CHAPTER 3

DOUBLE-AUCTION MARKETS

3.1 Introduction

Vernon Smith was drawn to Chamberlin's classroom auctions because they provided direct evidence regarding specific propositions of neoclassical price theory. As noted in the first chapter, Smith thought that there was a clear explanation of why the observed volume of trades exceeded the competitive equilibrium quantity. The problem with Chamberlin's decentralized auctions, Smith conjectured, was an insufficiency of public information about available bids and offers. Smith (1962, 1964) investigated this hypothesis by conducting a series of laboratory markets similar to Chamberlin's auctions, except that instead of allowing traders to mill about the room and haggle over prices in small clusters, all bids and offers were centrally and publicly recorded.[1] This modified set of trading rules has come to be known as a double auction, to contrast it with the one-sided nature of standard auctions in which a single seller receives bids from a number of buyers. In a one-sided, ascending-bid auction for a single "prize," buyers raise price bids until only one interested bidder remains. With multiple prizes (commodity units), buyers raise bids until the number of units demanded is reduced to a level that equals the number of commodity units offered for sale. The situation is reversed when there are multiple sellers competing for the sale of a fixed number of units or "contracts" sought by a single buyer. In this case, sellers compete by reducing price offers until there is no excess supply. In a double auction, both processes occur simultaneously, and trades occur somewhere in the midst of the initial bids and offers.

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[1] A second major difference was that Chamberlin's markets only lasted for one period. In contrast, Smith allowed the same group of subjects to trade in a sequence of market periods, each with identical supply-and-demand structures.

Smith's double-auction markets generated competitive prices and quantities, and they did so under a remarkably robust set of circumstances. In fact, markets organized under double-auction trading rules appear to generate competitive outcomes more quickly and reliably than markets organized under any alternative set of trading rules. For this reason, double-auction markets have been frequently investigated as a standard against which the performance of other institutions is evaluated.

Interest in the double auction was further enhanced by the similarity of its trading rules with those used in major securities markets. Continuing developments in communications technology make electronic stock exchanges imminent, and analysis of market performance in computerized laboratories allows some insight into the possible effects of alternative forms of automation. As a result of their efficiency and applicability, double-auction markets have been more extensively analyzed than markets organized under any other set of trading rules.

This chapter introduces the procedures, performance properties, and some applications of the double auction. Laboratory procedures and performance measures are explained in detail in section 3.2. The role and effects of computerization are discussed in section 3.3. Sections 3.4 and 3.5 survey evidence on the resilience of price convergence properties to structural and environmental factors, such as changes in supply-and-demand conditions. The results of double auctions in multiple, related markets are surveyed in section 3.6. Section 3.7 pertains to double auctions for multiperiod assets that pay periodic dividends. The final section contains a brief summary.

3.2 Double-Auction Procedures and Performance

Regardless of whether bids and offers flash across a computer screen or are called out by aggressive traders in a "pit," trading is intense in a double auction. The volume of bid and offer messages also makes this institution informationally rich. Before discussing experimental results, it is instructive to give the reader some insight into how a laboratory double auction works, and how traders make decisions. Therefore, the first part of this section pertains to the mechanics of double-auction trading. The second part pertains to standard measures of market performance that are used by experimentalists.

A Double-Auction Trading Period

Double-auction markets are divided into a sequence of trading intervals, or periods. Each period lasts a preset amount of time. Usually three to five minutes are sufficient when five to ten units are being traded, although more time is needed in markets with a high volume. At the beginning of a period, buyers are endowed

with unit valuations, and sellers with unit costs. This value and cost information is presented to participants in the form of record sheets like those shown in table 3.1 for a representative buyer, B4, and a representative seller, S1.

Table 3.1 Buyer and Seller Record Sheets

Record Sheet — Buyer B4			
Unit 1	(1)	Unit Value	4.60
	(2)	Purchase Price	4.30
	(3)	Unit Profit (1) – (2)	.30
Unit 2	(4)	Unit Value	4.40
	(5)	Purchase Price	
	(6)	Unit Profit (4) – (5)	
	(7)	Period Profit (3) + (6)	

Record Sheet — Seller S1			
Unit 1	(1)	Sales Price	4.30
	(2)	Unit Cost	3.70
	(3)	Unit Profit (1) – (2)	.60
Unit 2	(4)	Sales Price	
	(5)	Unit Cost	4.40
	(6)	Unit Profit (4) – (5)	
	(7)	Period Profit (3) + (6)	

First look at the buyer record sheet on the left side of table 3.1. Buyer B4 may potentially purchase two units in this trading period, one valued at $4.60, and a second at $4.40. Typically, buyers are required to purchase higher-valued units before lower-valued units. Buyers' profits are calculated as the difference between the unit value and the purchase price. Earnings are zero on units not purchased. For example, if B4 agreed to purchase a first unit for a price of $4.30 (listed in entry (2)), B4 would earn $.30, as listed in entry (3). Similarly, seller S1's record sheet on the right side of the table shows two units, one with a cost of $3.70 and the other with a cost of $4.40. Sellers must sell lowest-cost units first (except in the case of a decreasing-cost producer, where the reverse rule is enforced). Sellers earn profits as the residual of the contract price over unit costs. If, for example, S1 agreed to sell a first unit for $4.30, then S1 would earn $.60, as shown in entry (3). Production is typically to fulfill orders, so there is no cost incurred on unsold units.

Often the researcher may wish to prohibit unprofitable actions, such as bids above unit values or offers below unit costs. Trades at a loss are usually the result of misunderstanding or keystroke errors, and such trades send noisy signals to the market. On the other hand, trades at a loss may be the result of deliberate efforts to punish one's competitors by taking business away from them, for example, with predatory pricing. Even if this behavior is extremely unlikely, experimentalists are hesitant to rule out particular trading strategies, and an intermediate path is to provide a warning and give subjects a chance to confirm a trade at a loss.

In a double auction, buyers call out bids as they compete to make the highest bid, and at the same time, sellers call out offers as they compete to make the lowest offer. Any seller may accept a standing bid at any time, and any buyer may accept a standing offer. Table 3.2 illustrates the manner in which negotiations might be recorded. As indicated in the first line on the left side of the table, seller S2 opens negotiations by raising a hand and announcing his/her identity (S2), and the offer ($5.00). In the following line, B4 opens bidding by announcing an identity (B4) and a bid ($4.10). These opening propositions form the initial bid/ask spread; they "stand" as most favorable contract terms until accepted or improved upon by other traders. In most double auctions that are done orally, nonimproving bids and offers are not permitted, so the next offer would have to be below $5.00, and the next bid would have to be above $4.10. As indicated in the subsequent rows of the table, seller S2's opening offer is improved by the remaining three sellers, while buyers B1 and B2 join B4 in improving (raising) the standing bid. Negotiations for the first unit end when one trader accepts the terms proposed by another, as illustrated by the underlined row where B4 accepts S1's offer of $4.30.

When a contract is struck, the experimenter circles it on the board, and the contracting parties (in this case B4 and S1) record the price on their record sheets and calculate profits, as shown in table 3.1. One common procedure is for a contract acceptance to invalidate all outstanding bids and offers, and therefore, an improvement rule does not constrain the initial bid or offer on the next unit, which would be the second unit for B4 and S1, and the first unit for the others. Negotiations continue until time expires or, in some implementations, until there is a unanimous vote to terminate the period.[2]

The negotiations summarized in table 3.2 constitute the entire set of bids and offers in a five-minute (300 second) trading period.[3] The shaded columns show the time at which each acceptance was made, where time is measured as the number of seconds remaining in the period. It is worth noting that buyers and sellers typically

[2] In particular, the unanimity stopping rule is a feature of the popular NovaNet (formerly PLATO) computerized double-auction mechanism, discussed below. In the NovaNet environment, voting to close a period does not impair a trader's ability to make or accept contracts. Trading periods are rarely stopped by vote.

[3] The data in table 3.2 are from records of experiment 15, an initial NovaNet computerized session reported by Williams (1980). Much of the experimental data presented in this chapter are generated by NovaNet sessions, due to the ease of accessing information from this large, public database.

Table 3.2 Sequence of Contracts for Period 5

Time	Bid	Offer
296		S2 5.00
294	B4 4.10	
293		S3 4.50
291	B1 4.20	
285	B2 4.21	
284		S1 4.40
279		S3 4.39
276		S4 4.35
271	B4 4.25	
267	B2 4.26	
265		S3 4.34
261		S1 4.30
254	B4 accepts	
249	B2 4.20	
245		S3 4.39
244	B1 4.22	
241	B2 4.23	
237		S4 4.35
230		S3 4.34
209	B1 4.25	
208		S4 4.31
205	B2 4.26	
203		S2 accepts
198	B4 4.20	
194	B1 4.22	
190		S3 4.40
188	B4 4.25	
180		S4 4.35
176	B3 accepts	
171		S1 4.45
167	B4 4.20	
165	B1 4.22	
164		S2 4.40
161	B4 4.25	
160		S4 4.35
151		S2 4.34
143		S4 4.32
135		S2 4.31
131		S3 4.30
121		S4 4.29
118	B1 4.26	
112		S3 accepts
64		S3 4.28
15	B4 4.25	
13		S4 accepts
10		S2 4.30

see nothing other than their own values or costs and a "ticker tape" list of bids, asks, and transactions. Prior to continuing, you may find it instructive to consider what inferences about the structure of this market are obvious from either the B4 or the S1 record sheet in table 3.1, and from table 3.2. As discussed in chapter 1, it is not often clear to participants that there is any reason why a particular price and quantity combination is generated.

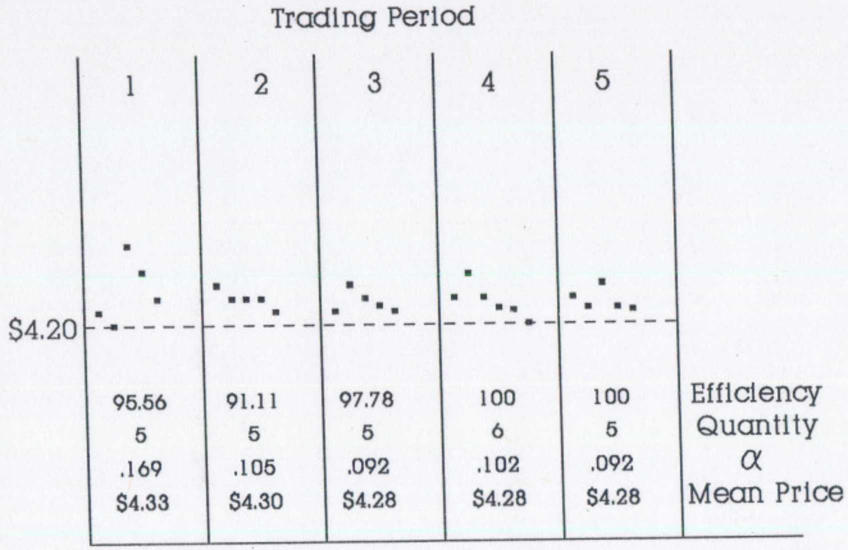

Figure 3.1 A Sequence of Contract Prices in a Double-Auction Market (Source: Williams, 1980)

The contract prices for a series of trading periods are plotted in chronological order as a sequence of dots in figure 3.1. The prices for each period are separated by vertical lines, and the period number is shown at the top of the figure. In period 1 the contract prices are scattered above the dashed line at $4.20, but the range of contract prices narrows in subsequent periods. By period 5 (listed in table 3.2), all contracts fall in the range between $4.25 and $4.35.

Evaluating Market Performance

Market supply-and-demand functions for the session in figure 3.1 are generated by combining individuals' cost and valuation information. There are four buyers and four sellers, and the market supply-and-demand curves are shown in figure 3.2. The identification numbers at each step indicate buyer and seller identities for each unit.

Demand and supply intersect at a price of $4.20, and the quantity traded in a competitive equilibrium will be 5 or 6.

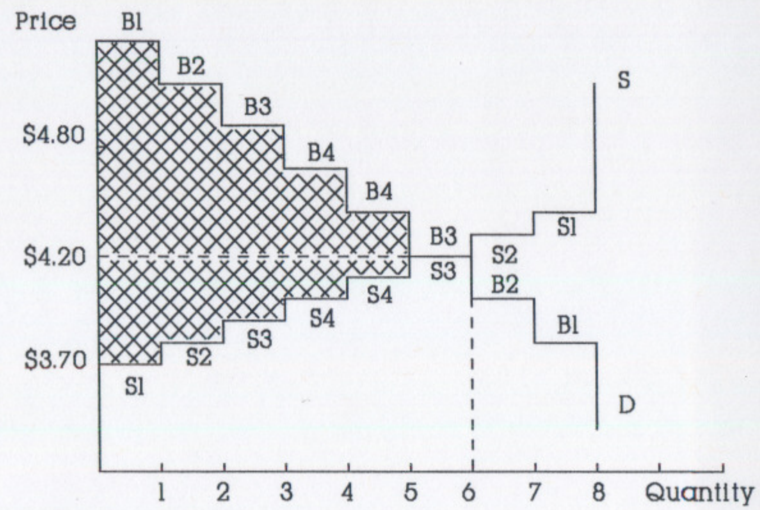

Figure 3.2 Induced Supply and Demand Arrays

The ambiguity of the quantity prediction is noteworthy. The discrete nature of supply-and-demand step functions often results in a horizontal overlap (a quantity tunnel) or a vertical overlap (a price tunnel). These tunnels can be avoided by having either demand or supply cross a flat segment of the other curve.[4]

Several aggregate measures of market performance in each period are shown at the bottom of figure 3.1. The market quantity and mean price measures are quite close to the competitive predictions. One useful measure of closeness is the market efficiency measure introduced in chapter 1. It is instructive to discuss this measure in more detail.

