Experimental Methods in the Political Economy of Exchange

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Traditionally, economics has been considered a nonexperimental science. In the last quarter century experimental methods have become a growing part of the economist's effort to more fully understand how individual motivation, individual information, and exchange rules relate to market outcomes in different institutions. Empirical support has been found in a wide variety of different experiments for the theoretical proposition that markets serve to aggregate the dispersed information of individuals to produce wealth-creating outcomes for society. A number of different experiments are presented to illustrate the type of questions addressed, including some in which the process is governed by political institutions such as majority rule.

EXPERIMENTAL METHODS IN ECONOMICS HAVE THE SAME scientific function that such methods have in geology and astronomy—that is, to supplement natural observations with knowledge of principles obtained from testing conjectures and formal theories under controlled laboratory conditions. Thus geologists and astronomers use principles governing the physics of matter that have been well tested in laboratory environments to help guide and interpret field observation. Likewise, experimental economists seek to establish principles of market and individual behavior in controlled laboratory environments before presuming, without evidence, that such principles can be used to interpret (or estimate parameters from) field data. Economics is noteworthy for its use of abstract theory, but rarely is such theory subjected to rigorous testing. The development of laboratory methods in the last quarter century has changed the ground rules by challenging economic theorists to submit to a new, difficult, and unaccustomed discipline, but it has also brought new standards of rigor to the data-gathering process by requiring the economist (like the astronomer and geologist) to assume responsibility for a source of data that can be replicated by other researchers. In this article, I hope to convey an appreciation for the scientific power and breadth of this rapidly developing methodology, which has begun to change the way economists think about their scientific mission (*1*).

Exchange Institutions and the Creation of Wealth

Since the work of Adam Smith political economists have hypothesized that the enormous production in modern economies originated with exchange institutions that allowed human and physical capital to become specialized while supporting diversity in consumption. Smith's great insight was to see exchange as a positive sum game capable of yielding net betterment for all parties to exchange, but also to understand that this wealth-creating process was not perceived ("invisible hand") by the individual (*2*). This remarkable theorem states that individuals, left to their own "betterment seeking" (which each defines in his own way), will cooperate through exchange to create wealth far exceeding what they would produce in isolation.

But what is the basis for believing that Smith's theorem has any empirical validity under the conditions postulated by its modern formulation? We have historical observations suggesting that greater wealth is associated with the use of exchange institutions, but any such association does not have the demonstration power of an experiment.

An Experimental Design

An example of an experimental design that provides a simple modern treatment of Smith's proposition is illustrated in Fig. 1A. Four buyers (B1, . . . ,B4) can each purchase a maximum of four units of the commodity. Each buyer is assumed to associate decreasing marginal value to successive units of the commodity. Thus buyer B1 places a maximum value of $5.85 on the first unit consumed, $5.20 on the second, and so on, as indicated. In keeping with the hypothesis that individual circumstances are unique, each buyer is assumed to have a distinct declining marginal valuation for the commodity. In the laboratory we want buyers to be well motivated to buy low, so we inform them that they will be paid in cash the difference between each marginal assigned value and the price paid in the market for the corresponding unit. Thus if B2 buys two units, one at $5.20 and a second at $5.10, he or she will earn a cash profit of 70 cents. If we arrange all 16 assigned values from highest to lowest, the result is a theoretical willingness-to-pay (inverted demand) schedule (*D* in Fig. 1A). Similarly, three sellers, S1, S2, S3, have distinct (in this example, constant) marginal costs representing lower bounds on the prices at which each can profitably sell his or her respective capacity outputs (five units). Seller 1 is most favorably situated with a marginal supply cost of $4.95 per unit, S2 is the next most eager seller, and S3 the highest cost seller. We motivate our laboratory sellers to sell high by paying them a profit equal to the difference between the actual sales price and the marginal cost of the corresponding unit. Thus if S1 sells two units at price $5.15, the profit is 40 cents. If we array all 15 assigned marginal costs from lowest to highest, the result is the theoretical willingness-to-accept (inverted supply) schedule (*S*).

This experimental design makes plain a characteristic of exchange

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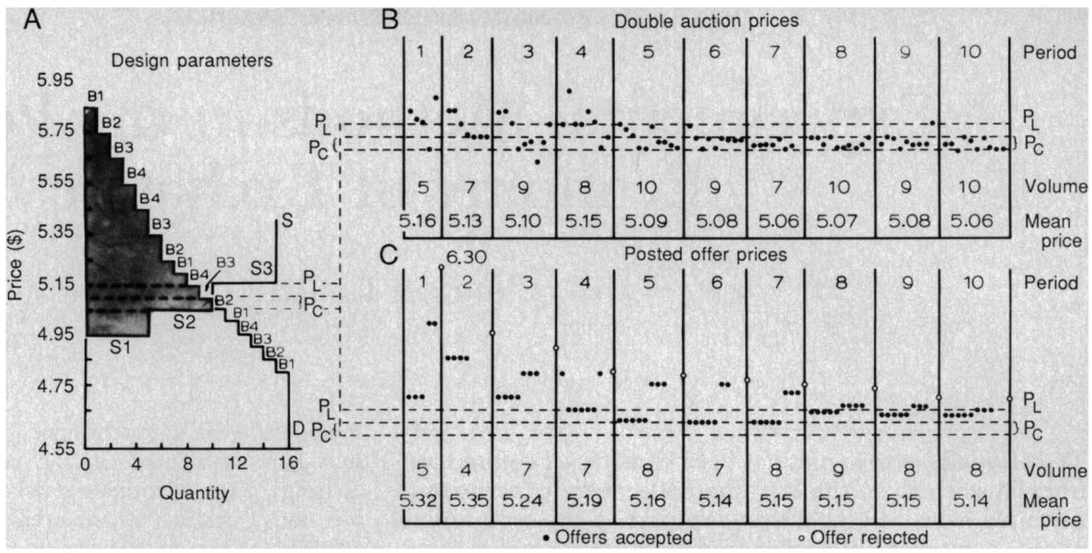
Fig. 1. Comparison of double auction and posted offer pricing institutions. In (B) the mean price in period 10 was within the interval P_c in five of six subject groups; in (C) it was above the interval P_c for five of six subject groups.



