loss (bids below their values and asks above their costs).

Even a cursory glance at the results in these three panels makes it clear that most of the difference between the market outcomes of unconstrained random behavior in the top panel and profit-motivated human behavior in the bottom panel is accounted for by a single simple constraint on algorithms: do not bid above your value and do not ask below your cost, i.e., do not incur any losses. This level of "rationality" is hardly beyond human faculties and at market level it yields prices and allocative efficiency (not shown here) which is comparable to the theoretical equilibria even in absence of optimization, memory, or learning on part of these algorithmic traders. Gode et al. (2004) show a similar result for ZI traders converging near the Pareto optimal allocations in an Edgeworth box.

In a second example, Jamal et al. (2012) have taken this work a step further by examining the ability of markets populated by minimally intelligent algorithmic

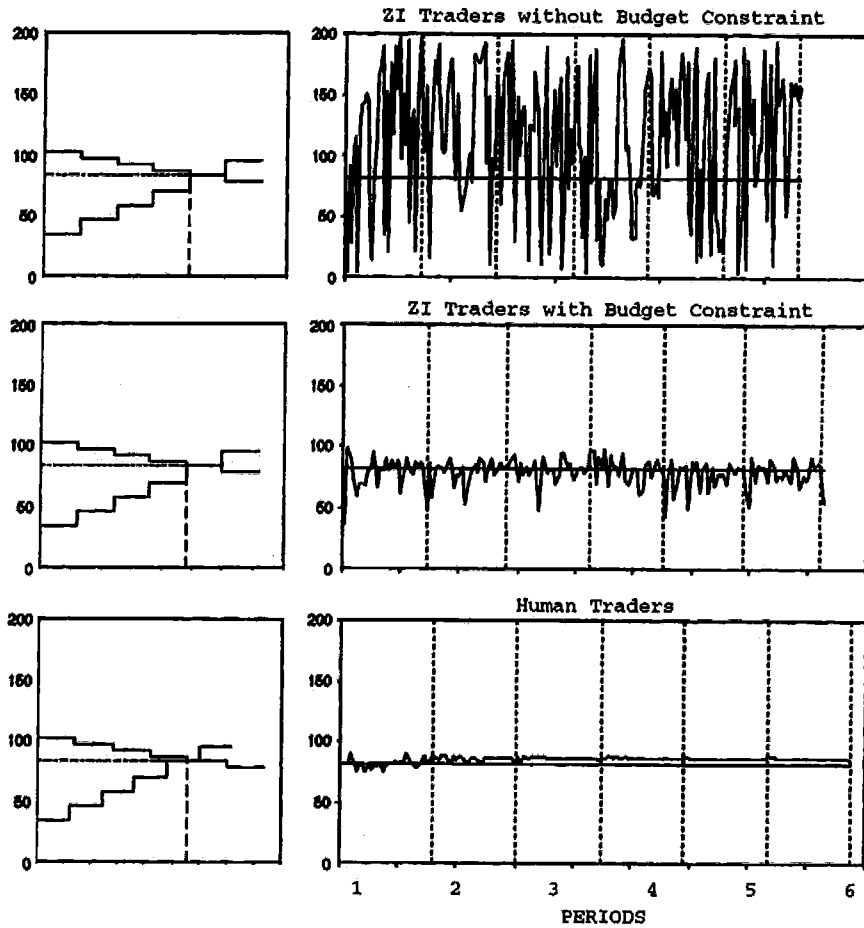
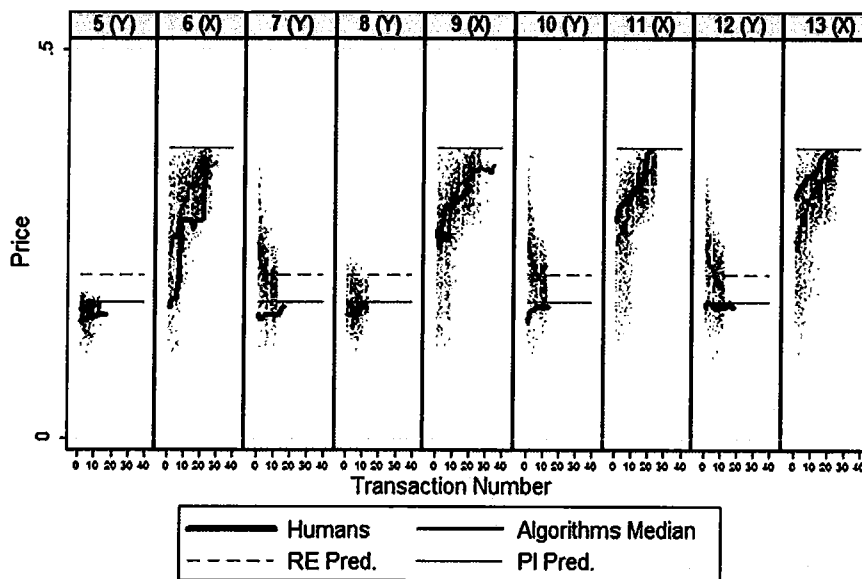