Of all the combinations of trades that could take place, competitive price theory predicts the combination that maximizes the surplus generated in exchange (the

[4] In early experiments, many designs employed a horizontal overlap in combination with trading "commissions," which ranged from $.05 to $.15 and were paid to both the buyer and seller for each contract. These commissions were used to induce the trade of marginally profitable units, such as the second units for B3 and S3 in figure 3.2. When commissions are used, buyers are not permitted to pay more than the valuation of a unit, even though the buyer would be willing to pay value plus commission. Similarly, sellers are not permitted to sell below cost. Without such restrictions, commissions would simply shift the demand curve up and the supply curve down by the commission amount, thus eliminating the quantity tunnel by creating a price tunnel. Commissions of this type are now used infrequently, mostly because commissions in naturally occurring markets do not generate the same incentives as those created by per-unit commissions in the laborat

shaded area in figure 3.2). This maximum surplus will be denoted by ε_c. Efficiency, E, is simply the proportion of this maximum surplus that is extracted:

$$E = \frac{\Sigma(MV_i - P_i) + \Sigma(P_i - MC_i)}{\varepsilon_c} \times 100,$$

where the summation is over the indices of units actually traded. Table 3.3 presents a summary of the surplus extracted in the trading period 5 of the session in figure 3.1. Note that since ε_c = \$4.50, and since total buyer and seller surpluses are \$2.58 and \$1.92, respectively, the market is 100 percent efficient. Efficiency calculations for each of the five trading periods in this session are printed in figure 3.1 below the sequence of contracts. Note that E is close to 100 percent in every period. This high efficiency is characteristic of double-auction markets. Many students and others are surprised that a market with private cost and value information can effectively maximize the total earnings of all participants combined, without them being able to conspire against the experimenter![5]

It is far from necessary that the act of profitable trading alone generates E values close to 100 percent for the market design in figure 3.2. Consider first an efficient sequence of contracts, where the buyer with the highest unit value (B1) trades with the lowest-cost producer (S1), the buyer with the second highest unit value (B2) trades with the second-to-lowest-cost producer (S2), and so on, until B3 and S3 strike the sixth contract in the market period by trading their second units and earning only the sales commission. All of these contracts could be consummated at a single price of \$4.20. Now consider a second possible sequence of trades, identical to the first, except that B4's second purchase is S2's high-cost unit (costing \$4.30) rather than S4's high-cost unit (costing \$4.10), at a price of \$4.35. Excluding S4 from the market in this way lowers the total surplus by \$.20, which is the cost increase resulting from the inclusion of an inefficient extra-marginal unit that costs \$4.30 instead of \$4.10. Efficiency losses would be larger if the sale of S2's second unit precluded the sale of a unit with an even lower cost. Still larger surplus losses can arise from more volatile price swings. For example, if S1 makes a contract at \$3.75 to sell his/her low-cost unit (cost \$3.70) to B1, who is purchasing a low-value unit (value \$3.80), then some buyer will be precluded from striking an efficient contract. If B2 were precluded from trading, then \$1.20 (or the difference between the value of B2's first, high-value unit and B1's second, low-value unit) would be lost.

[5] In fact, even sophisticated individual behavior may not be an important prerequisite for obtaining efficient competitive outcomes in a double-auction market. Using simulated buyers and sellers, Gode and Sunder (1989) observe that very crude strategies (involving "zero intelligence") extract nearly all of the possible gains from exchange.

Table 3.3 Efficiency Calculations for Trading Period 5

	BUYERS				SELLERS			
Unit	ID	Unit Value	Price	Profit	ID	Price	Unit Cost	Profit
1	B4	4.60	4.30	.30	S1	4.30	3.70	.60
2	B2	5.00	4.26	.74	S2	4.26	3.80	.46
3	B3	4.80	4.35	.45	S4	4.35	4.00	.35
4	B1	5.20	4.26	.94	S3	4.26	3.90	.36
5	B4	4.40	4.25	.15	S4	4.25	4.10	.15
	Total Buyer Surplus			2.58	Total Seller Surplus			1.92

The efficiency index E can be quite sensitive to market structure and should therefore be interpreted with care. For example, increasing the value of B1's first unit from \$5.20 to \$10.20 in figure 3.2 would raise the maximum market surplus by the same amount, from \$4.50 to \$9.50. Nearly two-thirds of that surplus is extracted (\$6.00/9.50), however, if B1 manages to complete a single contract at the competitive price. Moreover, a failure to trade a marginal unit provides a much lower efficiency loss as a percentage of \$9.50 than as a percentage of \$4.50. The likelihood of efficiency losses is increased by the presence of extra-marginal units close to the competitive price. This may be seen by counterexample in figure 3.2. By raising the costs of the second units for S1 and S2 by \$6.00 and lowering the values of the second units for B1 and B2 by \$3.00, extra-marginal units could never trade. Efficiency losses caused by extra-marginal trades are impossible under these circumstances.

Even if a market is 100 percent efficient, the proportion of the available surplus going to buyers and sellers may vary widely in the process of adjustment. A measure of the distribution of surplus is often useful, particularly in discussions of dynamics. In the market example being discussed, sellers receive \$1.50 and buyers \$3.00 if all contracts are made at the equilibrium price. In trading period 5, buyers extracted .86 (\$2.58/\$3.00) of the surplus that would go to them at the competitive price, while sellers extracted 1.28 (\$1.92/\$1.50).

In some contexts, it is desirable to measure the extent to which sellers are able to profit from increases in prices over the competitive level. The standard basis of comparison is the profit level that results from a monopoly (joint-profit-maximizing) price. The index of monopoly effectiveness, M, first used by Smith (1980), is simply the ratio of the excess (supracompetitive) profits actually earned by sellers in a trading period to excess (supracompetitive) profits earned by sellers at the monopoly price, or

$$M = \frac{\pi - \pi_c}{\pi_m - \pi_c},$$

where π = actual sellers' profits in a trading period, π_c = sellers' profits in a competitive equilibrium, and π_m = sellers' profits under the hypothesis of joint profit maximization.

For the market structure shown in figure 3.2, sellers would earn \$3.70 if three units were traded at the profit-maximizing price of \$4.80. Since sellers earn \$1.50 if all contracts are made at the competitive price, the index of monopoly effectiveness for the trading period 5 in table 3.3 is [\$1.82 – \$1.50] /[\$3.70 – \$1.50], or .26. Notice that $M = 100$ if all contracts are struck at the profit-maximizing price, and $M = 0$ if all contracts occur at the competitive price. Unlike E, which is bounded between 0 and 100, M may exceed 100 if a seller successfully price discriminates, and M may fall below 0 if buyers earn more than predicted under the competitive hypothesis.

A final performance measure to be considered is the coefficient of convergence. It is often useful to have some measure of pricing behavior that captures both price variability and the deviation of prices from the competitive level. The most common measure, α, is the square root of the variance of prices around the predicted equilibrium price. This variance is calculated

$$\alpha^2 = \frac{\sum_{k=1}^{Q} (P_k - P_e)^2}{Q},$$

where Q = the number of contracts in a trading period, P_k = the k^{th} contract price, and P_e = the competitive equilibrium price. By letting m and s^2 denote the mean and variance of observed prices in a period, and decomposing, we obtain[6]

$$\alpha^2 = s^2 + (m - P_e)^2.$$

Thus α^2 equals the variance in prices plus the squared deviation of mean price from the competitive equilibrium. If all contracts are made at the competitive price

[6] This decomposition can be verified by adding and subtracting the mean price, m, to each of the $P_k - P_e$ terms, and using the fact that the sum of the deviations from the mean is zero: $\Sigma(P_k - m) = 0$.

prediction, then $\alpha^2 = 0$. Note that α is unbounded from above and increases with price volatility and with deviations of the mean price from the competitive prediction. Values of α for each trading period of the session summarized in figure 3.1 are listed below the prices for that period. Observe that α drops substantially after the first period.

Performance in Standard Environments

Hundreds of laboratory double auctions are reported in the literature. The performance measures discussed above can be used to compare outcomes of these auctions with competitive predictions. Table 3.4 presents summary performance measures for double-auction sessions from seven selected studies. In every instance but one (Smith and Williams, 1982), the sessions summarized are control sessions, against which a variety of treatments were subsequently evaluated. The set of studies included in table 3.4 is by no means comprehensive. Rather, these studies are chosen for the comparability of data and the diversity of environments. The experiments were conducted in five locations, in either computerized (NovaNet) or oral environments, by four different sets of authors, using various combinations of experienced, inexperienced, and mixed-experience participants. Studies included between two and twelve sessions; the number of sessions is listed in parentheses below the site code. Sessions varied from three to fifteen periods in length (not shown in the table), with computerized sessions generally having more periods.

The three columns on the far right of table 3.4 present the average price deviation, $P - P_e$, the average efficiency, and the average quantity deviation, expressed as a proportion of the competitive quantity: $(Q - Q_e)/Q_e$. These double-auction markets clearly tend to generate competitive predictions. Price deviations never exceed five cents, at least 94 percent of predicted trades took place, and mean efficiency fell below 97 percent in only one NovaNet study using inexperienced participants (Smith and Williams, 1982).

3.3 Computers and the Double Auction

As should be clear from table 3.2, the double auction generates a large amount of data in a fairly short time. Accurately recording these data presents a formidable task. In addition, a researcher conducting an double auction orally must ensure that participants do not record profits incorrectly or make contracts that violate instructions, for example, trade at a loss. These burdensome record-keeping and monitoring requirements suggest clear benefits of computerization. Moreover, computerization standardizes the presentation of instructions and restricts subtle verbal and visual communications between participants during a trading period, allowing clearer isolation of treatment variables. A third advantage of

Table 3.4 Performance in Selected Double Auctions

Study	Site (# mkts.)	Experience	Environment	$P–P_e$ ($)	Efficiency	$\frac{Q–Q_e}{Q}$
Smith and Williams (1981)	IU/UA (4)	X	NovaNet	–.01	99.4	.02
Smith and Williams (1982)	IU/UA (12)	NX	NovaNet	–.03	95.8	.05
Smith and Williams (1983)	UA (6)	M	NovaNet	.01	97.8	.06
Isaac and Plott (1981b)	CIT/PCC (3)	X	Oral	–.05	99.9	.04
Mestelman and Welland (1988)	MMU (5)	NX	Oral	.02	97.3	.04
Mestelman and Welland (1991)	MMU (5)	NX	Oral	.02	98.0	.02
Joyce (1983)	MT (2)	NX	Oral	.04	98.7	.04

Site Key:
IU Indiana University
UA University of Arizona
CIT California Institute of Technology
PCC Pasadena City College
MMU McMaster University
MT Michigan Tech

Experience Key:
NX inexperienced
X experienced
M mixed

computerization derives from the recent interest in creating electronic stock exchanges.[7] A computerized laboratory market allows field-testing of some aspects of an electronic stock exchange.

[7] The Securities and Exchange Commission received a congressional mandate to move toward the creation of a national stock trading system in 1975, and electronic automation was a key motivation for the mandate. Automation is also becoming more important as some stock exchanges begin to allow after-hours trades. See, for example, George Anders and Craig Torres, "Computers Bypass Wall Street Middlemen and Stir Controversy," in *The Wall Street Journal*, August 28, 1991, p. A1.

The first computerized double-auction program was written by Arlingtoı Williams in 1977, for use on the NovaNet (formerly PLATO) computer network This program provides self-paced interactive instructions, complete control of thı decision-making process, and complete data recording. Other versions of : computerized double-auction are now available.[8]

Effects of Computerization

A quick comparison of the computerized double auctions at the top of table 3.4 with the oral double auctions at the bottom does not reveal any clear difference; and convergence to the competitive equilibrium is obvious in both cases. But these comparisons are a little messy, because the table contains no pair of computerized and noncomputerized markets that use the same supply-and-demand structure. In initial NovaNet double auctions, Williams (1980) found increased price variability in the computerized markets relative to comparable oral markets. This higher variability probably reflects additional control over nonverbal, nonprice communications, since both the information and negotiating rules are identical in computerized and oral environments. Therefore, the added "noise" in the price sequence is probably a desirable feature of computerization.

Williams also conducted computerized sessions with subjects who had previously participated in a NovaNet double auction. Prices in these sessions were much less volatile; they were similar to prices observed in comparable noncomputerized (oral) double auctions with inexperienced subjects. Consider the price sequences in figure 3.3, where prices are plotted as deviations from the competitive level, which is indicated by the horizontal line at 0.[9] Although prices eventually cluster about the predicted level, both with inexperienced subjects (top panel) and with experienced subjects (bottom panel), there is less price variability in the latter case. This difference is representative of many computerized sessions, and for this reason experience has come to be regarded as an important treatment. Efficiencies in figure 3.3 are very high, regardless of experience. With inexperienced subjects, efficiencies exceed 94 percent in all but the first two periods, and efficiencies exceed 97 percent in all periods with experienced subjects.