that is easily misperceived by economic agents, namely that the buyer profits just as dependably as sellers (voluntary exchange is mutually beneficial). This is because "profit" is the surplus enjoyed by a buyer who purchases for less than his willingness-to-pay just as a seller's "profit" is the surplus obtained when units are sold for more than her willingness-to-accept. In Fig. 1A the total such (consumer-producer) surplus is represented by the intersection of the area under the demand schedule and above the supply schedule (shaded area in Fig. 1A). This surplus measures the maximum possible social gain created by the existence of a market institution. However, it is important to emphasize that no subject in the experiments that we report has knowledge of Fig. 1. Each subject knows only his or her own values or costs.

Any exchange institution will be efficient if the surplus shown in Fig. 1 is realized in trade; that is, any pairing of the ten highest valued demand units with the ten lowest cost supply units at any vector of compatible prices will yield a set of efficient trades. However, such a pairing would be most likely to occur if the market were organized in such a way as to produce an equilibrium market clearing price, and corresponding trades, such that demand and supply are equal. In Fig. 1A, this is any price in the interval $P_c = (5.05, 5.10)$.

The Double Auction Pricing Institution

So far, the "environment" of exchange has been illustrated (Fig. 1A), and how an exchange institution can be evaluated in terms of its ability to allow the surplus defined by the environment to be realized through trade. What kinds of institutions might be used to organize the exchange process? There are many; I present two that have been studied extensively: The double "oral" auction and the posted offer institution. Historically the double auction has been the preferred method of trading in the organized securities and commodity exchanges. At the University of Arizona and at Indiana University a computerized version of this auction is used. Under the rules of this real time institution any buyer may enter a bid to buy one unit, and any seller may enter an offer to sell one unit. The best (highest) bid and best (lowest) offer entered are displayed publically to all traders as the standing bid and offer. Any other bids entered are ordered in a queue from highest to lowest, and any other offers are ordered from lowest to highest. Waiting bids and offers are not displayed; they represent an "electronic book" corresponding to the specialist's book on the New York Stock Exchange. The maker of any such bid or offer may withdraw it at any time. But a "standing" bid or offer cannot be withdrawn by the maker. Any new bid (offer) may become the new standing bid (offer) if it is higher (lower) than the currently standing bid (offer). Thus bids and offers must improve the "bid-ask" spread to become "standing." Anytime a standing bid (offer) is accepted by a seller (buyer) we have a binding contract at that price. Since it is not possible in field environments for agents to know the maximum buying prices of buyers or minimum selling prices of sellers, in the typical laboratory market each trader is informed only of his own value or cost situation. However, all traders are continuously informed as to the public information (bids, offers, contracts) provided by the auction institution.

The contract prices in sequence for each of ten trading periods are charted in Fig. 1B. Each period lasted 300 seconds, with each subject assigned the same set of values (costs) in each period. Except for learning each trading period is a pure replication of the market environment in Fig. 1A. In this design, in addition to the competitive equilibrium price set, $P_c = (5.05, 5.10)$, based on the supply response of the two intramarginal sellers, S1 and S2, we also have the "limit price" equilibrium, P_L, determined by seller S3 whose cost defines the external supply margin. Any attempt by sellers S1 and S2 to cooperate in boosting prices above the competitive range will be limited by the profitable entry of S3 at any price above P_L. Of six experiments with this design only one, with inexperienced subjects, stabilized at prices slightly below P_L; the remaining five stabilized in the set P_c. Consequently, under double auction trading with two intramarginal sellers, price discipline is only weakly dependent on an external supply margin to limit price increases.

Several hundred experiments by different researchers with many variations on the design in Fig. 1A have established the robustness of the static competitive equilibrium prediction with the double auction institution (*3*). For example, the use of middlemen, a group of agents who buy from producers in one market and resell to the buyers in a distant second market, does not alter the equilibrium tendencies illustrated in Fig. 1B (*4*). Similarly, if demand or supply or both follow a regular alternating period or seasonal cycle, and a third class of agents is given the right to speculate (buy in low price periods for resale in high price periods), a tendency to converge toward intertemporal competitive equilibrium is observed (*5*). This latter result has been found to extend to the case in which buyer-induced values (demands) are random (*6*). Although static competitive price theory predicts these empirical tendencies in the double auction institution, it does not help us to understand the rich

