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The Mechanics of Automated Trade Execution Systems*

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The algorithms of three automated trade execution systems are compared with respect to price discovery and quantity determination in markets for futures, options, and stocks. Efficiency of these systems is measured using the classical benchmark of Walrasian equilibrium pricing; welfare is measured in terms of trader and customer surplus. Floor trading is analyzed similarly and provides another benchmark for comparison of system performance. *Journal of Economic Literature* Classification Number: 314. © 1990 Academic Press, Inc.

1. INTRODUCTION

The potential for efficiently discharging the fundamental tasks of price discovery and quantity determination in financial markets via automated systems has been formally recognized since 1963.[1] The focus of this paper is on the most controversial of automated procedures, computerized trade

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[1] See Special Study of Securities Markets, Report of the Special Study of the Securities and Exchange Commission (1963), in H. R. Doc. No. 95, 88th Congress, 1st Session, pt. 2 at 358 and 678.

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execution itself. Professional and academic debates are centered around the efficiency of computerized execution versus floor trading with respect to availability of information, the efficiency of the market in terms of price setting, and the amount of liquidity available under the two systems. Such arguments have not been grounded in the actual process generating prices and quantities by computer, but in speculation as to the results of any such computerized process.[2]

The purpose of this paper is to analyze existing systems, either under recent regulatory review or in operation, with respect to the price discovery and quantity determination process. Regulatory concerns demand a clear statement of such trade execution algorithms as well as a benchmark by which performance may be measured. With respect to the former, Ruder and Adkins (1990) interpret parts of Section 11A of the 1975 Securities and Exchange Act as identifying the Commission's obligation "to see that technological change introduced into the market is functionally sound and workable." An understanding of how the computer is expected to set prices and quantities is essential to any such evaluation. In Sections 6, 11A, and 15A, there is reference to the idea that automation of markets should impose no unnecessary burdens on competition, should "perfect the mechanism of a free and open market," and should foster "fair competition" among and within markets comprising a national market system. In the same spirit, the phrase "in the public interest" figures largely in the debate over whether an automated execution system qualifies as a market for futures trading under the Commodity Exchange Act of 1974. The public interest is defined in Section 3 of the Act as (i) reliable price discovery, (ii) broad-based price dissemination, and (iii) effective hedging against price risks. Section 5(g) states that any market must show that its activities are not contrary to the public interest, and the first requirement is central to this paper. A competitive benchmark for system performance is required here as well, because the Commodity Futures Trading Commission Regulation 1.38 states:

> All purchases and sales of any commodity for future delivery, and of any commodity option . . . shall be executed openly and competitively by open outcry or posting of bids and offers or by other equally open and competitive methods in the trading pit or ring or similar place provided by the contract market.

Given the Commission's mandate to "determine the feasibility of trading by computer,"[3] the definition of the public interest, and the language

[2] A variety of different perspectives is contained in the *Proceedings of the CFTC Conference on Automation in the Futures Industry*, on file at the Commodity Futures Trading Commission. Melamad (1977) is the most complete defense of floor trading relative to automated trade execution. More recent discussion and references can be found in Lucas and Schwartz (1989).

[3] Commodity Exchange Act, Section 18, 7 U.S.C. (Suppl. V, 1975).

above, it is clear that the main issue in any debate over floor versus machine is the competitiveness of the price discovery process.

The classical benchmark of Walrasian equilibrium pricing is used to provide a standard of competitive behavior. Total surplus is used as the welfare measure. The Walrasian paradigm is a classic competitive standard in market analysis and can be applied to allow cross-system comparisons of pricing, as well as to provide a measure of pricing efficiency for floor trading scenarios. It is admittedly not the only possibility, and other standards that are richer in terms of strategic behavior might be developed and applied. The algorithms themselves are complicated in such a way as to preclude a mathematically rigorous analysis along such lines at this stage in the research, and it is well known that satisfactory theory does not even exist for strategic floor trading in the context of continuous open auctions. The analysis as presented here has the advantage of clarifying all aspects of the implementation of automated trade execution systems, while allowing cross-system comparisons relative to a commonly accepted benchmark.

