HOW TRADING INSTITUTIONS AFFECT FINANCIAL MARKET PERFORMANCE: SOME LABORATORY EVIDENCE

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The effects of trading institutions on market efficiency and trading volume are examined. The trading institutions are computerized versions of continuous double auction and "clearinghouse" markets. Traders are experienced, profit-motivated undergraduates. The traded good is a financial asset whose monetary value is state- and trader type-contingent. Traders possess asymmetric private information on asset value. The results show that clearinghouse markets are as informationally efficient as double auction markets and almost as allocationally efficient; the double auction encourages greater trading volume but the clearinghouse provides greater depth; public orderflow information enhances double auction performance but impairs clearinghouse performance.

I. INTRODUCTION

Trading institutions vary considerably across contemporary financial markets,[1] but most can be classified into one of two basic types. The continuous double auction (DA) allows traders to submit public offers to buy or to sell and to accept other traders' offers at any moment in time. The double auction institution offers immediacy but non-uniform transaction prices. The other basic trading institution, the clearinghouse (CH), gathers offers and clears them at a unified price at a prespecified time. It sacrifices immediacy for uniform transaction prices.[2]

The two types of institutions have coexisted and evolved for centuries but now are emerging in new electronic versions. Market participants and policy makers would like to know which institution or variant or combination is most efficient, but theoretical and empirical work to date provides little guidance.

This paper reports on a series of laboratory asset markets experiments designed to compare variants of the double auction and clearinghouse trading institutions. The markets are small (usually with eight or nine traders) but the traders are profit motivated and experienced with the trading institutions. The traded asset has

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1. See Schwartz [1988, chapter 2] for a fairly recent survey of the trading institutions used in most major financial markets around the world.

2. Unfortunately, the literature is not consistent in its terminology for market institutions. The double auction institution sometimes is referred to as a "bid-ask market" or a "continuous two-sided auction." The clearinghouse institution is often referred to as a "call market" and occasionally as a "[sealed] double auction."

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uncertain market value and traders receive useful but inconclusive private information; they can only learn the asset's true value during the course of trade.

Laboratory markets offer several advantages for empirical study of financial market institutions. First, private information is observable (even controllable) in the laboratory and therefore the investigator can directly measure market efficiency.[3] Second, the complexity of the environment can be varied systematically in the laboratory and its effects on market performance can be separated from the effects of the market institution and other forces. Finally, the market institution itself is controllable in the laboratory, so it is possible to make valid causal inferences on how the market institution shapes market performance.

I begin with a survey of relevant literature and other preliminaries in the rest of this section. Section II outlines the laboratory procedures: the creation of trading environments of varying complexity, the electronic implementation of the clearinghouse and double auction trading institutions, the computation of theoretical benchmark prices and allocations, and the measurement of market performance. Section III collects the results. Following an illustrative account of a double auction trading period and a clearinghouse trading period, I use descriptive statistics to summarize market performance in each of the thirty-nine experiments. The main conclusions are based on statistical comparisons of market performance across alternative market institutions. The clearinghouse institution does surprisingly well. It delivers greater market depth than the double auction, discovers prices at least as efficiently, and produces final allocations almost as efficient as the double auction. The main institutional variants examined in this paper concern the amount of information made public regarding order placement ("orderflow"). The data suggest that public display of the orderflow enhances double auction efficiency but may impair clearinghouse efficiency. A study of trading volume shows higher volume in the double auction. In both institutions volume increases when important private news arrives and when the trading period is about to end. The paper concludes with a brief summary and discussion of the results.

A companion paper, Friedman [1991], considers the effects of awarding various privileges to some but not all traders. Copeland and Friedman [1987; 1991] provide useful background information on laboratory procedures and computerized double auction markets. Instructions for the current experiments are available on request.

The Need for Empirical Work

A skeptic might argue that empirical work is unnecessary: the mere fact that the double auction and clearinghouse institutions both persist in major financial markets implies that both are highly efficient, because a more efficient institution would displace less efficient institutions. Political considerations aside, this Darwinian argument is undercut by the observation that the efficiency of an institution generally is environment-dependent and the financial environments of the 1990s may differ significantly from those of the past. For example, the New York Stock Exchange (NYSE) was organized as a clearinghouse until 1869 when a distinctive ("specialist") version of the double auction emerged. The standard explanation is an environmental change: the increased trading volume and the increased number of differentiated assets made the double auction relatively more efficient (Schwartz [1988,

3. Section II below will offer three specific measures of market efficiency. The underlying concepts are informational efficiency (asset prices reflect fundamental value), allocational efficiency (final asset allocations exhaust gains from trade), and market depth (transactions costs are small).

136]). In the present era of computer networks, however, it is no longer clear that the double auction has a relative advantage in higher volume environments.

The Darwinian skeptic could respond that even if efficiency is environment-dependent, laissez-faire policy will select the best trading institution for whatever the future trading environment will be. For example, the Chicago Mercantile Exchange, the Chicago Board of Trade and Marche a Terme International de France recently launched an electronic double auction called Globex, and R. Stephen Wunsch and his associates at the Arizona Stock Exchange now use an electronic clearinghouse for after-hours stock trading. The Darwinian presumption is that these (or other new entrants) will survive if and only if they are more efficient than other available trading institutions.

Two externalities in financial market trading weaken the Darwinian presumption. First, a trader with (possibly costly) private information reveals some of it costlessly to other traders when he transacts—a public-good type externality whose extent depends in part on the trading institution. A trader might actually prefer trading in an inefficient institution if it reveals less of his information.[4] Second, traders prefer to trade in already popular markets because of their greater liquidity—a network externality which favors the current trading institution.[5] I conclude that empirical work is necessary for informed policy decisions on market institutions. Empirical work may also provide the basis for a deeper theoretical understanding of financial markets.

Previous Empirical Literature

Standard empirical work comparing market institutions "is virtually nonexistent...[primarily because] it would be hard to discern differences [in market performance] arising from the trading mechanism itself from differences due to dissimilarities in securities and environment," according to Amihud and Mendelson [1987, 534]. They try to finesse the problem by comparing NYSE close-to-close price changes to open-to-open changes, noting that the opening price is set in a clearinghouse institution while the rest of trade is double auction. They do find differences between the price change distributions which they interpret as suggesting greater price volatility under the clearinghouse institution. Stoll and Whaley (1990) reach the same conclusion in a more recent and thorough study of the NYSE data. Neither paper considers the alternative interpretation that the clearinghouse institution was *chosen to reduce* returns variance at opening, which might otherwise be even greater.[6] Evidently a controlled experiment is required to resolve the question.

The main laboratory comparisons of market institutions so far are two series of perishables (non-asset) market experiments by Smith et al. [1982] and McCabe et al. [1990]. In the first study, the authors find that a computerized double auction performs better than the alternative institutions in terms of allocational efficiency

4. Indeed, more than a year after this comment was first written, Wunsch reluctantly modified his auction rules to allow traders to temporarily hide large extramarginal orders. Current details can be obtained from AZX, Inc., 20 Exchange Place, New York, NY 10005.

5. A clearcut case of a network externality allowing a less efficient institution to survive lies at my fingertips. My Qwerty keyboard is far less efficient than the Dvorak and other keyboard layouts, yet I use Qwerty because others do.

6. In a recent working paper, Amihud and Mendelson [1991] find increased volatility at the opening call but not at the midday call in the Japanese stock market. This finding is consistent with my alternative interpretation, but again is inconclusive because there is no way to separate environmental effects from market institution effects in existing field data.

and speed of price convergence, with the exception of possibly superior performance by a recontracting version of the clearinghouse institution. The authors note major discrepancies between (Bayesian) Nash equilibrium predictions and observed performance, particularly for their clearinghouse variants. The second study looks at two new continuous time institutions, in some sense hybrids of the double auction and clearinghouse, in the context of buyers-only multiple unit auctions. They find that the ascending "English clock" auction is highly efficient, comparable to the double auction, but that the descending "Dutch clock" auction is rather inefficient.

A separate strand of laboratory research, recently surveyed by Sunder [1992], examines asset market performance. Here traders have imperfect information on asset value. The main issue is informational efficiency, the extent to which transaction prices reflect all available information or approximate the fundamental value. On the whole, these studies report a very high degree of informational efficiency. The main exception is Smith et al. [1988] who report substantial price bubbles when inexperienced subjects trade long-lived assets. These studies employed the double auction institution exclusively; only very recently has the clearinghouse been examined in laboratory asset markets.[7]

7. Two very recent studies deserve mention. Van Boening et al. [1992] replicate the asset market environment of Smith et al. [1988] and find bubbles about as often with the clearinghouse institution as with the double auction. McCabe et al. [1992] examine variants of an institution conceptually similar to the *book*=2 clearinghouse described in section 2.2 below. They find that some variants of their institution, which they call the Uniform Price Double Auction (UPDA), can produce efficiencies comparable to those of the double auction in a fairly demanding perishables (non-asset) environment.