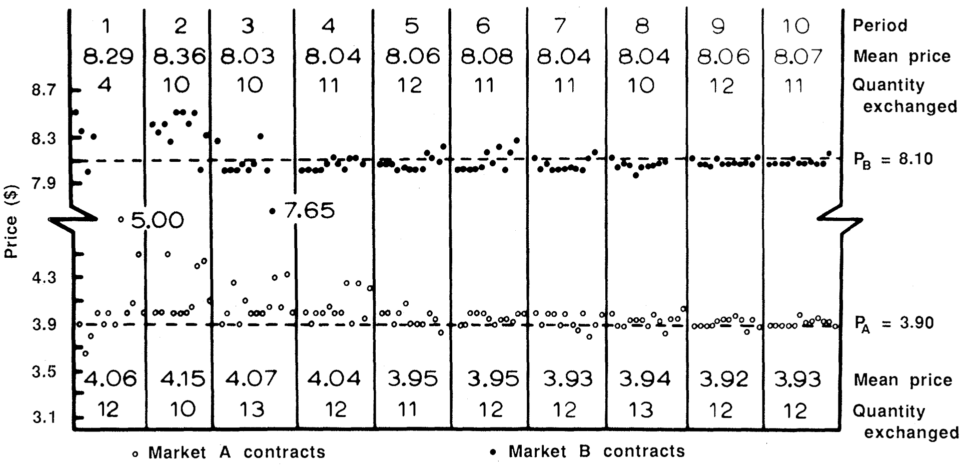


Fig. 2. Double auction pricing in two interdependent markets. In 10 of 15 experiments the mean price deviates by less than 5 cents from the competitive equilibrium price in both markets in period 1.

dynamic convergence patterns revealed in a number of experimental studies. For example, the tendency for prices to converge from above (Fig. 1B) is a general characteristic of double auction trading when the surplus (profits) of buyers exceeds that of sellers, whereas convergence tends to be from below if sellers' surplus exceeds that of buyers (*7*). Static price theory makes no statement about these empirical regularities. Similarly, experiments with a price ceiling just above P_c, which is therefore not binding and has no effect on the static equilibrium price, in fact yields a reduced speed of convergence, and the convergence path is from below (*8, 9*). Furthermore, when such a price ceiling is removed after the market has stabilized, we observe an explosive temporary rise in prices before they converge back toward P_c (*8*). Efforts to model double auction trading as a dynamic process (*10*) may ultimately provide a better understanding of these results.

In another line of experimental research alternative institutions of exchange have been studied to determine in what sense, if any, institutions matter. In Fig. 1C the results of an experiment that replicates the environment of Fig. 1A are illustrated but with different subjects trading under posted offer pricing rules (*11, 12*). Under these rules in each period each seller selects a private take-it-or-leave-it price offer that is then posted (displayed on each agent's computer screen), and buyers queue up to make individual purchases in sequence. Prices under posted offer tend to be higher, converge more slowly and less reliably, and produce less efficient trades than under double auction (Fig. 1, B and C). We see in Fig. 1C a tendency for the market to stabilize at prices just below P_L defined by the supply cost of S3. Of six experiments with different subjects, in five the mean price exceeded P_c in period ten.

A Multiple Market Double Auction

Each buyer's maximum bid prices for successive units are design constants in Fig. 1A. However, field environments are characterized by multiple markets that in general are interdependent. This interdependence is captured in the case of two substitute commodities, where x_i and y_i, defined on the nonnegative orthant, are the quantities of each that are purchased by individual i. A buyer is hypothesized to behave as if he has a preference ordering $u^i(x_i,y_i)$ which is increasing and concave in (x_i,y_i). The buyer's budget constraint is $x_i\ P_x + y_i\ P_y \leqq T_i$ where (P_x,P_y) are the commodity prices and T_i is the buyer's expenditure limit. Classical theory (*13*) derives the demand functions $x_i = d_x^i(P_x,P_y)$ and $y_i = d_y^i(P_x,P_y)$ for each i, and from the additivity (noninteraction) hypothesis the market demand functions are $X = D_x(P_x,P_y) = \Sigma_i d_x^i$ and $Y = D_y(P_x,P_y) = \Sigma_i d_y^i$. In a laboratory experiment we motivate subjects to behave as if they had preferences $u^i(x_i,y_i)$ by guaranteeing to pay $V^i(x_i,y_i)$ dollars in U.S. currency if i purchases the bundle (x_i,y_i), where V^i is some particular increasing, concave functional form. We also endow the subject with a fixed budget of T_i "tokens" (the exchange medium). So long as our subject strictly prefers more money according to some (unobserved) increasing function $U_i(V^i)$, then $u^i = U_i[V^i(x_i,y_i)]$ becomes the subject's "as if" preference function, and we can calculate the demand functions from $V^i(x_i,y_i)$ and the token endowment, T_i (*14*). It should be emphasized that the individual interdependent demand functions d_x^i and d_y^i, derived from a particular payoff function V^i, do not define firm maximum willingness-to-pay limit prices as in the single market representation in Fig. 1A. In the two-market model, i's demand prices P_x for successive units of x are different depending on the actual price realizations for P_y. Hence, the demand for either commodity is an opportunity cost demand—that is, what one is willing to pay for units in one market depends on the value of the alternate opportunity of spending one's limited token income in the other market. This defines a more difficult social task for Smith's "invisible hand" (*2*).