The work is further motivated by the sheer extent of the automation of the transaction process in financial securities markets. Table I contains a partial listing of automated trade execution systems in operation today. The use of automation in the trading of stocks, futures, and options is steadily increasing. Existing exchanges are modifying systems or adopting new ones, and most new or planned exchanges have an automated trade execution component. The number of nonexchange automated systems is growing as well. The Toronto Computer-Assisted Trading System (CATS), which covers 800 of 1600 stock listing and handles about 20% of TSE volume is currently undergoing an overhaul to accommodate much more extensive automated execution in a larger number of securities and with higher volume.[4] This system is being licensed worldwide, and Tokyo's Computer-Assisted Order Routing and Execution System is quite similar to it. The Copenhagen Stock Exchange plans to fully automate stock trading, and other Scandinavian exchanges are expected to institute the same system as Copenhagen. The Vancouver Stock Exchange has plans to phase in an automated system to replace the existing floor. Similar activity is present in options and futures. The Stockholm Options Market uses a screen-based, floorless system; small orders are executed automatically. The floor-based Sweden Futures and Options Exchange also has an internally developed automated trading system. Tokyo's trading in its government bond future is by automated execution, while Ireland's planned exchange for domestically oriented futures and options is

[4] See Bunting (1989) for details as to the revision of the Toronto system. Much of the information on planned automated execution systems comes from a situation analysis report by R. DuFour, Executive Vice-President of the Chicago Board Options Exchange, August 1988.

TABLE I

EXTENT OF AUTOMATION OF THE TRADE EXECUTION PROCESS[a]

SCOREX		
PSE	1969	
PACE		
Phlx	1976	
MAX		
MSE	1981	
BEACON		
BSE	1988	
DOT		
NYSE	1976	(Specialist backup only)
NSTS		
CSE	1978	
SOES		
NASDAQ	1985	
RAES		
CBOE	1985	Options
GLOBEX		
CME	1989	Futures
SAEF		
UK	1989	(Adjunct to autoquote system, 1986)
CATS		
Toronto	1977	(Revised system operational, 1990)
Madrid	1989	(Revised system, different design, 1987)
Paris	1986	
Brussels	1988	
Sao Paulo		
CORES		
Tokyo	1982	
SOFFEX		
Geneva	1988	Options and futures

[a] This list is not a complete enumeration of all automated execution systems worldwide. See text for additional information.

by the use of a fully automated system. The list could go on, and nonexchange systems swell the count.

Three such systems are examined in this paper with respect to their mechanics and operating efficiency, covering futures, options, and stock trading. An algorithmic description of each system is given in Section 2 in a common format: order eligibility, trade price, trade quantity rules, maximization of total trade size (extent of exposure to the market), and the priority rules for standing orders. Section 3 is devoted to an examination of the performance of these systems. The futures trading system is a potential replacement for floor trading. Price discovery, quantity determination, and total surplus (trader profit) of this automated system and the trading floor are examined relative to the benchmark of Walrasian clearing. The automated system is found to perform slightly better than floor trading in terms of surplus per trade, a commonly used measure in experimental markets. Improvements over floor trading also are found in the price discovery process. The options and stock systems operate in tandem with a trading floor. A floor market simulation is used to transmit relevant information to the automated trade execution systems and to monitor the price quotations of individual traders. Surplus loss to market makers using these systems is documented in absolute terms and as a percentage of average trading price on the floor. It is found that market makers lose between approximately 6 and 9% of average trading prices when dealing on the system rather than on the trading floor. Sensitivity of these results to the number of traders on the systems relative to the number on the floor and to the arrival rate of news to the floor is investigated. A summary of system characteristics and a brief discussion of the large-order handling capability of the futures system are given in the last section.

2. TRADE MATCHING ALGORITHMS

Futures Trading: The Globex System

The Chicago Mercantile Exchange (CME) submitted the basic organization, rules, and amendments to existing exchange rules concerning the Globex trading system to the CFTC in a series of letters beginning May 11, 1988.[5] Globex is to be an automated system for trading CME futures and options outside regular floor trading hours in Chicago. A small number of CME contracts (currencies) are to be traded on the system at first, but it is envisioned that all CME contracts, as well as other domestic and even foreign exchanges' contracts eventually will be traded via Globex. Special spread markets for important standard instrument combinations are to be traded as separate instruments. Only good-until-cancelled limit orders will be accepted when the system starts up; market orders are not accepted.

The geographical scope of this operation is potentially quite large. The system will operate under the aegis of "partner exchanges," which include the CME, Tokyo, and France's MATIF (Marche a Terme International de France); additional memberships are expected. The CME is developing the system as a joint venture with Reuters, which currently boasts offices in 170 cities and has over 165,000 terminals currently active in 118 countries.

[5] The original proposal is published in 55 *Federal Register* 25528, July 7, 1988. The system was approved in February 1989.

The precise nature of information to be offered on the Globex display has been in a state of flux since this research began. The CME currently advertises a screen showing (for any given instrument) the best bid and offer with size, the last sale price and quantity, associated spot market prices, and the limit order book, the last as a "pop-up" screen option. The limit order book was envisioned as a feature to be added much later when the system originally was proposed and approved.