[8] The task of programming a "real-time" environment is still far from trivial, and was an impressive technical feat in the mid 1970s. Williams's NovaNet double auction was the only computerized double auction available for most of a decade. Additional versions of the computerized double auction have been created, both for mainframe computers (e.g., Hackett, Battalio, and Wiggins, 1988; Friedman and Ostroy, 1989) and for networked personal computers (e.g., Johnson, Lee, and Plott, 1988; Gode and Sunder, 1989; Forsythe, et al., 1992).

[9] These data are from a symmetric four-seller, four-buyer design reported by Smith and Williams [illegible]

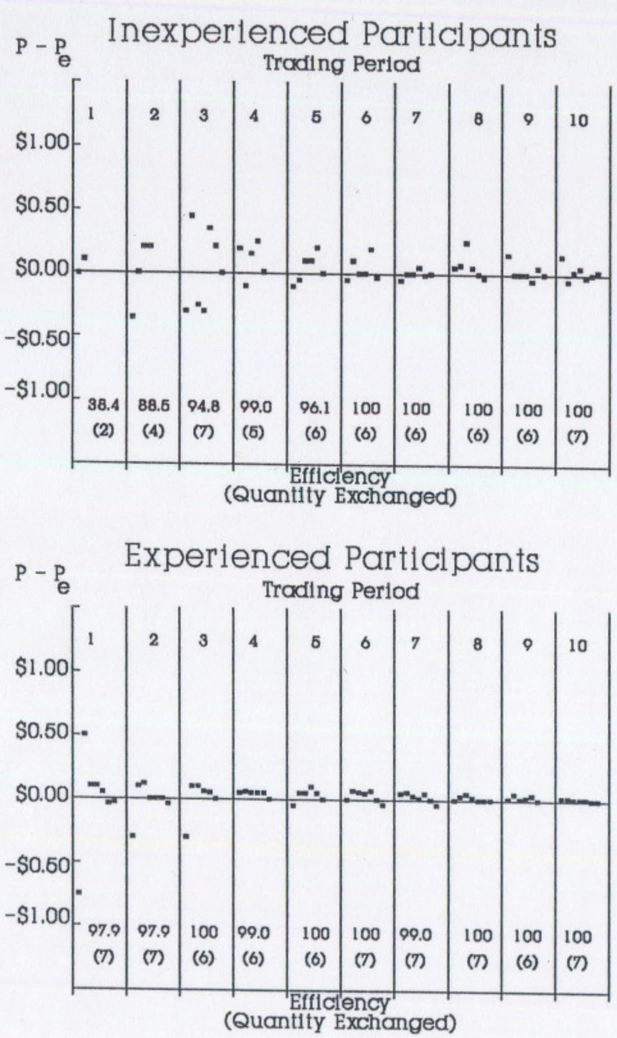

Figure 3.3 Representative Contract Price Series for Experienced and Inexperienced Double-Auction Sessions (Source: Smith and Williams, 1983)

Bid/Offer Acceptance Procedures

Computerization facilitates the use of more sophisticated trading rules. In particular, consider the rules that determine which bids and offers are permitted.

Smith and Williams (1983) evaluated the effects of four alternative rules. Under Rule 1, the most recent quote is displayed, whether or not it represents an improvement, that is, a bid that exceeds the highest outstanding bid or an offer that is below the lowest outstanding offer. Under this rule, a nonimproving quote bumps the better quote off of the display. Bidding Rule 1Q appends a temporal queue to Bidding Rule 1; all bids and offers are displayed to the market for a minimum of three seconds. Any bids or offers that arrive prior to expiration of the three-second minimum are queued by time of arrival and are displayed in subsequent three-second increments. In contrast, Rule 2 specifies a bid/ask spread-reduction rule that allows only bids and offers that improve the standing bid/ask spread. Bidding Rule 2Q appends a rank-order queue to Bidding Rule 2. Under Bidding Rule 2Q, the highest bid and the lowest offer are publicly displayed to the market, as in Bidding Rule 2, but buyers and sellers may also submit non-spread-reducing bids and offers, which are queued in rank order. These stored bids and offers become the standing quotes in the event that contracts remove the more attractive quotes. Also, while participants may not invalidate a standing bid or offer, they may pull out of the rank-order queue at any time.

The variation of experience and the four bidding rules generates an eight-cell (2 × 4) matrix of treatments. Smith and Williams investigated these effects in a four-buyer, four-seller market with symmetric supply-and-demand schedules. The authors conducted a total of twenty one sessions, with three sessions in each inexperienced cell and two sessions in each experienced cell, except for the cell with experience and Bidding Rule 2Q, which had three sessions. Using as data points the coefficient of convergence, $\alpha_i(t)$, for trading period t of session i, Smith and Williams estimated the parameters of an exponential decay function:

$$\ln \alpha_i(t) \;=\; a + bt + cx_s,$$

where $x_s = 1$ if participants were experienced, 0 otherwise.[10] Figure 3.4 illustrates the exponential decay function estimated for each bidding rule, with experienced subjects. In the absence of queues, varying the bid/offer acceptance procedures makes little difference in performance, as suggested by the near overlap of estimated equations for Bidding Rules 1 and 2. Smith and Williams conjecture that Bidding

[10] Contract prices in one period are unlikely to be independent of those in preceding periods. For this reason, the pooling of $\alpha_i(t)$ observations across trading periods in session i violates the independence assumptions of classical statistical inference. This use of nonindependent observations raises an important methodological issue. Statistical techniques for autocorrelated data generally require much longer time series than the eight to fifteen trading-period sequences that comprise most sessions. Thus, strict use of only truly independent observations in a cross-sectional analysis often implies that only one data point is generated per session, severely restricting use of the rich information set. Some researchers insist on tests that satisfy independence. Others provide results based on interrelated data, along with the caveat that statistical results should be interpreted as being descriptive rather than as true tests. As discussed in chapter 9, we have some [illegible]

Rules 1 and 2 are behaviorally similar because participants tend to submit quotes that reduce the bid/ask spread, regardless of whether such behavior is required by the trading rules.

The addition of queues, however, has a clear effect on the convergence measure. As illustrated in figure 3.4, the temporal queue in Bidding Rule 1Q impedes convergence, while the rank-order queue in Bidding Rule 2Q facilitates convergence. Smith and Williams conjecture that the rank-order queue (or specialist's book) facilitates convergence because it adds competition away from the margin, as people jockey for position in the queue. In contrast, a temporal queue raises negotiation costs, so agents agree to inferior contracts more easily.

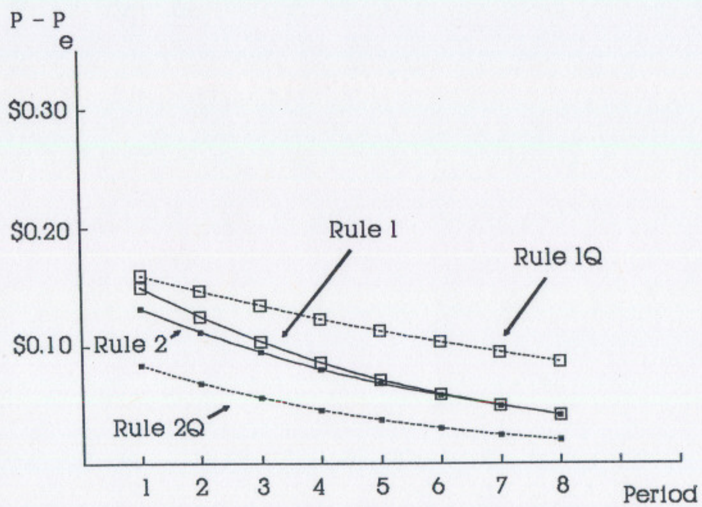

Figure 3.4 The Effects of Alternative Bid/Ask Acceptance Rules on the Price-Convergence Path (Source: Smith and Williams, 1983)

Due to its strong convergence properties, Bidding Rule 2Q is commonly used as a default in the computerized double-auction markets discussed below. Bidding Rule 2, however, is most frequently employed in noncomputerized (oral) double auctions because of the difficulty of manually maintaining a rank-order queue. It is worth noting that Bidding Rules 2 and 2Q replicate bid/offer acceptance procedures in many modern stock and securities exchanges.[11] Therefore, the

[11] For example, the bid/offer spread reduction rule corresponds to Rules 71 and 72 of the NYSE (Leffler and Loring, 1963).

superior performance of Bidding Rule 2Q suggests some natural selection of efficient contracting rules in markets.[12]

3.4 Double-Auction Results: Design Effects

Once a theory receives support in a baseline environment, the next step is one of "stress testing," or conducting boundary experiments to discover the limitations of the theory's application. This section surveys a series of design boundaries: the effects of variations on the shapes and stability of supply-and-demand arrays.

A Design with Extreme Earnings Inequities

The first boundary to be considered involves rectangular demand and supply functions that have only a single step and intersect to form a "box." This box design results when all sellers' units have the same cost, and all buyers' units have the same value. These designs are not realistic in the sense that they do not conform to standard assumptions of diminishing marginal utility or increasing costs. But extreme or limiting variations in the shapes of supply-and-demand curves provide evidence relevant to the limits of application of competitive price theory. Design extremes may also provide some insight into the price adjustment process.

Before proceeding, the reader should reconsider the asymmetry of the design in figure 3.2 above. If all trades take place at the competitive price, buyers receive two thirds of the possible surplus, while sellers only receive one third of the surplus. As the sequence of contract prices in figure 3.1 suggests, this earnings disparity does not interrupt the ultimate convergence to the competitive price, although the convergence is from above. The most extreme earnings inequity results when traders on one side earn all of the surplus in equilibrium. For example, consider the double lines labeled as D_1 and S_1 on the left side of figure 3.5. In this case, each of four buyers is given four units at a constant per unit valuation of $6.80, resulting in a market demand of 16 units at prices up to $6.80, and zero at any higher price. Three of the four sellers in this design are endowed with three units, and a fourth

[12] Computerization has also stimulated institutional change. For example, it is now possible to design electronic markets in which traders in different locations can contact each other without going through the brokers that handle trades on large stock exchanges. One alternative is to have buyers and sellers send in bids and offers, which are arrayed into demand-and-supply functions. Since such messages can originate in different locations at all hours of the day or night, it is convenient to have all trades be consummated at a preannounced time at a common price determined by the crossing of supply and demand. At any previous time, traders can observe the tentative price determined by bids and offers received to date, but the price is not final until the market is "called." These call markets, which are used in several securities exchanges, raise a number of interesting design issues that are considered in the

seller is endowed with two units, all at a constant per-unit cost of $5.70, generating a market supply of 11 units at prices down to $5.70, and zero at any lower price. An excess demand of five units remains at every price between $6.80 and $5.70. The double-lined supply-and-demand curves determine a unique competitive equilibrium E1, with a price of $6.80 and a quantity of 11.[13] Sellers earn all surplus if all trades occur at the equilibrium price.

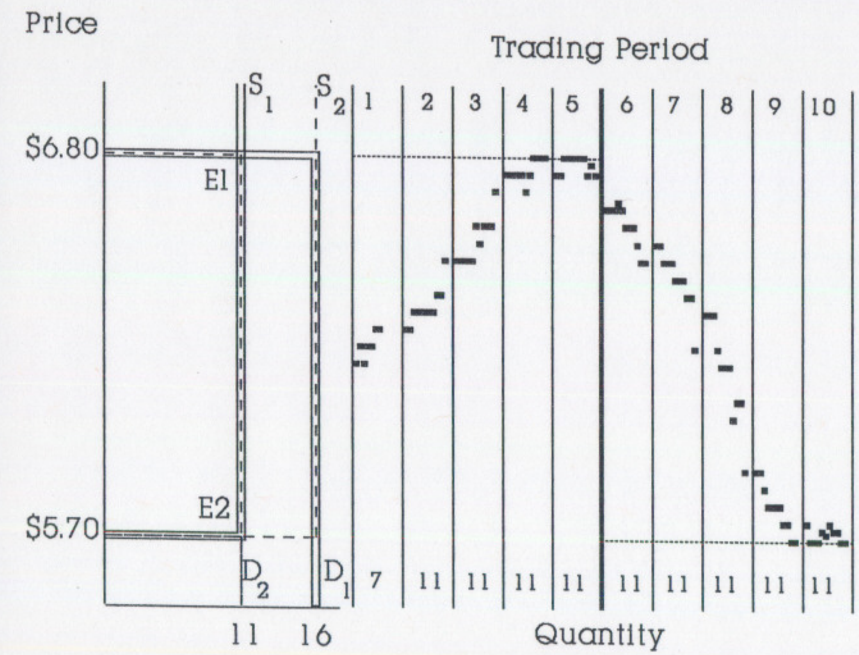

Figure 3.5 Contract Prices for a Box Design: First with Excess Demand, then with Excess Supply (Source: Holt, Langan, and Villamil, 1986)

This excess demand design was used in the first five periods of the session shown on the right side of figure 3.5.[14] Notice that prices in period 1 begin about midway between the costs and values. Prices climb in response to excess demand and reach the competitive prediction of $6.80 by period 5. Prior to each period, record sheets with the values and costs were passed out without comment, so the

[13] This allocation satisfies the formal definition of a competitive equilibrium: There is an allocation resulting from eleven trades at a price of $6.80 with the property that (1) no buyer or seller can increase his/her utility by changing the amount produced or purchased, taking the price of $6.80 as given, and (2) the market clears in the sense that eleven units are supplied and demanded.