Theoretical Literature

Existing theory provides some insight into the double auction and clearinghouse institutions, although few direct comparisons. The standard theory of competitive markets assumes a version of the clearinghouse institution in which traders' offers are taken to be excess demand functions (or correspondences). The "Walrasian" clearinghouse institution then produces a market clearing price in the usual manner. Most analysis of this institution makes the "truth-telling" or "price-taking" assumption that traders' offers reflect true willingness to pay. (See also Mendelson [1982].) Roberts and Postlewaite [1976] show that truthtelling is not a Nash equilibrium strategy except in the "large numbers" limit in which each trader's feasible trade is negligible relative to aggregate desired trade. The presumption then is that the clearinghouse institution will generally produce less than the socially efficient volume of trade.

Building on previous work by Vickrey [1961] for one-sided auctions and by Chatterjee and Samuelson [1983] for two-sided bargaining, Satterthwaite and Williams [1989] analyze a simple clearinghouse market as a game of incomplete information. They show that in Bayesian Nash equilibrium the difference between traders' offers and true reservation values is bounded by an expression of the form K/n, where n is the number of traders on one side of the market. It follows that allocational efficiency in the simple clearinghouse quickly approaches 100 percent as the number of traders increases. Friedman and Ostroy [1991] argue that clearinghouse markets can more fruitfully be analyzed as games of complete information (see also Smith [1989]). Adapting previous work by Dubey [1982] and others, they derive non-truthtelling Nash Equilibria for simple clearinghouse markets which are 100 percent efficient. The efficient equilibria exist as long as there are at least two buyers and two sellers.

Theoretical analysis of the double auction institution is a formidable task because offers to buy and sell may convey important information in continuous time. Wilson [1987] is the only published attempt to analyze the double auction as a game of incomplete information. He derives necessary conditions for a Bayesian Nash (sequential) equilibrium which imply some inefficiency in a simple double auction market, but at worst only a few of the least valuable trades are missed. Friedman [1984] offers a partial analysis of simple double auction markets as games of complete information, and concludes that in Nash equilibrium satisfying a renegotiation-proofness condition, at worst only a single (and least valuable) trade will remain unrealized.

The theoretical literature mentioned so far deals only with simple markets for goods whose private value is known to both buyer and seller. Asset markets are theoretically interesting largely because traders typically possess only partial and possibly asymmetric information on the good's value. Kyle [1989] considers the information aggregation properties of the clearinghouse mechanism when noise traders are present as well as traders who may possess private information. His game-theoretic model predicts that clearing prices will reveal some but not all of the private information. A previous paper, Kyle [1985], considers the process by which a double auction trader with superior information extracts maximum surplus over time. Lindsey [1990] uses an extension of the Kyle [1985] model to argue that efficiency of the double auction may be impaired when all traders have access to orderflow information.

An extensive set of articles known as the "market microstructure" literature derives theoretical properties of asset markets from trader optimization problems involving a fairly detailed specification of the market institution. See the Schwartz [1988] textbook for a recent introduction and Cohen et al. [1986] for a survey. Ho, Schwartz and Whitcomb (1985) offer an immediately applicable clearinghouse market model in which traders' true excess demand functions are downward-sloping due to risk aversion. Imposing the constraint that each trader's order must consist of a single price/quantity limit order, they employ a formal argument (based ultimately on monopolists' marginal revenue calculations) to conclude that announced supply and demand (aggregated limit orders) is highly inelastic, much more so than true supply and demand (aggregated excess demand). This conclusion implies considerable price instability in simple clearinghouse markets, as the inelasticity transforms small quantity fluctuations into large price fluctuations. (The Friedman and Ostroy [1991] game-theoretic analysis reaches the opposite conclusion—their Nash equilibria are efficient precisely because traders announce highly elastic demands and supplies.)

Direct theoretical comparisons of the double auction and clearinghouse institutions are scarce and inconclusive. Zabel [1981] argues that a dynamically optimizing trader with sole posting privileges in a double auction market may stabilize transaction prices relative to clearinghouse clearing prices, but some authors (e.g., Cohen et al. [1986, 23]) argue the opposite.

To summarize, neither the theoretical nor the empirical literature as yet provides any reliable comparison of the double auction and clearinghouse institutions. My own reading of the literature available when I began the project in 1988—particularly Smith et al. [1982] and Ho et al. [1985] as well as the Walrasian literature and Zabel [1981]—led me to expect that traders would substantially understate their true willingness to trade in the clearinghouse institution, and therefore it would be less efficient than the double auction.

II. LABORATORY PROCEDURES

The Market Environments

Each experiment reported here consists of a series of twelve or more trading periods (sometimes called "market days"), each lasting at most five minutes. The market participants in each experiment, the "traders," are typically eight or nine undergraduates who buy and sell asset units (called "shares") for cash, using various computerized trading institutions described below. At the end of the experiment the traders are paid the profits they earn, ranging from $10 to $30 in a typical experiment. The stakes seem sufficient to strongly motivate the traders to seek strategies that will increase profit. Due to the market complexities, traders generally appear to require experience in one or two experiments before they become comfortable with their strategies. The data reported here exclude experiments using inexperienced traders.[8]

Asset units are valuable because each share pays a trader-specific liquidating dividend (the "payout") at the end of a trading period. Differences in payout values provide traders with gains from trade in a risky or "nonstationary" environment.[9] More specifically, in each experiment there are two or three different trader types with each type consisting of three or more individual traders. Each trader has two possible per-share payouts, denoted *G* or *B* in Table I. In the simpler treatment of risk, called *Hom* (for homogeneous states), a single random event determines whether all trader types receive the *G* payout or the *B* payout. Most experiments reported here employ a more complex treatment of risk, called *Het* (for heterogenous states). Here the payout is determined separately for each trader type by an independent random event. For example, consider schedule C of Table I. There are two trader types and therefore four equally likely overall states, denoted *GG, GB, BG* and *BB*. In state *BG*, for instance, all type 1 traders receive the *B* payout $0.30 and all type 2 traders receive the *G* payout $1.70 per share held at the end of the trading period.

In the simplest treatment of information arrival, traders receive news of their own actual payout just before the beginning of the trading period. Even with this immediate (*Im*) news treatment, traders face uncertainty regarding the market value of the asset because they don't know other traders' realized payouts. In the more complex treatments, each trader begins each trading period uncertain of her own payout, but is privately notified by

8. Details of training procedures are as follows. Traders were recruited from large sophomore- and junior-level economics classes. Those who agreed to participate were given copies of the instructions and invited to attend a training experiment using the basic double auction institution. Each training experiment began with a ten to fifteen minute oral review of the instructions, a question and answer period and a short written quiz. Then three or four practice trading periods (no cash payments) were conducted on the computer system with questions permitted. When all traders were ready, a computerized eight to fourteen period experiment was conducted. A few individuals with unusually low profits and quiz scores were eliminated and the remaining (80–95 percent) participants were entered into the pool of trained traders, which typically numbered around forty individuals. Except for a few last-minute replacements, the traders in reported experiments were all drawn from the pool of trained traders. The data from training experiments have been saved but are not analyzed here because these experiments contain relatively few trading days, are usually dominated by beginner errors, and often contain computer bugs, since beta testing for new versions of the program often was conducted with inexperienced subjects.

9. Differing payouts are intended as counterparts of trading incentives for participants in contemporary asset markets such as differing tax brackets, differing non-marketable assets held in portfolios, and differing risk preferences. Traders begin each trading period with a new endowment, typically three shares and $20.00 cash. They earn trading profit by purchasing shares at prices below their own payout and by selling shares for prices above own payout. Hence, both traders earn trading profits when a trader with lower payout sells to a trader with higher payout at an intermediate transactions price. Traders accumulate profits from one trading period to the next, and take home the total earned for all periods in the experiment (or, in some cases, a preannounced fraction of accumulated trading profit, e.g., 50 cents on the dollar).

TABLE I
Payout Schedules

Schedule	Type 1		Type 2		Type 3	
	G	*B*	*G*	*B*	*G*	*B*
A	$2.00	.30	1.70	.80	1.20	1.00
B	$1.90	.40	1.75	.75	1.00	1.00
C	$2.00	.30	1.70	.80	x	x
D	$1.80	.40	1.40	.80	x	x

Notes:
[1]Typically three or four traders of each type participate in an experiment.
[2]The states *G* and *B* are generally likely. The realized state is determined independently in each trading period.
[3]Initial endowment for each trader is three shares and $20.00 cash.

the computer ("gets news") before the end of the period. The usual news treatment is sequential (*Seq*): traders of different types receive payout news at different times, the sequence being random. An alterative treatment is *Sim*, in which traders of all types receive news simultaneously.

These treatments allow for a considerable range of environmental complexity, ranging from rather transparent (*Im/Hom* news with two trader types) to quite opaque (*Seq/Het* news with three trader types). As explained below, one can compute a priori equilibrium predictions of trading activity and market efficiency for each environment independent of the trading institution. The actual market outcomes can then be compared to the equilibrium forecast across market institutions.

The Market Institutions

All market institutions examined here are computerized, implemented as programs which collect orders and compute and report outcomes. This subsection will briefly describe the main market institutions and a few variants, which currently run under UNIX on a Sun workstation and networked terminals or PC's.