The rules governing the automatic trade execution system are as follows.[6]

1. *Order eligibility*. A new order is eligible to be matched with a standing order, and a trade will result, whenever the following conditions occur:

1.1 One order is a buy order and the other is a sell order.

1.2 The two orders are for the same contract.

1.3 The price of the buy order is greater than or equal to the price of the sell order.

2. *Trade price*. If an order match is possible according to the criteria of Rule 1, then the trade will take place at the price of the standing order.

3. *Trade quantity*. If an order match is possible according to Rule 1, then the trade will take place for a quantity equal to the smaller of the

3.1. remaining quantity of the new order;

3.2. remaining quantity of the standing order.

4. *Maximization of total trade size*. If there are multiple standing orders eligible for matching against a new order, then matching will be considered in priority sequence until one of the following conditions is attained:

4.1. the new order is completely filled;

4.2. all eligible standing orders have been considered.

5. *Standing order priority*.

5.1. Price: for buy orders, higher price is higher priority; for sell orders, lower price is higher priority.

5.2. Quantity: a standing order for "primary quantity" has a higher priority than that for "supplementary quantity" if they are both at the same price. A standing order for supplementary quantity has priority over a standing order for primary quantity if the supplementary quantity is at a better price. A supplementary quantity order may be executed only in conjunction with its associated primary quantity.

5.3. Time: Within the same price and quantity type, older orders have higher priority.

[6] These rules are summarized in CME Responses to Questions Contained in CFTC Letter Dated October 6, 1988, Exhibit 1, Question No. 25, January 1989.

There also are special rules governing the setting of an opening price in the Globex system. Rule 5.2 requires some additional explanation. When entering an order, a trader can specify a primary quantity and a secondary quantity. The secondary quantity is excluded from the best bid and offer display and is executed only after all shown quantities at a specific price are filled. The secondary is executed with the same priority as the displayed quantities. Once the displayed quantity of an order is fully executed, any unfilled secondary quantity is cancelled. In other words, a trader need not "show his hand" completely at the time of entering a potentially large order.

Consider the following set of bids and offers for one specific contract:

	Bids			Offers		
Time	Price	Primary	Secondary	Price	Primary	Secondary
10:00	35.65	2	2			
10:01	35.67	2	1			
10:02	35.65	1	3			
10:03				35.63	6	

Trade execution begins with the primary quantity of two contracts at 35.67 executed against two of the six offered; the execution price is 35.67, the price of the standing order. The associated secondary quantity of one also is bought at that price. The remaining three offered contracts are executed against the two primary and one of the two secondary bids entered at 10:00. The remaining secondary quantity entered at 10:00 is dropped from the system; it cannot stand alone. The standing bid in the market now is at 35.64 for one primary order and three secondary. The transactions record will show three contracts traded at 10:03 for 35.67 and three contracts traded at 10:03 for 35.65.

Options Trading: The RAE System

The Chicago Board of Options Exchange (CBOE) Retail Automated Exchange System (RAES) was approved as a pilot program in January 1985 and first implemented on February 1, 1985.[7] The system has been approved as permanent and has been expanded from trading in a single index options contract to include additional index options as well as options on 178 equities.[8] RAES is designed for small public customer orders and marketable limit orders for eligible series of options contracts; eligibility is defined by series that are expected to have the highest public

[7] See Securities and Exchange Release No. 21695, January 28, 1985.

[8] See Securities and Exchange Release No. 25995, August 19, 1988.

customer value. Quantities of no more than 10 index options contracts and no more than five equity options contracts only are allowed.[9]

RAES operates in tandem with the options trading floor during regular floor trading hours, which allows the pricing of market orders based on floor trading information. There are three classes of participants that are important in discussing this system: firms that enter orders, market makers currently signed on to RAES, and the trading crowd on the floor. The trading crowd also is comprised of market makers and "locals," who trade primarily for their own accounts. CBOE rule 8.7 requires that transactions of a market maker "constitute a course of dealings reasonably calculated to contribute to the maintenance of a fair and orderly market." Market makers include broker-dealers who regularly accommodate customer order flow, but such individuals regularly trade for their own accounts as well. In fact, a registered market maker has "a continuous obligation to engage . . . in dealings for his own account when there exists . . . a lack of price continuity," also according to rule 8.7. Trading proceeds by open auction in the larger trading pits, just as in futures markets. Trading in options on stock index futures has this flavor. Market making operations for options on many stocks are quieter operations, sometimes with a single market maker essentially handling only customer orders brought by runners from brokers' booths. The crowd is trading continuously, and the best bid and offer are known (via quote reporters) all of the time. This information is transmitted to RAES. Firms on the CBOE's Order Routing System automatically have their small public customer orders routed into RAES. A customer market order is assigned a price based on the floor's best bid and offer; RAES orders to buy are executed at the lowest offering price and orders to sell receive executions at the highest bid. Execution is accomplished by assigning each order to a market maker on RAES on a rotational basis; the order of rotation is randomly selected at the beginning of the trading day.[10] Public dissemination of RAES sales information is prefixed with a code indicating automatic execution, and a display of all RAES transactions is available to the RAES market makers and participating firms. Limit orders are processed in the same fashion, subject to certain restrictions summarized in the rules below and assuming that the order can be executed to sell for a higher price than the limit or to buy at a lower price than the limit.[11]