[14] The data are from Holt, Langan, and Villamil (1986), who used experienced participants and paid buyers and sellers a nickel trading commission.

demand-and-supply shifts in period 6 were privately implemented. Buyers, who were probably quite frustrated after period 5, would notice that they had fewer units on their record sheets for the sixth period. Sellers, who had been making over $1.00 on each unit in period 5, were probably delighted to see that they had extra units in period 6. These changes resulted in the dashed-line demand-and-supply curves, D_2 and S_2, on the left side of figure 3.5, which generate a new equilibrium, E2, characterized by excess supply. Notice that the new equilibrium prediction was created solely by reducing the number of buyers' units (to 11) and increasing the number of sellers' units (to 16). This excess supply immediately affected the market: In period 6 the initial contract price was lower than any in the previous two periods. Prices decayed further in subsequent periods and dropped almost completely to the equilibrium prediction by periods 9 and 10. Very similar results have been reported earlier on variants of this design.[15] This tendency for severe excess demand or excess supply to push prices to extreme, "inequitable" levels has been observed with subjects in the United States, Canada, and China.[16]

Finally, notice that the transaction quantities are given at the bottom of figure 3.5, and that each of the 11 units at the predicted quantity sold in every trading period but the first. Therefore, efficiency was 100 percent in every period but the first, since efficiency and trading quantity are directly related in this constant-cost/constant-value design. The interesting point is that *any* price between $5.70 and $6.80 would yield a surplus-maximizing outcome; but only one of these prices is a competitive equilibrium. In this sense, competitive price theory provides a more precise description of the equilibrium data than is provided by a theory based on surplus maximization.

A Box Design with Multiple Price Equilibria

Even if competitive price theory predicts well in this context, there is the issue of what prices will result when there is a range of competitive equilibria. The typical assumption seen in theoretical models is that prices will stabilize near the midpoint of the equilibrium range. On the other hand, it is common to observe a sequence of laboratory prices at the same level during an adjustment process, as in figure 3.5. Such flat steps in the price sequences occur too frequently to be caused by chance; they seem to be the result of a tacit consensus reached during the

[15] See Smith (1964), Smith (1981), and Smith and Williams (1989). In one session with a box design in Smith and Williams (1989), participants were paid no trading commission. Prices tended to stabilize between $.05 and $.10 away from the equilibrium. Smith and Williams cite this result as evidence that a $.10 commission is necessary to induce marginal trades.

[16] See Kachelmeier and Shehata (1990), who found no evidence of a significant cultural effect in this box design.

negotiations. The empirical question is whether such a consensus could cause prices to stabilize at a point that is far from the midpoint of a range of competitive prices.

Consider the design on the left side of figure 3.6; any price between \$5.50 and \$6.60 is a competitive, market-clearing price, and a horizontal line is drawn at the midpoint of equal surplus division, for purposes of reference. Smith and Williams (1988) conducted a series of five NovaNet double-auction markets with this design, using four buyers and four sellers in each session. All participants had institution experience and were paid a \$.10 per unit trading commission. The sequence of contracts for the first four trading periods of one of these sessions, labeled B2x, is shown immediately to the right of the supply-and-demand arrays in figure 3.6. Notice that only ten units are traded in each of these initial periods, and that prices tend to favor sellers.[17] The sequence of *mean* contract prices for all fifteen periods of session B2x is presented in the enlarged middle box on the far right side of the figure. For example, the first dot in the mean contract price chart, shown on the right hand side of figure 3.6, is the average of the ten first-period contract prices for session B2x shown in the middle of the figure. The sequence of mean contracts for the remaining four sessions (B1x, B3x, B4x, and B5x) is arrayed above and below the mean contract price chart for B2x. For purposes of comparison, the vertical height of each of the right-hand mean-price charts corresponds to the \$1.10 difference between seller costs and buyer values. It is clear from these charts that prices do not tend to the equal rent split. But there is little reason a priori to expect an equal rent split. Unit value and unit cost information is private, and it would indeed be surprising if buyer and seller bargaining strategies were so universally similar that they regularly split an unknown difference!

Another interesting implication of the mean contract price charts is that the double-auction institution tends to produce a certain behavioral stability. Although the mean price shows some propensity to drift up or down from period to period within a session, there is a clear inertia. Moreover, it is not only the mean prices that exhibit stability, as indicated by the low variability of contract prices for the first four trading periods of session B2x.

Supply-and-Demand Instabilities

Most double auctions are conducted with repeated stationary designs, where the same agents are given the same induced costs and valuations in a sequence of repeated trading periods. A limiting stability boundary would involve random underlying shifts in supply and demand. However, rather than starting with results of this chaotic design, consider first the effects of simple repeated nonstationarities, in the form of simple demand and/or supply cycles.

[17] However, efficiency tends to be high with this design. Even in session B2x, all 11 possible units traded in 8 of the final 11 trading periods (not shown).

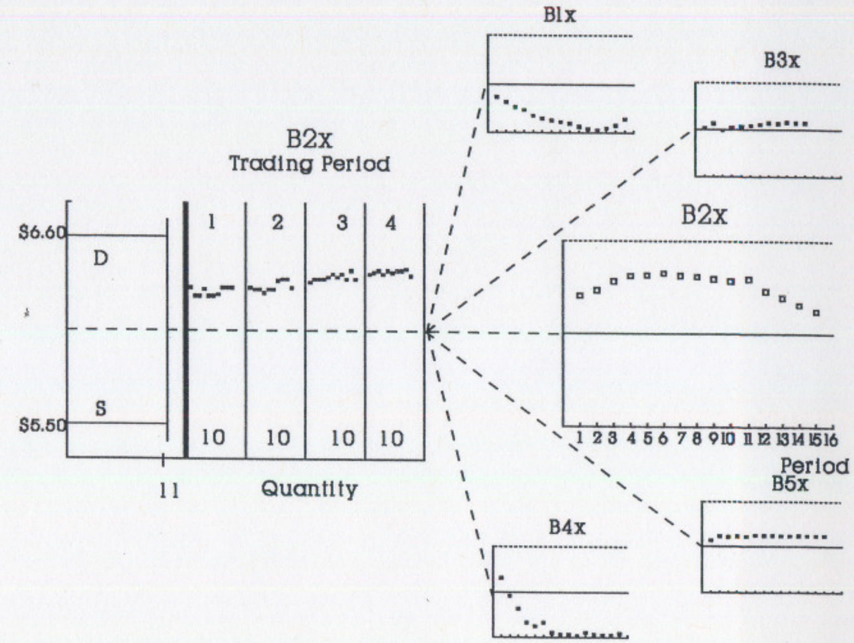

Figure 3.6 The Box Design and Mean Prices for Five Box Design Sessions (Source: Smith and Williams, 1989)

The supply-and-demand arrays on the left side of figure 3.7 illustrate a cyclical design used by Williams and Smith (1984). Market supply and demand alternate between S_l and D_l (drawn with heavy lines) in odd-numbered periods, and S_h and D_h (drawn with the light lines) in even-numbered periods. This cycle shifts the competitive price prediction by \$1.60, from \$3.00 in odd periods to \$4.60 in even periods, while the competitive quantity prediction remains constant at 7 units. Traders respond quickly to this nonstationarity. The data on the right side of figure 3.7 show a clear tendency to gravitate to the competitive prediction in each period.

The results in figure 3.7 were replicated by Davis, Harrison, and Williams (1991), who also investigated markets in which either demand or supply cycled, while the other curve stayed stationary. The two left-hand vertical bars in figure 3.8 pertain to the four sessions in which both demand and supply cycle between high-price and low-price phases.[18] All summary data are plotted as deviations from the

[18] The sessions summarized in figure 3.8 involved four buyers and four sellers, all with experience. Participants were paid a \$.05 commission per trade in every design except for the cycling supply-and-demand design (where the intersection of supply and demand ...

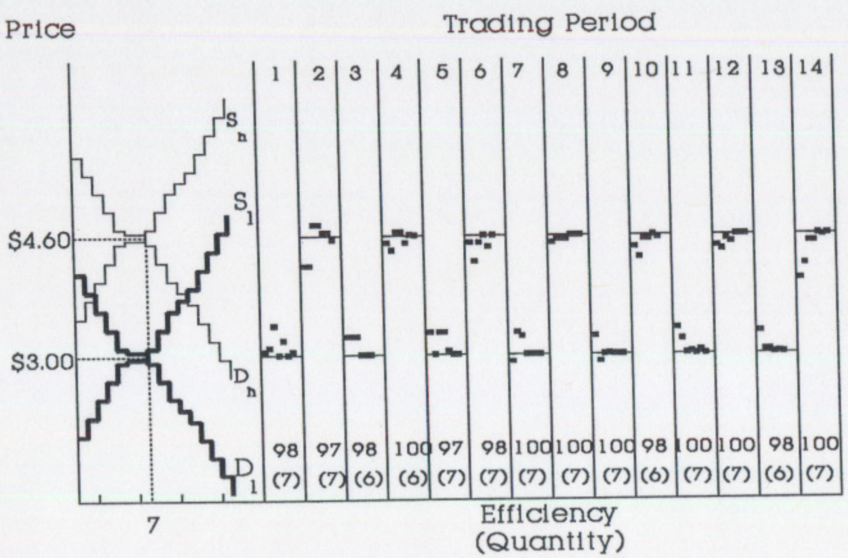

Figure 3.7 Contract Price Sequences with Cycling Supply and Demand (Source: Williams and Smith, 1984)

equilibrium price for the relevant phase, high or low. In the low phase of the cycling-supply-and-demand design, the closing price "*" overlaps the "·" that denotes the mean price, and both of these are just below the equilibrium price for this low phase. The two "—" symbols indicate the upper and lower limits of a price band that contains 95 percent of the data.[19] The second bar from the left shows the summary price data for the high-price phase of this design; notice that the mean closing price is quite close to the equilibrium, but that mean prices lag below when both demand and supply shift up together.

The two vertical bars in the center of the figure summarize price data from three sessions in a second design, where demand remains stationary and supply shifts outward in the low-price phase and inward in the high-price phase. The competitive price prediction varies by $.80 in this design, while the competitive quantity prediction varies by 4 (from five to nine units). Notice that mean prices are above the equilibrium in the low phase and below the equilibrium in the high phase, although closing prices are at the equilibrium level. This same pattern is observed for the case of cycling demand, shown on the two vertical bars on the right side of the figure. The market response to nonstationarities worsens when either supply or demand shifts. This difference indicates something about the nature of bargaining

[19] This band has no other statistical interpretation, since the observations are not independent.

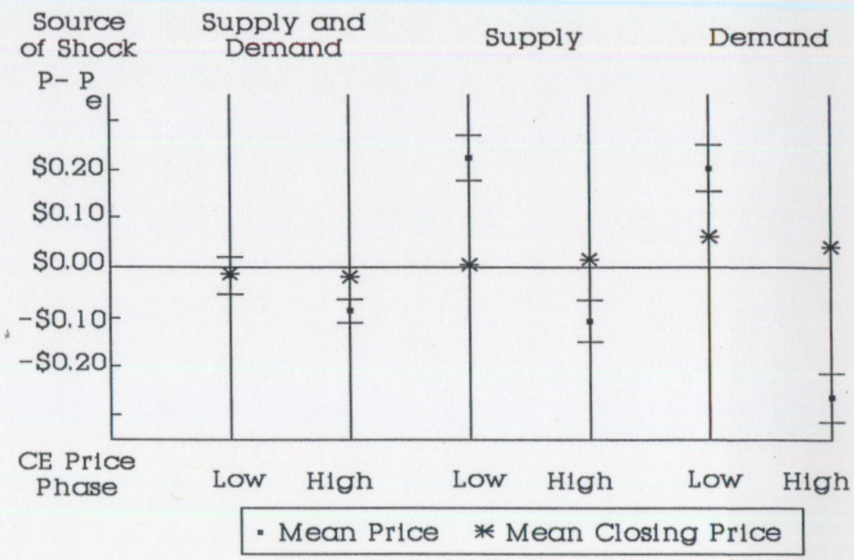

Figure 3.8 Mean and Closing Prices for Sessions with Cycling Supply and/or Cycling Demand (Source: Davis, Harrison, and Williams, 1991)

in the double auction. When both supply and demand cycle, both buyers and sellers are given incentive adjustments that signal a change in the equilibrium price. In contrast, when only supply or only demand cycles, the side of the market enjoying (suffering from) the change each period tries to maintain the old price (or convince the other side that less favorable price quotes are reasonable). Although prices in the previous period affect the initial prices in the subsequent period, the prices are driven toward the competitive price near the end of each trading period as the distance between the unit value and the unit cost for remaining untraded units shrinks.