Fig. 10.18 Price paths in double auction markets populated by ZI (unconstrained), ZI (budget constrained) and human traders (Source Fig. 1 p. 124 in Gode and Sunder 1993)

traders to disseminate information and achieve RE equilibria. Figure 10.19 compares the price paths observed by Plott and Sunder (1982) with profit-motivated human traders, against the price paths observed in the same markets with simple algorithmic traders defined by two features: (1) Newell and Simon's means-end heuristic to adjust the aspiration level on the basis of observed transaction prices using a first order adaptive process; and (2) zero-intelligence (i.e., random) bids and asks relative to these aspiration levels. The single price path of human markets is shown in blue against the cloud of algorithmic price paths from 50 independent replications, and the median of the 50 paths shown in red line, all against a background of RE equilibrium prediction in green line and PI equilibrium prediction in broken line. The results suggest that in price paths (as well as in allocative



**Fig. 10.19** Dissemination of information in markets with minimally-intelligent traders (*Source* Jamal et al. 2012, Fig. 3) (Color figure online)

efficiency not shown here), minimal levels of rationality in individuals suffice to take markets close to their equilibria, although the latter are derived from strong rationality assumptions.

These findings have several interesting implications. First, the extraction of surplus appears to be a characteristic of this auction and the environment in which it is conducted; striving by individual participants to maximize their profits is not necessary for the extraction of surplus.

Second, since stronger forms of individual rationality reduce the cross-sectional dispersion of the profits of traders, the maximization assumption may still be quite relevant to the equity considerations. Paradoxically, profit maximization seems to be associated with lowering, not raising, profit dispersion across individuals. In addition, a lower price variability in markets populated by human traders (who attempt to increase their profits) suggests that other aspects of market behavior may be sensitive to profit-maximizing behavior.

Third, in the experimental economics literature, the percentage of the maximum possible surplus extracted has often been used as an index of learning and rationality and of the control attained in an experimental economy. Such inferences may not be appropriate for market mechanisms that yield all their surplus to ZI traders.

Fourth, we already know that when double-auction markets aggregate and disseminate information about the state of the world, human traders can significantly improve their ability to extract surplus through learning (see Plott and Sunder 1982, 1988). When populated by ZI traders, such markets may be less efficient.

More work is needed to separate the effects of the structure from profit-oriented trader behavior on market performance.

Finally, these results may help reconcile the predictions of neoclassical economic theory with its behavioral critique (Sunder 2006). Economic models assume utility-maximizing agents to derive market equilibria and their welfare implications. Since such maximization is not always consistent with direct observations of individual behavior, some social scientists doubt the validity of the market-level implications of models based on the maximization assumption. Our results suggest that such maximization at the individual level is unnecessary for the extraction of surplus in aggregate. Adam Smith's invisible hand may be more powerful than some may have thought: when embodied in market mechanisms such as a double auction, it may generate aggregate rationality not only from individual rationality but also from individual irrationality.

### *10.2.13 Market as Artifacts*

Markets are powerful social institutions. They probably evolved in human societies because their efficiency had survival value. We can usefully distinguish between the inner and outer environments of an artifact (see Simon 1996). The former are designed to obtain a degree of insulation across variations in the latter, so the artifact can serve the function for which it is created or used. The inner environment of markets is defined by their rules; their outer environment includes the behavior of agents.

A claim that the predictions of the first fundamental theorem in economics are approachable in classical environments without actual or attempted maximization by participants might have been met with skepticism until recently. Thanks to a largely serendipitous discovery using computer simulations of markets, we can claim that weak forms of individual rationality, far short of maximization, when combined with appropriate market institutions, can be sufficient for the market outcomes to approach the predictions of the first fundamental theorem. These individual rationality conditions (labeled zero-intelligence) are almost indistinguishable from the budget or settlement constraints imposed on traders by the market institutions themselves. They are even weaker than Simon's concept of bounded rationality.

ZI traders are only an important first step toward using computer simulations with artificially intelligent traders to explore the structural properties of markets. Such simulations—the “wind tunnels” of economics—have already given us interesting discoveries. For example, we now know that the market level tradeoff between the level and the probability of execution of an ask would exist even if no trader included such a tradeoff in his strategy.

As social artifacts, markets are the arena for the interplay of demand and supply. The functionality of markets can be assessed by their robustness to certain environmental variations and responsiveness to others. We prefer markets to be robust

## Viloudaki, Elizabeth

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**Subject:** FW: New publication

**From:** Sunder, Shyam  
**Sent:** Sunday, August 30, 2015 5:43 PM  
**To:** Viloudaki, Elizabeth  
**Cc:** Whitbread, Diane  
**Subject:** New publication

Dear Liz:

This paper has been published in the book you gave me on Friday. Please follow the routine for new publications (add to folder with a new number, CV, annual report, pdf to my website, and abstract to ssrn via Cowles Foundation). Since the published version does not have an abstract, I shall write one.

Thanks.

Shyam

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Published on February 3, 2014

Daniel Friedman, R. Mark Isaac, Duncan James, and Shyam Sunder. 2014. *Risky Curves: On the empirical failure of expected utility*. London: Routledge.

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