[9] Option price is a factor in determining eligibility as well. Currently, options with a price over seven dollars in the indexes and ten dollars in the equities cannot be traded through RAES.

[10] See Securities and Exchange Release No. 25995, August 19, 1988, and No. 26373, December 28, 1988, for eligibility requirements for makers on the system.

[11] Limit order book priority is a potential problem, because there is no consolidated limit order book for both the floor and the automated execution system. If limit order protection is

The rules behind the RAES algorithm can be summarized as follows.[12]

1. *Order eligibility*. A new order is eligible to be matched with a standing order, and a trade will result, whenever the following conditions occur:

1.1. A market order or limit order to buy or sell in a particular option class is entered into RAES.

1.2. The limit order satisfies the following criteria:

a. The limit order can be executed to sell for a higher price or buy for a lower price, but the limit order will not be executed to sell for less or buy for more than the specified limit.

b. The order's limit price is under \$3 and the floor market quote at the time of order entry is \$0.50 or less from the limit price.

c. The order's limit price is \$3 or more and the floor market quote is \$1 or less from the limit price.

1.3. At least one market maker is signed onto the system in the option class corresponding to the market or limit order.

2. *Trade price*. If an order match is possible according to the criteria of Rule 1, then the trade will take place with an eligible market maker at the best floor market quote available at the time of order entry; i.e., orders to buy are executed at the lowest offering price and orders to sell receive

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not guaranteed, public customers could be discouraged from entering limit orders, which in turn might negatively affect pricing efficiency in the market. Limit orders on the floor's book have priority over RAES orders, with the exception of IBM and S&P 100 contracts. If a RAES order would be executed at the price of an order on the limit order book, the RAES order is rerouted to either the entering firm's broker in the floor trading crowd via printer or to the firm's floor booth. The order then is executed in the ordinary manner on the floor. The CBOE may suspend limit order protection in RAES under "unusual market conditions," and guidelines for such action are rather vague, to include a finding that market operations "do not otherwise allow for the prompt and efficient handling of RAES order which would be rerouted" (see letter to Holly H. Smith, Special Counsel, Division of Market Regulation, SEC, from Frederic M. Krieger, Associate General Counsel, CBOE, dated May 10, 1988). The text's description of the computer algorithm for automated execution is presented under the assumption that an order actually reaches the computer system in the first place, abstracting from rerouting of orders. IBM and S&P 100 contracts are traded on the system even when the limit price on the book is greater/less than the current best offer/bid in RAES. These contracts are extremely liquid. Between April and June of 1987, in cases for which a RAES execution in IBM options reached the book, orders at that price were removed before a price change or the end of the trading day in 94.5, 87.2, and 94.9% of the instances, by month. The median time in which RAES IBM orders were filled before booked orders was between 2 and 6 min; the average time was between 13 and 24 min. See *Report on RAES Pilot in Equity Options for the Period September 1986–June 1987*, on file as an exhibit to Securities and Exchange File No. SR-CBOE-87-35, 1987.

[12] Rules 1, 2, and 5 are contained in Securities and Exchange Release No. 21695, January 28, 1985. The remainder were obtained from Mr. John Shalvis, a RAES operations specialist at the CBOE. The algorithm as presented here is an updated version of that in Domowitz and Gardner (1990), being more complete in several respects.

executions at the highest bid. Limit orders will not be executed to sell for less or buy for more than the specified limit.

3. *Trade quantity.* A market maker is responsible for providing up to 10 contracts upon demand.

4. *Maximization of total trade size.* Every order is matched with only one market maker in the rotation.

5. *Standing order priority.* The priority of a standing order, relative to other standing orders for the same contract, is based on the following:

5.1. Price: all incoming orders are executed at the best price currently posted in the market;

5.2. Rotation: market makers are assigned incoming orders on a rotating basis without regard to the market maker's particular bid or offer.