The market is completed by adding sellers with specified separable marginal cost functions $s_x^j(P_x)$ and $s_y^j(P_y)$, giving the additive total supplies $S_x(P_x) = \Sigma_j s_x^j$ and $S_y(P_y) = \Sigma_j s_y^j$. In an experiment the functions $V^i(x_i,y_i)$ or $s_x^j(P_x)$ and $s_y^j(P_y)$ are presented to each subject in the form of tables defined on integer values of units purchased or sold. Market clearing price (P_x^c,P_y^c) and quantities (X^c,Y^c) are defined by the equilibrium conditions: $X^c = D_x(P_x^c,P_y^c) = S_x(P_x^c)$ and $Y^c = D_y(P_y^c) = S_y(P_x^c,P_y^c)$. Each subject is given information only on his or her own tabular presentation of V^i or s_y^j. No subject has knowledge of these equilibrium prices, although some versions of classical theory have made the implausible assumption that economic agents are completely informed.

All contract prices for a typical experimental economy consisting of six buyers and six sellers trading simultaneously in two markets are illustrated in Fig. 2. The parameters of the induced preference function $V = \delta(\alpha x^{\rho} + \beta y^{\rho})^{1-\rho}$, token endowments and seller costs were selected to give equilibrium prices $(P_x^c,P_y^c) = (8.10, 3.90)$ and exchange quantities $(X^c,Y^c) = (12, 12)$. The convergence tendencies in this experiment are similar to the results of 15 experiments reported by Williams *et al.* (*15*). The most important feature of these results is that the high predictive power of demand theory in the single market setting extends to the budget constrained interdependent two-market setting (*16*). Subject traders, in effect, solve a set of simultaneous nonlinear equations using double auction trading rules, without being aware that this is the market consequence of their behavior.

Bubbles and Crashes in Stock Market Trading

Experimental methods have been used to examine the intrinsic value dividend theory of stock price determination (*17*). One objective of this research was to see whether "bubbles and crashes" in stock market prices could be observed in the laboratory, and, if so, to characterize their dynamic behavior over time. The environment is one in which subject agents ($n = 9$ or 12) are each given endowments of cash and shares: for example, \$2.25 and three shares, \$5.85 and two shares, and \$9.45 and one share in one experimental design. At the end of each of 15 trading periods (using double auction exchange rules) a dividend in cents, drawn from a distribution—for example, $\tilde{d} = (0, 8, 28, 60)$ with equal probability and expected value $E(\tilde{d}) = (0 + 8 + 28 + 60)(1/4) = 24$ cents, is paid on each share held in the account of each investor. Investors also receive any capital gains (losses) occurring on any share sold to another investor at a price higher (lower) than the price paid for it. Note that all value arising from share ownership in this market is derived from dividends. Net capital gains summed across all investors must be zero. The intrinsic value dividend theory of share prices states that the market price of a share will tend to a level representing the (discounted) expected sum of all future dividends. In the laboratory investors are given complete probabilistic information on the dividend structure and know in each period what is the expected cumulative dividend value of a share.

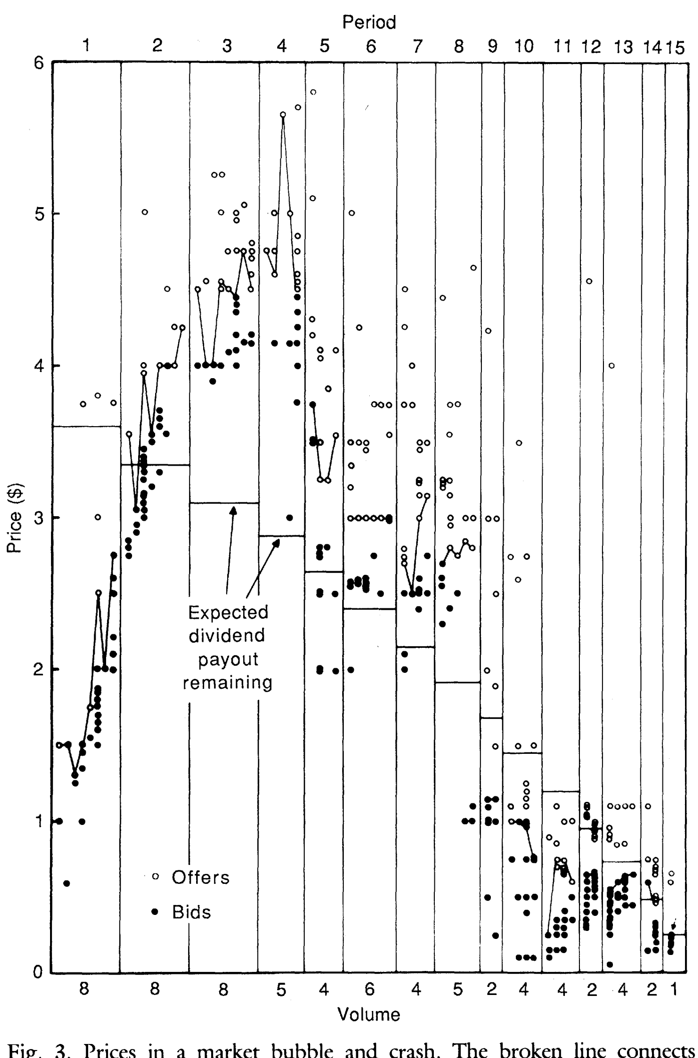


Fig. 3. Prices in a market bubble and crash. The broken line connects successive bids (offers) that were accepted to form contracts. The step function indicates that the expected dividend value of a share declines each period by the expected one period dividend value (24 cents). The least squares prediction equation for the change in mean price in successive periods based on excess bids is $\overline{P}_t - \overline{P}_{t-1} = -0.12 + 0.063\ (B_{t-1} - O_{t-1})$. The standard error of the intercept is 0.16 and of the slope is 0.016.