The role of the closing price in a trading period as an indicator of the underlying competitive price is further illustrated in figure 3.9. The top part of this figure presents the sequence of contract prices for one of the cycling-demand sessions summarized on the right side of figure 3.8, with closing prices indicated by asterisks. Notice the tendency for prices to adjust more slowly than was the case with cycling supply and demand in figure 3.7. The bottom part of figure 3.9 presents the price sequence for a session where supply and demand are subject to random (i.e. noncyclical) shocks between trading periods, with the equilibrium price indicated by a horizontal dashed line. The volatility of prices is increased, but the proximity of the closing price to the competitive prediction in each trading period is remarkable.

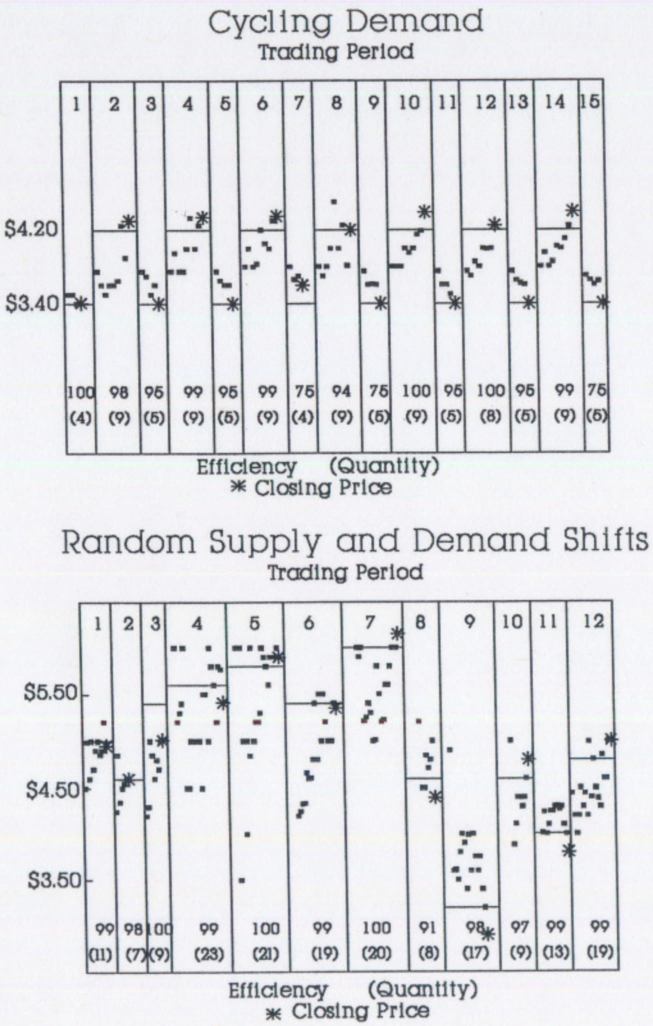

Figure 3.9 A Session with Regular Cycling Demand, and a Session with Random Demand and Supply Shocks (Sources: Williams and Smith, 1984, and Cox and Oaxaca, 1990)

The slower price adjustment for the random-shift design does not have much of an effect on efficiency, as can be seen by comparing the efficiency numbers in the bottom part of figures 3.7–3.9. Efficiency comparisons here are a little tentative,

as the market structure in the random-shift treatment differs from the structures of the other treatments.[20]

Summary

Competitive price, quantity, and efficiency predictions are resilient to each of the design boundaries discussed in this section. Competitive price levels are eventually reached, even in the presence of severe earnings inequities, for example. The competitive price prediction begins to break down only when supply-and-demand nonstationarities become sufficiently complex. The boundary experiments reviewed here provide considerable insight into the process by which a behavioral equilibrium is generated in double auctions: First, even under conditions of severe earnings inequities and conditions of random supply-and-demand adjustments, traders manage to extract the bulk of possible gains from exchange, at least for the market structures that have been investigated to date. Second, and as a consequence of traders extracting maximal surplus, the closing price represents an unbiased signal regarding the underlying equilibrium, as marginal units that are near the intersection of supply and demand tend to be traded at the end of a period, and contracts for these units must be struck at near-competitive prices. Third, there is some price inertia, in both experiments with box and nonstationary designs; traders have a tendency to negotiate initial prices that are close to those realized at the end of the previous period. Thus, in a repeated stationary design, equilibration probably occurs as a consequence of participants striking contracts near the competitive prices forced by the sale of marginal units in preceding period(s).

3.5 Double-Auction Results: Structural Boundaries

The design boundaries considered in the previous section have not been of much interest to economists in general. In contrast, industrial organization economists are primarily concerned with a variety of market characteristics and trade practices that may generate noncompetitive outcomes. How do laboratory double-auction markets respond to variations in these more standard structural variables?

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[20] The sequence of contract prices shown at the bottom of figure 3.9 is one of twenty-five sessions reported by Cox and Oaxaca (1990), who were interested in generating laboratory data to evaluate the performance of standard econometric techniques for the estimation of supply-and-demand functions. These markets each used ten experienced participants. At the beginning of each trading period, a participant drew a role assignment as one of five buyers or five sellers, and a valuation or cost schedule. Costs and valuations were drawn from a discrete version of linear supply and demand arrays. The additive random shocks to supply-and-demand were drawn from a uniform distribution on [–.4, .4]. A definite price prediction was essential to the Cox and Oaxaca study, so shocks were constrained in a way that supply and demand intersected with horizontal overlap

This section reviews the results of experiments designed to assess the effects of alterations along the environmental and structural boundaries that are the focus of antitrust analysis. This literature is quite limited, as the drawing power of competitive predictions remains high in all but the most extreme alterations.[21] We begin by considering the effects of limitations on the number of sellers, and particularly the problem faced by the double-auction monopolist. The effects of market power and opportunities for conspiracy are examined subsequently.

Limitations on the Number of Sellers

Many of the experiments reviewed above involved as few as four sellers, so it is clear that a very large number of sellers is not necessary to generate competitive outcomes. The question remains: what is the minimum number of sellers sufficient for competitive outcomes? Smith and Williams (1989) addressed this numbers boundary in an experiment composed of five monopoly markets and four duopoly markets.[22] Each of the duopoly markets generated prices much closer to the competitive level than to the joint-profit-maximizing price, and the competitive quantity was consistently exchanged in most trading periods. Moreover, sellers did not extract a supracompetitive portion of the surplus; the index of monopoly effectiveness was negative for the last three trading periods in three of the four duopolies.

The temptation of duopolists to price below each other is not an issue in a monopoly, but the monopolist has another dilemma caused by the sequential nature of double-auction price negotiations. At first blush, the ability to negotiate prices individually would appear to be an advantage. Since no Robinson-Patman laws discourage price discrimination in the laboratory, the monopolist may substantially increase profits by charging each buyer a price just equal to the buyer's unit valuation. In practice, however, negotiating prices for individual units often becomes more of a handicap than an asset. Although perfect price discrimination maximizes profits in a static monopoly, the act of selling units at different prices informs buyers that the monopolist can make profitable sales at lower prices.

Consider figure 3.10, where the monopoly price is determined on the left by the point on the demand curve that is above the intersection of marginal revenue

[21] Markets organized under other trading rules appear much more susceptible to variations in standard environmental parameters. See, in particular, the next chapter on posted-offer markets.

[22] Supply-and-demand arrays for the monopoly design were configured in a manner very similar to the market illustrated in figure 3.2. Duopoly experiments were conducted with variants of the monopoly design. In two of the four duopolies, cost steps on the supply array for the monopoly design were split between the sellers. In the remaining duopoly sessions, each seller had the same cost structure as the monopolists, and demand was doubled to preserve the competitive price prediction. Participants were paid either a $.05 or $.10 trading commission in all but one duopoly session. Also, participants were institution-experienced in all but one (duopoly) session.

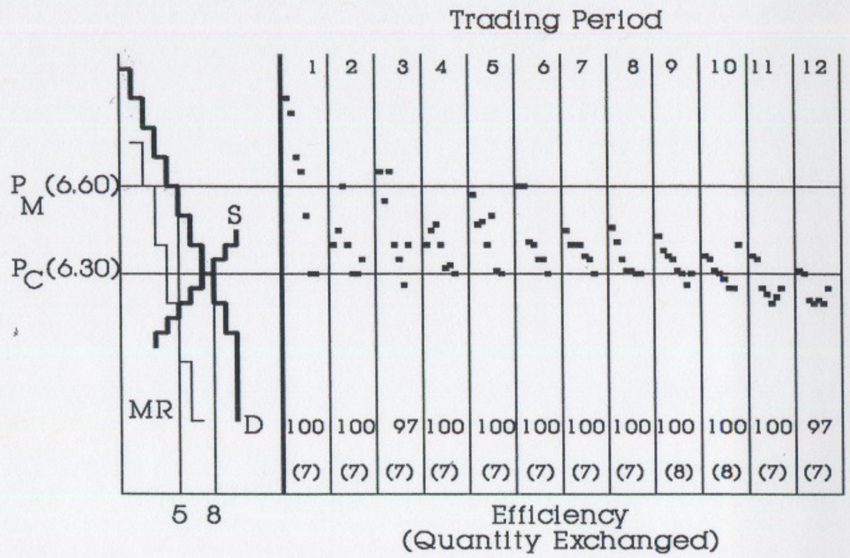

Figure 3.10 Predictions and Prices in a Double-Auction Monopoly (Source: Session M4xs from Smith and Williams, 1989)

(labeled MR) and marginal cost (labeled S). In the first period of this session, the seller starts with high prices, which price discriminate against buyers with units on the upper part of the demand curve. The final prices in this period are at the competitive level, and efficiency is 100 percent, as would be expected with price discrimination. This strategy is not as successful in subsequent periods, as buyers resist high prices after learning that the seller can sell units at lower, competitive prices. By periods 7 and 8, the monopolist is unable to obtain any contracts within twenty cents of the monopoly price, and mean prices fall below even the competitive level in periods 11 and 12. This tendency for prices to fall *below* the competitive levels was observed in the final periods of three of the five monopoly markets, yielding a negative index of monopoly effectiveness in these final periods.[23]

Conspiracies

Given the failure of double-auction monopolists to extract monopoly rents, it would seem unlikely that implicit or even explicit conspiratorial opportunities would

[23] Failed efforts at price discrimination were a predominant characteristic of all monopoly sessions reported by Smith and Williams (1989), although the monopolist managed to keep the mean price above the competitive level in two sessions. Smith (1981) reported similar results.

generate substantial price increases. This conjecture is supported by Isaac and Plott (1981a), who report an experiment with opportunities for sellers to conspire. Each of their (oral) double-auction sessions was composed of four buyers and four sellers. Buyers and sellers were in separate rooms; bids and offers were transmitted from room to room via telephone. Unknown to buyers, the sellers were given the chance to discuss prices between trading periods. Each seller meeting lasted for three minutes, and discussion was unregulated, except that cost information could not be disclosed, and side payments as well as physical threats were prohibited. Although sellers regularly tried to implement price-fixing agreements, given the opportunity, they were unable to maintain collusive prices. The four sellers encountered the same problem as double-auction monopolists. Although they could agree on a method of allocating reduced quantities at higher prices, the temptation to sell low-value units in the closing moments of a period was enticing, particularly if all sellers had completed the trades agreed upon by the cartel. Once again, buyers, upon seeing that sellers could afford to sell at lower prices, would refuse to accept higher prices in subsequent periods.[24]

Price Controls

The allocative inefficiencies of binding price regulations are well known; if regulation prevents price from separating high-value consumers from low-value consumers, then an inefficient amount of the good will be produced, and less efficient forms of allocation, such as queues or discrimination, may arise. Some industrial organization economists have further argued that even *nonbinding* price regulations cause inefficiencies, because they represent focal prices about which tacit conspiracies may form.

Isaac and Plott (1981b) report a series of sessions where both binding and nonbinding controls are variously imposed and/or removed from a double-auction market. Price controls prompted efficiency losses, but not exactly in the manner expected. Binding price ceilings indeed reduced market prices, but they generated even larger efficiency losses than might initially be expected. The price ceilings cause efficiency losses by inhibiting the formation of some contracts that would take place at the competitive price. Moreover, market efficiency falls because buyers with unit values below the competitive price are sometimes able to displace buyers with higher unit values. Finally, the removal of price controls, regardless of whether they were binding or not, caused a large increase in price volatility, as buyers and sellers searched for a market price free of the restraint.

Nonbinding price controls, however, do not appear to serve as the focal point for tacit conspiracies. To the contrary, not only do markets with nonbinding controls

[24] Isaac and Plott's results were replicated in the NovaNet environment by Isaac, Ramey, and Williams (1984). For a related result, see Clauser and Plott (1991).

appear to converge to the competitive price prediction, the prices appear to approach the competitive price in a way that makes potential conspirators worse off. With a nonbinding price ceiling slightly above the competitive price, for example, prices converge to the equilibrium from below.