To illustrate these rules, consider the following record of market makers' activity for a specific contract:

Trader	Assigned rank	Price	Price*	Quantity
A	First	$3\frac{3}{8}$	$3\frac{1}{2}$	10
B	Second	$3\frac{1}{8}$	$3\frac{1}{4}$	5
C	Third	$3\frac{1}{2}$	$3\frac{1}{2}$	10
A	Fourth	$3\frac{3}{4}$	$3\frac{1}{2}$	10

Three market makers are logged onto the system. The three traders' assigned order was set by random selection at the beginning of the trading day. "Price" denotes the best market offer at the time individual orders to buy "at market" are sequentially entered in RAES. The first such market order to buy 10 contracts is routed to the system and priced at $3\frac{3}{8}$. Trader A is assigned the transaction; the trade is executed at $3\frac{3}{8}$. By the time the second order to buy five contracts at market is entered into RAES by a firm, the best floor offer has changed to $3\frac{1}{8}$. Trader B is assigned the five contracts at that price. A limit order to buy 10 contracts at $3\frac{1}{2}$ now is entered into RAES. At the time of entry, the best quote on the trading floor is $3\frac{1}{2}$ also. Trader C is assigned the trade at $3\frac{1}{2}$. A firm enters another limit buy order at $3\frac{1}{2}$. Trader A would ordinarily be assigned the trade being next in the rotation, but the floor offer has shifted to $3\frac{3}{4}$. The limit order cannot be filled at the current market price, and execution does not occur.

Each of these market makers is trading on the floor during this period, but may not be offering to trade at the best floor quote at every instant in time. The column labeled "Price*" contains the market makers' individual offers to sell on the floor at the time of the customer order entries described above. Trades with A and B have generated implicit market maker losses relative to what these traders are offering on the trading floor. This situation is analyzed in detail in Section 3.

Stock Trading: The SOE System

The National Association of Securities Dealers Automated Quotation system (NASDAQ) was developed to facilitate the trading of over-the-counter (OTC) stocks. The surge in trading volume that began in the fall of 1982 motivated greater automation of the order execution process in the OTC market,[13] and the NASD filed a proposal for its Small Order Execution System (SOES) with the SEC in October 1984. The system was speedily approved and began operation in January 1985.[14] SOES now accounts for about 13% of all OTC transactions.[15]

SOES provides automatic execution of limited size orders at the best available NASDAQ quotation at the time of order entry. As with RAES, there are three classes of participants: firms or individuals who enter orders, market makers currently logged onto the automated execution system, and the "trading crowd," which here is a group of NASD dealers and market makers who work over a telephone network instead of a trading floor. Market makers on SOES constitute a subset of the telephone dealers; participation in SOES now is mandatory for all dealers who make markets in NASDAQ National Market System securities.[16] All market makers on the telephone network enter bid and ask quotes into the NASDAQ system. These quotes are transmitted to SOES. Public customer orders of limited sizes are routed into SOES. An order to buy at market is assigned a price based on the best NASDAQ quote available at the time of order entry. Such an order then is assigned to the market maker on SOES who is offering the best price at the time of order entry for execution; this price may not be the same as the best NASDAQ quote, because a market maker who is not currently participating in SOES may still be dealing over the telephone network at the time. The order is executed at the best NASDAQ quote, regardless. An automated centralized limit order book was established within SOES in February 1989, and limit orders are handled in a fashion similar to the RAES.[17]

[13] See Simon and Colby (1986).

[14] See letter from J. M. Cangiano, Secretary of the NASD, to M. J. Simon, SEC, October 18, 1984, and the attached file SR-NASD-84-26. A description of the SOES system is contained therein. See also Securities Exchange Act Release No. 21743, February 12, 1985.

[15] See Securities Exchange Act Release No. 26361, December 22, 1988.

[16] The role of, and restrictions on, market makers were topics of post-1987 reforms following the market break. See Securities and Exchange Act Release No. 25291, June 9, 1988, and Release No. 26361, December 22, 1988.

[17] See Securities and Exchange Act Release No. 26476, January 26, 1989, for a description of the limit order file. Orders are executed when the best NASDAQ quote is equal to or

A customer order may be designated for routing to a particular market maker within SOES by prior arrangement, a practice called "preferencing." The market maker agrees in advance to execute the trade at the best NASDAQ price, regardless of the individual market maker's current quotations. This practice in essence replicates the telephone system's "old boy network," and approximately 50% of all orders are preferenced.