In the above example, this value is $15\ E(\tilde{d}) = \$3.60$ in period 1 before the first dividend payment, \$3.36 in period 2, \$3.12 and so on to 24 cents in period 15, as indicated by the horizontal lines for each period in Fig. 3. To date we have observed 13 of 21 market experiments that exhibit a price bubble and crash similar to the one shown plotted in Fig. 3. Four of the 21 experiments, all with experienced investors (who had participated in one or more previous experiments), converged more or less quickly to near the intrinsic value dividend price and followed its decline to the end.

The following price adjustment hypothesis characterizes the dynamics of these markets: $\overline{P}_t - \overline{P}_{t-1} = -E(\tilde{d}) + \beta(B_{t-1} - O_{t-1})$, $\beta > 0$, where $\overline{P}_t - \overline{P}_{t-1}$ is the change in mean prices from period $t - 1$ to t, B_{t-1} is the number of bids entered in $t - 1$, and O_{t-1} is the number of offers. The expression for lagged excess bids is $B_{t-1} - O_{t-1}$, and is postulated to provide a surrogate measure of the excess demand for shares arising from investors' endogenous capital gains expectations. The hypothesis is that mean price changes consist of an intrinsic value dividend component, $-E(\tilde{d})$, plus an excess demand component due to capital gain expectations that is linearly increasing in lagged excess bids. The regression estimate of this equation is shown in Fig. 3 for that experiment. All 13 bubble and crash experiments yield estimates $\hat{\beta} > 0$, 10 of which are significantly greater than zero. Furthermore, in only one of the 13 experiments is the intercept $\hat{\alpha}$ significantly different than $-E(\tilde{d})$. Consequently, the intrinsic value dividend theory, as an equilibrium concept, cannot be rejected, although it must be rejected as an instantaneous predictor of the mean price.

Single Object Auctions

The distinct concepts of an environment, an institution, and behavior that underlie all market experiments are most easily illustrated in single object auctions. In this theory (*3*) an environment consists of a list of agents $\{1, \ldots, N\}$, a list of commodities or resources $\{1, \ldots, K\}$, and certain characteristics of each agent i, such as the agent's value preferences (utility) u^i, resource endowment r^i, and knowledge endowment k^i. Agent i is characterized by the vector $E^i = (u^i, r^i, k^i)$ defined on the K dimensional commodity space. A microeconomic environment is defined by the vector $E = (E^1, \ldots, E^N)$, that is, the set of circumstances that are hypothesized to condition agents' interaction through institutions. The superscript i identifies the individual, but also implies that these circumstances are in their nature personal. It is the individual who likes, works, knows, and makes. Institutions define the "property" right rules (human rights to act) by which agents communicate and exchange commodities within the limits and opportunities inherent in E. Since markets require communication to effect exchange, the rules governing message rights are as important as rights to goods. An institution specifies a language $M = (M^1, \ldots, M^N)$, consisting of message elements $m = (m^1, \ldots, m^N)$, where M^i is the set of messages that can be sent by i (for example, the range of bids that can be entered by a buyer). An institution also defines a set of allocation rules $a = [a^1(m), \ldots, a^N(m)]$ and a set of cost imputation rules $c = [c^1(m), \ldots, c^N(m)]$, where $a^i(m)$ is the commodity allocation to i and $c^i(m)$ the payment by i, each as a function of all messages. Each agent's rights (and obligations) are defined by $I^i = (M^i, a^i(m), c^i(m))$, and a microeconomic institution is defined by the collection of these human right characteristics, $I =$

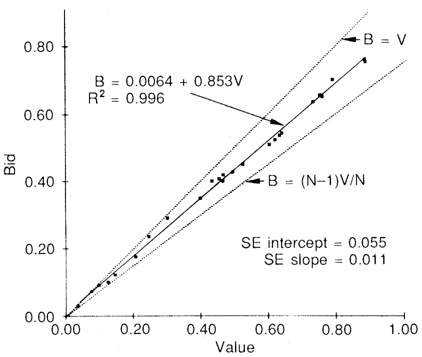


Fig. 4. Bidding behavior for a typical subject in an auction with $N = 4$ bidders. Bids, B, within the triangle defined by the rays, $B = V$ and $B = (N - 1)V/N$ (the risk neutral bid function), which vary linearly with value, are consistent with subjects bidding as if risk averse with utility that is log linear in monetary rewards.

$(I^1, \ldots, I^N)$. Finally, a microeconomic system is defined by the conjunction of an environment and an institution, $S = (E, I)$.

Now consider an auction for a single object such as a painting or antique vase, as an example of S. Let agents be characterized by an independent, certain monetary value each associates with the object $V_1, \ldots, V_N$; that is, the vector (u^i, r^i) is expressed in the simple reduced value form, V_i, for one unit. Agent i is assumed to know the number of bidders, N, and V_i, but possesses only uncertain probabilistic information, $P(V)$, on the values of others; that is, $E^i = (V^i, P(V), N)$.