In the continuous double auction trading institution, each trader at any moment can enter a bid (an offer to buy an asset unit for a specified amount of cash) or an ask (a similar offer to sell) from her interactive terminal, can use the terminal to accept the current best (highest) bid or best (lowest) ask offered by her fellow traders, and can cancel her outstanding bid or ask. The computer serves as the only communications link between traders. It also serves as the record-keeping device and enforces the rules. For instance, transaction requests that would result in a negative cash or asset position are not executed, but rather generate descriptive error messages. News messages notifying traders of actual payout are displayed on traders' screens. For instance, in a three-minute *Seq* trading period with two types of traders, news typically appears at one minute for one trader type and at two minutes for the other type.

Available software permits several variants of the double auction.[10] Here I discuss only a variant called *book* which provides enhanced orderflow information. In the default treatment *book*=1, only the best bid and ask are displayed. In the *book*=2 treatment, a trader has a modified screen display which shows all bids and asks, arrayed from best to worst. NASDAQ's distinction between Level 1 and Level 2 screens is similar, as explained in Schwartz [1988, 54–55]. Unlike NASDAQ, anonymity is preserved here in that a trader does not see trader identification for orders other than her own, and here traders can transact at a keystroke.

In the clearinghouse institution, traders enter bids and asks at their terminals as in the double auction, but multiple orders are allowed and are not executed immediately. Rather, at the end of the clearing period (typically lasting sixty seconds) or when all traders indicate they are ready, the bids and asks are aggregated respectively into market supply and demand curves, and the market is cleared in the usual fashion. That is, the price (or the midpoint of the range of prices) is found at which the supply revealed by the asks equals the demand revealed by the bids, and all higher bids and lower asks are filled at this clearing price. Thus the clearinghouse can be described as a "batch" (discrete time) institution which provides a uniform price to all transactors in each clearing.[11]

Typically there is a clearing after each news event and (except in the *Im* news treatment) an initial clearing before the first news event. For example, in a *Seq* experiment with two trader types there are three clearings per trading period. This convention effectively equalizes immediacy across the market institutions, allowing sharper comparisons of efficiency and trading volume.

Available software permits several variants of the clearinghouse, and again I will confine the present discussion to variants in orderflow information. In the first clearinghouse variant, *book*=0, traders submit bid and ask orders "blind" in that they have no direct knowledge of what orders other traders are submitting. In the variant *book*=1, traders' screens display a continuously updated "indicated price," the price at which the market would clear if no further orders were received. Such information is made available in the opening procedure on the Toronto Stock Exchange. The final variant, *book*=2, gives traders a continuously updated summary description of the order book. Near-marginal orders (five orders on either side of the indicated price) are displayed and allow the trader to see the ceteris paribus price impact of any new orders she might contemplate. With the exception of the recent "hidden orders" option mentioned in footnote 4, the Wunsch auction features this complete sort of orderflow information.

Table II lists the payout parameters and treatments for all thirty-nine experiments.

10. Here are a few details for the curious. The basic double auction enforces strict price-time priority: the best bid (or ask), sometimes known as the standing or market bid (or ask), is the highest bid (lowest ask) not yet accepted since the beginning of the trading period, and ties in price are resolved in favor of the earlier bidder (asker). Each transaction price is the best bid (or ask) at the time it was accepted. The trader holding the best bid (or ask) is allowed to cancel it if it has not yet been accepted. The ability to cancel seems crucial for active bidding given the arrival of news during the trading period. The main variants on the basic double auction are called *post*—some traders are not allowed to enter bids and asks; and *delay*—notification of new best bids and asks is delayed a few seconds to some or all traders. These variants are explained in the companion paper.

11. Again there is strict price-time priority. When there are excess bids (or asks) at the clearing price, those bids (or asks) are filled on a first come, first served basis. Of course, better priced bids and asks are filled first, regardless of the time placed within the trading period. The main variants of the clearinghouse discussed in the companion paper are called *pull*—offers may or may not be cancellable, offsettable or improvable; and *extratime*—some traders may be allowed more time than others to enter offers.

TABLE II
Experimental Design

Experiment (Number of Days)	Payout Schedule	Constant Features (institution; environment)	Treatment Variables [* = privileged traders only]
Chm1 (18)	C	CH, *book* = 2; Seq, 2x4 traders	*pull*=0: Days 9-16 *extratime*>0: Days 5-8, 13-16
Chm2 (14)	C-$0.05	CH, *book* = 2; Seq, 2x4 traders	*pull=0:* Days 1-8 *extratime*>0:* Days 5-8,13-14
Chm3 (20)	C	CH, *book* = 2; Sim, 2x4 traders	*pull=O:* Days 9-16 (20) *extratime*>0:* Days 5-8,13-16
Chm4 (24)	C+$0.15	CH, *book* = 2; Seq, 2x4 traders	*pull=2:* Days 3-18 *extratime*>0:* Days 3-18
Chm5 (20)	D (switch types Day 11)	CH, *pull* = 2; Seq, 2x4 traders	*book=1:* Days 1-10; =2: Days 11-20 *book*=2, extratime*>0:* Days 3-10,13-20
Dam2 (20)	D+$0.15 (switch types Day 11)	DA, *delay* = 5 sec; Seq, 200 sec., 2x4 traders	*book*=2, delay*=0, arb*:* Days 3-10, 13-20
Spec 1 (12)	A- $0.05 S	DA; Seq, 240 sec., 3x3 traders	*post=0, post** = 1: Days 5-8
Spec2 (18)	B	DA, *delay* > 0; Seq, 240 sec., 3x3 traders	*delay*=0:* Days 5-18
Spec3 (20)	B+$0.10	DA, *delay* > 0; Seq, 240 sec., 3x3 traders	*delay*=0:* Days 3-20 *arb*:* Days 3,5,7,9,11,13,15,17,19
Spec4 (20)	A	DA; Seq, 240 sec., 3x3 traders	*post=0, post*=1:* Days 3-8 (*=2x2, Days 5-6) *book*=2: Days 5-10, 20; *book*=2:* Days 11-19
Comm 1 (16)	A-$0.05	DA; Seq, 240 sec., 3x3 traders	*comm:* Days 5-8, 13-16 Het: Days 1-8, Hom: Days 9-16
Chs1 (17)	C (switch @ 16)	CH; IM, 1 cl/Day, 2x4 traders	*book**=2, extratime * > 0 : Days 4-15
Chs2 (23)	C+ $0.15 (switch @ 19)	CH; IM, 1 cl/Day, 2x4 traders	*book*= 2: Days 1-4, 13-16 *book*=1: Days 5-8, 17-20
Chs3 (19)	C+$0.10 (switch @ 11)	CH; IM, 3 cl/Day, 2x4 traders	*book*= 2: Days 1-5, 16-19
Das1 (30)	C-$0.05 (switch@16)	DA, *delay > 0;* Im, 120 sec., 2x4 traders	*book**=2: Days 4-15 *arb*, book** =2: Days 19-30
Das2 (32)	C-$0.05 (switch@17)	DA, *book=2;* Im, 120 sec., 2x4 traders	*post=0, post*=1:* Days 3-4, 11-12,12, 19-20,27-28 (*=2x3) Days 5-6, 13-14, 21-22, 29-30 (*=2x2) Days 7-8, 15-16, 23-24, 31-32 (*=2x1)

TABLE II continued
Experimental Design

Experiment (Number of Days)	Payout Schedule	Constant Features (institution; environment)	Treatment Variables [* = privileged traders only]
Book1 (23)	D+($.05,-.05	DA; Seq. 150 sec., 2x3 traders	*book**=2: Days 5-8, 17-20 *book*=2: Days 9-16
Book2 (23)	D	DA; Seq, 2x4 traders	*book**=2: Days 5-8, 17-20 *book*=2: Days 9-16
Dad1 (24)	D+($.10,-.05	DA; Seq. 150 sec., 2x4 traders	*delay*=2: Days 9-12, 21-24 *delay*=5: Days 5-8, 13-16
Cbk1 (23)	D+($.15,$0)	CH; Seq, 150 sec., 2x4 traders	*book**=2: Days 5-8, 17-20 *book*=2: Days 9-16
Cbk3 (22)	C-.05	CH; Seq, 2x4 traders	*book*=2: Days 1-4,13-16 *book*=1: Days 5-8, 17-20 *book*=0: Days 9-12, 21-22
Che1 (14)	C+$.25 (switch@12)	CH, *book*=2; Seq, 180 sec.; 2x4 traders	*extratime*=15: Days 1-4, 13-14 *extratime*=0, *extratime**=15: Days 5-12
Che2 (20)	C+($.10) (switch@13)	CH, *extratime**=15 sec., *book*=2; Seq, 3 cl/day, *book*=2, 2x4 traders	T=45 sec.: Days 1-4, 9-12,17-20 T=60 sec.: Days 5-8, 13-16 (no *extratime**, Days 9-16)
Chi1 (24)	C+$-.05,.10) (switch@11)	CH, *book*=2; Seq, 3 cl/day, 2x4 traders	*pull*=3: Days 4-10, 14-21
Dch1 (23)	C+$0.10 switch@13	*book*=2; Seq, 180 sec., 2x4 traders	DA: Days 1-6, 18-23 CH: Days 7-17
Dch2 (23)	C+$0.10 switch@13	*book*=2; Seq, 180 sec., 2x4 traders	DA: Days 7-17 CH: Days 1-6, 18-23
Dch3 (18)	C+(,-.05) switch@13	*book*=2; Seq, 180 sec, 2x4 traders	DA: Days 1-6 CH: Days 7-18
Dch4 (24)	C+$0.05 switch@13	*book*=2; Seq, 180 sec, 2x4 traders	DA: Days 7-18 CH: Days 1-6, 19-24
Chc (16)	A-$0.05	CH, Seq, 4cl/day, 3x3 traders	*book*=2: Days 1-4, 9-12 *book*=1: Days 5-8 *book*=0: Days 13-16
Cdch (20)	A	*book*=2; 3x3 expert traders Seq, 200 seconds	DA: Days 1-5, 16-20 CH: Days 6-15
Sdch (40)	D+$0.05	*book*=2; Sim, 75sec, 2x4 traders	DA: Days 1-10, 31-40 CH: Days 11-30