I summarize the SOES automatic execution algorithm as follows.[18]

1. *Order eligibility*. A new order is eligible to be matched with a standing order, whenever the following conditions occur:

1.1. A market or limit order is entered to buy or sell;

1.2. At least one market maker is posting a bid and offer for the particular stock;

1.3. The best quote in the NASDAQ system is equal to or better than the price of a limit order.

A trade will not be executed whenever the following condition occurs:

1.4. Two limit orders which are able to be matched are entered between the best bid and offer.

2. *Trade price*. If an order match is possible according to the criteria of Rule 1, then the trade will take place at the best market maker quote in the NASDAQ system.

3. *Trade quantity*. Market makers are required to provide up to 100, 200, 500, or 1000 shares per order, depending on the particular stock in question.

4. *Total trade size*. Every incoming order is assigned to only one market maker. If the market maker's exposure limit balance is greater than zero at the time of order entry, the market maker must trade up to the maximum execution limit for the security in question.

5. *Standing order priority*. The priority of a standing bid/offer, relative to other standing bids/offers for the same stock, is based on the following:

5.1. Price: for buy orders, higher price has higher priority; for sell orders, the lower price has higher priority.

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better than the limit price on a first-in, first-out basis. Limit order protection is not guaranteed. It is possible that an execution may not occur for an eligible limit order. For example, suppose the file contains three orders to sell a security at 6, and the best quote reaches or goes beyond 6. SOES attempts to execute all three orders at the best quote. If the best quote falls to $5\frac{3}{4}$, and the system has executed only two of the three orders, SOES will not execute the last order. It remains in the limit order book until the market again breaks past the limit.

[18]Rules numbered 1.1, 1.2, 5.1, 5.2, 5.3, and 5.4 are taken from the SOES Users Manual, revised June 1989. Rules 1.3, 6.1, and 6.2 come from the SOES Limit Order User Guide, January 1989. Rules 4 and 1.4 are found in Securities and Exchange Act File No. SR-NASD-84-26, October 18, 1984, and Release No. 26476, January 26, 1989, respectively. This represents an update of the rules outlined in Domowitz and Gardner (1990), being more complete in some respects.

5.2. Rotation: Order rotation includes only market makers logged onto SOES with the best price quotes at the time an order is received.

5.3. Prearrangement: Any broker with a customer order may choose to execute the order with a particular market maker in the system if that person has agreed beforehand to meet the best quote in the NASDAQ system.

5.4. Locked/crossed market: In a locked or crossed market, i.e., when the offer price of one market maker is the same or lower than the bid price of another market maker, orders are executed against the best bid and offer regardless, and prearrangements are not valid in such circumstances.

6. *Incoming order priority.* All market or limit orders entered into SOES must conform to the following rules:

6.1. Time priority: all executable orders must be executed on a first-in, first-out basis;

6.2. Limit order types: allowable types include fill-or-kill, day orders, good-till-cancelled, and good-till-date.

Rules 2 and 5.2 require some clarification. During the pilot phase, all (unpreferenced) SOES orders were rotated among all market makers logged onto the system. The setup was the same as that of RAES in the sense that execution would occur against market makers on a rotational basis without regard for the market makers' individual bids or offers. Under the current arrangement, execution takes place at the best quote in the NASDAQ system, similar to RAES, but only against market makers with the best SOES quotes at the time of order entry. There may be no "rotation" as such; an example, may clarify this. Consider the following display:

	Traders	Bid	Ask
	A	$30\frac{1}{4}$	$30\frac{3}{4}$
s	B	$30\frac{1}{8}$	$30\frac{5}{8}$
s	C	30	$30\frac{1}{2}$
s	D	$29\frac{7}{8}$	$30\frac{3}{8}$

An *s* in an SOES display indicates current participation in the system. In this case, the screen shows trader B with the best SOES bid and trader D with the best SOES ask. The best quotes in the NASDAQ system here are a bid of $30\frac{1}{4}$ (trader A) and an ask of $30\frac{3}{8}$ (trader D). In this situation, all unpreferenced buy orders entered while this screen remains valid are routed to trader B for execution at a price of $30\frac{1}{4}$, subject to the caveat that trader B's exposure limit was not reached; all unpreferenced sell orders are routed to trader D for execution at $30\frac{3}{8}$. Market maker C would not be executed against without a preferencing arrangement.

The exposure limits referred to above and in Rule 4 concern the maximum total number of shares a market maker is required to trade at the best quote, given a fixed SOES quote on the part of the market maker. This figure is not the same as in Rule 3, which holds for any individual trade. The minimum exposure limit allowed at a fixed quotation is five times the individual order size limit on both the buy and the sell sides. Suppose trader B above adopts the minimum exposure for a security with a 1000-share trade maximum; the beginning limit balance is 5000. Further, suppose trader B must execute five trades in succession for a total of 4500 shares; the exposure limit balance is now 500. If this trader is hit again for 1000 shares, such a trade is honored, since the beginning balance is above zero. This last trade reduces the balance below zero, and trader B is no longer required to honor trades at the market quote. That burden would now shift to trader C, who has the next best quote in SOES. Trader B has only 5 min to establish a new quote on SOES, which automatically reactivates the limit order exposure balance to 5000. Failure to do so results in a penalty.