There are many different auction institutions (*18*). In the "English" (e) auction, bids are announced from the floor in ascending order until the auctioneer is unable to solicit a new higher bid, in which case the item is awarded to the last bidder at a price equal to the amount bid. In the "Dutch" (d) auction, the auctioneer (in Holland an electronic clock is used) starts at a high offer price and lowers the price until the first buyer shouts "mine" (or depresses a button stopping the clock). The object is awarded to this buyer at the accepted offer price. In sealed bid auctions, each of N bidders submits a written bid. There are two versions: The most common is the first price (f) auction in which the highest bidder wins and pays the amount he bids. A less common version is the "second price" (s) auction in which the highest bidder wins but pays the amount bid by the second highest bidder.

In all four auction institutions the language M is bids whose elements are the same for all bidders and consists of the set of positive numbers. If the agents are numbered in descending order of the bids then the f institution, $I_f = (I_f^1, \ldots, I_f^N)$ is defined by the rules $I_f^1 = [a^1(m) = 1,\ c^1(m) = b_1]$ and $I_f^i = [a^i(m) = 0,\ c^1(m) = 0]$, $i > 1$, where $m = (b_1, \ldots, b_N)$ consists of all bids tendered; that is, one unit is awarded to agent 1 (the high bidder), who pays his bid b_1, while all others receive and pay nothing (we assume no access fee for bidding). In contrast, for the s auction, $I_s = (I_s^1, \ldots, I_s^N)$, where $I_s^1 = [a^1(m) = 1,\ c^1(m) = b_2]$ and $I_s^i = [a^i(m) = 0,\ c^i(m) = 0]$, $i > 1$; that is, the unit is awarded to agent 1 who pays the second high bid, b_2.

A microeconomy is driven by the choices of agents in M. In the static description of an economy, agent behavior can be defined as a function (or correspondence), $m^i = \beta(E^i \mid I)$ carrying the characteristics of i into a choice m^i, conditional upon the rights specified by the institution I. Given the behavior of each agent, the rules of the institution determine the outcomes $a^i(m) = a^i[\beta(E^1 \mid I) \ldots, \beta(E^N \mid I)]$, and similarly for $c^i(m)$. Thus agents choose messages, but institutions (the social rules) determine allocations. A theory of agents' behavior deduces a particular β function from assumptions about $S = (E, I)$. In the s auction it is a dominant strategy to bid one's value; that is, $b_i = \beta(V_i \mid I_s) = V_i$, for all i. A bid below V_i increases the risk of losing the auction without changing the price paid, whereas a bid above V_i risks having to pay more than V_i. The predicted result is that $b_1 = V_1$ is the winning bid and agent 1 pays the price V_2. Similarly, in the e auction, agent 1 will eventually exclude agent 2 by raising the standing bid to V_2 (or somewhat above) and obtain the item at this price. Thus theory asserts that the e and s auctions are isomorphic institutions.

Experimental studies of the e and s auctions (in which, say, the values V_i are assigned at random, and the winning bidder is paid $V_1 - b_1$ in U.S. currency) show that the two auction institutions are approximately equivalent (*18*). English auction prices tend to be slightly above V_2, and s auction awards tend to be at prices slightly below V_2. This is because discreteness leads to some overbidding in the e auction, whereas in the s auction not all subjects perceive that it may be in their self-interest to bid value. However, over time in a sequence of auctions, many of the subjects in this latter category "learn" to follow the dominant strategy. Both types of auctions are very efficient—some 95 to 97% of the awards are to the person with the highest item value.

The f and d auctions are technically the most interesting of all these institutions because each agent's optimal strategy depends on the strategies followed by the others. Vickrey (*19*) showed that if each agent maximizes expected surplus $(V_i - b_i)$ in an environment with $P(V) = V$ (the V_i are drawn from the linear distribution function on [0, 1]), then a distinct noncooperative bidding strategy for the environment $E_i = (V_i, P(V) = V, N)$, is for each i to bid $b_i = \beta(V_i, P(V) = V, N \mid I_f) = (N - 1)\ V_i/N$ in an f auction. This strategy defines a noncooperative equilibrium in the sense that if any $N - 1$ bidders use this strategy then this strategy will maximize the expected profit of the remaining bidder. It is easy to prove (*20*) that the f and d auctions are isomorphic. Thus each bidder should plan to accept the standing offer in a d auction when it falls to $b_i = (N - 1)\ V_i/N$. This is because the real time d auction is noninformative; that is, each i's knowledge that at each instant no buyer has yet accepted the standing offer will not yield an incentive to change the f auction bidding rule.