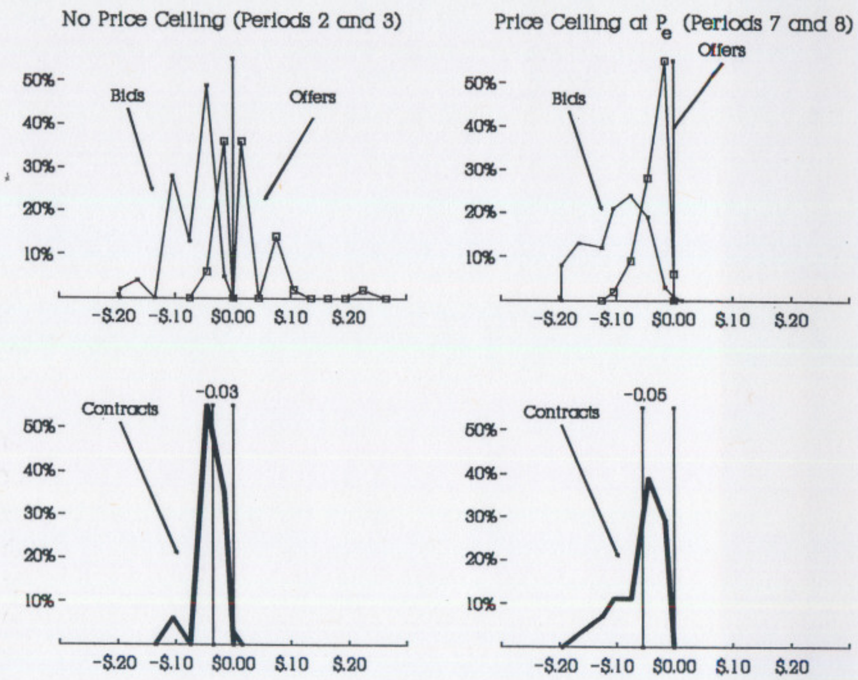

Figure 3.11 Bid, Offer, and Contract Frequency Polygons, With and Without a Nonbinding Price Ceiling (Source: Session 2pda26, Smith and Williams, 1981)

Smith and Williams (1981) conducted an experiment composed of sixteen double-auction markets to examine more carefully the effects of nonbinding price controls.[25] Each session was composed of three five-period "weeks." At the end of each week, supply-and-demand arrays were shifted by a competitive-price-disguising constant. In the second and third weeks, a price ceiling or floor was imposed at one end of the competitive price range (the design included a vertical overlap at the competitive quantity). Smith and Williams found that nonbinding controls affected the price-convergence path by truncating the range of acceptable bids and offers. Figure 3.11 illustrates the effect of a nonbinding price ceiling on

[25] Each session used four buyers and four sellers. All participants had institution experience and were paid a $.10 per trade commission.

bids, offers, and contracts in the second and third periods of an unregulated week (shown in the left panels), and in the second and third periods of a regulated week (shown in the right panels). Bid and offer distributions are illustrated in the upper panels as dotted and thin solid lines, respectively. Contract price distributions are illustrated in the lower panels as thick solid lines. All distributions are illustrated in terms of deviations from the competitive prediction. In comparing the left and right sides of the figure, note the change in the distribution of offers. While many offers are well above the $0.00 deviation in the upper left panel, they are truncated by the ceiling in the upper right panel. This asymmetry causes prices to be lower: As indicated by the vertical dashed lines in the lower panels, average prices were two cents lower in the presence of the nonbinding price ceiling.

Market Power

Are there *any* conditions under which double-auction markets do not generate competitive outcomes? The only known exception is an experiment with a "market-power design" reported by Holt, Langan, and Villamil (1986) and replicated by Davis and Williams (1991). Market supply-and-demand arrays for this design are shown on the left side of figure 3.12. The market is composed of five sellers and five buyers. All participants received a $.05 per-unit trading commission. Two of the sellers, S1 and S2, are each endowed with a large portion of total market sales capacity in this design. Units that pertain to these two sellers are identified with lines extending from the seller identifier to cost steps in figure 3.12. It is apparent from the figure that 16 units trade at the competitive price in this design. Note also that S1 and S2 each have a single low-cost unit, two intermediate-cost units, and two high-cost units. At the competitive price, S1 and S2 will only earn the nickel sales commission by trading the high-cost units. Moreover, there is a horizontal overlap of only one unit at the competitive price.

Both S1 and S2 possess market power in this design in the following sense: If either of these sellers withhold their two high-cost units, market supply shifts two units to the left and intersects market demand at a price deviation of $.25. If prices were to rise by $.25 as a result, then this withholding would be unilaterally profitable for either seller, as the extra $.25 earned on the sale of each of the three lower-cost units more than makes up for the $.05 commission lost on each of the unsold high-cost units.

The sequence of contracts for a representative market is shown on the right side of figure 3.12. Prices stabilize nearly $.20 above the competitive level. Holt, Langan, and Villamil observed prices consistent with market power exercise in four of their seven sessions, but outcomes were competitive in the other three sessions. Davis and Williams (1991) generated similar results in a series of eight NovaNet double-auction sessions, although price deviations were somewhat smaller (on the order of $.10 to $.15) and more homogenous (with fewer competitive outcomes).

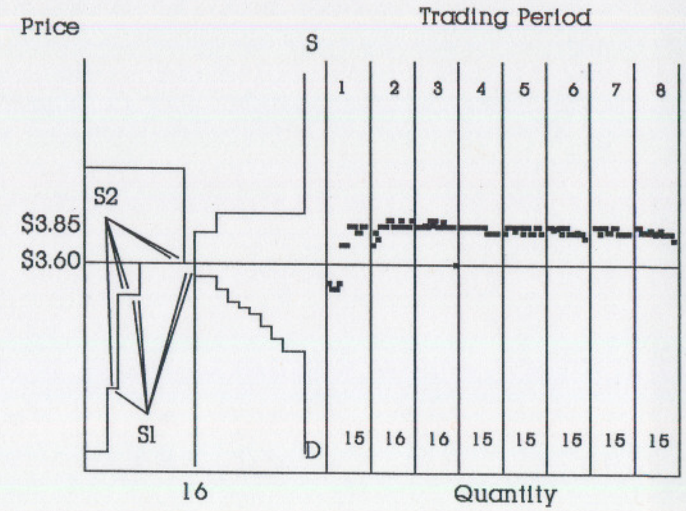

Figure 3.12 Contract Prices for a Session with Market Power (Source: Holt, Langan and Villamil, 1986)

There is some disagreement as to the source and importance of the observed deviations, since excess supply at supracompetitive prices is only one unit in this design (e.g., Plott, 1989, p. 1125). In any event, it is not the case that price increases were caused by withholding. Note in figure 3.12 that at least fifteen units traded in each period.

Summary

Behavior in the double auction appears as resilient to structural boundaries as it is to design boundaries. Competitive predictions are somewhat weakened when the market is reduced to only two sellers, but competitive price, quantity, and efficiency levels are often observed, even in monopolies. The only exception seems to be in an extreme market power design with excess supply of only one unit at supracompetitive prices. Markets organized under double-auction rules also appear to generate competitive outcomes in the face of opportunities for implicit, and even explicit conspiracy.

3.6 Multiple, Interrelated Double-Auction Markets

The combination of robust convergence properties and the similarity with securities markets has resulted in a wide range of experimental applications of the double-auction institution. These applications are primarily motivated by issues in finance and are the subject of the next section. A limited number of studies, however, have focused directly on the effects of generalizations of standard laboratory procedures. For example, Plott and Gray (1990) report that allowing traders the option of trading multiple-unit blocks has little effect on the performance of double-auction markets. Similarly, Mestelman and Welland (1987, 1988) find that performance is unaffected by permitting interperiod inventory carryovers or by requiring sellers to make production decisions at the beginning of each trading period. The remainder of this section pertains to two other modifications: (a) allowing middlemen traders to buy, sell, and inventory units across periods, and (b) allowing simultaneous trading in two related markets.

Middlemen and Seasonal Adjustments

The role of middlemen as efficiency-enhancing agents represents a natural extension of the study of cyclical price adjustments, which was considered in the previous section. Middlemen, who make profits by purchasing inventories of nonperishable goods in low-demand periods and selling inventories in high-demand periods, are often perceived as being nonproductive. Intertemporal arbitrage, however, can create surplus, just as the act of trading creates surplus.

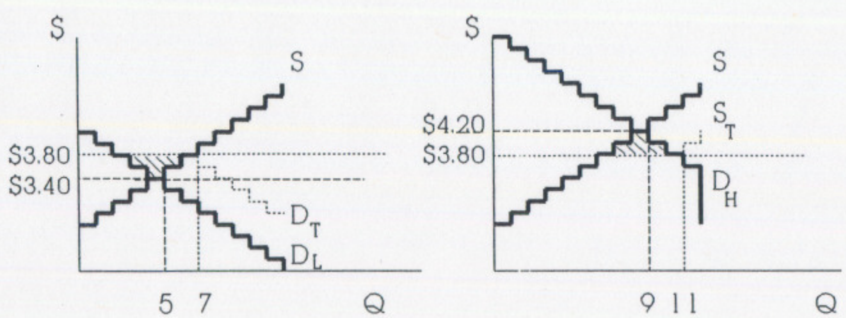

Figure 3.13 Efficiency Gains from Middlemen in an Intertemporal Equilibrium

The efficiency-enhancing role of the middleman is illustrated in figure 3.13. In a low-demand period, shown on the left side of figure 3.13, the demand (D_L) intersects supply (S) at a price of $3.40 and a quantity of 5 units. Efficient trading would generate a total surplus of $4.00. In a high-demand period, shown on the right side of figure 3.13, D_H intersects S at a price of $4.20, and a quantity of 9.

Maximum surplus is $14.40 in a high-demand period. Now consider the introduction of a class of traders who can buy, sell, and inventory units across periods. These middlemen could earn profits by buying units in a low-demand period at a price of about $3.40 and then selling them in the high-demand period for something slightly less than $4.20.

Competition between traders would reduce the profits from carrying inventories; trader costs rise as they vie with buyers and each other for units in low-demand periods. Similarly, trader revenues fall as they compete to sell units in high-demand periods. Absent storage costs, the inventory/sales role of traders creates a single-price, intertemporal equilibrium represented by the horizontal dotted line at $3.80, as demand shifts out to the dotted line D_T in low periods and supply shifts out to the dotted line S_T in high periods. In effect, trader purchases increase demand and raise the market price to $3.80 in periods of low demand, and the carryover increases supply and lowers price to $3.80 in periods of high demand. As a consequence, 7 units trade in low-demand periods, and 11 units trade in high-demand periods (if participants are paid a trading commission to induce the sale of zero-surplus units).

Two features of this intertemporal equilibrium are notable. First, as the difference between the acquisition cost and the sales price of inventoried units goes to zero, middlemen earnings are reduced to only trading commissions. Second, the middlemen create surplus. Purchasing units in periods of low demand generates an extra $.80 of surplus, shown by the shaded area on the left side of figure 3.13, so maximum surplus is 120 percent of that available in the market without middlemen ($4.80/$4.00). Selling units out of inventory in periods of high demand also generates an extra $.80 of surplus, shown by the shaded area on the right of figure 3.13, and maximum surplus is roughly 106 percent of that available in high-demand periods without middlemen ($15.20/$14.40).

Figure 3.14 shows a sequence of contract prices for a session conducted in this design reported by Williams and Smith (1984). There were four buyers, four sellers, and two traders. All participants had institution experience, and they were paid a $.05 trading commission on each transaction. Traders were given a $5.00 endowment at the outset of the experiment to finance initial purchases. Units purchased by traders had a maximum life of two periods, and a scrap value to traders of $1.00.[26] The odd-numbered periods were those with low demand.

As figure 3.14 suggests, middlemen do enhance efficiency in these markets. Except for the (preannounced) final period, efficiency exceeds the 100 percent level that is attainable without traders in all but one period (period 5).[27] The stability of

[26] The practical effect of the $1.00 scrap value is that it places a nonzero lower bound on prices for decaying inventoried units.

[27] Knowing that period 15 is the final period, traders would be irrational to purchase inventories for future sale.