Additional rules concerning trade size exist that do not affect the execution algorithm but are of some interest relative to the trading and quantity rules in Globex. Volume in Globex is essentially unlimited, and the secondary quantity feature there as well as the exposure of any order to multiple standing orders reflects an interest in maximizing total trade size. Trading in SOES is indeed restricted to small orders. Regulations are on the books that are meant to prevent attempts to circumvent SOES order size limits by deliberately breaking up orders that are too large into a series of smaller orders designed for automatic execution. The practice of executing part of a single order in SOES with the remainder "executed away" also is forbidden. Nevertheless, in 1988 the NASD became concerned that SOES participants were using the system to execute orders for so-called professional traders, defined as traders executing five or more offsetting trades in the same security in the same day for roughly the same offsetting size. This would seem to be an unnecessary restriction for an automated system, yet the SEC allowed this ban, in the same spirit as restrictions on volume, taking a stand as to what constitutes a "good" versus "bad" trading practices with respect to the fostering of market efficiency.[19]

[19] See securities and Exchange Release No. 34-26361, December 22, 1988. The Commission not only linked size limits with "professional trading," but also stated that "it is beneficial to overall market liquidity to preclude professional traders from access to SOES."

3. PRICE, QUANTITY, AND SURPLUS DETERMINATION

The purpose of this section is to examine price, quantity, and trader surplus determination in the three automated trade execution systems. Floor trading will be examined similarly, in order to provide the relative standard relating to the requirements of the 1974 Commodity Exchange Act, as noted in the Introduction. Walrasian clearing will serve as the common benchmark. The analysis is divided into two parts. The first concerns Globex performance as a potential substitute for the trading floor. RAES and SOES operate in tandem with a floor or telephone trading operation and rely on market information outside the automated system; they are analyzed separately and with a different methodology given this complication.

Globex and Open Outcry Auction

Futures, options, and, to a large extent, stocks are traded in open outcry auction markets. Trades are executed as soon as bids and offers match; but, at a given point in time, only a fraction of the trading crowd trades at a continuous market clearing price, which is determined by a subset of the supply and demand curves manifest in the market.

The basic rules of trading are quite simple. Once a trader calls out a bid or offer, any subsequent bid or offer must be higher, respectively lower, than the standing order in the market, with the caveat that any bid or offer is good "only while the breath is warm." A contract is traded when the outstanding bid or offer is accepted. If more than one trader attempts to accept the bid, say, there are rules of thumb on trading floors that determine how such orders are split.

This process differs from the classical competitive benchmark of the Walrasian auction. In this case, there is an auctioneer who calls out tentative prices in reaction to demand and supply pressures in the market. Trades are executed only when a price is found at which the total supply of an asset equals the total demand. All trades are carried out at this price, and the market clears. This is the classic example of an optimal "call" market. The continuous market clearing of the outcry auction is replaced by periodic clearing, but with a theoretical benefit; the Walrasian batch market is more likely to encompass the entire available supply and demand schedule, leading to better price discovery and quantity determination.

Simplifying assumptions are made in order to analyze the floor trading process, as in Monroe (1988). The continuous trading on the floor is broken into small discrete periods, and the number of traders is limited to six players. Individual trades are for a single contract. Demand curves are assumed to slope down in the short run, an assumption that has both empirical and theoretical support in these markets.[20] Each trader has a reservation price, permitting "stepped" supply and demand curves. Changes in trader expectations that would shift supply and demand schedules are not permitted during the period of contracting in the examples. These conditions permit calculations of the continuous market clearing prices, and the Walrasian price, quantity, and total trader surplus for any given trading scenario.

Consider the situation depicted in Fig. 1. Three supply-side traders with reservation prices of 1, 2, and 3 (labeled S_1, S_2, and S_3, respectively) stand ready to transact with three demand-side traders with reservation prices of 3, 2, and 1 (D_3, D_2, and D_1). In a Walrasian auction, all transactions, Q_c units, occur at the clearing price P_c, and the total buyer/seller surplus is equal to the shaded area. In Fig. 1, the competitive clearing price of 2 is used by the Walrasian auctioneer to execute S_1 and S_2 requests to sell against the D_3 and D_2 buy orders, yielding a final quantity of 2 contracts transacted. The total trader surplus of 2 is generated by D_3 buying one contract one dollar below his reservation value, and by S_1, selling a contract for a dollar above reservation value. The Walrasian outcome is, therefore, a price of 2, a quantity of 2, and a surplus of 2.