TABLE II continued
Experimental Design

Experiment (Number of Days)	Payout Schedule	Constant Features (institution; environment)	Treatment Variables [* = privileged traders only]
Sdch2	D	Im, 2x4 traders, 1cl/Day 75 sec for DA, 50 sec for CH	DA: 11-30; CH: 1-10, 31-40 *book*=*0*: 1-5, 16-22, 26-35
Cdch2 (20)	A+.05	Seq, *book*=*2*; 3x3 traders, 200 sec	DA: 1-5, 16-20 CH: 6-15
Post2 (52)	C+.10	DA;Im, 75 sec, 2x6 traders	*post*=*0*, *post**=*1*: Days 5-28, 33-48 *book*=2: Days 1-24; *book*=*0*: Days 25-52
Post3 (52)	C+.05	DA; Im, 75 sec, 2x6 traders	*post*=*0*, *post**=*1*: Days 5-28; 33-48 *book*=2: 1-24, *book*=*0*: 25-52
Che3	C+.05	CH, *extratime**=*15* sec, *book*=2; Seq	T=45 sec: Days 5-8, 14-16 T=60 sec: Days 1-4, 9-12, 17-20 (no *extratime:* Days 9-16)
Dad2	D	DA, *book*=*0*; Seq, 2x4 traders, 160 sec	*No delay*: Days 1-2, 13-14, 29-31 *delay*=*5*, *delay**=*0*: 3-6, 9-12, 15-18, 21-28 *delay*=*5*: 7-8, 19-20
Chi2	D	CH, *book*=2; Sim 2x4 traders 1 clearing/ day, 75 sec.	*pull*=*0*: 1-4, 29-32, 33-36, 61-64 *pull*=*1*: 5-8, 25-28, 37-40, 57-60 *pull*=2: 9-12, 21-24; 41-44, 53-56 *pull*=*3*: 13-16, 17-20, 45-48, 49-52
Cbk2r (23)	D	CH: Seq, 2x4 traders, 150 sec.	*book*=2: 5-8, 17-20 *book*=2: 9-16

Notes:

1. The main market institutions are DA (continuous double auction) and CH (discrete clearing house or call). The main variants involve the orderflow information *(book)* available to traders. Asterisks refer to privileges available to some but not all traders.

2. The DA markets use *book*=*1* (only the best bid and ask are publicly displayed) except where *book*=*2* (all bids and asks publicly displayed) is indicated. Other DA variants not examined in the present paper include *post* (the suspension of bidding and asking rights for some traders), *delay* of orderflow information, *arb* (an arbitrage privilege available in conjunction with *delay*) and *comm* (limited trading commissions).

3. The CH markets use *book*=*0* (no orderflow information) except where *book*=*1* (continuously updated public display of tentative clearing price) or *book*=2 (continuously updated public display of near-marginal orders) is indicated. Other CH variants not examined in the current paper include *pull* (the default is *pull*=*1*, orders can be cancelled but not offset; *pull*=0,2,3 respectively forbid order cancellation, allow offset and allow improvement), and *extratime* for privileged traders.

4. The payout schedules A, B, C and D are presented in Table 1. The notation switched indicates that the assignment of traders to types is switched at Day d. The notation $C + (-x, y)$, for instance, means that the schedule C payouts are shifted down x dollars for type 1 traders and up y dollars for type 2 traders. $C + x$ means that payouts are shifted up x dollars for traders of all types. The notation nxm (e.g., 2x4) indicates that there are n trader types and m individual traders of each type.

5. The news content is Het (heterogeneous) except where indicated as Hom (homogeneous). The news arrival is indicated as either Seq (sequential across trader types), Sim (simultaneous to all *types* sometime during the trading period), or Im (immediate to all types at the beginning of the trading period.)

For the sake of completeness, the table lists all treatments used, including some (denoted by asterisks) that pertain to privileged traders. Privileges are central to the companion paper but are peripheral here, so the analysis below excludes trading periods with privileged traders. Most readers will find it sufficient to skim the table, noting that the relevant trading institutions (the double auction and clearinghouse and their orderflow "*book*" variants) have been tested in a wide variety of environments.

Equilibrium Forecasts

Traders know the trading institution from instruction and experience, but their direct knowledge of the laboratory environment is (purposely) quite limited. Each trader knows his own payout and endowment parameters and knows (ex post) his news arrival time but does not know the parameters or the news (or even the news arrival times) of other traders. To analyze the situation faced by traders as a game of incomplete information is a daunting task, particularly in the case of double auction markets (and clearinghouse markets with *book* > 0) since continuous-time strategies then must be chosen. Fortunately, much simpler complete-information approaches seem successful at organizing the data in market experiments with several trading days (see Smith [1989], and Friedman and Ostroy [1991]). Presumably traders learn to behave as if they acquire the relevant information from market outcomes.[12]

The simplest complete information theory (referred to in the experimental literature as RE, TRE or FRE, for true or fully-revealing rational expectations) assumes risk neutrality and treats all private information as if it were public. One computes true rational expectations equilibrium prices as follows. First, for each payout relevant state z (e.g., $z = GB$), set the final equilibrium price $p(FE, z)$ equal to the highest payout in that state; e.g., in schedule C of Table I, $p(FE, GB) = \max\{\$2.00, \$0.80\} = \$2.00$.[13] Next, for each time of interest, look at all news messages received so far in the trading period and update the state probabilities $\pi(z)$. For example in schedule C the probabilities are initially .25, but after B news to type 2 traders the probabilities become $\pi(GB) = \pi(BB) = .50$ and $\pi(BG) = \pi(GG) = 0$. Finally, set the FRE equilibrium price p^* equal to the expected FE price, using the updated state probabilities. In the $2B$ example, we get $p^* = (.5)\, p(FE, GB) + (.5)\, p(FE, BB) = (.5)(\$2.00) + (.5)(\$0.80) = \$1.40$ as the equilibrium price when the news $2B$ arrives. Thus one obtains a price forecast for every subperiod (i.e., every time interval between news events or beginning or end of the trading period) of a double auction market and for every clearing in a clearinghouse market.

It should be expected that the true rational expectations equilibrium price will tend to exceed actual transaction prices because (a) willingness to pay may lie below expected value because of risk-aversion and, perhaps more importantly, (b) the division of gains from trade is highly asymmetric in rational expectations equilibrium with all the gain going to sellers and none to buyers. Another disadvantage of the rational expectations

12. There is a deep theoretical issue there: what information do players really need to implement a "complete information" Nash equilibrium (or Rational Expectations Equilibrium)? An emerging body of theoretical literature on evolutionary or learning dynamics suggests that the information requirements can be surprisingly modest. The point is important but tangential to present concerns, so the reader is referred to Friedman and Ostroy [1991] for further discussion and literature citations.

13. The logic here basically is that in a typical experiment the four traders with the highest payout will bid the price up to their payout level because their demand is very large at that price (given the \$20 per capita cash endowment) while asset supply is fixed at three shares per capita. It follows that the traders with highest payout will hold shares at the end of the trading period.

equilibrium concept is that it makes no distinctive prediction regarding asset allocation. Most equilibrium concepts (including this one) predict that at the end of a trading period all shares will be held by traders who value them most highly (i.e., the type with the highest realized payout; see the previous footnote). This requirement is nothing more nor less than Pareto optimality or allocational efficiency. Some other equilibrium theories also predict allocations at the end of subperiods or clearings other than the final one, but true rational expectations does not.

The virtues of true rational expectations as an equilibrium concept more than compensate for these drawbacks. First of all, true rational expectations is very simple conceptually and computationally. It applies equally well to all market institutions and variants. Moreover, it represents the benchmark of a fully efficient market, in the Fama [1970] sense of strong-form informational efficiency as well as the more recent sense of fully-revealing rational expectations equilibrium. That is, the rational expectations equilibrium price is the asset's fundamental value. Last but not least, it has usually been the best asset price predictor among several alternative candidates considered in previous asset market experiments, including some experiments of comparable environmental complexity (e.g., Copeland and Friedman [1987; 1991]).[14]

Market Performance Measures

I employ three measures of market efficiency. Informational efficiency is measured in each subperiod (or clearing) in which transactions occur as the root mean squared deviation (RMSE) of transaction prices from the fully efficient true rational expectations price forecast. For example, if there were two transactions at prices \$1.00 and \$1.10 in a subperiod of a double auction market with rational expectations price (fundamental value) \$1.20, then RMSE = $(1/2\ (20^2 + 10^2))^{1/2} \approx 15.8$.[15] In a clearinghouse clearing, the root mean squared deviation reduces to the absolute difference between the clearing price and the rational expectations price.