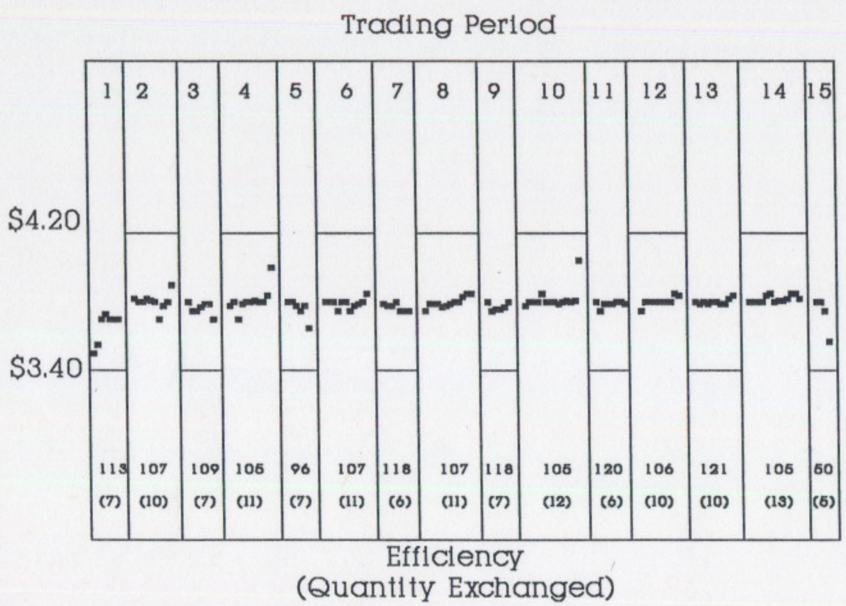

Figure 3.14 A Sequence of Contract Prices for a Nonstationary Market with Middlemen (Source: Session It-1, Williams and Smith, 1984)

prices across periods is also notable. Compare figure 3.14 with the sequence of contracts generated in this same cycling demand design, shown in the top of figure 3.9.[28]

A slight change in the interpretation of the middlemen experiment suggests a broader application. Think of middlemen as "producers" who buy a commodity (an input) in one market and sell it (as an output) in another. In most situations, the transformation from input to output is not 1 to 1, but is subject to diminishing returns. Goodfellow and Plott (1990) conducted an experiment where the production process involved a nonlinear transformation from input to output. There were three types of traders: input sellers, producers, and output buyers. The producers were buyers in the input market and sellers in the output market. Both markets were double auctions. The competitive equilibrium involved an input price and an output price that simultaneously equate supply and demand in both markets. It is much

[28] The results shown in figure 3.14 are representative of those reported by Williams and Smith (1984); Williams (1979); and Miller, Plott, and Smith (1977). However, convergence to an intertemporal price was somewhat less pronounced in sessions using a design where both supply and demand shift (Williams and Smith, 1984). Plott and Uhl (1981) report similar (uniform-price) results for a single session of a market composed of middlemen who purchased and sold in locationally distinct markets.

harder to calculate the competitive equilibrium for this market than for case of linear transformations between inputs and outputs: The anticipated output price affects the demand for the input, the input price affects the supply of output, and none of these effects are linear. The simultaneous determination of these two market-clearing prices would probably take most economists longer than the fifteen to twenty minutes that it took for the laboratory sessions to reach the competitive equilibrium.

Multiple commodities

One reason it is useful to review performance of the double auction in more complicated environments is to demonstrate the role of a market as a *decentralized* optimizing device. In the Williams, Smith, and Ledyard (1986) design, to be discussed next, participants trade for two commodities that are related in consumption.

Supply for commodities x and y was induced in the usual manner, with an integer-valued version of a linear cost function. Unlike the experiments reviewed above, however, sellers were able to sell each of the two commodities simultaneously in a trading period.

Moreover, the induced valuations of buyers were interdependent. Rather than providing a single-dimensional unit value array, an integer-valued version of a two-commodity utility function was induced by paying a dollar amount $V_i(x_i, y_i)$ to subject i for the purchase of a bundle of commodities (x_i, y_i). For example, table 3.5 provides the valuation schedule for an individual facing an integer-valued version of a C.E.S. utility function: $V = c(ax^r+by^r)^{1-r}$, with $a = .77$, $b = .23$, $c = .606$ and $r = .25$. This individual was endowed with $40.20 in "tokens" that could be used to purchase units of x and y. These tokens retained their value only within a trading period.

The complexity of purchase decisions in this context is clear from table 3.5. In making purchases, participants must evaluate the increased payoff of purchasing an extra unit of x or y, given past purchases and current prices. For example, suppose that at current prices and token income, the buyer can purchase two units of x and four units of y, which yields a total earnings of $2.10 (see the shaded entry in the table). If the price of x equals the price of y, the person could increase earnings from $2.10 to $2.23 by purchasing one more unit of y and one less unit of x. But if the price of y were twice as large as the price of x, then purchasing one more unit of y would mean giving up all x and only earning $1.11. The relative prices determine the slope of the discrete analogue of the budget line, and absolute price and income levels determine its intercepts. These experimental procedures provide an incentive for subjects to maximize the function $V_i(x_i,y_i)$ subject to the token constraint: $T \geq x_i P_x + y_i P_y$, where T is the endowment of tokens and P_x and P_y denote the prices of x and y, respectively. Induced utility maximization yields the

Table 3.5 Payoff Table for a Two-Commodity Double Auction

Units of Y \ Units of X	0	1	2	3	4	5	6	7	8
0	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01
1	0.22	0.61	0.72	0.80	0.86	0.92	0.97	1.02	1.07
2	0.44	1.05	1.21	1.33	1.43	1.52	1.59	1.66	1.73
3	0.66	1.46	1.67	1.82	1.94	2.05	2.15	2.23	2.31
4	0.89	1.85	2.10	2.28	2.43	2.55	2.66	2.77	2.86
5	1.11	2.23	2.52	2.72	2.89	3.03	3.16	3.28	3.38
6	1.33	2.60	2.92	3.15	3.34	3.50	3.64	3.77	3.89
7	1.55	2.97	3.32	3.57	3.77	3.95	4.10	4.24	4.37
8	1.77	3.32	3.70	3.98	4.20	4.39	4.56	4.71	4.85

individual demand functions:

$$x_i = d_{ix}(P_x, P_y)\,, \qquad y_i = d_{iy}(P_x, P_y).$$

Market demand functions, denoted by capital letters, are obtained by summing the individual demands of each subject index *i*:

$$X = D_x(P_x, P_y) = \Sigma d_{ix}\,, \qquad Y = D_y(P_y, P_x) = \Sigma d_{iy}.$$

The market supply function is obtained in a similar manner by summing individual sellers' marginal cost functions:

$$S_x(P_x) = \Sigma s_{ix}\,, \qquad S_y(P_y) = \Sigma s_{iy}.$$

The market clearing conditions

$$X = D_x(P_x, P_y) = S_x(P_x)\,, \qquad Y = D_y(P_x, P_y) = S_y(P_y)$$

are then used to calculate the two equilibrium prices and the two equilibrium quantities. For the parameters used in the experiment, these turn out to be \$3.90 and 12 for market *x*, and \$8.10 and 12 for market *y*. Given these prices and the token

income of \$40.20, the buyer could afford to purchase two units of *x* and four units of *y*, which results in earnings of \$2.10 (recall that the token dollars are worthless after the experiment). Since the price of *y* is about double the price of *x*, it is straightforward to verify that there is no other feasible commodity bundle in table 3.5 that yields higher earnings. Other buyers had different incentives.

The attainment of equilibrium in this market is analogous to the solution of a set of simultaneous nonlinear equations, although subjects are unaware that this is the market consequence of their behavior. Figure 3.15 displays the price sequences for one session using this design; prices in both markets are within a nickel of the competitive price prediction in the last three periods.[29] This same convergence standard was satisfied in ten of the fifteen sessions reported in this study. Figure 3.15 also lists the exchange quantities under the price sequence for each market. In each of the last three periods, at least eleven of twelve predicted units traded in each market.

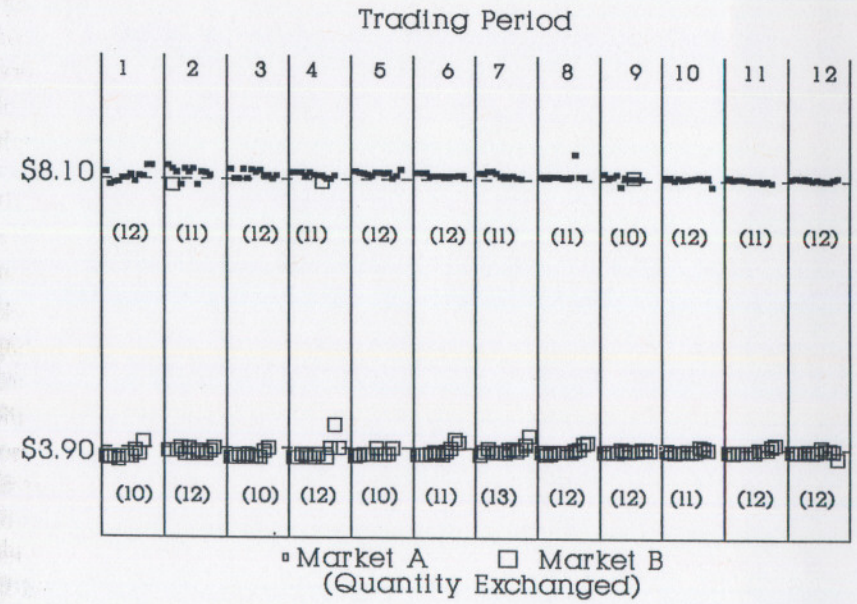

Figure 3.15 The Price Sequence for a Multiple-Commodity Double Auction (Source: Session 4pda009, Williams, Smith, and Ledyard, 1986)

29 Participants in this session had both role and environment experience.

3.7 Double-Auction Asset Markets

When Smith designed the oral double-auction institution, his intention was to create an environment that paralleled organized stock and security exchanges, such as the New York Stock Exchange. These exchanges are, of course, much more complex than the simple commodity markets studied thus far. One important difference between standard double auctions and markets for financial assets regards the nature of the traded good: Rather than having value for a single period, financial assets are typically long-lived. Thus, assets derive their value not just from current sales or valuation, but from a stream of dividends that accrue over time. Uncertainty becomes a problem when goods are long-lived, because the current value of an asset depends on expectations regarding future dividend streams and resale prices. Heterogenous attitudes toward risk and time can alter expectations and affect the value of an asset.

This section introduces the experimental literature regarding asset markets. The presentation is divided into two parts. First we describe how to set up a laboratory market for trading a single asset, and then we review some of the general findings relevant to this particular design. Of special interest is the concept of a *rational expectations equilibrium*, fundamental to much macroeconomic and financial theory. In general, this equilibrium is just a requirement that beliefs and expectations be consistent with rational actions based on these expectations. The specific example that follows will help clarify this general notion.

A Laboratory Asset Market

This section describes a laboratory asset market devised by Smith, Suchanek, and Williams (1988). The design involves nine participants, who engage in trading under double-auction rules for fifteen periods. Unlike a market for a single-period asset, the number of trading periods is important for determining the value of the asset. This information is publicly announced at the beginning of the session. Also, unlike a market for single-period goods, there is no distinction between buyers or sellers. Rather, all agents are *traders*, who each possess a portfolio consisting of cash and units of the asset. During the session, traders may buy and sell asset units, subject to the limitations of their portfolio. Trader portfolios are summarized in table 3.6. As is clear from the table, the initial portfolios need not necessarily be identical. In this case, there are three different cash/asset portfolio combinations, ranging from three asset units and an initial cash balance of $2.25, to one asset unit and an initial cash balance of $9.45.

The multiperiod nature of an asset changes the way that values are induced. Rather than determining buyer valuation through redemption values, or seller valuation through sales costs, the value of each asset unit is derived from a stream of dividends that it generates throughout the session. This dividend stream is not

Table 3.6 Endowment Portfolios in a Nine-Trader Asset Market

Trader Identities	Asset Units	Initial Cash Balance	Expected Value of Portfolio
Traders 1 – 3	3	$2.25	$13.05
Traders 4 – 6	2	$5.85	$13.05
Traders 7 – 9	1	$9.45	$13.05

certain. At the end of each trading period, the experiment monitor draws and publicly announces a common dividend for all asset units. Prior to the start of the next trading period, each trader's cash holdings are augmented by the product of the dividend and the number of units held. The dividend draw is from one of four equally likely alternatives: $.60, $.28, $.08, and $.00. Since the alternatives are equally likely, the expected per-period dividend draw is $.24.

Asset units retain no residual, "buyout" value at the end of the fifteenth period in this design. Thus, the intrinsic value of the asset is derived entirely from its dividend stream. At any point during the session, the value of an asset may be calculated from the number of remaining dividend draws. For example, during the fifteenth period of a session, only a single dividend draw remains, so the expected value of the asset is $.24. Similarly, two dividend draws remain during the fourteenth period, so the expected value of the asset is $.48. Reasoning backward, it follows that each asset unit has an expected value of $.24(15) = $3.60 at the outset of the session. By adding each trader's initial cash balance to the product of $3.60 and the number of asset units, one can show that the expected value of each portfolio in table 3.6 is $13.05.

In addition to dividend payments, capital gains or losses may be realized by traders through the purchase and sale of assets. Each trader may buy and sell asset units as often as desired, subject to two limitations. First, traders may not sell units that they do not own at present (no short sales), and they must pay for asset units with current cash balances (no margin purchases). Second, "churning" is prohibited, for example, traders may not create a false sense of market activity by buying and selling asset units from themselves. At the end of the session, participants are paid the accumulated cash balance in their portfolio.

In this design, units have the same intrinsic value for all participants. Thus, trade should occur only if traders have divergent attitudes toward risk or different expectations regarding asset values. Although a scattering of differences in risk and time preferences would motivate some trading, most economists would probably expect low trading volume, at prices close to the intrinsic value. In particular, rational expectations rules out bubbles via a backward induction argument, which for simplicity is presented under the assumption of risk neutrality: At the end of the final period, there is no future, so expectations are irrelevant and units should be traded at the expected dividend value of $.24. Therefore, the only rational expectation for the last period's price is $.24, so units will trade for $.48 in the second-to-last period, and so forth. Given the known, finite horizon, no general speculative price increase should be observed.

Some Central Results

The three panels of figure 3.16 illustrate the mean contract prices and underlying values for a representative series of three sessions reported by Peterson (1991).[30] In each panel, the expected underlying value is shown as a dashed line. The kinks in the dashed line illustrate the discrete decline in intrinsic value following the payment of each period's dividend. The solid line connects the observed mean contract price in each trading period. Trading volume for these same three sessions is illustrated in the three panels of figure 3.17.

