Microeconomic Systems as an Experimental Science

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Study nature, not books...

Louis Agassiz

After studying economics for six years I have reached the conclusion that there is no difference between discovery and creation...

[Graffiti by an unknown student]

The experimental literature contains only a few attempts to articulate a "theory" of laboratory experiments in economics (Charles Plott, 1979; Louis Wilde, 1980; my articles, 1976a, pp. 43–44, 46–47; 1976b; 1980). It is appropriate for this effort to have been modest, since it has been more important for experimentalists to present a rich variety of examples of their work than abstract explanations of why one might perform experiments. Wilde's contribution provides an integration and extension of the earlier papers, and brings a fresh perspective and coherence that invites further examination. This seems to be the time and place to attempt a more complete description of the methodology and function of experiments in microeconomics.

The formal study of information systems in resource allocation theory (Leonid Hurwicz, 1960) and the laboratory experimental study of resource allocation under alternative forms of market organization (Sidney Siegel and Lawrence Fouraker, 1960, Fouraker and Siegel, 1963; my 1962, 1964 articles) had coincident beginnings and, in important respects, have undergone similar, if mostly independent, intellectual developments. The similarity of intellectual development in these two new endeavors is represented by the increasing focus upon the role of institutions in defining the information and incentive structure within which economic outcomes are determined. While the $(\text{new})^2$ welfare economics (Stanley Reiter 1977) was articulating a formal structure for the design and evaluation of allocation mechanisms (institutions) as *economic variables* (Hurwicz, 1973), experimentalists were comparing the performance of experimental economies in which the rules of information transfer and of contract appeared as *treatment variables* (Plott and myself, 1978; my 1964, 1976a articles). Since it is not possible to design a laboratory resource allocation experiment without designing an institution in all its detail, it was foreordained by the nature of the questions asked, that the work of experimentalists would parallel that of the $(\text{new})^2$ welfare economics.[1]

In the sequel, the definition of a microeconomic system will be developed. Then the laboratory market or resource allocation experiment will be developed and discussed as an example of a microeconomic system. This framework will be used to provide a taxonomy for laboratory experimentation which allows the methods, objectives and results of such experiments to be interpreted and perhaps extended.[2] An important message of the paper which has been emphasized before (Plott, 1979, p. 141; my 1976b article, p. 275), but was articulated more satisfactorily by Wilde (1980), is that laboratory microeconomies are real live economic systems, which are certainly richer, behaviorally, than

*University of Arizona. I am grateful to the National Science Foundation for research support, and for many significant encounters over the years which have helped to shape my thinking about experimental microeconomy. Although any list is bound to omit some key sources of inspiration, in addition to the many authors cited in the references, I particularly want to mention Sidney Siegel, Jim Friedman, Charlie Plott, Martin Shubik, and Arlie Williams.

[1] Experimental microeconomics includes the study of individual choice behavior. For an excellent description of the methodology and some of the results from the experimental study of human and animal choice behavior, see the survey by John Kagel and Raymond Battalio (1980).

[2] Nothing in this paper will be very helpful to anyone desiring to learn the important techniques and mechanics of conducting experiments. For explanations of experimental procedures, it will be necessary to consult the references. But learning to run experiments is like learning to play the piano—at some point you have to start practicing. The classic model of good experimental technique is still to be found in Fouraker and Siegel (1963).

the systems parameterized in our theories. Consequently, it is important to economic science for theorists to be less own-literature oriented, to take seriously the data and disciplinary function of laboratory experiments, and even to take seriously their own theories as potential generators of testable hypotheses. Since "the discovery of new facts is open to any blockhead with patience and manual dexterity and acute senses" (attributed to Sir William Hamilton in N. R. Hanson, 1971, p. 23), it is equally important that experimentalists take seriously the collective professional task of integrating theory, experimental design, and observation.

I. Microeconomic System Theory

A. *Defining a Microeconomic System*

In defining a microeconomic system two distinct component elements will be identified: an environment and an institution.

1. *The Environment*

The environment consists of a list of N economic agents $\{1,\dots,N\}$, a list of $K+1$ commodities (including resources) $\{0,1,\dots,K\}$, and certain characteristics of each agent i, such as the agent's utility function u^i, technology (knowledge) endowment T^i, and a commodity endowment vector ω^i. Hence, the ith agent is characterized by the vector $e^i=(u^i,T^i,\omega^i)$ whose components are assumed to be defined on the $K+1$ dimensional commodity space R^{K+1}. Hence, a microeconomic *environment* is defined by the collection of characteristics $e=(e^1,\dots,e^N)$. This specification defines the environment as a set of initial circumstances that cannot be altered by the agents or the institutions within which they interact. The reader should appreciate that by appropriate interpretation this definition does not rule out learning, that is, changes in preferences and/or technology. But if learning is to be part of the economic process, then one must specify agent preferences and technology in terms of learning (or sampling or discovery) activities. In this case the fixed environment would specify the limitations and search opportunities for altering tastes and knowledge in an economy with changeable tastes and resources. It should be noted that, in an experimental environment, e will include some circumstances that cannot be altered by the agents because they are control variables fixed by the experimenter—a matter to which I will return later.

A subtle but important feature of the environment deserves emphasis: the superscript i on the characteristic of each agent i means that the initiating circumstances in an economic environment are *in their nature private*. Tastes, knowledge, and skill endowments are quintessentially private: *I* like, *I* know, *I* work, and *I* make.[3]

2. *The Institution*

The above is no less true in societies with weak than in those with strong private property right systems. Whether private tastes matter little or are sovereign; whether or not an idea can be patented, copyrighted, or trademarked as alienable private property; and to what extent one has a property right in the fruits of one's "own" labor; these are all matters of the institution which is itself public in administration. It is the institution which specifies that soliciting for the purpose of prostitution is punishable by fines and imprisonment; that smoking in the hallway is to be allowed; that forms of indentured labor are prohibited (except in professional sports); that patents expire after seventeen years; that Ohm's law is not patentable; that price discrimination is illegal (except in the Treasury bill auction); that trespassers will be prosecuted; and that no one has the right to obstruct free use of the air by airlines above private land (except that, at one time, alcoholic beverages were not to be served in flights over Kansas).

It is the institution that defines the rules of private property under which agents may communicate and exchange or transform commodities for the purpose of modifying

[3] This does *not* mean that an individual's environmental state is autonomous and uninfluenced by others; it means merely that individual skills, knowledge, and willingness to work and buy are not publicly observable —only their consequences are observable.

initial endowments in accordance with private tastes and knowledge. Since all commodity exchange and commodity transformation must be preceded by interagent communication, *property rights in messages are as important as property rights in commodities or ideas*. Thus if stealing can lead to the charge of robbery or burglary, saying "your money or your life" can lead to the charge of attempted robbery. The institution defines the rights of private property which include the right to speak or not speak (you can't say "one hundred" at an auction unless you mean to bid \$100), the right to demand payment or delivery, and the right to exclude others from use, that is, to "own." The institution specifies:

a. A *language* $M=(M^1,\dots,M^N)$ consisting of messages $m=(m^1,\dots,m^N)$, where m^i is an element of M^i, the set of messages that can be sent by agent i. A message might be a bid, an offer, or an acceptance. The allowable messages M^i for i need not be identical to M^j for j. Thus buyers may tender written bids at an auction, while the seller may have the right to offer or not offer an item for sale, but may not be allowed to bid on his own item or announce a reservation price.

b. A set $H=(h^1(m),\dots,h^N(m))$ of *allocation rules* for each i. The rule $h^i(m)$ states the final commodity allocation to each i as a function of the messages sent by all agents. Since there may be an exchange of messages which precedes the allocation, m may refer to the final allocation-determining message.

c. A set $C=(c^1(m),\dots,c^N(m))$ of cost *imputation rules*. The rule $c^i(m)$ states the payment to be made by each agent in numeraire units (money) as a function of the messages sent by all agents. Note that C is redundant in that it could be included in the definition of H, but it will be convenient in many applications (as when there are no income effects) to distinguish between commodity allocations by H and payment imputations by C.

d. A set $G=(g^1(t_0,t,T),\dots,g^N(t_0,t,T))$ of *adjustment process rules*. In general, these rules consist of a *starting rule* $g^i(t_0,.,.)$ specifying the time or conditions under which the exchange of messages shall begin, a *transition rule* (or rules) $g^i(.,t,.)$ governing the sequencing and exchange of messages, and a *stopping rule* $g^i(.,.,T)$ under which the exchange of messages is terminated (and allocations are to begin).[4] For example, an English or progressive auction begins with an announcement by the auctioneer identifying the item to be offered for sale and calling for bids. The starting rule might also allow the seller to specify a reservation price. The transition rule requires any new bid to be higher than the previous standing bid. The stopping rule requires that no new overbid is obtained in response to a call from the auctioneer (for example, three calls for a "final" bid). In an unstructured bilateral negotiation, there is a starting "rule" in that bargaining cannot begin until there is a first bid or offer, and stops with an acceptance. Disputes concerning the negotiation process, and its outcome, are settled under the common law of contracts.

Each agent i's *property rights* in communication and in exchange are defined by $I^i=(M^i, h^i(m), c^i(m), g^i(t_0,t,T))$, which specifies the messages that i has the right to send; the starting, transition, and stopping rules which govern these communication rights; and finally the right to claim commodities or payments in accordance with the outcome rules that apply to messages. A microeconomic *institution* is defined by the collection of all these individual property right characteristics $I=(I^1,\dots,I^N)$.

It should be noted that none of the above rules of an institution need be formal as in a body of written law. A rule can be simply a tradition as, for example, in the Eskimo polar bear hunting party in which the upper half of the bear's skin, prized for its long mane hairs, was awarded to the individual hunter who (at great personal risk) was the first to fix his spear in the dangerous prey (Peter Freuchen, 1961, p. 53.)

[4]Note that the arguments of $g^i(t_0,t,T)$ are public "goods" or characteristics, i.e., the rules governing communication are common to all participating agents. Hence, when comparing the performance of alternative institutions, we are comparing alternative common outcome states.

3. *A Microeconomic System*

A microeconomic environment together with a microeconomic institution defines a *microeconomic system*, $S=(e,I)$.

B. *Agent Behavior*

1. *Outcome Behavior*

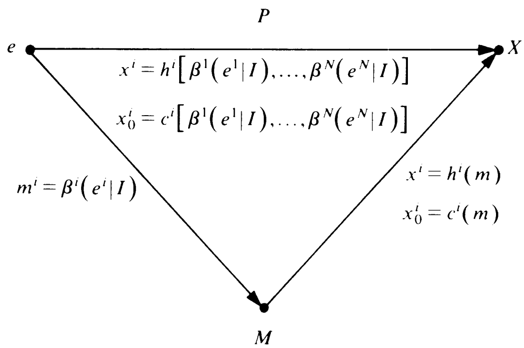
A microeconomy is closed by the behavioral actions (choices) of agents in the message set M. In the static description of an economy we are concerned only with the final outcome choices in M. Thus agent i's *outcome behavior* is defined by a function $\beta^i(e^i \mid I)$ which yields the allocation-determining message m^i sent by agent i with characteristic e^i, given the property rights of all agents defined by I. The conditional-on-I notation in β^i is intended to denote that the behavior function β^i depends upon I, that is, is a member of a class indexed by I. The mapping β^i may represent a single message transmission as in a sealed-bid auction, or it may constitute the final result of an exchange of messages in an iterative process such as a negotiation session in the London gold bullion market which stops to yield transactions only when there is agreement (unanimity) (H. G. Jarecki, 1976). Note that the β^i functions generate the message-sending behavior of agents, which need not be based on preference maximization. The latter is a theory (hypothesis) about behavior that could be false.

The branches of the triangle diagram in Figure 1 (compare Stanley Reiter, 1977) illustrate the conceptual process in which, given the institution, the message m^i depends on agent characteristics e^i, and the messages sent by all i in turn determine, via the institution, the outcomes

$$h^i(m)=h^i\left[\beta^1(e^1|I),\dots,\beta^N(e^n|I)\right]$$

and $$c^i(m)=c^i\left[\beta^1(e^1|I),\dots,\beta^N(e^N|I)\right].$$

The import of all this is that agents do *not* choose direct commodity allocations. *Agents choose messages, and institutions determine allocations via the rules that carry messages into allocations.* There is a social process that culminates in exchanges. Every country auc-



$$e^i=(u^i,\omega^i,T^i),\qquad I^i=\left(M^i,h^i(m),c^i(m),g^i(t_0,t,T)\right)$$
$$e=(e^1,e^2,\dots,e^N),\qquad I=(I^1,I^2,\dots,I^N)$$

FIGURE 1. A MICROECONOMIC SYSTEM

tion has its own rules and procedures of sale. The New York Stock Exchange specifies the admissible form in which orders to buy or sell shares may be tendered to its broker members by investors—"at the market," limit price, "stop" orders, etc.—and also specifies a detailed list of auction rules governing communication and exchange at each trading post.[5] Within the applicable procedural rules, all markets involve "do-it-yourself" (Robert Clower and Axel Leijonhufvud, 1975) exchange.