Allocational efficiency is defined in terms of deviations of actual final allocation from the fully efficient rational expectations allocation, with misallocations representing larger foregone gains from trade weighted more heavily. I use the summary statistic *AIE*, defined as the unrealized trading profit as a percentage of potential total trading profit in a given trading period. For example, in one trading period (discussed in section III below) the maximal total trading profit is \$18.90 when all shares are held by type 2 traders whose per share payout is \$1.65. The actual final allocation is optimal except that two shares were held by type 1 traders, whose payout is \$0.25. The foregone gains therefore are 2 x (\$1.65 – 0.25) = \$2.80, so in this trading period *AIE* = 100% x 2.80 / 18.90 = 14.8%.

The last efficiency concept is market depth, measured in a clearinghouse clearing as the difference between the best rejected (extramarginal) bid and ask prices. In double auction markets, the difference between the best (lowest) ask and

14. As explained in the cited papers, more complex equilibrium concepts based on partial revelation of private information can outperform true rational expectations in predicting the price and allocation of purchased information and in predicting asset allocation. So far, however, the alternatives have not improved on the true rational expectations asset price predictions.

15. The "actual price" could be measured in other ways. One could use only the closing price (the last transaction price in the superiod) or use the average midprice (the midpoint of the bid-ask interval averaged over the subperiod), for example. Copeland and Friedman [1987] and other authors who examined these variants found no noteworthy differences among them, so here the analysis of double auction prices will use all transaction prices, or occasionally (for comparison to the clearinghouse clearing price) the mean transaction price.

the best (highest) bid is recalculated every time either changes, and *spread* is the time-weighted average over the time when both bids and asks are present during a subperiod.[16] In some clearinghouse market clearings, there are no extramarginal bids or no extramarginal asks; in such cases *spread* is not defined. As a result, the *spread* data are a bit ragged, but still seem worth looking at. It appears to make little difference to the results whether spread is expressed in dollar terms, as below, or in percentage terms. Note that *higher* values of *RMSE*, *AIE* and spread mean *lower* efficiency.

The final performance measure is trading volume, measured in each subperiod (or clearing) as the number of shares sold (or bought). Although volume has no direct efficiency implications (other than that a minimum volume is required to move from the initial allocation to an efficient final allocation), it has some interest in its own right.

III. RESULTS

Qualitative Preview

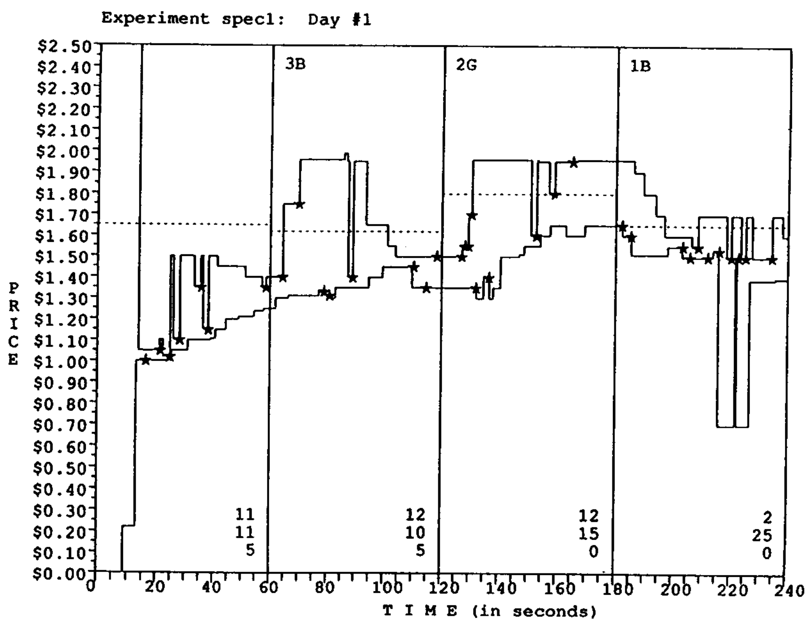
To provide the trader with a background against which the statistical analysis can be viewed, I begin with a description of events in a specific trading period for each institution. The periods are intended only to be illustrative, but they are not unrepresentative of initial behavior. A complete set of graphs is available on request.

Figure 1 shows the first trading period of the first double auction experiment, called *Spec*1. The three news events (notification of realized payout to each of the three trader types) divide the four-minute trading period into four one-minute subperiods, as indicated by the vertical lines in Figure 1. The market bid (the lower step-wise line) opened at twenty cents about fifteen seconds into the trading period and rose to $1.00 a few seconds later. Shortly thereafter the best ask opened at about $1.10 and, after three quick transactions (indicated by stars), bounced up repeatedly to $1.50 as four more transactions (all accepted asks) occurred in the first subperiod. At the end of the subperiod eleven shares were held by type 1 traders, eleven by type 2s and five by type 3s. The transaction prices are considerably below the unconditional (no news) true rational expectations price forecast of $1.65, resulting in a root mean squared deviation (*RMSE*) of 52.3 cents in this initial subperiod. Type 3 traders received B (low payout) news to begin the second subperiod, lowering the rational expectations price forecast to $1.625 for this subperiod. The news appeared to have little effect on the market since the eight transaction prices were generally a bit higher and share allocation changed little. In the third subperiod transactions prices again generally rose slightly, and type 2 traders (who received G news) were net purchasers of five shares from type 3s on a volume of nine shares. The final allocation deviated from the equilibrium forecast (recall that in final equilibrium, all shares are held by the high payout type, here type 2 traders) by the two shares still held by the type 1 traders.

Figure 2 shows the first period of the first clearinghouse experiment, *Chm*1, which features two trader types and four traders of each type. In the first clearing we see that type 1 traders sold three shares to type 2 traders at the price of $1.45. The second clearing occurred after type 2 trad-

16. Some practitioners (e.g., Steve Wunsch) and some academics (e.g., Robert Schwartz) have asserted that the clearinghouse institution has no bid/ask spread because all transactions execute at a uniform price. However, spread as defined here always represents the difference in transaction price for a new buy order as opposed to a new sell order. This provides an implicit measure of transactions costs that is valid across institutions. Although it may stretch common usage slightly, I will informally refer to the spread as a measure of market depth.

FIGURE 1
A DA Price-Time Graph



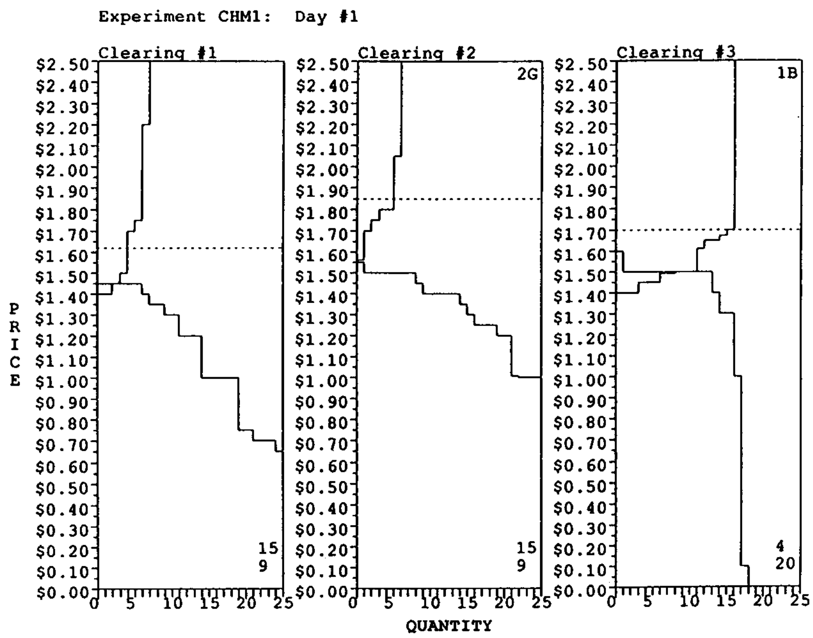
The upper step function is the best ask price, the lower step function is the best bid price, and stars indicate transaction prices. The horizontal dashed lines indicate the FRE price, the fundamental value of the asset. Vertical lines indicate news events, the trader type and content (eg, 3B for trader type 3 receiving notification of the lower payout) noted at the top of the line and the asset allocation (eg, 11, 11 and 5 shares held respectively by traders of types 1, 2 and 3 at the time of the news event) noted at the bottom of the line.

ers knew they would receive the higher payout (indicated by the "2G" in the upper right corner of the panel); no trades occurred but the best rejected bid and ask were within one or two cents of each other, near $1.55. The third clearing was preceded by *B* (low payout) news to type 1 traders, who sold eleven of the fifteen shares they held at a price of $1.50. The final clearing price then turned out to be twenty cents below the equilibrium value (indicated by a dotted line), and four shares were misallocated.