The left-most panel in each of the figures illustrates the results of an initial session in which participants had no previous experience with the asset market. (All participants, however, had participated previously in a standard double auction.) The mean price series in figure 3.16 reveals a large speculative "bubble" in contract prices, followed by a crash in the latter periods of the session. The quantity data in figure 3.17 show that the bubble arose under active trading in this initial session.

Predictions of the rational expectations equilibrium are much more nearly approximated when participants have experience with the institution. Seven of the nine participants who generated the "inexperienced" data series in figures 3.16 and 3.17 were subsequently brought back for a second session, along with two other participants who had previously participated in a single asset market session. Results of this "once-experienced" session are illustrated in the middle panels of figures 3.16 and 3.17. All nine of the participants in the once-experienced session were brought back for the "twice-experienced" session illustrated in the right-hand panels of the figures. Behavior in these second and third sessions is much more rational; the size of the speculative bubble diminishes and trading volume drops in each subsequent session. By the time participants are twice-experienced, a very low volume of trade is sustained, at prices very close to intrinsic value.

Consider some measures of the magnitude of speculative price increases and trading volume. Define *R* (Reach) as the normalized absolute price deviation from intrinsic value, or the ratio of price minus intrinsic value to intrinsic value. If all

[30] Even though the original design is due to Smith, Suchanek, and Williams, we present Peterson's results at this point because they clearly illustrate experience effects that turn out to be critical in this asset market context.

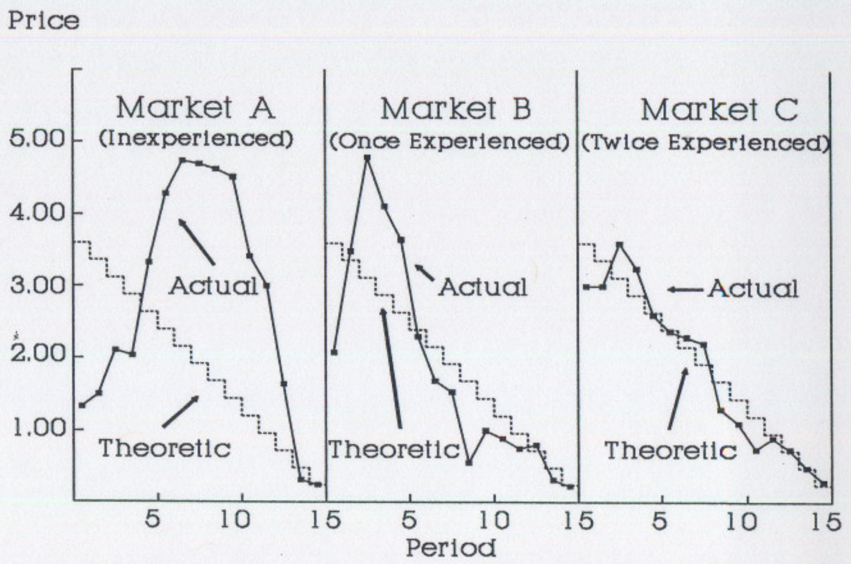

Figure 3.16 Intrinsic Value and Mean Prices in a Sequence of Three Double-Auction Asset Markets with the Same Participants (Source: Sessions 3pd295, 3pd296, and 3pd297, Peterson, 1991)

trades took place at intrinsic value, on average, this ratio would equal 0. Similarly, define *TO* (Turnover) as the average number of times each asset unit traded in a session. The higher *TO*, the greater the trading volume. In a rational expectations equilibrium with identical traders, both $R = 0$ and $TO = 0$.

Large bubbles were observed under conditions of active trading in ten sessions with inexperienced participants reported by Smith, Suchanek, and Williams (1988). On average, $R = 5.68$, and $TO = 4.55$ for these sessions. Speculative behavior diminished in three comparable sessions with once-experienced participants; *R* fell to 2.77 and *TO* fell to 3.2. Rational-expectations predictions are nearly met in two comparable sessions with twice-experienced participants. In these sessions, $R = .28$, and $TO = 1.7$.[31]

Given the high volatility of stock prices in the late 1980s, the speculative bubbles observed in laboratory sessions attracted considerable attention. Subsequent investigations have indicated that bubbles are not simply an artifact of the simple laboratory environment. King et al. (1991), for example, report that bubbles are

[31] Smith, Suchanek, and Williams (1988) report the results of twenty-six asset market sessions. A number of these sessions, however, involved special treatments designed to assess the nature of price bubbles. Summary statistics in this paragraph pertain to a subset of these sessions that were identified by King et al. (1991) as suitable for examination of experience effects.

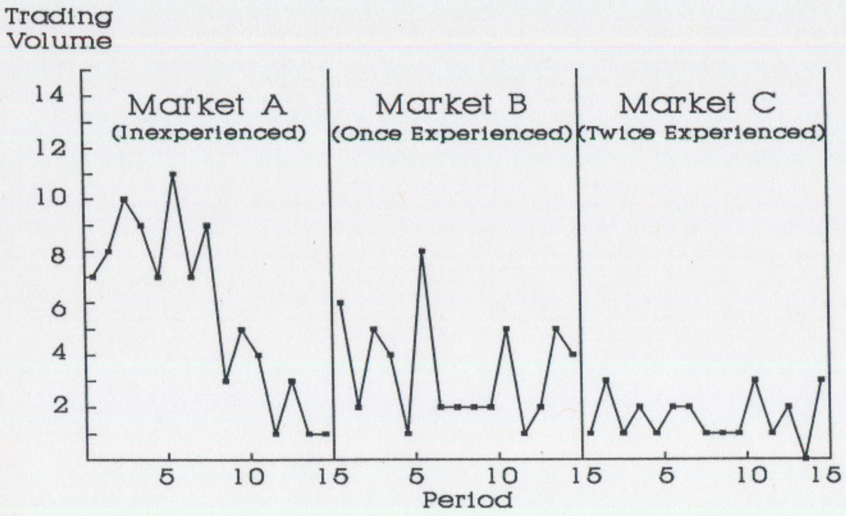

Figure 3.17 Transactions Quantities in a Repeated Series of Double-Auction Asset Markets (Source: Sessions 3pd295, 3pd296, and 3pd297, Peterson, 1991)

resilient to a number of institutional variations, including modifications that allow for short sales, margin buying, and brokerage fees. As might be expected, short sales and margin buying appear to exacerbate speculative behavior, since they give more latitude to aggressive, risk-taking agents. These authors also report that speculative behavior is resilient to portfolio variations and even to the injection of "insiders" who were informed of the persistence of speculative bubbles in the laboratory markets. Moreover, several rules intended to mitigate price volatility in the laboratory are not effective. In particular, limit-price-change rules appear to exaggerate speculative behavior, as such rules limit the maximum loss participants can sustain in any trading period.

Nor are the bubbles merely a consequence of an unsophisticated subject pool. Both the size and duration of speculative bubbles were undiminished in sessions conducted with business professionals (Smith, Suchanek, and Williams, 1988; Van Boening, 1990; King et al., 1991). Rather, it appears that the critical determinant of speculative behavior is common expectations that derive from common experience.

Although investigations of speculative bubbles suggest that they are remarkably robust, inferences regarding behavior of natural markets nevertheless remain precarious. This said, speculative behavior *may* play an important role in natural markets. In fact, Vernon Smith conjectured that the boom-and-bust behavior observed in natural markets is an inevitable consequence of divergent expectations and novice traders: "People panic. . . . They do it in our laboratory markets until

they learn that trading away from fundamentals doesn't yield sustainable, continuing profits. . . . [In the real world,] these bubbles and crashes would be a lot less likely if the same traders were in the market all the time. [But novices are always entering the market.]"[32] One important task for laboratory research is to evaluate institutional devices that are intended to reduce the likelihood and intensity of speculative bubbles.

3.8 Conclusion

In markets organized under double-auction trading rules, the predictions of the competitive model appear to be robust to a wide variety of supply-and-demand configurations, to very harsh restrictions on the number of agents, and to conditions regulating communications between sellers. Competitive price theory also does a good job of organizing data in some enriched double-auction market structures, for example, where participants purchase multiple commodities, and where middlemen can enhance efficiency via speculation in an intertemporal setting. Although the loss of control in markets where traders buy and sell multiperiod assets has important behavioral consequences when participants are inexperienced, even these markets generate rational expectations equilibria with experience, as participants come to share common expectations.

But exactly *why* does the double auction perform so impressively? When will it fail? Answers to these questions require articulation of a testable model of the underlying double-auction game. No generally accepted theoretical model of the double auction exists, though admirable efforts have been made by Easley and Ledyard (1986) and Friedman (1984). It is easy to see why theorists have had such difficulties with the double auction; the rich message and action spaces characterizing the double auction hopelessly swamp game-theoretic analyses, unless major simplifying assumptions are introduced. Rather than starting from first principles, tractable models of the double auction will likely have to be based on some set of behavioral assumptions, justified on the basis of observed responses, that clearly generate convergence in simplified variants of the double auction. As an effort to provide some bases for such assumptions, we close this chapter by summarizing the effects of the various treatments discussed above on the convergence path, or on the adjustment process of double-auction markets to the competitive price prediction. We offer four observations.

First, *complete information regarding supply and demand arrays is not only unnecessary, but it may impede the convergence process.* The very fact that markets

[32] Jerry Bishop, "Stock Market Experiment Suggests Inevitability of Booms and Busts," *Wall Street Journal*, sec. 2, p. 1, November 17, 1987. Bracketed parts were attributed to Smith but are not direct quotes.

generate competitive predictions when participants are provided only with private information about costs or values (and public information about prices) challenges standard assumptions about conditions necessary for convergence.[33] Furthermore, limited available evidence suggests that the addition of complete information may retard rather than facilitate convergence. Smith (1980) reports results of an eight-session experiment conducted in a "box" design with severe earnings inequities in equilibrium. Complete information regarding costs and valuations slowed but did not interrupt the ultimate convergence in these markets.

Second, *even though cost and value information is private, the negotiating process is sufficiently symmetric that participants tend to split the available surplus in initial contracts.* This effect was cleanly documented by Smith and Williams (1982), who report an experiment designed to evaluate the effects of such rent asymmetries. Six sessions were conducted in a design where two-thirds of the surplus went to buyers and one-third went to sellers, if all contracts were struck at the competitive price prediction. Another six sessions were conducted in a symmetric design where the rent distribution was reversed. Smith and Williams conclude that the distribution of the actual surplus is affected by the relative theoretical magnitudes of consumers' and producers' surplus; when producer surplus exceeds consumer surplus, the price path tends to the competitive equilibrium price from below. When consumer surplus exceeds producer surplus, the convergence path tends to the competitive price prediction from above.[34]

Third, *the closing price in a trading period tends to provide remarkably precise information about the underlying competitive price.* This was noted in experiments in nonstationary environments. The relationship between the closing price and the competitive price prediction was also important in monopoly experiments. Monopolists were unable to extract monopoly prices consistently because they attempted to exercise their market power through price discrimination rather than quantity restriction. In the double auction, price discrimination often results in competitive prices because buyers will not repeatedly accept less favorable contract terms than those extended to other buyers.

Finally, *early contracts appear to have an important influence on the terms of trade for later contracts.* This was observed in "box" design experiments with vertically overlapping supply and demand. The role of past prices on the range of contract terms is also illustrated by price inertia from period to period in nonstationary environments.

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[33] This point is elaborated by Smith (1982).

[34] Curiously, however, Smith and Williams find that the effects of changes in the distribution of the surplus are not symmetric. Perhaps because of the experience of subject pool members as buyers rather than sellers in natural markets, laboratory buyers tend to do better than sellers, and the contract path for markets characterized by relatively high buyer surplus tends to be closer to the competitive prediction than the contract path for a market with relatively high seller surplus.

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CHAPTER 4

POSTED-OFFER MARKETS

4.1 Introduction

There are many markets in which firms will only sell at publicly posted "list" prices. Such posted pricing became common in retail markets in the last century, when store owner/managers were forced to rely on numerous sales clerks in order to exploit economies of scale in operation. Posted pricing is also a consequence of government regulation. In industries such as shipping and alcoholic beverages, regulatory agencies sometimes require that prices be filed with the agency and that discounts not be granted.[1] Theoretical models of these markets are usually built on the assumption that sellers choose prices or other decisions simultaneously at discrete points in time.

The first oligopoly experiments with sellers making simultaneous and binding decisions were conducted in the 1960s (e.g., Fouraker and Siegel, 1963; Friedman, 1963, 1967, 1969; Dolbear et al., 1968; and Sherman, 1972). These early studies were designed to test predictions of alternative theories in Bertrand (price-setting) or Cournot (quantity-setting) environments. To approximate the assumed conditions of oligopoly theory, subjects with seller roles were typically presented with the payoff consequences of their own and others' decisions in tabular form, and the decisions of simulated buyers were subsumed in the construction of the tables.

[1] Ketcham, Smith, and Williams (1984) discuss the origins of posted pricing in the United States, and Eckel and Goldberg (1984) describe a regulatory price-posting process in the Canadian brewing industry.