2. *Response Behavior*

In the dynamic or process description of an economy we are concerned with, the exchange of messages in M that precedes the final allocation-determining messages. Agent i's *response behavior* is defined generically by a function f^i in the equation (compare Reiter, 1977)

$$m^i(t)=f^i\left(m(t-1)|e^i,I\right),$$

[5]In retail markets, sellers post offer prices, buyers respond by saying "I'll take it," but the result need not constitute an exchange as when the retailer has a stockout, or the chair is returned to the store after the customer finds that it does not match the living room rug. Institutions vary in the richness and composition of the message space. In stock and commodity markets, the items exchanged are simply defined and well standardized, but the message space is rich in the conditional bid, offer, and acceptance messages that can be sent. In retail markets, commodities are heterogeneous and rich in qualitative dimensions, which may help to explain why a price negotiation institution is not used.

which gives i's message response $m^i(t)$, at sequence point t, to earlier messages $m(t-1)$ by all agents. This response behavior might follow an optimal decision rule, a "rule of thumb," be random, or simply inexplicable. The starting rule triggers the first iteration of f^i, with subsequent messages given by f^i under the transition rules in I. The process stops with $m^i = m^i(T)$ when the stopping rule in I is actuated.

C. *System Performance*

Theorists view the framework we have been describing as one within which alternative resource allocation mechanisms can be evaluated. The traditional performance criterion is Pareto optimality, that is, the relation between outcomes in X (Figure 1) and microeconomic environments "should" be identical to the one provided by the Pareto correspondence criterion (P in Figure 1). Since utility functions and production possibility sets (technologies) are not observable, the evaluation of outcomes in X in terms of the Pareto criterion only has meaning in terms of the Pareto implications of a particular set of *assumptions* about preferences, technology, agent behavior, and institutions. Thus if certain standard conditions on the environment are satisfied, such as continuity and convexity, and if institutions and agent behavior correspond to those of the competitive mechanism, then the classical welfare theorems establish that the Pareto criterion is satisfied. In this literature, a *mechanism* can be defined as a formal theory or model of agent equilibrium behavior within some institution. Thus, in the competitive mechanism, agents maximize utility and profits given prices, and the "institution" (which is unspecified in the sense defined above) is assumed to produce market-clearing prices. An *adjustment mechanism* can be defined as a formal dynamic theory of a trading process for economic agents within some institution as defined above. Examples are the greed process (Hurwicz, 1960) and a stochastic trading process described by Hurwicz, Roy Radner, and Reiter (1975). In the latter, agents choose offers according to a fixed-probability distribution on the set of feasible trades for which utility will not be decreased. These offers are transmitted to a center where the institutional rules convert those offers which are compatible into binding contracts. The process is then iterated based on the commodity holdings prevailing after this transitional exchange. This process yields probabilistic convergence satisfying the Pareto criterion.

An important concept in the evaluation of a microeconomic system is that of incentive compatibility. In general, an institution's rules are *incentive compatible* if the information and incentive conditions that it provides individual agents are compatible with (i.e., support) the attainment of socially preferred outcomes such as Pareto optimality ($P.O.$). Specifically, in the theoretical literature, an allocation mechanism is incentive compatible if it yields Nash equilibria that are $P.O.$ This means that the *rules* specified in the *institution* in conjunction with the maximizing *behavior* of agents yields a choice of *messages* which constitute a Nash equilibrium whose *outcomes* are $P.O.$

A point which should be emphasized, because it bears on the relationship between laboratory experiments and the model of Figure 1, is the following. The mapping $h^i[\beta^1(e^1 \mid I), \ldots, \beta^N(e^N \mid I)]$: $e \to m \to x^i$, is generated by any microeconomy, particularly an experimental microeconomy, provided that we have a methodology for systematically varying the elements of E (and also I, if institutions as variables are to be studied) and observing the consequent elements in M and X. This is important because there may *not* exist in all contexts (or in any) a satisfactory theory or hypothesis allowing derivation of the β^i functions. If we can experiment, then we are not bound to study *only theoretical* systems that carry E into X. Experiments permit stable patterns of behavior in relation to institutions to be identified and to motivate more explicit theories.

II. The Microeconomic Experiment

With the above background it is now possible to attempt to say something coherent about the role of the laboratory experiment in the study of microeconomic sysems. Although the concepts in the (new)^2 welfare economics have been used primarily to explicate a class of exercises in normative theory, my particular version of it in the schema of Figure 1 has been developed for the purpose of defining exercises in *measurement*, *hypothesis testing*, and the *comparative performance of institutions*.

A. *Field Observations and the Possibility of a Microeconomic Science*

1. *What is Observable?*

It will be useful as a starting point to ask which of the elements that compose the schema of Figure 1 are observable (in principle) in the field. Among the observable elements of an economy are (*i*) the list of agents, (*ii*) the list of physical commodities and resources, (*iii*) the physical commodity and resource endowments of individual agents, (*iv*) the language and property right characteristics of institutions, and (*v*) outcomes. What is not observable are (*vi*) preference orderings, (*vii*) technological (knowledge, human capital) endowments, and (*viii*) agent message behavior $\beta^i(e^i \mid I)$, $i = 1,2,\dots,N$. These last elements are not observable because they are not only private, but to a degree *unrecorded*. Willingness to buy (preferences) and willingness to produce (technology and preferences) can at best only be inferred from agent point actions in the message space. Often we cannot even observe point messages, for example, we may know allocations and prices, but not all bids. In any case, we cannot observe the message behavior *functions* because we cannot observe (and vary) preferences.

As already noted, by making assumptions about preferences, technology, and behavior, we can "test" the logical consistency of such assumptions with the Pareto criterion. The empirical content of the assumptions, such as the monotonicity and convexity of preferences, tend to reflect idealizations, if not caricaturizations, of our *introspective* personal experience as economic agents.[6] But logical completeness laid upon a base of casual introspective "observations" cannot be sufficient to give us an understanding of the processes we would like to study. There is a vast difference between coherent conjecture (theory) and "true" (i.e., nonfalsified) knowledge of an observed process. If outcomes should turn out to be *P.O.* in the presence of certain institutions, we would like to know if we have predicted this property for the right reasons. If outcomes are not *P.O*, then it would be scientifically irresponsible not to be curious as to which part(s) of our theory is wrong and how to modify it.

2. *What Would We Like to Know?*

In terms of the schema of Figure 1 we would like to know enough about the economic environment, and about agent behavior in the presence of alternative institutions, to be able to classify institutions according to the mapping they provide from environments into outcomes. Are some institutions dependable producers of *P.O.* allocations? If so, how robust are these results with respect to changes in the environment? Do some institutions perform well for only certain classes of environments? If an institution performs well, are all its property right rules essential to this performance or are some redundant? Are some rules redundant for most environments, but become important under contingency conditions that involve unlikely changes in the environment?[7] These are just the tip of the great iceberg of questions that one would like to pose with some prospect of obtaining answers that are replicable, and (ultimately) insightful due to their theoretical coherence.

3. *Learning by "Listening to the Radio Play"*

Econometrics is and has been the mainstay of our attempts to fashion tools that enable us to learn what we would like to know. These tools have been developed primarily on the premises that (*i*) economics is a nonexperimental, or under certain limited cir-

[6]In this regard, it has not been clear that being an economic agent has had any advantages in the scientific study of economic behavior.

[7]For example, there are discretionary contingency conditions under which trading in a particular security is suspended for a time on the New York Stock Exchange, while on the Chicago Board of Trade, trading in a commodity is closed for the remainder of the day if price rises or falls from the previous day's close by a specified amount.

cumstances a field experimental, science, and (*ii*) preferences and technologies are not directly observable or controllable. It follows immediately from the discussion above that these premises prevent us from answering the most elementary scientific questions. What we can do with the tools of econometrics is the following: (*i*) We can specify a model of a market or markets based upon certain observable characteristics of the operant institution, on certain assumptions about preferences and/or technology, for example, Cobb-Douglas, fixed coefficients, *CES*, translog, etc., and upon some assumption about behavior, for example, static maximization of utility and/or profit. (*ii*) Using one of several different estimation procedures with different statistical properties, provided that the model is at least partially "identified," we can estimate, from data on outcomes, all or a subset of the parameters defined by the particular model that was specified. In other words, we can measure certain preference and/or technology parameters (income and substitution coefficients) and the effect of certain institutional rules (Did state law require or not require licensing? Did it prohibit or allow advertising by optometrists, etc.?). Furthermore, within the specifications of the model (the maintained hypothesis), we can test particular hypotheses about elasticities and income effects. Rarely are we able to obtain a test of the model specification. Hence, an econometric model provides a mapping from specifications into conclusions about preferences, technology, and institutions. Insofar as the conclusions are sensitive to the specifications, we are left with scientific propositions that are open-ended with respect to the environment, institutions, and agent behavior. Furthermore, since parameter identifiability and the properties of estimators depend upon model specification, the particular model chosen inevitably must be influenced partly by the technical requirements of the methodology and not only the scientific objectives of the exercise.

But these limitations of conventional econometric methodology have not foreclosed a positive contribution, which has been to allow us to deduce a great deal more information on economic structure from nonexperimental data than would otherwise be possible. Over twenty-five years ago, Guy Orcutt characterized the econometrician as being in the same predicament as that of an electrical engineer who has been charged with the task of deducing the laws of electricity by listening to a radio play. To a limited extent, econometric ingenuity has provided some techniques for conditional solutions to inference problems of this type.

But the econometric methodology is on particularly thin ice when the following scenario applies: Based on introspection, some casual observations of some process, and a contextual interpretation of the self-interest postulate, a model is specified and then "tested" by estimation using the only body of field data that exists. The results turn out to be ambiguous or call for "improvements" (some coefficients—for example, income—have the "wrong" sign or are embarrassingly close to zero), and now one is tempted to modify the model in ways suggested by these results to improve the fit with "reasonable expectations." Any tests of significance within the new model specification now become hopelessly confused if one attempts to apply it to the same data.[8,9]

The controlled field experiment is a recent development designed to relax some of the limitations of econometric methods when applied to the traditional sources of economic data. But the field experiment does not enable us to study the effect of controlled

[8]In effect, the whole process becomes an exercise in fitting a particular belief system to field data by manipulating model specification and perhaps estimation methods. There is nothing to prevent exactly the same procedure from being applied to experimental data. The difference is that one can always run another set of experiments. Also, the whole process, including the experiments, are subject to replication by another scholar. The skeptic with a different belief system can seek a set of "crucial" experiments that would enable the opposing hypotheses to be tested.

[9]Within professional econometrics, criticism such as this of naive econometric practice stretches back at least three decades, but recently the critique has grown louder, and constructive formal approaches have been offered in which, for example, the reporting procedures delineate the range of inferences that can be drawn from a given range of model specification (see Edward Leamer and Herman Leonard, 1981).

changes in preferences and/or technology. It does, however, provide important forms of control over institutional rules. Thus in a peak-load pricing experiment it is possible to vary pricing parameters and methods over a much larger range, and to sample scientifically a larger range of income and demographic variables than would occur naturally in ordinary consumer data obtained by "listening to the radio play." It is also possible to experiment with new and innovative pricing institutions. But one is still without control over preferences, and still unable directly to observe preferences and therefore behavior as a mapping from preferences to messages. That is, it is still necessary to interpret the data in terms of (*i*) assumptions about preferences, and (*ii*) assumptions about behavior (for example, static or dynamic maximization subject to constraint). Hence, it is *not possible* to evaluate alternative institutions in terms of their ability to produce optimal outcomes. But to the extent that one is interested in observed demand behavior (which may be underrevealing) with improved controls rather than evaluating the performance of institutions under alternative preference configurations, these limitations are not a valid criticism of the field experiment.

B. *Laboratory Experiments with Microeconomic Systems*

The fundamental objective behind a laboratory experiment in economics is to create a manageable "microeconomic environment in the laboratory where adequate control can be maintained and accurate measurement of relevant variables guaranteed" (Wilde, p. 138). "Control" and "measurement" are always matters of degree, but there can be no doubt that control and measurement can be and are much more precise in the laboratory experiment than in the field experiment or in a body of Department of Commerce data.

How laboratory experiments deal operationally with the problems of control, measurement, experimental design, and hypothesis testing is best seen by examining individual experimental studies. Attention here will be confined to a somewhat more abstract discussion of the principles and underlying precepts of experimental economics. In particular, the concept and objectives of a laboratory experiment will be related to the microeconomic model, consisting of an environment, an institution, and agent behavior, illustrated in Figure 1.

Returning to the question of what we would like to know tells us what we want to be able to accomplish with experiments. First we want to be able to control the elements of $S=(e, I)=(u^i, T^i, \omega^i; M^i, h^i, c^i, g^i)$. To control a variable means that we can fix and maintain it at some constant level, or, alternatively, set it at different levels across different experiments or at different points of time in the same experiment. Secondly, we want to be able to observe and measure the message responses of agents, m^i, and the outcomes h^i and c^i resulting from these messages. We want to measure outcomes because we want to be able to evaluate the performance of the system, S. We want to measure messages because we want to identify the behavioral modes, $\beta^i(e^i|I)$, revealed by the agents and test hypotheses derived from theories about agent behavior.