Statistical Procedures and Summaries

Table III provides an overall summary of market performance in each experiment, reporting the mean performance measures (and, in parentheses, the standard deviation and number of observations.) There is considerable variation across experiments in all four measures. For example, *Chs*2, a clearinghouse experiment with a very simple environment, has *RMSE* averaging less than two cents or about 1 percent, while *Das*2, a double

FIGURE 2
A CH Supply-Demand Graph



The increasing step function is the supply revealed by all submitted asks in the given clearing, and the decreasing step function is the demand revealed by the submitted bids. The intersection of supply and demand determines the clearing price and transaction quantity (use the midpoint if the intersection is a vertical line segment, and use the right endpoint if the intersection is a horizontal line segment.) The horizontal dashed lines indicate the FRE price, the fundamental value of the asset. The news event is indicated in the upper right corner, eg, 2G for trader type 2 receiving notification of the higher payout. The asset allocation after market clearing is indicated in the bottom right corner, eg, 15 and 9 shares held respectively by type 1 and type 2 traders after the second clearing.

auction experiment in which many traders were denied (bid and ask) posting privileges, has *RMSE* averaging almost eighty cents. Allocational inefficiencies, measured as unrealized gains from trade (*AIE*), usually were below 10 percent and were occasionally below 1 percent, but two experiments featuring the extratime variant of the clearinghouse institution had *AIE* slightly above 10 percent. Likewise, market depth, measured as the average spread, varied from only about five cents in *Chs*2 to over sixty-six cents in *Das*2. Variations in volume were less extreme but still substantial. The large standard deviation of most performance measures indicates considerable variation within as well as across experiments. In a given experiment the number of observations (Nobs) can vary across performance measures because *RMSE* is observed in a double auction subperiod only when transactions occur, while spread is almost always observed, and *AIE* is observed only in the final subperiod.

TABLE III
Performance Summary Mean (Standard Deviation; NOBs)

Sample	*RMSE* in cents		*AIE* in percent		*Spread* in cents		*Volume* in shares	
1. Chm1	11.6	(16.4; 53)	6.9	(10.4; 18)	12.2	(17.5; 53)	4.9	(3.6; 54)
2. Chm2	15.4	(16.7; 41)	10.6	(20.7; 14)	28.2	(31.3; 42)	3.3	(3.1; 42)
3. Chm3	20.5	(20.8; 60)	5.7	(6.6; 20)	20.1	(26.8; 59)	5.2	(3.4; 60)
4. Chm4	17.1	(16.8; 72)	2.6	(5.4; 24)	23.1	(30.5; 72)	5.1	(3.7; 72)
5. Chm5	10.3	(11.6; 60)	2.7	(4.4; 20)	11.8	(16.4; 60)	4.4	(3.9; 60)
6. Dam2	29.8	(25.8; 44)	3.5	(6.7; 20)	41.1	(22.4; 60)	5.8	(6.4; 60)
7. Spec1	34.9	(18.8; 45)	6.6	(9.9; 12)	47.0	(23.3; 48)	7.8	(4.8; 48)
8. Spec2	20.7	(14.8; 56)	2.2	(4.1; 18)	30.3	(17.3; 72)	5.5	(5.1; 72)
9. Spec3	33.9	(25.6; 72)	1.4	(2.3; 20)	39.6	(20.5; 80)	6.7	(5.8; 80)
10. Spec4	31.1	(22.9; 73)	3.7	(9.3; 20)	46.3	(30.4; 80)	5.7	(5.2; 80)
11. Comm1	26.0	(16.0; 62)	3.5	(5.5; 16)	30.1	(20.3; 64)	7.6	(5.6; (34)
12. Das1	13.7	(14.4; 30)	1.7	(5.7; 30)	32.4	(14.6; 30)	14.5	(2.8; 30)
13. Das2	78.7	(68.6; 30)	1.8	(4.0; 32)	66.3	(37.3; 32)	12.6	(2.4; 32)
14. Chs1	4.4	(3.5; 17)	1.3	(2.4; 17)	5.8	(4.5; 17)	11.1	(1.7; 17)
15. Chs2	1.7	(1.5; 23)	1.1	(2.8; 23)	5.2	(6.7; 23)	11.8	(1.1; 23)
16. Chs3	4.2	(13.2; 57)	0.2	(0.7; 19)	6.0	(11.8; 57)	4.2	(3.2; 57)
17. Book1	24.2	(17.3; 56)	4.7	(11.3; 23)	57.6	(30.3; 69)	4.4	(4.2; 69)
18. Book2	27.1	(16.4; 69)	4.9	(10.2; 23)	43.3	(20.0; 69)	9.2	(7.0; 69)
19. Dad1	36.8	(18.8; 72)	6.2	(7.7; 24)	42.3	(17.7; 71)	7.5	(3.3; 72)
20. DA: Dch1	21.7	(15.0; 36)	2.3	(4.5; 12)	34.8	(18.3; 36)	6.4	(4.2; 36)
Dch2	25.7	(22.6; 26)	8.3	(12.9; 11)	63.4	(36.2; 33)	5.2	(5.4; 33)
21. DA: Dch3	22.1	(8.4; 16)	2.5	(4.3; 6)	32.9	(15.3; 18)	8.1	(5.4; 18)
Dch4	24.2	(16.7; 28)	0.6	(1.5; 12)	42.0	(20.5; 36)	5.4	(5.5; 36)
22. DA: Sdch	17.7	(12.5; 20)	1.3	(2.1; 20)	26.1	(7.5; 20)	15.8	(12.5; 20)
Sdch2	23.8	(12.1; 20)	2.4	(2.4; 20)	35.6	(8.3; 20)	15.6	(2.6; 20)
23. DA: Cdch	15.7	(11.9; 34)	1.2	(1.9; 34)	26.4	(14.3; 40)	5.8	(11.9; 40)
Cdch2	28.1	(16.0; 33)	1.7	(3.5; 10)	38.6	(18.4; 40)	5.4	(6.1; 40)

TABLE III continued
Performance Summary Mean (Standard Deviation; NOBs)

Sample	*RMSE* in cents		*AIE* in percent		*Spread* in cents		*Volume* in shares	
24. Cbk1	14.3	(10.9; 69)	6.3	(7.3; 23)	10.3	(12.5; 69)	4.8	(3.0; 69)
25. Cbk3	16.3	(14.1; 66)	9.1	(10.3; 22)	9.6	(6.7; 66)	3.7	(2.5; 66)
26. Che1	21.5	(19.0; 42)	11.4	(7.9; 14)	14.1	(20.0; 42)	6.5	(2.9; 42)
27. Che2	18.0	(15.4; 60)	2.5	(4.5; 20)	15.0	(15.8; 55)	5.1	(4.2; 60)
28. Che3	24.0	(33.2; 60)	3.5	(7.0; 20)	19.1	(15.9; 60)	4.0	(3.6; 60)
29. Chi1	11.3	(12.5; 72)	3.8	(6.5; 24)	15.2	(16.8; 72)	4.4	(3.4; 72)
30. Chc	25.1	(18.5; 64)	3.1	(4.9; 16)	14.8	(13.1; 64)	5.1	(4.1; 64)
31. CH: Dch1	20.4	(16.9; 33)	2.6	(3.4; 11)	18.6	(12.1; 33)	6.4	(4.3; 33)
Dch2	27.2	(25.9; 36)	4.2	(3.9; 12)	31.5	(30.7; 36)	4.1	(4.0; 36)
32. CH: Dch3	20.9	(17.3; 36)	9.3	(13.2; 12)	15.5	(23.9; 36)	4.8	(3.9; 36)
Dch4	12.4	(12.4; 36)	2.5	(4.2; 12)	26.2	(25.6; 36)	4.8	(4.8; 36)
33. CH: Sdch	22.5	(25.0; 20)	2.7	(3.1; 20)	12.9	(10.4; 20)	14.1	(3.1; 20)
Sdch2	26.0	(17.2; 20)	4.2	(7.3; 20)	22.7	(19.6; 20)	13.1	(4.9; 20)
34. CH: Cdch	20.0	(19.8; 40)	2.8	(2.5; 10)	19.7	(27.7; 40)	5.2	(3.7; 40)
Cdch2	22.9	(14.6; 40)	7.4	(10.1; 10)	28.7	(21.7; 39)	4.5	(2.9; 40)
35. Post2	40.5	(24.8; 52)	5.6	(6.4; 52)	76.6	(39.9; 52	22.4	(7.3; 52)
36. Post3	27.2	(19.0; 52)	4.2	(5.6; 52)	49.1	(28.5; 52)	23.1	(5.7; 52)
37. Dad2	18.3	(14.9; 53)	0.7	(1.4; 24)	34.1	(16.4; 72)	4.4	(4.4; 72)
38. Chi2	22.7	(26.9; 43)	6.1	(7.6; 43)	20.7	(32.4; 37)	9.9	(3.7; 43)
39. Cbk2r	14.2	(21.0;69)	3.8	(7.7; 23)	14.1	(14.8, 69)	5.1	(3.6; 69)

The data in Table III are suggestive but inconclusive. The measured differences in market performance may reflect differences in the market institution, but also may reflect environmental differences and uncontrolled "nuisances" such as individual trader or group idiosyncrasies. Clearly the environment is important and performance is generally better in simpler environments. Group effects can also be important. For example, the most expert traders available (those with highest profit in previous experiments) were recruited for experiment *Cdch*, which also featured the most complex 3x3 *Seq/Het* environment. The result was better than average efficiency.