Experimental studies of f and d auctions for $E_i = (V_i, P(V) = V, N)$, where N = 3, 4, 5, 6, and 9, have established that d auction mean prices are somewhat lower than in f auction prices, but in both auctions the mean prices are too high to be consistent with the Vickrey risk neutral model (*20*). This last result in f auctions motivated the constant relative risk averse model (CRRAM) (*20*, *21*), based on the hypothesis that each i bids as if to maximize expected utility using the utility-of-surplus function $u_i = (V_i - b_i)^{r_i}$, where r_i is an element of [0, 1]. This leads to the linear equilibrium bid function $b_i(V_i) = (N - 1)V_i/(N - 1 + r_i) \geqq (N - 1)\ V_i/N$, which explains the overwhelming tendency of bidders (92%) to bid above the risk neutral bid. An astonishing property of bidding behavior (the subjects are absolutely naive in the sense of knowing nothing about bidding theory) is the great consistency with which most individuals submit bids showing high linearity with randomly assigned values (*21*). An example of a typical subject's bidding behavior is illustrated in Fig. 4. Furthermore, subjects bid higher in groups with larger N as predicted by the equilibrium bid function. From a sample of 33 subjects who returned for a second experimental session only 20% reveal linear bidding behavior that is statistically distinguishable from their previous session. The same test of the null hypothesis that the N bidders competing in the same auction are using the same linear bid function is rejected for 60% of the groups, which supports the proposition that individuals bid as if they had distinct risk attitudes, r_i. However, contrary to the theory, about 22% of the subjects' empirical bid functions have statistically significant intercepts. One modification of the theory which accounts for this is the postulate that $u_i = (V_i - b_i + w_i)^{r_i}$ if $V_i - b_i + w_i \geqq 0$, and $u_i = 0$, otherwise. If for any i, $w_i < 0$, the interpretation is that there is a threshold amount of money $|w_i|$ potentially to be obtained before the individual will enter a serious (nonzero) bid. When $V_i \leqq |w_i|$ the individual bids zero. Hence, linear regression may yield a significantly negative intercept. If for any i, $w_i > 0$, the individual is postulated to attach commodity value, or a utility of gambling, $u_i = (w_i)^{r_i}$ to winning the auction. Such an individual may even bid in excess of (low) assigned values of V_i in an attempt to "win" even if this involves a negative surplus, $(V_i - b_i)$. This extension of the theory is testable (although w_i is not observable) in the sense that we can run experiments in which individuals are paid (charged) a lump sum $w_i' > 0$ ($w_i' < 0$) in addition to being paid $(V_i - b_i)$ conditional on being the high bidder. The extended model predicts a parallel upward (downward) shift in the estimated bid function. These developments in the study of bidding illustrate a progressive research program in which there is continuing interplay between experimental testing and theory extensions that seek to increase the empirical content of the theory.

Exchange in Political Institutions

The theory of induced preference (*11*) has been used to drive innovative extensions of the methods of experimental economics to the study of political behavior. The extensions are based on the observation that the arguments of a reward function V^i can be common outcomes to all i, say $V^i(X_1, X_2)$ in the case of two "public goods" with outcome quantities (X_1, X_2) to all participants. Also the extensions exploit the fact that the institution may be a traditionally political institution which means simply that the messages, m_i, are votes for (or against) outcomes proposed through that institution. Under one institution a committee of N members may reach agreement on an outcome (X_1, X_2) in a plane by direct majority rule referenda with no agenda restrictions on the order in which proposals are voted upon. When preferences satisfy a certain condition on symmetry, it is possible to identify a distinct majority rule equilibrium (X_1^*, X_2^*) which has the property that it is stable against all proposals to move; that is, every proposal to move to some other point (X_1, X_2) will be defeated by majority vote when the rules resemble Roberts Rules of Order. The experimental results strongly support this theoretical model as against numerous other theories of political choice that have been proposed (*22*). However, a majority rule equilibrium exists only under special conditions on preferences. When these conditions are not satisfied we get a (indeterminant) cycle. So how can majority rule outcomes be obtained with the high frequency that we observe them in committees and elections? One hypothesis is that determinancy results because of the use of an agenda that structures the decision procedure and avoids cycles. This has been shown experimentally in environments with and without a majority rule equilibrium, in which the institution imposes an agenda that defines a particular sequence of pairwise comparisons to be selected by majority rule (*23*). Furthermore, it is shown that the final outcome chosen can be changed predictably by using a different agenda whether or not an equilibrium exists. In a third institution an electorate of N members uses a plurality voting rule to select among (n = 2, 3) candidates who announce "platform" positions in the (X_1, X_2) plane in response to periodic polls during a "campaign" (*24*). Outcomes tend to support the majority rule equilibrium in two-candidate elections, but not in three-candidate elections, where plurality applies. Still a fourth institution asks each of N voters to "bid" on each of n propositions by stating the amount he is willing to pay or requires to be compensated if the proposal passes, the winning proposal being the one with the largest unanimously approved nonnegative sum of the individual bids (*25*). Consider three propositions and six voters (Table 1). Each voter knows only his or her own value. Note that there is no majority rule equilibrium in this environment; P2 beats P1, P3 beats P2, and P1 beats P3 by a vote of 4 to 2 in each of these pairings. Yet P2 and P3 each yield a positive net gain for the electorate with P2 easily having the largest net social value, provided the losers, voters 4 and 5 are compensated by the gainers. Four of five experiments with cash-motivated undergraduate subjects using the above bidding institution reached a stopping rule equilibrium (unanimous consent signaled by a vote following each trial) in a maximum of ten trials in two experiments, and a maximum of six trials in three experiments.

Table 1. Voter valuation with three propositions and six voters.

Proposition	Voter valuation (dollars)						Total
	1	2	3	4	5	6	
P1	5	−30	−30	25	25	0	−5
P2	60	5	5	−10	−10	55	105
P3	−20	45	45	0	0	−25	45

An Experiment in Law and Economics

I will close with a brief report on an important recent discovery in bargaining behavior (*26*). According to the Coase theorem (*27*) in law and economics, parties capable of harming one another, but who can negotiate, will bargain to an efficient outcome whichever side has the legal right to inflict damage. Experimental results are uniformly consistent with this prediction. However, the "controller" subject who is endowed with this legal right by means of a coin flip invariably fails to extract the full individually rational share of the bargaining surplus that is predicted by game theory. Instead, the bargainers share the surplus equally, suggesting a "fairness" ethic. Hoffman and Spitzer hypothesized that subjects do not perceive an asymmetric property right as "legitimate" if it is awarded by a random coin flip. They proceeded to replicate their bargaining experiments, but with a treatment difference that awarded the controller condition to the subject who won a game of skill before the experiment. Now the controller may perceive that the position of advantage has been earned. The results are striking in that more than two-thirds of the controllers obtain individually rational shares of the joint surplus, whereas under the random assignment treatment none did.