In order to accomplish these objectives, laboratory experiments must satisfy several conditions, which will be referred to as *precepts* of experimental economics. They are *not* to be regarded as self-evident truths, and therefore are not properly to be considered as axioms.[10] However, with the modifications proposed by Wilde, they do constitute a proposed set of sufficient conditions for a valid controlled microeconomic experiment. Applying (or testing) these conditions in the

[10] In reference to the precept parallelism (see subsection 1.f below), this has been misunderstood or misread as follows: "Smith treats this 'parallelism' virtually as an axiom, while Kagel and Battalio go even farther and extend the principle not only beyond the limits of the laboratory but across the boundaries of the human species as well" (John Cross, 1980, p. 403). The word precept rather than axiom was used to guard against any notion that these precepts were self-evident truths, rather than key conditions for experimental validity. The truth of these precepts can only be established empirically. It is hard to find an experimentalist who regards anything as self-evident, including the proposition that people prefer more money to less.

laboratory (and in parallel field studies) requires some skill and thoughtful consideration. The issues that have motivated these precepts are important to have in mind when designing and executing laboratory experiments.

1. *Sufficient Conditions for a Microeconomic Experiment*

Control over preferences is the most significant element distinguishing laboratory experiments from other methods of economic inquiry. In such experiments, it is of the greatest importance that one be able to state that, as between two experiments, individual values (or derivative concepts such as demand or supply) either do or do not differ in a specified way. This control can be exercised by using a reward structure and a property right system to induce prescribed monetary value on (abstract) outcomes.

a. *Precept 1: Nonsatiation.* The concept of induced valuation (see the examples in subsection c below) depends upon (compare my 1976b article):

Nonsatiation: Given a *costless* choice between two alternatives, identical (i.e., equivalent) except that the first yields more of a reward medium (for example, U.S. currency) than the second, the first will always be chosen (i.e., preferred) over the second, by an *autonomous* individual. Hence utility, $U(V)$, is a monotone increasing function of the monetary reward, $U' > 0$, where V is dollars of currency.

b. *Precept 2: Saliency.* In order that subject rewards in a laboratory experiment have motivational relevance such rewards must be associated indirectly with the message actions of subjects. This is called

Saliency: Individuals are guaranteed the right to claim a reward which is increasing (decreasing) in the goods (bads) outcomes, x^i, of an experiment; individual property rights in messages, and how messages are to be translated into outcomes are defined by the institution of the experiment.

This statement of saliency modifies that of Wilde (1980) which relates rewards to the decisions of subjects. This modification is necessitated by the distinction made here between outcomes and messages. *In both the field and the laboratory, value is induced on messages by the institution* whose rules state how messages are to be translated into valuable outcomes. In the field outcomes are valuable because they have "utility" (i.e., agents have preferences). But in the laboratory we also have to induce value on outcomes with a monetary (or other) reward function. Thus in an experiment, in addition to giving a subject certain property rights defined by the institution under study, we must also give the subject a property right to rewards that are related appropriately to the realized experimental outcomes, x^i.[11]

[11]It is sometimes said that the use of currency to induce value on abstract outcomes in a laboratory experiment may be an artificial procedure peculiar to experimental methodology and is not the same thing as having "real preferences." Those who raise this question seem not to realize that all economic systems produce forms of intangible property on which value is induced by specifying the rights of the holder to claim money or goods. All financial instruments, including shares, warrants, and fiat money itself, have value induced upon the instruments by the bundle of rights they convey. Subject rights to claim money in return for their purchase and sale of intangible experimental "goods" are defined by the experimental instructions. This procedure is exactly of the form used by the airlines when, for promotional purposes, they issued travel vouchers to their passengers. These travel vouchers conveyed a legal right to redemption by the bearer as a cash substitute in the purchase of new airline tickets. As a consequence, value was induced on these travel vouchers and they soon commanded an active market price in all busy airports. An airline ticket itself is an abstract claim. It is *not* equivalent to a seat on an airplane. It is a right to *claim* a seat under specified conditions, for example, you can't have a seat if none is available, or if you insist on carrying oversize luggage, or if you want to board with your pet tiger, or if you are carrying a Colt 45, and so on. An important part of the property right rules of any institution is the specification of the conditions under which intangible goods can be redeemed in terms of other intangibles or commodities. Arrangements like these were invented in the context of *field* institutions eons before I or anyone thought of doing laboratory experiments. What we experimentalists have done is to adapt these ingenious institutions to the problem of inducing controlled preferences in experimental microeconomies. Obviously, the reward medium may make a difference, but this is easily studied as a treatment variable by anyone who is haunted by the thought that it is important. But to argue that preferences based on cash-induced value is somehow different than homegrown preferences over commodities is also to argue that preferences among intangible instruments in the field are also somehow different than commodity preferences.

Not all rewards are salient. At the University of Arizona we pay subjects $3 "up front" for agreeing to participate and arriving at the laboratory in time for the experiment. A second payment equal to a subject's cumulative earnings over the experiment, based on experimental outcomes, is paid when he/she leaves the laboratory. This second payment is a salient reward; the first is not.

c. *Examples and Discussion*. A few examples will be offered to illustrate the application of these precepts, and their role in driving an experimental economy.

Example 1. Suppose each of N subject agents are assigned the values $V_1, V_2, \ldots, V_N$ in dollars representing the currency redemption value of one unit of an abstract commodity to be sold at auction. The instructions to each subject state that the winner of the item at auction, say individual w, will have the unqualified right to claim $V_w - p$ dollars from the experimenter where p is the auction purchase price. Hence each i will have an incentive to pay as little as possible and yet win the item, but in no case pay in excess of V_i. If we assume that agents are numbered so that $V_1 > V_2 > \cdots > V_N$, then this ordered array of values represents the discrete induced (Marshallian) demand for units of the item, the supply of which is inelastic at 1.

Example 2. Consider the problem of inducing specified conditions of demand or supply on individual subjects in an isolated experimental market. Let subject buyers $i = 1, 2, \ldots, n$ each be given reward schedules $V_i(x^i)$ representing the currency redemption value of x^i units of an abstract commodity acquired by subject i in an experimental market. If x^i units are acquired by subject i, he/she has the right to claim $V_i(x^i)$ units of currency less the purchase cost of the x^i units, where $V_i(x^i)$ is increasing and concave in x^i. Demand is defined as the maximum quantity that can be purchased beneficially as a function of a given hypothetical price, p. Hence, if i purchases x^i units at the fixed price p, then i's currency earnings are given by $\pi_i(x^i) = V_i(x^i) - px^i$. If i's utility function for currency is $U_i(\pi_i)$, then from precept 1 subject i will wish to maximize $U_i[V_i(x^i) - px^i]$. An interior maximum results if and only if $(V_i' - p)U_i' = 0$, or $x^i = V_i'^{(-1)}(p)$, since $U_i' > 0$ and $(V_i' - p)^2 U_i'' + U_i'V_i'' = U_i'V_i'' < 0$.

This reward procedure induces the prespecified demand $V_i'^{(-1)}(p)$ on subject i. Hence, the experimentally controlled market demand is $\Sigma_{i=1}^{n} V_i'^{(-1)}(p)$ independent of the U_i, that is, we do not have to observe or know the U_i functions. In terms of my previous definition of a microeconomic environment, the market consists of two commodities, money x_0^i and one "good," x^i. In outcome space utility has the no-income-effects form $u^i(x_0^i, x^i) = U_i[x_0^i + V_i(x^i)]$ to be maximized subject to a budget constraint $\omega^i = x_0^i + px^i$ where the endowment $\omega^i = 0$, and $u^i = U_i[-px^i + V_i(x_i)]$.

Similarly on the supply side, let $j = n+1, \ldots, N$ subject sellers be given increasing convex cost functions $C_j(x^j)$, and, assuming x^j units are sold at price p, let j be allowed to claim cash earnings equal to $\pi_j = px^j - C_j(x^j)$. If utility for money is $U_j(\pi_j)$, then j will want to maximize $U_j[px^j - C_j(x^j)]$ which implies the inverse marginal cost supply function $x^j = C_j'^{(-1)}(p)$. Total supply is then $\Sigma_{j=n+1}^{N} C_j'^{(-1)}(p)$, and is controlled by the experimenter through the choice of the C_j functions.

The induced total demand $\Sigma_{i=1}^{n} V_i'^{(-1)}(p)$ and total supply $\Sigma_{j=n+1}^{N} C_j'^{(-1)}(p)$ become flows per period in experiments conducted over a sequence of periods in which the valuation and cost schedules for each individual are repeated in each period. If p is a competitive equilibrium ($C.E.$) price, then the cash reward per period for each buyer (seller) is the "consumer's" ("producer's") surplus for each buyer (seller). Consequently, each experimental subject has the monetary equivalent of the motivation that we interpret as applying to economic agents in any market outside the laboratory.

Example 3. Let each subject i be given an increasing quasi-concave function (in tabular form) specifying currency receipts, $V^i(x_1^i, x_2^i)$, that can be claimed by i for terminal quantities of two abstract goods (x_1^i, x_2^i). Then i's unknown utility for currency $U_i(\pi_i)$ induces utility $u^i = U_i[V^i(x_1^i, x_2^i)]$ on the Euclidean point (x_1^i, x_2^i). These claim rights induce on subject

i the experimentally controlled indifference map given by the level contours of $V^i(x_1^i, x_2^i)$, independent of i's utility of money. That is, if $U_i' > 0$, i's marginal rate of substitution of x_2^i for x_1^i is given by[12]

$$dx_2^i/dx_1^i = -U_i'V_1^i/U_i'V_2^i = -V_1^i/V_2^i.$$

These examples all apply to classical environments (no externalities), but this should not be misread to mean that the methodology is similarly restricted.[13] Thus in example 3, the induced value function for i might be $V^i(x_1^i, X_2)$ where X_2 is a public good (common outcome) for all individuals (see my 1979 article); or induced value could be $V^i(x_1^i, x_2^i, x_2^j)$ if j's holding of good 2 is an externality to i; or induced value might be $V^i(x_1^i, \Sigma_{k=1}^N x_2^k)$ if the total quantity of good 2 is an externality for i. One's ability to induce any arbitrary pattern of valuation (including "altruistic" interdependence) is limited only by the imagination in inventing the appropriate set of claim conditions.

Three qualifications to the nonsatiation precept have been discussed by myself elsewhere (1980) under the heading of *complexity*. These qualifications arise because the subjects in an experiment are drawn from the population of economic agents and therefore can be expected to have all the characteristics of such agents. Two of these qualifications stem from the adjectives "costless" and "autonomous" in Precept 1, and provide the justification for introducing Precepts 3 and 4 below.

The first qualification, which could sever the link between monetary rewards and control over preferences in a laboratory experiment, is the possibility that economic agents may attach nonmonetary subjective cost (or value) to the process of making and executing individual decisions. The subjective cost of transacting, that is, the cost of thinking, calculating, and acting (compare Jacob Marschak, 1968), need not be inconsequential. In example 1, suppose the values $V_1, V_2, \ldots, V_N$ are drawn from a probability distribution known by the subjects. Suppose subject k receives a value V_k which almost certainly is among the lowest values drawn. This individual is very unlikely to win the item auctioned, and may be poorly motivated to take the auction seriously. If there is a cost to thinking and calculating one's bidding strategy, this effort may not be expended when a "low" value is assigned. Similarly, if it is arduous for an individual to monitor quotations, make counteroffers, and execute transactions in a continuous auction, then willingness to pay may not be measured by the marginal induced value function. Note that this description of the problem suggests that transactional effort is more naturally related to agent messages, m^i, than to institutionally determined outcomes, x^i.

These considerations can be illustrated in terms of the example 2 above. Suppose that subject buyer i who receives a monetary reward π_i must send m^i messages (for example,

[12]As noted in my 1973 paper, this induced-value procedure could be used to study general pure exchange equilibrium between two trading groups with or without a medium of exchange ("stage" money). For example, one could give $N/2$ subjects the endowments $\omega^i = (\omega_1^i, 0)$, $i = 1, 2, \ldots, N/2$, and the remaining $N/2$ subjects the endowments $\omega^j = (0, \omega_2^j)$, $j = (N/2)+1, \ldots, N$, and thus set up "Edgeworth Box" trading between two groups each with homogeneous tastes within the group. To quote from my 1973 paper, "Production and a producers market could be added by introducing production function tables and trading in claims on labor input endowments.... But note that in such a general equilibrium model one would not have to introduce profit tables for producer subjects, as in partial equilibrium oligopoly experiments.... The (payoff) functions of 'consumer' subjects would be the entire driving force of the economy, inducing value, through production, upon artificial labor input endowments" (p. 23).