Direct comparisons of market institutions use the following general procedure. Collect two related groups of observations (call them the *X* sample and the *Y* sample) to be compared. Make sure the samples differ in terms of the market institution but are very similar in terms of the trading environment and other "nuisances." Then for each relevant performance measure compute the conventional *t*-statistic for the null hypothesis that the population means are the same. Since the data may not be normally distributed, also compute the nonparametric Wilcoxon statistic for the null hypothesis that the two samples have the same distribution. Roughly speaking, we have a possibly significant, significant or very significant difference in performance between the *X* and *Y* samples when the absolute values of both statistics exceed 1.0, 2.0 or 3.0 respectively.[17]

Comparisons of Market Institutions

Table IV reports seven comparisons of the market institutions. The first comparison is between X = all basic double auction subperiods and *Y* = all basic clearinghouse subperiods (clearings), where "basic" refers to the absence of special features (such as *delay*) or privileged traders. The 391 basic double auction subperiods had an average *RMSE* of 25.4, almost seven cents higher than in the 683 basic clearinghouse subperiods. This informational efficiency advantage for the clearinghouse institution is statistically very significant, with both the *t* and Wilcoxon statistics well over 5.0. The spread data also point to an efficiency advantage for the clearinghouse which is very significant economically as well as statistically. On the other hand, on average the double auction institution has greater allocational efficiency with only about 3.6 percent of potential gains from trade left unrealized per trading period, versus 4.7 percent in the clearinghouse, but the difference is not statistically significant. Volume in the double auction is about 1.6 shares per subperiod greater than in the clearinghouse, a very significant difference. Similar results arise from comparison 2, from which the noisier data from the first eight trading periods in each experiment have been excluded (*Ldays* only).

The third comparison in Table IV looks at the effect of enhanced orderflow information in the double auction institution. Public display of the orderbook (*book*=2) apparently increases informational efficiency and perhaps also allocational efficiency, but may reduce the spread between best bid and best ask and apparently reduces trading volume.

The effects of enhanced orderflow information may be quite different in the clearinghouse. Item 4a compares all fifty-four basic clearings with the indicated-price-only (*book*=1) clearinghouse variant to the sixty-four most environmentally similar clearings with the default treatment, full access to the orderbook (*book*=2). Despite the relatively small sample sizes, we have possibly significantly lower allocational and informational efficiency with *book*=2. Similar results arise in item 4b, comparing the "blind bidding" (*book*=0) variant to the default treatment;

17. More precise statements seem unwarranted here because observations are not really independent. Traders' expectations from previous periods and subperiods create some interperiod dependence. This means that data cannot be regarded as independent samples drawn from the population of all markets of the relevant type. Unfortunately, no widely accepted method is presently available to deal with the problem. (One method is to take only a single observation from each experimental session. This method drastically reduces the information content of the data but still doesn't completely cure the problem since experimenter and subject pool effects may still be present.) Consequently, the test statistics are best regarded as descriptive rather than as classical hypothesis tests. Sheltered by this caveat, I will continue to use the conventional and convenient terminology of hypothesis testing.

TABLE IV
Performance Comparisons

Samples: [X vs. Y]	*Statistic*	*Performance Measures:* RMSE	AIE	Spread	Volume
1. Basic DA vs. Basic CH	Nobs	391, 683	159, 316	433, 681	433,772
	Means	25.4, 18.5	3.6, 4.7	41.6, 17.2	7.4, 5.6
	t	5.70	–1.51	17.71	5.73
	Wilcoxon	8.49	–1.11	18.24	3.96
2. Ldays DA vs. Ldays CH	Nobs	245, 341	107, 214	277, 440	277, 498
	Means	24.5, 18.6	2.8, 4.1	43.1, 17.6	7.2, 5.9
	t	3.86	–1.74	14.44	3.45
	Wilcoxon	6.23	–0.44	14.62	1.79
3. Book=1 vs. Book=2: DA	Nobs	157, 167	62, 77	162, 191	162, 191
	Means	28.6, 23.9	4.9, 3.1	41.8, 45.1	8.6, 7.1
	t	2.45	1.23	–1.23	2.40
	Wilcoxon	2.56	1.09	–0.83	2.68
4a. Book=1 vs. Book=2: CH	Nobs	54, 64	29, 24	54, 64	75, 64
	Means	16.9, 20.5	3.7, 6.0	11.5, 12.5	5.5, 5.3
	t	–1.04	–0.99	–0.48	0.26
	Wilcoxon	–1.04	–1.19	–0.27	0.56
4b. Book = 0 vs. Book=2: CH	Nobs	38, 44	26, 28	38, 44	38, 44
	Means	14.8, 24.3	5.6, 4.7	10.7, 16.3	8.3 8.6
	t	–2.30	0.42	–1.97	–0.22
	Wilcoxon	–1.71	0.78	–1.63	–0.21
5a. DA vs. CH: Simple Environment	Nobs	54, 125	54, 87	54, 125	54, 125
	Means	29.5, 10.2	2.3, 2.0	35.9, 9.7	15.2, 8.8
	t	4.84	0.37	10.07	8.25
	Wilcoxon	6.94	2.18	8.80	7.33
5b. DA vs. CH: Matched Simple Environment	Nobs	40, 40	40, 40	40, 40	40, 40
	Means	20.7, 24.2	1.8, 3.5	30.8, 17.8	15.7, 13.6
	t	–0.89	–1.66	4.35	2.93
	Wilcoxon	0. 12	–0.09	4.57	2.20
6. DA vs. CH: Matched Intermediate Environment	Nobs	106, 141	41, 47	123, 141	123, 141
	Means	23.4, 20.2	3.5, 4.7	44.3, 23.0	6.0, 5.0
	t	1.36	–0.75	6.61	1.77
	Wilcoxon	2.61	–1.87	7.43	1.32
7. DA vs. CH: Matched Complex Environment	Nobs	67, 80	20, 20	80, 79	80, 80
	Means	21.8, 21.5	1.5, 5.1	32.5, 24.1	5.6 4.8
	t	0. 12	–1.98	2.41	1.06
	Wilcoxon	0.27	–2.31	3.83	0.62

Note: The number of observations (Nobs) and the means listed are for the first (X) and second (Y) samples respectively. The student *t* and Wilcoxon statistics refer to the null hypothesis that the *X* and *Y* samples have the same distribution.

in this case the more significant inefficiencies in the default clearinghouse appear to be in market depth (spread) as well as information efficiency (*RMSE*). Full access to the orderbook may encourage traders to withhold marginal orders, perhaps in an attempt to manipulate the clearing price.

The rest of Table IV disaggregates the basic data by environmental complexity in comparing the basic double auction and clearinghouse institutions. Early results suggested an advantage for the clearinghouse in simple environments, as in comparison 5a which considers all data from Im news experiments with two trader types. However, Table III data suggest that group effects can be very important in their own right and may interact with environmental effects. To eliminate such effects I ran three series of "matched-trial" or "within-groups" experiments in which the trading institution was switched between the double auction and clearinghouse in a balanced fashion.[18] Comparison 5b is restricted to the two matched-trial experiments using the simple environment. Only the differences in market depth and trading volume hold up; the informational efficiency and allocational efficiency measures actually show an (insignificant) advantage to the double auction institution in this environment.

Comparison 6 is restricted to the moderately complex *Seq/Het* 2-trader-type environment of experiments *Dch1-4*. The matched trial data confirm that in this environment the double auction produces wider spreads and higher trading volume, and suggest that it is slightly less informationally efficient but perhaps more allocationally efficient. Finally, comparison 7 looks at data from the two matched trial experiments with three trader types and *Seq* news (and, for *Cdch*, expert subjects). The results are a relatively small difference in spread, a virtual tie in informational efficiency and an economically and (perhaps) statistically significant advantage for the double auction in allocational efficiency.

It can be argued that the informational efficiency measure *RMSE* is biased against the double auction institution: in a clearinghouse subperiod (clearing) the actual price is constrained to be uniform while actual prices are dispersed in double auction subperiods. An alternative definition of *RMSE* is the absolute deviation in a subperiod or clearing of the *mean transaction price* from the fundamental value. This definition coincides with the original definition for clearinghouse data and eliminates the effects of price dispersion in the double auction data. In comparison 6 the redefinition reduces the mean *RMSE* in double auction subperiods from 23.4 cents to 18.3 cents, and the Wilcoxon and t-statistics become insignificant.

As a final refinement of the institutional comparisons, consider *differences* in allocational efficiency across matched pairs of double auction and clearinghouse trading periods. Pooling across all three environments we have 40 + 41 + 20 = 101 matched pairs. Allocational efficiency was greater in the double auction in r = forty-seven pairs, greater in the clearinghouse in w = twenty-six pairs, and equal (usually because both efficiencies were 100%) in the remaining twenty-eight pairs. The signs test

$$z = (r - w) / \sqrt{r + w}$$

is 2.46 and the simple t-statistic for the paired differences is 2.25, indicating a small but statistically significant advantage for the double auction in allocational efficiency.

18. Data from experiments with this matched trial design may actually *understate* the institutional differences in performance, because group learning in one institution may affect market performance in the other institution after the switch. Consequently, data from experiments with unmatched designs remain useful.