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2. As Adam Smith put it [*The Wealth of Nations* (Modern Library, Random House, New York, 1937), p. 423], each individual "intends only his own gain, and he is. . . led by an invisible hand to promote an end which was no part of his intention."
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13. Each i is assumed to be motivated to adjust his purchases so as to solve the problem: maximize $u^i(x_i, y_i)$ subject to the budget constraint. Standard Lagrange methods lead to the "marginal rate of substitution" (derivative) condition $u_x^i / u_y^i = P_x / P_y$, which together with the budget constraint (normalized by setting $T^i = 1$) yields demand functions as indicated in the text.
14. Since $u_x^i / u_y^i = V_x^i / V_y^i = P_x / P_y$, if $U_i' > 0$, it follows that the demand functions

can be calculated from V^i independently of the particular "utility of money" function U_i.
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16. This result is particularly significant because of the direct evidence from choice surveys showing that most people do not treat the implicit cost of foregone opportunities on a par with explicit incurred costs [see R. Thaler, *J. Econ. Behav. Organ.* 1, 39 (1980)]. Many other studies (see D. Coursey, J. Hovis, W. Schulze, *Q. J. Econ.*, in press) support the proposition that revealed behavior in the context of markets differs from that found in psychological choice surveys, with the former more consistent with "rational" choice theory than the latter.
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28. I thank J. Cox, J. Ledyard, G. Suchanek, J. Walker, and A. Williams with whom I have worked on a number of experimental studies from which I have drawn illustrative examples in this article, and to the National Science Foundation for financial support over many years, beginning in 1962, for experimental research in economics.

Molecular Analysis of the Hotspot of Recombination in the Murine Major Histocompatibility Complex

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Biological and serological assays have been used to define four subregions for the I region of the major histocompatibility complex (MHC) in the order I-A, I-B, I-J, and I-E. The I-J subregion presumably encodes the I-J polypeptide of the elusive T-cell suppressor factors. Restriction enzyme site polymorphisms and DNA sequence analyses of the I region from four recombinant mouse strains were used to localize the putative I-B and I-J subregions to a 1.0-kilobase (kb) region within the E_β gene. Sequencing this region from E_β clones derived from the two mouse strains: B10.A(3R), I-J^b and B10.A(5R), I-J^k initially used to define the I-J subregion revealed that these regions are identical, hence the distinct I-J^b and I-J^k molecules cannot be encoded by this DNA. In addition, the DNA sequence data also refute the earlier mapping of the I-B subregion. Analysis of the DNA sequences of three parental and four I region recombinants reveals that the recombinant events in three of the recombinant strains occurred within a 1-kb region of DNA, supporting the proposition that a hotspot for recombination exists in the I region. The only striking feature of this hotspot is a tetramer repeat $(AGGC)_n$ that shows 80 percent homology to the minisatellite sequence which may facilitate recombination in human chromosomes.

THE I REGION OF THE MAJOR HISTOCOMPATIBILITY COMPLEX (MHC) of the mouse encodes two class II or Ia molecules denoted I-A and I-E (*1–4*). The class II genes encode restricting elements for helper T cells and for some cytotoxic T cells. These Ia molecules are cell-surface heterodimers, $A_\alpha A_\beta$ and $E_\alpha E_\beta$, shown to be identical to the Ir gene products that regulate immune responses to specific antigens. Differing inbred strains of mice exhibit different constellations of I region alleles; these constellations are denoted haplotypes and are indicated by superscripts; for example, a mouse of the k haplotype has A^k_α, A^k_β, E^k_α and E^k_β genes.

Before the advent of molecular cloning of the MHC genes, the I region was considered by immunologists to include, as judged by recombinational analysis, four subregions, I-A, I-B, I-J, and I-E. These analyses were based on serological and biological (immune responsiveness) assays (Fig. 1) (*1, 2, 4*). The I-A and I-E subregions were serologically defined and encode the conventional Ia antigens. The genes for the A_α, A_β, and E_β polypeptides mapped to the I-A subregion, whereas the E_α gene mapped to the I-E subregion. The I-B subregion was defined by the regulation of immune responses to mouse immunoglobulin G_{2a} (IgG_{2a}) and lactate dehydrogenase B (LDH_B) antigens (*5, 6*). The I-J subregion was defined serologically by reagents directed against the I-J polypeptide, which is believed to be expressed as a component of secreted and membrane-bound suppressor factors of suppressor T cells (*7, 8*). Understanding the expression and function of the I-J polypeptide would provide major insights into how immune responses can be suppressed. Estimates of molecular size of the I-J polypeptide range from 20 to 25 kilodaltons (*9–11*). However, repeated attempts to purify enough I-J material for protein sequence analysis have failed.

Restriction enzyme site polymorphisms detected by genomic DNA blotting techniques have been used to correlate the genetic map with the molecular map of the major histocompatibility complex. By mapping the right-most boundary of the I-A subregion

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