[13]As, for example, when it is incorrectly claimed that an important assumption by experimentalists is that "individuals are motivated by self-interest" (John Chamberlin, 1979, p. 162), and, consequently, experiments "exclude important parts of 'political reality' in order to achieve internal validity" (p. 164). Nonsatiation requires people to prefer more money to less, whether they want to spend it, burn it, or give it to charity. Given nonsatiation, if we want to study the effect of preferences with the property that A gets positive (negative) satisfaction out of B's consumption, then we simply induce that preference property on A. When great care is used in an experiment to make induced value be the primary source of motivation, it is *not* for the purpose of making sure that subjects have a self-interested motivation; it is for the purpose that we *know* what were the preference patterns of the subjects in the experiment. It is not only fitting, but mandatory, that such preferences be interdependent if that is the purpose of the experiment.

bids) to obtain the reward π_i. The reward is commodious, but messages require discommodious effort. Assume the utility of money-with-effort is $U^i(\pi^i, m^i)$ where U^i is increasing in π_i but decreasing in m^i. Now let the purchase quantity depend on the messages sent according to the institutional rules, so that $x^i = h_i(m^i)$. Individual i now makes a costly choice by choosing m^i to maximize $U^i\{V_i[h_i(m^i)] - ph_i(m^i), m^i\}$. At a maximum we have $(V_i' - p)h_i' U_1^i + U_2^i = 0$, and the expression for induced demand becomes

$$x^i = V_i'^{(-1)}(p - U_2^i / U_1^i h_i') < V_i'^{(-1)}(p)$$

if $U_2^i < 0$, $h_i' > 0$. It follows that if there is a disutility associated with messages in the experimental task (i.e., with transacting through the institution to obtain outcomes), the induced demand is lower than in the absence of such a cost.[14]

d. *Precept 3: Dominance*. A condition sufficient to guarantee that we have not lost control over preferences has been suggested by Wilde (1980), namely,

Dominance: The reward structure dominates any subjective costs (or values) associated with participation in the activities of an experiment.

This precept is suggested by the fact that the most common means of rendering nonmonetary task utilities inconsequential is to use payoff levels that are judged to be high for the subject population. The principle here can be seen by letting α be a scale parameter that determines reward level in the induced demand example. Then utility becomes $U^i\{\alpha V_i[h_i(m^i)] - \alpha ph_i(m^i), m^i\}$ and the resulting demand is $x^i = V_i'^{(-1)}\{p - U_2^i / U_1^i h_i' \alpha\}$. As α increases demand approaches $x^i = V_i'^{(-1)}(p)$ provided that $lim_{\alpha \to \infty} U_2^i / U_1^i h_i' \alpha = 0$. A sufficient condition for the latter is that the marginal rate of substitution U_2^i / U_1^i be nonincreasing in α.[15]

But high payoff levels are not the only means of satisfying the dominance precept. A second procedure is to pay a small "commission," say five or ten cents, for each subject's transaction.[16] For example, in the induced demand illustration if the "commission" is β, utility is $U^i\{V_i[h_i(m^i)] - (p - \beta)h_i(m^i), m^i]$, and demand is $x^i = V_i'^{(-1)}(p - \beta - U_2^i / U_1^i h_i') \cong V_i'^{(-1)}(p)$ if $-\beta \cong U_2^i / U_1^i h_i'$. Actually β can be thought of as a type of "nonsalient" reward in which the objective is to compensate for transactions cost and thus allow theories which abstract from transactions cost to be tested.[17]

e. *Precept 4: Privacy*. The second qualification to the nonsatiation precept which carries a potential for losing control over

[14] This suggests a kind of "principle of indeterminacy of induced preference," i.e., we know what are the induced preferences in a given experiment only within a margin of error which is determined by the subjective costs of individual choice in the message space. Although experimentalists have devised various ways of finessing this margin of error, one should always have the question of dominance (see below) in mind when designing and running experiments. Since these subjective costs are part of the cost of operating an institution, they should be viewed, not as a nuisance, but as part of the problem of comparative institutional analysis.

[15] An early path-breaking experimental study of the binary choice, or Bernoulli trials, game by Siegel (1961) systematically varied reward level. The results showed an increase in the proportion of reward maximizing choices when the reward level was increased for a constant task complexity. Furthermore, when the task complexity was increased holding reward level constant, this treatment reduced the proportion of reward maximizing choices.

[16] Plott and I (1978, pp. 143–44) report two experiments with identical induced supply and demand conditions but one experiment paid a commission in addition to earned surplus, while the second paid only earned surplus. In the first experiment (#3, p. 143), volume was always below (17–18 units) the competitive equilibrium quantity (20 units) while in the second experiment (#4, p. 144) volume was 19 units in one, and 20 units in seven of eight trading periods. An alternative to commissions has been used by myself and Arlington Williams (1981b) in which the design permits a range of *C.E.* prices to be defined. Within this range, trades with positive gains between all intramarginal buyers and sellers are possible, and each individual reveals his/her supply price of transacting.

[17] A third procedure can be directly inferred from the Siegel (1961) results, namely to design the procedures, displays and computing aids of an experiment so as to make the experimental task as simple and transparent for the subject as is possible without, of course, compromising the essential features of the institution under study. That is, task complexity may be an important part of the *difference* between two institutions in which case such features must be preserved. But if a computing or display aid is used to simplify the subject's task in experiments comparing two institutions, one should use the same aid in both institutional treatments.

preferences is the fact that individuals may not be autonomous own-reward maximizers. Interpersonal utility considerations may upset the achievement of well-defined induced valuations. Thus subject i's utility may depend upon both i and j's reward, or $U^i[\pi_i, \pi_j] = U^i[V_i(x^i) - px^i, V_j(x^j) - px^j]$ in the induced demand example. If this "consumption" externality condition prevails, then i's induced demand will not be independent of j's demand. However, this kind of interdependence is effectively controlled by the experimental condition of "incomplete" information, first defined and studied by Siegel and Fouraker (1960) in experimental studies of bilateral bargaining. Under incomplete information subjects are informed only as to their own payoff contingencies. This leads to a precept that, following Wilde (1980), I call

Privacy: Each subject in an experiment is given information only on his/her own payoff alternatives.

Induced value privacy would be an important experimental condition to reproduce in the laboratory quite apart from the technical requirement of controlling interagent payoff externalities. This is because privacy is a pervasive characteristic, in varying degrees, of virtually all market institutions in the field. Keep in mind that monetary rewards for nonsatiated subjects in the laboratory have the same function that commodity utility indicators (preferences) serve in field microeconomies. In field microeconomies we never observe the preferences of others.[18]

A third qualification to the nonsatiation precept causes no difficulties in inducing value. As with their counterparts in the economy, experimental subjects may attach "game value" to experimental outcomes (as to messages). Thus winning the item at auction may be joyful quite apart from the satisfaction obtained from possessing or consuming the item. Consequently, in an experiment a make-believe "point" profit $V_i(x^i) - px^i$ may have subjective value $S_i[V_i(x^i) - px^i]$. If S_i is monotone increasing in "points," then such gaming utilities reinforce rather than distort the effect of any explicit reward structure. This qualification would hardly merit mentioning except that it explains why results consistent with maximizing behavior are sometimes obtained in experiments with no monetary rewards. Some evidence indicating that experimental results are less consistent under replication over time, when no rewards or only random rewards are used, is provided in my article (1976b, pp. 277–78).[19]

f. *Precept 5: Parallelism.* Nonsatiation and saliency are sufficient conditions for the existence of an experimental microeconomy, that is, motivated individuals acting within the framework of an institution, but they are not sufficient for a *controlled* microeconomic experiment. For this we also must have dominance and privacy, since individuals may experience important subjective costs (or values) in transacting, and may bring invidious, egalitarian, or altruistic cannons of taste to the laboratory from every day social economy. Precepts 1–4 permit us to study laboratory microeconomic environments in which real economic agents exchange real messages through real property right institutions that yield outcomes redeemable in real money.

Insofar as we are only interested in testing hypotheses derived from theories, we are done, that is, Precepts 1–4 are sufficient to provide rigorous controlled tests of our abil-

[18]It might be thought that privacy should not apply where subjects function as firms in a market experiment in which they are assigned cost functions since costs can be observed from corporate published records in the field. But this is not a correct interpretation because assigned (marginal) cost functions in an experiment represent well-defined willingness-to-sell schedules, and subject earnings (exclusive of "commissions") exactly measure realized producer's surplus. Corporate records yield accounting costs and accounting profits which differ for different purposes (stockholder reporting, income taxation, regulatory reporting); the relation between such measures and willingness to sell is obscure if not misleading.

[19]If gaming utilities are associated with messages instead of outcomes, the problem may be more serious and is formally equivalent to the problem of subjective transaction cost discussed above, i.e., messages may yield subjective utility rather than disutility and this may compromise our control over induced valuation. Of course, the same phenomena are evident in nonlaboratory economies when people enjoy their jobs, like trading futures, or prefer Dutch to English auctions because of the "suspense" experience in Dutch auctions.

ity as economists to model elementary behavior. Microeconomic theory abstracts from a rich variety of human activities which are postulated not to be of relevance to human economic behavior. The experimental laboratory, precisely because it uses reward-motivated individuals drawn from the population of economic agents in the socioeconomic system, consists of a far richer and more complex set of circumstances than is parameterized in our theories. Since the abstractions of the laboratory are orders of magnitude smaller than those of economic theory, there can be no question that the laboratory provides ample possibilities for falsifying any theory we might wish to test.

Once replicable results have been documented in laboratory experiments, one's scientific curiosity naturally asks if these results also apply to other environments, particularly those of the field. Since economic theory has been inspired by field environments, we would like to know, if we were lucky enough to have a theory fail to be falsified in the laboratory, whether our good luck will also extend to the field. Even if our theories have been falsified, or if we have no theory of certain well-documented behavioral results in the laboratory, we would like to know if such results are transferable to field environments.

A sufficient condition for this transferability of results can be summarized as a final precept (compare my 1980 article).

Parallelism: Propositions about the behavior of individuals and the performance of institutions that have been tested in laboratory microeconomies apply also to nonlaboratory microeconomies where similar *ceteris paribus* conditions hold.

Harlow Shapley (1964, p. 67) has applied the term "parallelism" to the similarity of evolutionary steps and attained ends in earth animals, but I use the term more comprehensively to generalize the important conjecture that "as far as we can tell, the same physical laws prevail everywhere" (Shapley, p. 43). The data of astronomy and meteorology, like those of economics, fall into the category of "listening to the radio play," but scientific progress in both astronomy and meteorology has depended on the maintained hypothesis that the physics of mass motion and the thermodynamic properties of gases studied in laboratory experiments have application to the stars and the climate. The abundance of opportunities to make nonexperimental measurements in astronomy and meterology that have not yet contradicted these physical laws means that this maintained hypothesis is yet to be falsified.

In biology, parallelism means that if tobacco smoke, or injected tobacco tars, produce more cancer tumors in treatment group rats than in control group rats, then the likelihood is increased that the greater incidence of lung cancer in human cigarette smokers is due to the cigarette smoke and not to some spurious characteristic of cigarette smokers. Obviously parallelism does not state that all mammals are subject to the same maladies; that hydrogen atoms exhibit the same excitation state in the sun's interior as on the earth's surface; or that Northern Hemisphere storms are indistinguishable from Southern Hemisphere storms. In each of these cases the appropriate proposition requires narrower *ceteris paribus* conditions. Only man, chimpanzees, and monkeys are susceptible to Type 1 polio virus infection; the excitation state of hydrogen atoms depends on temperature; and Northern Hemisphere meteorological conditions differ from those of the Southern Hemisphere. *Which kinds of behavior exhibit parallelism and which do not can only be determined empirically by comparison studies.*

What parallelism hypothesizes in microeconomy is that if institutions make a difference, it is because the rules make a difference, and if the rules make a difference, it is because incentives make a difference. That is, whatever the context of the particular microeconomy—the laboratory (using induced values), the primary market for U.S. Treasury bills, or the auctioning of scarce job interview slots among Chicago Business School graduates whose bids are denominated in "points," and constrained by a fixed endowment of such points—parallelism says that the incentive effects of different bidding rules are qualitatively the same;

if rule A produces lower bids than rule B in one market, it will do so in other markets.[20] Will these incentive effects be the same quantitatively? The answer is likely to be "no" unless the different microeconomies are comparable in terms of the types of bidders, the stakes involved, and so on. The more narrowly defined is the alleged parallelistic phenomena, the more narrowly defined must be the *ceteris paribus* conditions across the different microeconomies. If one is interested in parameter estimation, as in a field experiment with the negative income tax, with the idea of applying the estimates to a population, then the representativeness of the sample is of obvious importance. But if one is testing a theory which assumes only that economic agents are motivated to bid so as to maximize expected utility, any sample of agents not likely to be saturated in money is sufficient to initiate a program of research. If the theory is not falsified in several replications, then one can begin to ask whether the results generalize to different subject pools and to field environments. But what is most important about any particular experiment is that it be relevant to its purpose. If its purpose is to test a theory, then it is legitimate to ask whether the elements of alleged "unrealism" in the experiment are parameters in the theory. If they are not parameters of the theory, then the criticism of "unrealism" applies equally to the theory and the experiment. If there are field data to support the criticism, then of course it is important to parameterize the theory to include the phenomena in question, and this will affect the design of the relevant experiments.

The appropriate way to falsify parallelism with respect to some particular aspect of behavior is to show that some replicable property of a theory or institution in a laboratory microeconomy is falsified with field data. A few parallel studies have been reported by John Ferejohn, Robert Forsythe, and Roger Noll (1979), Michael Levine and Plott (1977), and myself (1980). In these cases the results are reassuring in the sense that there are several laboratory findings that appear also to characterize nonlaboratory microeconomies. But more such studies are welcome, and are necessary, if answers of substance are to be provided to questions of parallelism.