Trading Volume

Visual inspection of the clearinghouse volume data suggests two possible regularities: (a) trade tends to be concentrated in the last clearing, and (b) the arrival of important news seems to provoke more trades. The following multiple regression tests these conjectures:

$$(1)\qquad V_{tc} = a_0 + a_1 DC2_{tc} + a_2 DC3_{tc} + a_3 DN1_{tc} + e_{tc}$$

where V denotes the trading volume in shares, t and c index the day and clearing, DXn denotes a (0, 1) dummy variable, and e denotes the error term. The timing dummies identify the clearing within each day t: for n = 1,2,3 the dummy DCn_{tc} is 1 if the clearing number $c=n$ and is 0 if $c \neq n$. Since the experiments examined here always have three clearings per period, one of these dummies is redundant, so *DC1* is dropped in equation (1). The news dummy *DN1* indicates whether (*DN1* = 1) or not (*DN1* = 0) type 1 traders receive news in the given clearing. (Type 1 traders' news is the most important in terms of affecting fundamental value.) An alternative news dummy for equation (1) measures the absolute value of the equilibrium price change from the previous clearing:

$$\Delta F = |p^*_{tc} - p^*_{tc-1}|$$

for the second and third clearings in period t, and of course is zero in the first clearing.[19]

The regressions were run using ordinary least squares (OLS) on the basic clearinghouse and double auction data from Table IV, omitting experiments which did not conform to the standard format of two trader types with four traders of each type, three clearings per period and three endowed shares per trader. The results appear in Table V. Column (2) reports that average trading volume in the first (no news) clearing was 2.45 shares. There was a small (about 0.7 share) but significant (t = 2.19) increase in average volume in the second clearing, and a substantial (almost 2.4 shares) and highly significant (t = 7.44) increase in average volume in the final clearing. The news effect is even stronger: on average about 3.5 extra shares change hands when important news arrives. The alternative specification reported in column (1) gives generally consistent results except that the fit is poorer and the second period effect becomes insignificant. The coefficient estimate 0.06 for ΔF suggests that about three extra shares change hands in a clearing when type 1 traders receive news, because then the fundamental value typically changes about fifty cents.

The rest of Table V reports similar results for double auction markets. Column (4) indicates that on average about three and a third shares trade before the first news event, and about one extra share trades in the middle subperiod. The significant timing effect again is an extra three shares in the final subperiod. The news effect again is even stronger than the timing effect: on average more than seven extra shares trade when type 1 traders receive their news. Thus, for instance, the average trading volume is more than 3 + 3 + 7 = 13 shares in the final subperiod when type 1 traders are the last to receive news. Column (3) reports closely parallel estimates using the alternative proxy ΔF for the news effect, but again the fit is not as good: $\bar{R}^2$ falls to .37 from .53. One could employ more sophisticated specifications and regression techniques, but given the balanced samples and the consistency of the results there is no reason to expect any change in the conclusions.

19. News is important to the extent that it changes the asset's fundamental value or changes the degree of uncertainty. *DN1* captures both effects, and ΔF directly measures the first effect.

TABLE V
Trading Volume Regressions

Data NOBS	(1) Basic CH 538	(2) Basic CH 538	(3) Basic DA 198	(4) Basic DA 198
Coefficient:				
Const.	2.86	2.45	3.32	3.32
(t-stat)	(12.29)	(11.26)	(5.94)	(6.90)
DC2	-0.22	0.69	0.48	0.94
(t-stat)	(0.56)	(2.19)	(0.47)	(1.28)
DC3	2.09	2.38	3.35	3.03
(t-stat)	(5.40)	(7.44)	(3.20)	(3.85)
DN1		3.52		7.23
(t-stat)		(12.53)		(10.50)
ΔF	0.06		0.13	
(t-stat)	(7.09)		(5.61)	
Adj. R^2	.23	.34	.36	.53

Note: The OLS coefficients (and associated t-statistics) are reported for two linear regressions for Clearinghouse data in columns (1) and (2) and for two linear regressions for Double Auction data in columns (3) and (4). The text defines the dummy variables *DC2* and *DC3* for clearing or subperiod number and *DN1* for news arrival and the variable ΔF for the change in the asset's fundamental value.

Early studies of double auction markets for perishables (e.g., Smith [1982]) noted that volume often tends to be heavier late in a trading period, even though buyers and sellers in a perishables environment typically have repetitively stationary known values so that there are no news events. Copeland and Friedman [1987] report greater asset market trading volume in periods with three news events than in periods with one news event. The present findings extend and refine these stylized facts, and provide grist for theorists who wish to explain trading volume.

IV. DISCUSSION

In a perfectly efficient asset market, prices would track fundamental value, gains from trade would be exhausted, and a trader could buy or sell without affecting asset price. In the laboratory one can directly measure how close actual trading institutions come to perfection.[20] The present study of thirty-nine laboratory asset markets finds a generally high degree of

20. The point deserves to be underlined. Empirical studies of field data usually emphasize asset price volatility, with the presumption that greater volatility (i.e. variance of transaction prices) implies lower informational efficiency. However, asset price will be quite volatile in a perfectly efficient market whenever important (but usually unobservable) information arrives. Valid inferences on informational efficiency therefore are difficult with field data. By contrast, experimentalists can use direct measures such as the root mean squared deviation to isolate the inefficient portion of the volatility, the degree to which asset price fails to track fundamental value.

efficiency in markets organized either as a continuous double auction or as a periodic clearinghouse. It also finds measurable differences in market performance attributable to differences in environmental complexity and trader expertise as well as to differences in trading institutions. The data analysis points to several general conclusions.

1. Overall, the double auction trading institution appears to provide slightly more efficient asset allocations than the clearinghouse. In matched trials (reported in Table IV, comparisons 5b to 7), the average unrealized gains from trade ranged from 1.5 percent to 3.5 percent in the double auction and from 3.5 percent to 5.1 percent in the clearinghouse, a statistically significant difference.

2. Overall, the double auction and clearinghouse institutions have about the same informational efficiency. In matched trials, deviations from fundamental value (*RMSE*) averaged about twenty to twenty-five cents in both institutions, while the fundamental value typically fluctuated over a $1.00 to $2.00 range. The only statistically significant difference here was a lower *RMSE* for the clearinghouse in the moderately complex environment, but this difference became insignificant after eliminating the effects of within-period price dispersion in the double auction.

3. Temporal consolidation of orders in the clearinghouse institution does provide greater average market depth. In matched trials, the average spread between marginal selling and buying prices ranged from thirty-one to forty-four cents in the double auction, but only from eighteen to twenty-four cents in the clearinghouse.

4. Available evidence suggests that public orderflow information in the double auction enhances informational and allocational efficiency but reduces trading volume and perhaps widens the bid-ask spread. In the clearinghouse, on the other hand, public orderflow information appears to reduce informational efficiency (i.e., to increase *RMSE*) and market depth. Limited orderflow information ("indicated price") appears to produce the greatest allocational efficiency in clearinghouse markets.

5. Trading volume averages about 20-40 percent higher in the double auction than in the clearinghouse. In both trading institutions, volume is increased by the arrival of new private information and by the impending end of a trading period.

The second conclusion is perhaps the biggest surprise. Folk wisdom among experimentalists (at least until recently) held that the double auction institution has unsurpassed efficiency. The theoretical work of Ho, Schwartz and Whitcomb [1985] predicts that the clearinghouse will produce excessive asset price variability but reasonably good allocations, and Amihud and Mendelson [1987] and Stoll and Whaley [1990] interpret the NYSE data as supporting this view. But the laboratory data show that clearinghouse prices track the fundamental value extremely well, with no more (and perhaps less) excess volatility than double auction prices.[21] Theory (and folk wisdom) may have to be reconsidered.

The fourth conclusion regarding double auction markets contradicts available theoretical analysis (Lindsey [1990]). Enhanced orderflow information may simply be a more efficient substitute for exploratory bidding and trading in the double auction. In the clearinghouse, on the other hand, detailed orderflow information may encourage attempts to manipulate price. I am not aware of any theoretical literature which addresses this point.

21. The present experiments often used informationally rich variants of the clearinghouse institution, multiple clearings per period, and experienced traders. These innovations probably give the clearinghouse institution a "better shot" than in most previous laboratory implementations. The fourth conclusion (and, indeed, every new conclusion) should be confirmed in other laboratories before it is fully accepted.

The other conclusions contain no real surprises, but they convert some reasonable conjectures into stylized facts. The last conclusion, for example, extends previous empirical findings and underlines the need for a coherent theory of trading volume and its role in price discovery.

Reliable policy recommendations require further confirmation in the laboratory and field, but some tentative comments may now be in order.[22] Present results suggest that neither the double auction nor the clearinghouse has a tremendous efficiency advantage in any of the environments considered. The proper choice of market institution therefore may depend mainly on secondary considerations. The double auction would be favored where immediacy and high volume are desired, and the clearinghouse would be favored for its greater depth where trading intrinsically is thin and where customers desire a uniform price. For securities markets with these characteristics, the indicated price (*book*=1) variant of the clearinghouse seems especially promising.

22. A referee suggests, and I agree, that future experiments should take a closer look at how the number of traders affects clearinghouse market performance. He (or she) offers the very plausible conjecture that an open order book may work better in the clearinghouse with more traders.

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