In terms of the evidential standards and precedents that have been established in this literature, it is not appropriate to list reasons (unencumbered by documentation) why experimental situations might be different from what one imagines might be important about "real world" behavior (Cross, p. 404). Speculation about a list of differences between two microeconomies (laboratory or nonlaboratory) is not the same thing as showing empirically that the microeconomies exhibit different behavior and that this is because of factors appearing in the list. Nor is it likely that experimentalists will be diverted from their work by "an approach to research in economics alternative to experiments... called the phenomenological approach" in which the leading example cited is that of the discredited[21] "Phillips curve a simple empiri-

[20] Parallelism has been criticized because it "specifies *ceteris paribus* conditions without naming the variables which are required to be held constant" (Cross, 1980, p. 404). The answer is that the variables to be held constant are those that were constant in the laboratory experiments whose results are alleged to apply to nonlaboratory microeconomies. Such a list is always well defined in advance by the initiating studies and therefore it is ingenuous to conclude that "Given such broad residual powers to restrict the applicability of the principle, counter-examples to the proposition would certainly be hard to defend" (p. 404). Thus, in experiments that compare the incentive effects of discriminative and competitive auctions (Propositions 3 and 14 below), subjects are drawn from the same subject pools, and induced values are drawn from the same distribution under the same information conditions. Clearly, if preferences and/or the population of bidders is different in two nonlaboratory (or any) environments, these differences may swamp any incentive differences due to the different auction rules. But many experiments have established that some behavioral laws are robust with respect to changes in preferences and the type of subjects, in which case this fact would become the (less restrictive) working hypothesis to be tested in nonlaboratory environments. In the context of parallelism, *ceteris paribus* means the same thing that it does in demand theory when we say that the effect of price on the demand quantity may be dominated by the effect of income if the latter is allowed to vary.

[21] See Robert Lucas (1981) for a discussion of the status of the Phillips curve doctrine. The Phillips curve

cal regularity" (Frank Stafford, 1980, p. 408). It is this type of example that motivated some of us long ago to begin exploring experimental methods.

2. *An Example of a Microeconomic Experiment: Two Sealed-Bid Auction Institutions*

An example of a simple laboratory experiment will be used to illustrate the definition of a microeconomic system developed in Section I. As noted above nonsatiation and saliency are sufficient to allow such an experiment to be defined.

a. *An Experimental Microeconomy with Two Institutional "Treatments."* Consider experiments in which a single unique item is to be sold in a sealed-bid auction organized under the alternative first and second price sealed-bid auction rules (William Vickrey, 1961).

(i) Environment: There are $N>1$ subject agents. The unique item is offered for sale (by the experimenter) at zero cost (i.e., is offered inelastically). Each i knows that the values V_k for all k are independent drawings from the uniform density $(\bar{V})^{-1}$ on $[0,\bar{V}]$. Initially, each i knows his/her own V_i but does not know V_j, for all $j\neq i$. Hence $e^i=(V_i,\bar{V},N)$.

(ii) Agent property rights in message space: The language M consists of bids in dollars for the unique item. One and only one bid is admissible by each individual. Thus $m^i=b_i$ is i's bid in dollars, $0\leqslant b_i<\infty$, $i=1,\dots,N$. Let the bids be numbered so that $b_1>b_2\dots>b_N$ (assuming no ties). Then $m=(b_1,\dots,b_N)$ is the set of messages sent by N agents.

(iii) Agent property rights in outcome space: I identify two distinct institutions.

The first price auction. Define $I_1=(I_1^1,\dots,I_1^N)$, where $I_1^1=[h^1(m)=1;\ c^1(m)=b_1]$, $I_1^i=[h^i(m)=0;\ c^i(m)=0]$, $i>1$, that is, the item is awarded to the first (highest) bidder and all other i get nothing; the first bidder pays what he/she bid and all other i pay nothing.

The second price auction. Define $I_2=(I_2^1,\dots,I_2^N)$, where $I_2^1=[h^1(m)=1;\ c^1(m)=b_2]$, $I_2^i[h^i(m)=0;\ c^i(m)=0]$, $i>1$, that is, the item is awarded to the first bidder at a price equal to the amount bid by the second highest bidder. All others receive and pay nothing.

(iv) Agent property rights in rewards: If $i=1$, the experimenter guarantees the payment V_1-b_1 (or b_2) to agent 1. If $i>1$, the payment is 0 to i.

b. *Agent Behavior.* Agent behavior carries the environment e^i into bids b_i depending upon the institution I_i. If i is assigned value V_i, then $e^i=[V_i,\bar{V},N]$ and agent behavior *as observed* is

$$b_i=\hat{\beta}^i\left[e^i|I\right]=\begin{cases}\hat{\beta}_1^i[e^i], & \text{if } I=I_1, \quad \forall i.\\ \hat{\beta}_2^i[e^i], & \text{if } I=I_2, \quad \forall i.\end{cases}$$

The information state of the environment also allows a Nash equilibrium ($N.E.$) *theory* of agent behavior to be specified. If i has constant relative risk aversion r_i (unobserved by the experimenter), that is, the utility of money to i is $[V_i-b_i]^{r_i}$, then individual i's $N.E.$ bid is (see Cox, Roberson, and myself, 1982) given by

$$b^i=\beta^i\left[e^i|I\right]=\begin{cases}\dfrac{(N-1)V_i}{N-1+r_i}, & \text{if } I=I_1, \quad \forall i.\\ V_i, & \text{if } I=I_2, \quad \forall i.\end{cases}$$

In the first price auction, the $N.E.$ strategy is to bid a constant proportion of one's value

literature is a good example of the incredible life that an economic system of belief can enjoy in the absence of a rigorous methodology of falsification. The methodology of curve fitting with data which do not change much from year to year elevated the Phillips curve to an "empirical regularity" that would still be riding the crest of "fine-tuned" policy were it not for the fact that "nature" (perhaps aided by such policy) finally gave us the "crucial" national experiment in which both inflation and unemployment were so outrageously high that belief in the tradeoff doctrine was no longer sustainable outside of a coterie of devout disciples. For me, the doctrine expired its last gasp in 1971 when in a lecture by a prominent economist it was concluded that the Phillips curve had shifted and that we now had to accept a higher inflation rate to achieve the targeted unemployment rate. At that point it became clear that the whole doctrine was like that of the earth-centered universe which could accommodate any new observation by a Ptolemic juggling of the epicycle via the device of introducing a "movable eccentric" (Arthur Koestler, 1963, p. 67).

depending upon N and r_i. In the second price auction the *N.E.* strategy (also a dominant strategy equilibrium) is to submit a bid equal to value, that is, to fully reveal demand independent of N and r_i.

c. *System Performance*. Suppose the experimental economy consists of T trials $t = 1,\ldots,T$. One measure of performance might be the percentage of all awards which were to the highest value bidder (the percentage of *P.O.* awards), T_P/T, where T_P is the number of auctions in which the highest bidder also had the highest value.

Efficiency can be defined as $V_w(t)/V_h(t)$ where $V_w(t)$ is the value drawn by the winning bidder and $V_h(t)$ is the highest value in auction t. A second measure of performance is mean efficiency across T auctions, $\bar{E} = T^{-1}\Sigma_{t=1}^{T}V_w(t)/V_h(t)$.

III. Types of Microeconomic System Experiments

There are many ways of classifying experiments (Abraham Kaplan, 1964, pp. 147–54). I propose to keep things straightforward in this section by considering only two broad classifications—functional and methodological. The functional classification of experiments follows directly from my definition of a microeconomic system. The methodological classification will be limited to only a few very comprehensive categories which can be readily identified in the experimental economics literature.

A. *A Functional Classification of Experiments*

The universe of "interesting" experiments is defined naturally by the set of all possible or feasible elements of a microeconomic system (i.e., if S_e is the set of all environments, and S_I the set of all institutions, this universe is the product of S_e and S_I). Since an experiment yields observations on elements in X and in M, what classes of experiments can we conduct? We can do experiments in which (A) the environment is a variable or (B) the institution is a variable. Within either of these classes, we can compare system performance (outcomes) or individual behavior (messages). For any environment and institution, we can do experiments which (C) compare outcomes (or messages) with a theory or theories. Essentially hypothesis testing directed at theory falsification is a type of comparison in which one or more sets of outcomes (or messages) in the comparison are predicted by theory(ies). Consequently, in all experimental studies we are in some sense making comparisons—comparing observed outcomes arising from different environmental or "institutional treatment" conditions, or comparing observed with theoretical predicted outcomes.

Examples of experimental studies in which the environment is varied include (*i*) the extensive oligopoly studies by Fouraker and Siegel (1963), and James Friedman and Austin Hoggatt (1980) in which the number of participants and the cost or demand conditions are varied, (*ii*) the speculation experiments of Miller, Plott, and myself (1977), and Williams (1979) in which demand is varied in a cyclical "seasonal" pattern, and (*iii*) the committee decision experiments reported by Morris Fiorina and Plott (1978) in which the committee size and induced preferences were varied. Experiments comparing different institutions of contract include (*i*) studies of the effect of discriminative versus uniform pricing (see Section IV.C) on the bids (messages) submitted and the outcomes in sealed-bid auctions (my 1967 article), (*ii*) a comparison of outcomes in Dutch and English auctions (V. Coppinger, myself, and J. Titus, 1980), and (*iii*) studies of the effect of binding or nonbinding price ceilings or floors in continuous double auction trading (see Section IV.B) (R. Mark Isaac and Plott, 1981a; myself and Williams 1981a).

Studies in which both the environment and the institution are varied include (*i*) a comparison of markets with and without speculation under cyclical demand (Williams, 1979), (*ii*) comparisons of discriminative versus uniform price rules under alternative induced demand conditions (Miller and Plott, 1980), and (*iii*) comparisons of first and second price sealed-bid, and Dutch auctions using different numbers of bidders (Cox, Roberson, and myself, 1982).

Experiments comparing observed outcomes with theoretical outcomes or predictions include (*i*) the bilateral bargaining experiments of Fouraker and Siegel (1963) comparing observed outcomes with the Bowley-Nash theory predictions, (*ii*) the public good experiments reported in my 1979 article comparing observed outcomes with the Lindahl and free-rider theories, and (*iii*) the asset market experiments of Plott and Shyam Sunder (1982) comparing experimental outcomes with the predictions of rational expectations theory.

B. *Methodological Classification of Experiments*

Philosophers of science (see, for example, Karl Popper 1959; Hanson 1969, 1971; Kaplan 1964) have written extensively on scientific methodology, particularly experimental methodology. Although most of this work relates to the physical sciences, the main features apply to any experimental effort. An insightful perspective is provided by considering various kinds of microeconomic experiments in terms of their methodological objectives (compare Kaplan, pp. 147–54).

1. *Nomothetic Experiments — Establishing the "Laws" of Behavior*

These are the law-giving experiments that employ replication and rigorous control to reduce error in testing well-defined hypotheses. Nomothetic experiments provide the most compelling and objective means by which each of us, as scientists, comes to see what others see, and by which, together, we become sure of what it is that we think that we know. It is useful to distinguish between nomo-theoretical experiments, concerned with establishing laws of behavior through a process of testing theories, and nomo-empirical experiments designed to test propositions about behavior that are suggested by observed empirical regularities in field data or pilot experiments.

a. *The Importance of Theory*; *When does the Priest Wear Robes*? Theory is fundamental to scientific methodology for three reasons:

(*i*) Theory economizes on the statement of behavioral regularities. It is a shorthand way of summarizing more detailed and complex descriptions. Thus Newton's theory (the inverse square law of attraction) provides a much simpler statement than defining an ellipse and explaining that this is the orbit of a planet around the sun, explaining that the distance traversed by a falling body is proportional to the square of the time of descent, and so on. These and many more terrestrial and solar system observations were shown to be deducible from the simple inverse square law.

(*ii*) Theory brings a coherence—an underlying pattern or rationale—that integrates otherwise diverse observations and phenomena into a single whole. Wo(men) experience this result as a liberating understanding (Eureka!) of the whole that is easier to comprehend, to appreciate, to impart to the uninitiated. Thus plate tectonic theory provides an explanation of the worldwide pattern of earthquake activity, and of volcanic activity; explains why the geology of the continents differ from that of the ocean floor; provides one rather than a hierarchy of anecdotal explanations of mountain formation; and also accounts for geophysical data on the earth's interior. In the space of twenty years, this new (general equilibrium?) theory has ignited a renaissance of interest and research in the geological sciences (see, for example, C. L. Drake and J. C. Maxwell, 1981).

(*iii*) Theory can chart the path to new observations based upon predictions of phenomena or events for which there was previously no special motivation or search. Thus the theory that the late Pleistocene wave of large animal extinctions was due to paleo hunter cultures (Paul Martin, 1967) has accelerated the search for evidence that early man may have predated these extinctions in North America. Similarly, a variety of new particles have been predicted by theory, then discovered, in modern physics.

The crowning success of theory in the physical sciences, which is associated so dramatically with Newtonian physics, has elevated theory to the pinnacle of respect, and theorists to an undeclared priesthood in most of the sciences. Yet theory achieves its scientific importance only when closely allied with observation (and, ultimately, vice versa).

Newtonian mechanics created a scientific revolution, not because of the aesthetic beauty of the inverse square law, but because it acccounted for two distinct bodies of observation: Galileo's experimental law of falling bodies, namely that the distance traversed was proportional to the square of the time of fall; and Kepler's three laws of planetary motion distilled from a lifetime of study of the mass of astronomical observations recorded with astonishing accuracy by Tycho Brahe (Koestler, 1963, pp. 496–509). Newton showed that these (and other) empirical laws were derivable from one theoretical gravitational law of attraction—an intellectual triumph which easily established him as the founder of theoretical physics. But it was Galileo who is associated with the necessity of investigating the *how* of things before attempting to explain the *why* of things, and who thereby was enshrined as the founder of modern physics. "The introduction of this point of view really marks the beginning of modern science, and it is to it that the remarkable scientific developments since the sixteenth century have been largely due" (Millikan, Roller and Watson, 1937, p. 3). That this is a metaphorical image of Galileo has been made clear by modern historians of science. However, as noted by Robert Butts, "It also seems to me true that although Galileo did not invent experimentation, he did most importantly modify the epistemological point of doing experiments" (1978, p. 59).

The Galileo-Kepler laws contained the same information as did Newton's law. What was missing in the former was the nifty but insightful interpretation of the latter.

b. *The Necessity for Replicable Empirical Laws—Would You Scale a Mountain Without a Rope?* The priority importance of Galileo's experimental law to the Newtonian system is evidenced by the countless experiments which later confirmed Newton's theory. Indeed, perturbations in the planet Mercury were inconsistent with the Newtonian system so that it was actually the evidence from experimental mechanics that made Newton credible. Only later was the Mercury puzzle explained by Einstein's relativity theory extending the Newtonian mechanics. Ultimately, sophisticated experiments have confirmed that Newton's theory was only an approximation, albeit a good one at "ordinary" velocities small relative to the speed of light. Hence new ropes have made it possible for physics to scale new heights. But, it is the rope that allows the new position to be sustained, lays the basis for a new ascension, and occasionally sparks a totally new transformation (for example, the influence of the Michaelson-Morely experiment on Einstein).

The history of science by no means implies that rigorous observation must precede theoretical speculation. But it is difficult to get off the ground in the absence of a stable pattern of observations and a frank recognition of the ecclesiastical pretense of theory unsupported by measurement. The genius often attributed to Galileo was the revolutionary idea that if you were curious about how a stone falls, then the thing to do was to try it. From the observation that a stone, dropped from the mast tip of a moving ship, shares the ship's forward motion, he inferred that if the earth moved, surface objects would share the earth's momentum, and would not be left behind as claimed by received (ecclesiastical) theory. It is often said that it was the failure to combine controlled systematic observation with rigorous reasoning that accounts for the failure of science to develop more fully in ancient Greece, China and India (Kaplan, 1964, p. 144–45).

In Section IV below is provided a summary, in proposition form, of some of the candidates for the list of nomothetic results from experimental microeconomy. Any such list must of course be subject to further replication or modification by new experimental evidence.

2. *Heuristic Experiments*

Heuristic or exploratory experiments are used to provide empirical probes of new topics of inquiry. Such experiments are less likely to follow a rigorous design pattern than nomothetic experiments because (a) the objectives may not be as sharply defined by theory or by a hypothesized pattern which is thought to characterize previous experimental results, and (b) the procedural mechanics of the experiment may be new and untested. Heuristic experiments may provide nomotheoretical contributions because they may be fortuitously adequate for distinguishing between two or more hypotheses with very distinct, widely separated, outcome implications; but they may be conducted for no better articulated reason than to just "see what will happen." Although there is widespread scientific prejudice against this latter type of "grubbing in the facts," I think this view is much too rigid and purist, and carries the prospect of needlessly discouraging an important source of new discoveries. Science needs the wings of heuristic experiments as much as the foundational support of nomothetic experiments. It is through exploratory probes of new phenomena that attention may be redirected, old belief systems may be reexamined, and new scientific questions may be asked. The early oligopoly (Hoggatt, 1959) and competitive market (my 1962 article) experiments were of this tentative, exploratory character. An excellent recent example is provided by the Plott and Wilde (1982) experiments dealing with products or services requiring seller diagnosis and recommendation (for example, physicians and repairmen) based on uncertain information.

3. *Boundary Experiments*

Whenever a theory or an empirical regularity has received replicable support from several independent experimental or other empirical studies, and is thereby established as a behavioral law with some claim to generality, it is natural to ask whether one can design experiments that will test for those extreme or boundary conditions under which the law fails. Kaplan (1964, p. 150) refers to such inquiries as boundary experiments. These experiments have an obviously important function in establishing the limits of generality of a theory, and setting the stage for important new extensions in theory.

A few examples of boundary experiments in economics will help to illustrate the concept. The double auction (see Section IV.B below) is a remarkably robust trading institution for yielding outcomes that converge to the *C.E.* It achieves these results with a small number of agents, under widely different supply and demand conditions, with each individual agent having strict privacy, that is, the agent only knows his/her own value or cost conditions. Several sets of experiments have been conducted to test the boundary of application of these conditions. One set of experiments (my 1981a article; myself and Williams 1981b) used only one or two sellers (Propositions 5 and 8 below). Only in the one-seller experiments is there a failure to arrive consistently at *C.E.* outcomes, thus establishing "one" as the limiting number of sellers at which competitive price theory fails under double auction trading.

A one-seller experiment can also be viewed as a boundary experiment testing the limits of applicability of cartel theory. A cartel may fail to achieve monopoly outcomes because of incentive failure or "chiseling" incentives by cartel members; because of internal cartel enforcement problems; or because of external demand uncertainty or strategic countervailing behavior by buyers. An experiment using only one seller controls for all the internal circumstances that can cause a breakdown in cartel agreements. Hence single seller behavior provides the extreme boundary of behavior for a cartel. If one individual has difficulty achieving monopoly outcomes when demand is unknown, within a given exchange institution, then one expects a group of cartel conspirators to have even more difficulty in achieving a monopoly result (Propositions 8 and 9 below).

Another type of boundary experiment is represented by the supply and demand schedules shown in Figure 2. This experimental design has been used to test whether the *C.E.* tendencies of double auction would continue to hold under rent asymmetries so extreme that at the *C.E.* all the exchange surplus is earned by the buyers. This was a boundary experiment that failed, that is, the design in Figure 2 yields rapid convergence to the *C.E.* for an excess supply quantity $(Q_s - Q_d)$ of 5 or 8 units (see my 1965; 1976a articles).

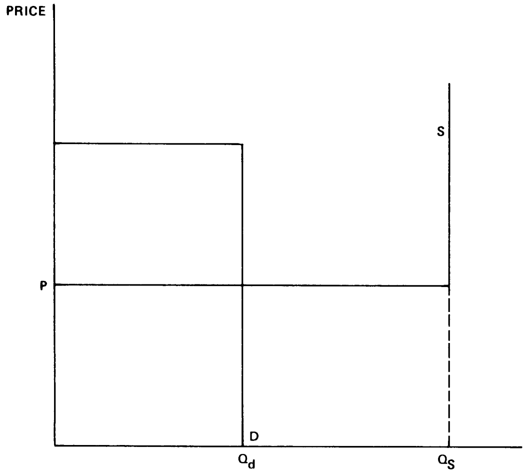


FIGURE 2

IV. Some Institutions and Some Corresponding Experimental "Stylized Facts"

In what follows each of several institutions that have been studied experimentally will be described very briefly, and some of the principal "stylized facts" from these experiments will be summarized in the form of brief empirical propositions. Reference to the original studies will be necessary for readers desiring more comprehensive detail.

There are two basic kinds of auctions—continuous or "oral" auctions, and sealed-bid auctions. In *continuous auctions* an agent may alter his/her bid in response to the bids of others or the failure of a bid to be accepted, that is, an exchange of messages occurs according to specified rules of negotiation prior to each contract. In *sealed-bid auctions* each agent submits one message to a center, which then processes the messages according to publicized rules, and announces aggregate or summary information describing the outcome. The important difference between the two kinds of auctions is the greater information content of the continuous as compared with sealed-bid auctions. Either auction may of course be repeated over time which generates a history of outcome information, but in addition the continuous auction provides a message history between successive contracts. In the experiments reported below the contracting process is repeated sequentially sometimes for as many as twenty or more consecutive periods.

A. *Auctions for a Single Item*

From the long history and great variety of auctions (Ralph Cassady, 1967) for the sale of a single item offered by a seller, two continuous auctions, the English and Dutch, and two sealed-bid auctions, the first and second price auction, have been identified for experimental investigation.

English. The process begins with a call for a bid. Once a bid is announced it remains standing until it is displaced by a new bid, which is required to be higher. The process stops with an irrevocable award of the item to the standing bidder when, in the auctioneer's judgment, no new overbid can be elicited. Anonymity is easily preserved by working out a signalling code with the auctioneer (Cassady, 1967, pp. 150–51).

Dutch. The seller's offer price starts at a level judged to be well in excess of what the highest bidder is likely to pay, then lowered in increments by an auctioneer or clock device until one of the buyers accepts the most recent offer to form an irrevocable contract.

First Price. The process begins with a request for bids to be tendered. Privately each bidder submits a bid price. When all the bids have been received by the center, or by the seller, the award is made to the highest bidder at a price equal to the highest bid.

Second Price. This auction is identical to that of the first price, except that the award is made to the highest bidder at a price equal to the second highest bid.

PROPOSITION 1: *Using the subscripts e(English), d(Dutch), 1(First), and 2(Second), and letting* E_e, E_d, E_1, *and* E_2 *be measured either by the mean efficiency or the proportion of P.O. awards, then* $E_e \cong E_2 > E_1 > E_d$.[22]

[22]Propositions 1–3 are based on the theoretical analysis and the experimental results (from a total of about 1,000 auctions) reported by Coppinger, myself, and Titus (1980) and Cox, Roberson and myself (1982). Both of these studies were stimulated by the prior theoretical work of Vickrey (1961).

These measures of E vary somewhat depending upon the particular procedure for inducing demand (random from an announced distribution, random from an unannounced distribution, random level of linear demand), but the efficiency ordering appears not to be affected by this procedure.

PROPOSITION 2: *English and second price auctions which are theoretically isomorphic, that is, are subject to the same analysis and which predict identical allocations, appear to be equivalent behaviorally. Dutch and first price auctions which are theoretically isomorphic are not equivalent behaviorally.*

Although English auction prices are higher and the awards slightly more efficient than in the second price auction the difference is not significant. Contract prices in first price auctions are significantly higher, and are more efficient, than in Dutch auctions. This behavioral difference between first price and Dutch auctions can be explained either by a model which postulates a nonmonetary utility for the "suspense of waiting" in the real time Dutch auction or by a model which postulates a systematic underestimate of the Bayes' Rule risk of loss in not stopping the Dutch price decline (Cox, Roberson, and myself, 1982). The second model is consistent with the results of independent experiments testing Bayes' Rule (David Grether, 1980), while the first model is consistent with the reported impression of subjects that they enjoy the "suspense of waiting" in the Dutch auction. Given two theories each predicting prices to be lower in Dutch than in first price auctions, one naturally asks if there is a "crucial"[23] experiment that will discriminate between the two theories. In this case a simple such experiment is to replicate an existing set of Dutch and first price auction experiments with all parameters unchanged except that the monetary reward level is doubled. The reported difference between Dutch and first price auction behavior should narrow if the "suspense of waiting" model is correct, while the differences should not narrow if the "Bayes rule underestimation" model is correct.

PROPOSITION 3: *Prices, allocations, and individual bids in the first price auction require the rejection of Nash equilibrium models of bidding behavior based on the assumption that all bidders have the same concave utility function. But the experimental results for $N > 3$ bidders are consistent with a Nash equilibrium model based on the assumption that bidders have power utility functions with different coefficients of constant relative risk aversion.*

All models which achieve tractability by assuming that bidders share the same risk neutral or risk averse utility function flounder on the rocks of predicting that individual bids will be ordered the same as individual values. Consequently, these models predict *P.O.* allocations, whether or not bidders are risk averse, which is not what we observe.

B. *Double Auctions*

The institution most extensively studied by experimentalists has been some version of the double auction (*DA*) rules that characterize trading on the organized security and commodity exchanges. This is because *DA* was one of the first institutions to be studied experimentally, and from the beginning demonstrated "surprising" competitive properties. These properties of *DA* especially recommended its use in testing propositions based on competitive price theory. It is an

[23]The quotation marks are used because Hanson shows convincingly that the so-called "crucial" experiment can yield deceptive results. For example, the experiments of Fresnel, Young, and Foucault rejected the hypothesis that the velocity of light in water should be greater than its velocity in air, which was interpreted as implying a rejection of "Hypothesis I," that light consists of particles (rather than waves). As noted by Hanson, the experimental result means either that "light does not consist of high-speed particles, or the assumptions required to give Hypothesis I teeth are (in part or completely) false. One of these assumptions would be... that light must be either wavelike or corpuscular, but not both.... Every experiment tests, not just an isolated hypothesis, but the whole body of relevant knowledge that is involved by the logic of the problem, the experiment, and the hypothesis" (1969, pp. 253–54).

example of a continuous auction and was probably an outgrowth and generalization of the English auction with origins in Babylon and Rome (Cassady, 1967, pp. 26–29). The following description of *DA* applies to only one of the versions that has been used extensively in experiments. In this description each contract is for a single unit.[24]

Double Auction (Leffler and Farwell, 1963, pp. 186–92). After the market opens an auction for a unit begins with the announcement of a price bid by any buyer or a price offer by any seller. Any subsequent bid (offer) must be at a higher (lower) price to be admissible. Once a bid (offer) has been made public, that is, is "standing", it cannot be withdrawn. A binding contract occurs when any buyer (seller) accepts the offer (bid) of any seller (buyer). The auction ends with a contract. If the standing bid (offer) was not part of the contract (for example, if a buyer other than the one with the standing bid accepted the standing offer), the maker of that bid (offer) is no longer bound to it unless the bid (offer) is now re-entered. Following a contract a new auction begins when a new price bid (offer) is announced. The new bid (offer) may be at any level, and may involve "signalling." This process continues until the market "day" comes to an end.

Although different studies report the use of alternative versions of these *DA* rules, the experimental results do not differ in terms of their equilibrium properties.[25] These propositions are based on the results of perhaps 100 to 150 *DA* experiments reported in the literature.

PROPOSITION 4: *Allocations and prices converge to levels near the competitive equilibrium* (*C.E.*) *prediction. This convergence is rapid, occurring in three to four trading periods or less when subjects are experienced with the institution* (*but not the particular induced values*).[26]

Even in the first period of trading, the allocations and price tendencies are generally such as to reject monopoly (monopsony) behavior in favor of the *C.E.* (Isaac and Plott, 1981; my 1962, 1964, 1965, 1976a articles; myself and Williams, 1981a,b; 1982). Repeated "signalling" with high (low) offers (bids) is common, but ineffective.

PROPOSITION 5: *Convergence to C.E. prices and allocations* (*Proposition* 4) *occurs with as few as six to eight agents* (*most experiments have used eight*), *and as few as two sellers* (*Smith and Williams*, 1981b).

Many economists express surprise, if not discomfort, when presented with the evidence for Proposition 4 and particularly Proposition 5. The idea that a *C.E.* is an ideal "frictionless" state not likely to be approached in any observable market—and certainly not without a "large" number of agents with its assumed concomitant "price-taking" behavior—is a deeply ingrained belief based on untested theory going back to Cournot. Since Cournot's theory does not specify an institution, it is unclear in what context the theory is supposed to have relevance. As for price-taking behavior, note that every agent in *DA* is as much a price maker (announcing bids or offers) as a price taker (announcing acceptances). Empirically it is now thoroughly documented that this institution exhibits strong *C.E.* tendencies.

PROPOSITION 6: *Complete information on the theoretical supply and demand conditions*

[24]On the New York Stock Exchange there are also trading post rules governing multiple unit contracts.

[25]The *DA* trading procedure has been programmed for the PLATO computer system (Williams, 1980; myself and Williams, 1982). This program allows subjects in an experiment to negotiate and trade with each other entirely through individual computer terminals. In a comparison of oral with computerized *DA* trading, differences appear to disappear with the use of experienced subjects (Williams, 1980). A comparison of experimental results using four variations on the computerized *DA* rules is reported by myself and Williams (1982). These different rules yield different price dynamics, but do not affect equilibrium or efficiency.

[26]This proposition applies to environments in which supply and demand are stationary over all the periods of an experiment. Work in process suggests that this result may not generalize to environments with period-by-period shifts in demand (Glenn Harrison, Williams, and myself).

of a market (i.e., agent knowledge of the induced values and costs of all agents) is neither necessary nor sufficient for the rapid convergence property in Proposition 4.

That complete information is not necessary is established by the large number of *DA* experiments that have shown rapid convergence when such information was withheld. That complete information is not sufficient follows from the results of eight experiments, using the "swastika" design of Figure 2. In four of these experiments complete information was withheld; in two, complete information was provided; and in two, the information was incomplete for the first two to three trading periods, and then switched to complete for two additional trading periods. In these experimental comparisons, the incomplete information condition yielded more rapid convergence than the condition of complete information (my 1980 article, p. 357 ff).[27]

PROPOSITION 7: *Price convergence tends to be from above (below) the C.E. price when consumer's surplus is greater (smaller) than producer's surplus (my* 1962, 1965, 1976a *articles; myself and Williams,* 1982).

PROPOSITION 8: *Experiments with one seller and five buyers do not achieve monopoly outcomes, although some replications achieve the C.E. outcome. Buyers tend to withhold purchases (and repeatedly signal with high bids) giving the seller a reduced profit, especially at the higher prices. This encourages contracts near the C.E. price, but normally at a loss in efficiency due to the withheld demand (my* 1981a *article).*

This "counterintuitive" result runs roughshod over most belief sysems. But if *C.E.* theory (as conventionally taught) is questionable, monopoly theory is more seriously questionable: The *DA* institution yields the *C.E.* even if the "large" number story is not right, but with *DA* (also see Propositions 19 and 20 below) monopoly theory goes begging for evidential support.[28]

PROPOSITION 9: *Experiments with four buyers and four sellers in which the sellers (or the buyers) are allowed to "conspire" (i.e., engage in premarket, and between market conversation about pricing strategies) do not converge to the monopoly (or monopsony) outcome; neither do they seem to converge dependably to the C.E. Furthermore, the conspiring group often makes* less *than the C.E. profit (Isaac and Plott,* 1981a; *my* 1981b *article).*

PROPOSITION 10: *Binding price ceilings (floors) yield contract price sequences which converge to the ceiling price from below*

[27] In this supply and demand design (Figure 2), complete information means that both buyers and sellers are aware of the extreme asymmetry in the gains from exchange at prices near the *C.E.* Consequently, sellers hold out for higher prices under complete rather than under incomplete information. Similarly, buyers bid higher or accept higher offers, perhaps because of egalitarian motives or because they do not want to risk failing to make a contract if sellers succeed in their effort to maintain prices above unit cost.

[28] Before rejecting the experimental outcomes as "unrealistic," i.e., contrary to your belief system, consider the following points: (A) There is perhaps a tendency to think casually in terms of the perfect information textbook monopoly diagram in which the monopoly outcome seems transparent. But remember that the subject monopolists in Proposition 8 do *not* know their demand curves except as demand is revealed by real subject buyers. (B) Implicit perhaps in monopoly thinking is the assumption of a large number of buyers. Here we have only five buyers, which of course is more than enough to yield the *C.E.* if there are at least two sellers (Proposition 5). Hence, if you say, "Oh, the result follows because there are only a few buyers," then you have to tell me why a large number is necessary for monopoly but not for a *C.E.* (C) There is *no* institution in textbook monopoly theory, but there is an implicit assumption that buyers reveal 100 percent of demand, while the seller optimally underreveals supply. Hence, implicit in monopoly theory is an asymmetric processless assumption from which the conclusion is unassailable but trivial.

Proposition 8 is consistent with monopoly theory under random demand, but since this theory predicts either a higher or a lower price than if demand were certain (Leland, 1972, p. 289), this fact is not very satisfying. Also, it is not clear how these "uncertainty" models are related to experiments in which demand is *unknown* by all agents but is stationary. Does the appropriate uncertainty involve randomness in behavior, or sampling theory?

(above). If the price ceiling (floor) is nonbinding, i.e., if it is above (below) the C.E. price, prices converge to the C.E., but along a path which is below (above) the price path in a market without a price ceiling (floor). If a binding price ceiling (floor) is removed, this causes a temporary explosive increase (decrease) in contract prices before the C.E. price is approached (Isaac and Plott, 1981a; *myself and Williams,* 1981a).

The significance of this proposition for price theory is that a binding price control does *not* quickly freeze prices at the control level, and a nonbinding control has demonstrable effects on the dynamics of market price behavior. Neither of these characteristics is part of conventional price theory. My article with Williams (1981a) presents data on the bid and offer distributions, with and without price controls, which show clearly that nonbinding controls affect the bargaining-contracting process, although convergence to the *C.E* price ultimately occurs. The explosive price changes that Isaac and Plott (1981a) show can follow the removal of a price control is reminiscent of the similar behavior of field observations. However, the latter phenomenon is sometimes explained as due to "pent-up" demand, that is, an accumulation of unsatisfied demand. This cannot be the explanation in the cited experimental markets because all sales are for immediate current period demand. Hence, the observed price dynamics must be due to expectations as they affect current bargaining strategies in the *DA* institution. Also rejected by the experimental data on nonbinding controls is the hypothesis that the control price will provide a collusive "focal point" for price determination.

PROPOSITION 11: *Asset markets with eight or nine agents converge slowly (eight or more two-period trading cycles) toward the C.E. (rational expectations) price and efficiency determined by the cumulative two-period dividend value of the asset. Convergence is greatly hastened by introducing a first-period "futures" market in second-period holdings, which enables second-period dividend values to be reflected in (or discounted by) period* 1 *asset prices more quickly (Forsythe, Palfrey, and Plott,* 1982).

PROPOSITION 12: *Asset markets with nine or twelve agents in which the asset yields an uncertain state-contingent dividend, known in advance only by a subset of insiders* (3 *or* 6), *converges toward the C.E. (rational expectations) price and efficiency (Plott and Sunder,* 1982).

Propositions 11 and 12 break new experimental ground in studying asset markets under the *DA* intitution, and demonstrating that the competitive properties of this institution extend to asset markets. The results provide qualified support for the rational expectations theory. In Proposition 11, market replication over time is sufficient to allow private information on divergent induced dividend values across periods to be reflected in asset prices. In Proposition 12, full information on dividend state contingencies by a subset of agents is sufficient to allow asset prices to reflect these dividend values.

Perhaps the most important general feature of the experimental results summarized in all the above *DA* propositions is the support they provide for what might be termed the Hayek hypothesis: *Markets economize on information in the sense that strict privacy together with the public messages of the market are sufficient to produce efficient C.E. outcomes.* This statement is offered as an interpretation in hypothesis form of what Hayek meant in emphasizing that "the most significant fact about this (price) system is the economy of knowledge with which it operates, or how little the individual participants need to know in order to be able to take the right action..."(Hayek, 1945, p. 35).

C. *Sealed-Bid Auctions*

There are two types of sealed-bid auctions which apply when there is a single seller offering a specified quantity of a homogeneous commodity in inelastic supply (i.e., without specification of a reservation price).

Discriminative Auction. The process begins with the seller announcing the quantity,

Q, to be offered and requesting that bids be tendered. Each buyer submits a bid (or bids) stating price(s) and corresponding quantity(ies). When the last bid has been received, all bids are arrayed from highest to lowest by price, and the first Q bid units in this ordering are accepted at prices equal to the bid price stated by each successful buyer. A random or proportionality rule is normally used for allocation among tie bids at the lowest accepted price. The process ends with a private communication of the outcome of each individual bid and a public announcement of a truncated summary of the results (as in the auctioning of U.S. Treasury securities); the highest and lowest accepted bid, and the total quantity of bid units that were tendered.

Competitive (or Uniform-Price) Auction. The procedure in this auction is identical to that of the discriminative auction except that the highest Q bid units are all accepted at a *uniform* price equal to the bid price specified by the $Q+1$th (in some versions, the Qth) bid unit.

The discriminative and competitive auctions are multiple-unit generalizations of the first and second price auctions, respectively. A large number of discriminative and competitive auction experiments, conducted under various conditions of induced demand, number of bidders, and quantity offering, have been reported in the literature. These studies form the empirical basis for the following propositions:

PROPOSITION 13: *When all individual values are identical and based on a single draw from a rectangular distribution (made after all bids have been entered) the following results obtain:*[29]

(a) *If $F_C^t(p)$ and $F_D^t(p)$ are the proportions of accepted bids specifying a price of p or higher in auction period t under competitive and discriminative auction rules, respectively, then $F_C^t(p) \geqq F_D^t(p)$ for all t, that is, within the acceptance sets, bids in competitive auctions are at prices at least as high as those in discriminative auctions.*

(b) *Seller revenue in the final ("equilibrium") auction in a sequence is greater in competitive than in discriminative auctions in eight of fourteen paired experiments.*[30]

Proposition 13 is based on thirty-three experiments reported by M. W. Belovicz (1979, p. 314) and myself (1967), with the number of bidders varying from thirteen to thirty-four and each bidder submitting either one, two, or an unspecified number of unit bids.

PROPOSITION 14: *When aggregate induced demand is linear and fixed, but individual private assignments are random (i.e., the assignments are without replacement) and are made prior to the submission of bids, the bids satisfy Proposition* 13(*a*). *However, if the slope of the linear induced demand is sufficiently low (i.e., steep) seller revenue is greater in discriminative than in competitive auctions; if the slope of induced demand is increased seller revenue becomes smaller in discriminative than in competitive auctions (Miller and Plott,* 1980).[31]

The ordering property of the bids in Propositions 13 and 14 is consisent with theories showing that when each bidder is a buyer of at most one unit, bidders have an incentive to bid their "true" (or induced) value in competitive auctions but to bid less than this value in discriminative auctions (Vickrey, 1961, 1962).[32]

[29] This environment was designed to capture the essential features of the market faced by dealers in U.S. Treasury bills who buy in the primary auction for resale in the secondary market. Dealers buy under bid acceptance uncertainty for resale at an uncertain post-auction price.

[30] Reported incorrectly as 5 in 15 in my 1980 paper, Table 2.

[31] The higher revenue from the discriminative rules when demand is sufficiently steep can be explained as follows: The highest value intramarginal bidders face a high opportunity cost of failing to have their bid accepted. Consequently, they bid more, and the discriminative treatment increases seller rent relative to the case in which demand is less steep and valuations less diverse.

[32] However, it should be noted that in some of the experiments of Proposition 13 and in all of the experiments of Proposition 14, bidders could submit more than a single unit bid.

Since new Treasury security offerings at auction are small relative to the outstanding stock of Treasury securities and the large stock of closely competing private securities, it seems credible to conjecture that the demand for Treasury securities is highly elastic. This suggests the likelihood that the revenue from primary auctions of Treasury securities would be greater in a competitive than in a discriminative auction.

Sealed Bid-Offer (Double) Auctions. Bids are tendered by buyers and offers are tendered by sellers. Experimental markets have examined two different bid-offer rules. (A) $P(Q)$: Each buyer (seller) submits a demand (supply) schedule, that is, specifies a bid (offer) price for each unit demanded (supplied). (B) PQ: Each buyer (seller) submits a single bid (offer) price and corresponding quantity. Under either $P(Q)$ or PQ the bids are then arrayed from highest to lowest by price, and the offers from lowest to highest. A selection algorithm, which incorporates a rule for handling tied bids (offers), determines a single market-clearing price and corresponding quantity. Except for excluded tie bids (offers), bids equal to or greater (offers equal to or less) than this price are accepted. The process ends with a private communication of the outcome resulting from each individual's bid (offer), and a public announcement of the market-clearing price and quantity.

The institution which I call $P(Q)$ above is used on the New York Stock Exchange to obtain the opening price each day in each stock based on the accumulation of buy and sell orders after the previous day's close (J. Hazard and M. Christie, 1964, pp. 177–78). Also it has been proposed that the $P(Q)$ procedure be used in the development of a completely computerized national market for trading all securities (Mendelson, Peake, and Williams, 1979). However, $P(Q)$ has a theoretical "defect," namely it provides an incentive for each agent to underreveal demand (supply), and therefore its outcomes are not *P.O.* The institution which I call PQ corrects this defect. This institution, proposed by Pradeep Dubey and Martin Shubik (1980), has been shown by them to have the property that each *C.E.* is also a Nash equilibrium and is therefore incentive compatible. Intuitively the all-or-nothing feature of PQ compared with $P(Q)$, enables PQ to neutralize the incentive to strategically "hold back," and is thereby similar to the second price auction (compare Vickrey, 1976, p. 15).

Three institutions, DA with "good" *C.E.* behavioral properties (Propositions 4 and 5); $P(Q)$ with theoretically "poor" incentive properties; and PQ with theoretically "good" incentive properties, have been compared experimentally under conditions in which the environment is held constant while the institutional treatment is varied (my article with Williams, Bratton, and Vannoni, 1982). The results are summarized in the following:

PROPOSITION 15: *Based on the prior empirical performance of DA and theory pertaining to $P(Q)$ and PQ, we expect the efficiency of allocations in these three institutions to be ranked $E[DA] \cong E[PQ] > E[P(Q)]$ and the deviation of prices from the C.E. to be ranked $p[DA] \cong p[PQ] < p[P(Q)]$. The experimental results suggest the contrary observed ordering $E[DA] > E[P(Q)] > E[PQ]$ and $p[DA] < p[P(Q)] < p[PQ]$.*

In terms of the observed experimental outcomes, DA performs (somewhat) better than $P(Q)$, and $P(Q)$ better than PQ. The poor performance of PQ is accounted for by what appears to be a persistent tendency of subject agents to raise their offers (lower their bids) in an attempt to influence price. By comparison with $P(Q)$, this leads to a higher proportion of missed trades because of the block-trading characteristic of PQ. Even with the use of experienced subjects this property of PQ persists, whereas with experience the DA and $P(Q)$ institutions show improved performance.

Sealed Bid-Offer (Double) Auctions: Unanimity Tatonnement. A variation on the $P(Q)$ and PQ institutions called $P(Q)v$ and PQv is the following: After the market-clearing price and quantity has been determined, a *conditional* allocation in the form of accepted bids and offers is made. Each agent, some portion of whose bid (offer) was accepted, is then asked to vote "yes" or "no" as to whether the allocation should be finalized, that is, only the active traders on a given trial are enfranchised. If all such traders vote yes, the process stops and each individual executes a long-term contract for T times the outcome of that trial. Otherwise the process proceeds to another repeat bid-offer trial with a maximum of T trials.

Unanimity voting in the above sense provides a procedure for operationalizing the concept of tatonnement in which contracts are not binding until a final exchange of messages triggers a market outcome. The London Gold Bullion Exchange appears to be the only ongoing market that uses unanimity voting as a message exchange stopping rule (Jarecki, 1976).

PROPOSITION 16: *Measured in terms of efficiency and deviations from the C.E. price, PQv provides no improvement over PQ. P(Q)v performs better than P(Q) and appears to be the equal of DA (Smith et al.* 1982).

Propositions 15 and 16 (which are based on forty-eight experiments) are important in confirming our expectation that the rules ought to make a difference as to what we observe in a market. These propositions also make clear that not just any institution one might wish to define has *C.E.* properties as good as *DA*. Finally, although there are many experimental studies which provide empirical support for the static Nash equilibrium hypothesis (compare Smith et al., 1982, Section III.A), the hypothesis fails to receive support in the context of the sealed bid-offer auction. Something else, perhaps having to do with lumpiness, is driving the results.

D. *Posted Pricing*

Our experience as economic agents does not normally include any of the institutions discussed so far. The ordinary retail markets of daily life use what has been called the posted offer institution (Plott and myself, 1978) in which sellers display take-it-or-leave-it price offers to buyers. With only a few exceptions (such as "big ticket" items like automobiles and houses) the buyer does not bargain with the seller over price. Less well known, but important, is the existence of markets in which buyers post the bid prices at which they are willing to buy. Thus refiners post bids for crude oil, and canners post bids for produce and other foods.

Posted Offer (Bid) Pricing. The process begins with each seller (buyer) privately selecting a take-it-or-leave-it price offer (bid). These prices are then publicly posted so that they are visible to each buyer and seller. Next a buyer (seller), selected at random, chooses a seller to whom a quantity response or offer is made. The seller (buyer) then responds with an acceptance of all or any part of the buyer's (seller's) quantity offer which forms a binding contract. (However, the seller must accept at least one unit, i.e., the seller may not post an offer price and then refuse to sell any units at that price.) If any part of the quantity offer is not accepted the buyer (seller) may choose a second seller (buyer) and make a quantity response, and so on. When the first buyer (seller) has finished trading, a second, selected at random (without replacement) proceeds to choose a seller (buyer), makes a quantity offer, and so on. This process stops when the last buyer (seller) has completed the exchange cycle. The trading period ends without any further public announcement.[33] Note that under posted offer (bid) pricing, only the sellers (buyers) can "signal" by raising (lowering) their price quotations.

Several experimental studies have investigated the properties of this institution. A few of these properties are summarized below.

PROPOSITION 17: *If $G_o^t(p)$ and $G_b^t(p)$ are the proportions of contract prices at p or higher in trading period t under the posted offer and*

[33] In the PLATO computerized version of "posted offer," seller prices are displayed on each buyer's and seller's terminal screen. Besides a price, each seller also selects the maximum number of units that he/she is willing to deliver, but this information is not public. When a buyer purchases the last unit from a seller, the message "stock out" replaces that seller's price on each buyer's screen. This procedure preserves the privacy of sales and "stockage" for each seller as in the typical, retail market. Also, the computerized version has options requiring buyers to pay a fixed fee, corresponding to shopping cost, to obtain a seller's price quotation. Alternatively, the seller may be charged a fee, corresponding to price advertising.

posted bid institutions, respectively, then $G_o^t(p) \geqq G_b^t(p)$ *for all* $t > 1$ (*W. Cook and E. Veendorp*, 1975; *Plott and myself*, 1978; *my* 1976a *article*; *F. Williams*, 1973).

This proposition establishes the empirical characteristic that posted pricing operates to the advantage of the side with the posting initiative. If sellers post offers convergence is from above the *C.E.* price.

PROPOSITION 18: *Experiments with single seller posted-offer pricing, in both increasing and decreasing cost environments, yield convergence to the monopoly price. This convergence appears to be faster with increasing cost* (*my* 1981a *article*) *than with decreasing cost* (*Don Coursey, Isaac, and myself*, 1981). *The slow convergence* (*at least fifteen periods*) *in three of four replications under decreasing cost appears to be attributable to the fact that buyer withholding of purchases* (*more likely in earlier periods at the higher posted-price offers*) *impacts the seller's most profitable units.*

This proposition supports monopoly theory, but only within the institutional context of posted-offer pricing, which from Proposition 17 operates to the advantage of sellers. If single sellers achieve monopoly outcomes under the seller-favored posted-offer institution, how well would they fare under the unfavorable posted-bid institution? If buyers post bids to a single seller will this provide a form of decentralized institutional restraint of monopoly power?

PROPOSITION 19: *In a market with one seller and five buyers using posted-bid pricing, prices tend to converge to the C.E. price, but volume and efficiency are somewhat below the C.E. levels* (*my* 1981a *article, pp.* 96–99).

Consequently posted-bid pricing does serve to severely limit monopoly power, but the resulting market falls short of achieving *C.E.* outcomes. However, the average efficiency (three replications) exceeds that which would have prevailed at the monopoly equilibrium.

PROPOSITION 20: *In decreasing cost environments in which demand is insufficient to support more than a single seller, but the market is "contested" by two sellers with identical costs, there is a strong tendency* (*six experimental replications, each with fifteen to twenty-five trading periods*) *for posted-offer prices to decay to the C.E. price range* (*Coursey, Isaac, and myself*, 1981).

This proposition provides empirical support for the contested market hypothesis (Elizabeth Bailey and John Panzar, 1980), and for the effect of "bidding to supply a market" in disciplining market power (Harold Demsetz, 1968).

In all of the experimental studies summarized above, it should be noted that institutions are being examined in their *pure* form, without the modifications that might result from attaching supplemental secondary institutions sometimes observed in the field. Thus, if an award fails to be *P.O.* at an organized Dutch auction, there may be an additional "aftermarket" exchange in which the successful Dutch bidder resells the item to the highest value agent. Similarly, "first-cut" inefficiency in posted-offer retail markets may be corrected by the end-of-season "sale" or via the Sears Roebuck special discount catalogue. But studying institutions in their purest form enables one to better understand why some institutions develop secondary correctional procedures and others do not. Also, an institution that makes efficient allocations saves the cost of running secondary markets.

In Section II.B it is stated that one of the scientific objectives of experimental microeconomy is to "measure messages because we want to identify the behavioral modes, $\beta^i(e^i|I)$, revealed by the agents and test hypotheses derived from theories about agent behavior." The reader should note that only Proposition 3 in the above list directly addresses this particular objective. This paucity of experimental results reflects the limited extent to which economic theory has dealt directly with institutional specifications and agent message behavior within these specifications. Bidding and auctioning theory is one of the few exceptions to this generalization. It follows that if future experimental research is to test theories of the message behavior of agents, it is essential that more such theory be developed. In the absence of such theory, experimental research is likely to be directed to comparisons between observed outcomes, and the standard static competitive, monopoly or Nash models of final outcome allocations. This means that all those messages in an experiment, which did not also represent allocations, will be subjected to very limited, if any, analysis, and what analysis is provided will not be guided by explicit theory.

V. Epilogue

At the heart of economics is a scientific mystery: How is it that the pricing system accomplishes the world's work without anyone being in charge? Like language, no one invented it. None of us could have invented it, and its operation depends in no way on anyone's comprehension or understanding of it. Somehow, it is a product of culture; yet in important ways, the pricing system is what makes culture possible. Smash it in the command economy and it rises as a Phoenix with a thousand heads, as the command system becomes shot through with bribery, favors, barter and underground exchange. Indeed, these latter elements may prevent the command system from collapsing. No law and no police force can stop it, for the police may become as large a part of the problem as of the solution. The pricing system—How is order produced from freedom of choice?—is a scientific mystery as deep, fundamental, and inspiring as that of the expanding universe or the forces that bind matter. For to understand it is to understand something about how the human species got from hunting-gathering through the agricultural and industrial revolutions to a state of affluence that allows us to ask questions about the expanding universe, the weak and strong forces that bind particles, and the nature of the pricing system, itself. But what can we as economists say for sure about what we know of the pricing system? It would appear that after 200 years, we know and understand very little. Incredibly, it is only in the last 20 of these 200 years that we have seriously awakened to the hypothesis that property right institutions might be important to the functioning of the pricing system!

Laboratory research in microeconomics over the past two decades has focused on the simplest and most elementary questions—some might say simple-minded questions. This is because the premises of this research are that we possess very little knowledge that can be demonstrated; that the roots of our discipline require a complete reexamination; that we are only just at the beginning. Above all, we need to develop a body of knowledge which clarifies the difference between what we have created (theory as hypothesis) and what we have discovered (hypothesis that, to date, is or is not falsified by observation).

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