The construction of trading scenarios is best explained by example. Trader S_1 calls out an offer at his reservation price of 1, say.[21] Suppose D_2 responds first, and a trade occurs for one contract at a price of 1. Total surplus thus far is 1. The scenario continues with S_3 calling out an offer at $p = 3$. D_3 makes the counter bid, because this price exceeds all other demand-side reservation values. The trade takes placed at a price of 3. No surplus is generated for this transaction, since both parties have traded at their reservation prices. Trading ends for the period; the reservation prices of the remaining traders do not overlap.

There are 720 possible trading sequences based on Fig. 1. A sequence is simply a pattern of arrivals in the bidding process. In the example above, the sequence consisted of S_1 calling out first, followed by D_2, and then by S_3, with the final feasible bid made by D_3. Each of these 720 possible patterns is taken to be equally likely. This assumption is as plausible as any other in this regard; the configuration of the market is fixed and there is no theoretical reason to believe that one's reservation value influences arrival time in the market.

The trading institution (i.e., the floor or Globex) and an assumption

[20] Empirical support is contained in studies by Schleifer (1986) and Harris and Gurel (1986). Heterogeneous expectation concerning asset prices motivate the assumption from a theoretical point of view; see Black (1971) for additional discussion.

[21] Trader S_1 could call out an offer anywhere between the reservation price of 1 and 3 to generate a feasible trade, of course. Offering at the reservation price is a simplification for expository purposes.

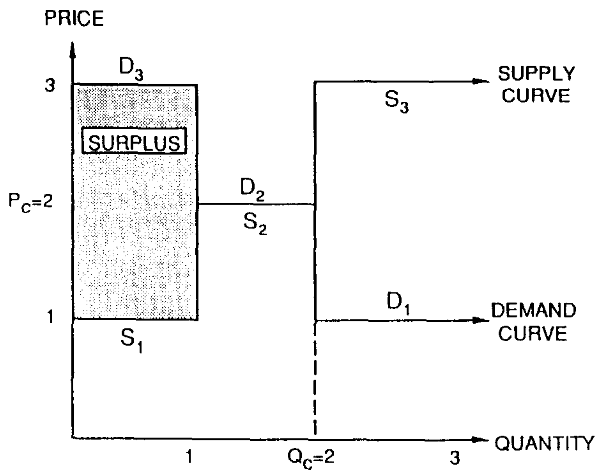

FIG. 1. Market reservation values.

concerning the likelihood of a trade given any feasible pairing of buyer and seller within a sequence transform sequences into trading scenarios. An initial pairing is generated; S_1 is paired with D_2 under floor trading rules in the previous example. Trade between the two occurs with some probability. Trade occurs with probability one in the example. After it has been determined whether trade did or did not occur, the next feasible pairing is generated according to the sequence and the institution, S_3 and D_3 in the example, given that trade did indeed occur between S_1 and D_2. Once again, trade occurs with some probability. The end of the sequence has been reached, given that the second trade occurs, and the process terminates.

Any given pairing may or may not produce a trade and each sequence may lead to several possible scenarios. For example, it was implicitly assumed in the example that the trade between S_3 and D_3 occurs with probability one. An alternative assumption might be that a trade between these two rarely occurs, because it generates no profit for either party. In that case, the sequence of the example can generate a scenario in which only S_1 and D_2 trade.

In fact, an assumption that all feasible trades occur with probability one allows for suboptimal behavior and unlikely floor trading possibilities, in particular. A simple solution to this problem is based on the fact that trader profits are the same as total surplus here. The probability that any trade will occur is made a function of the profit that can be made on that trade. By setting the probability of zero-profit trades to zero, all unlikely trading scenarios are ruled out. Considered from the trading standpoint as

TABLE II
TRADING PROBABILITY PROFILES

	Surplus/profit		
Market state	$S = 0$	$S = 1$	$S = 2$
1	0.0	0.25	0.75
2	0.0	0.25	0.95
3	0.0	0.25	1.00
4	0.0	0.50	0.75
5	0.0	0.50	0.95
6	0.0	0.50	1.00
7	0.0	0.75	0.95
8	0.25	0.75	0.95
9	0.50	0.75	0.95
10	1.00	1.00	1.00

a simple strategy, i.e., the effort to complete a trade is increasing in the profitability of that trade, such a strategy is in fact more sophisticated than that of the weakly rational traders of Gode and Sunder (1990). Traders in their setting simply avoid losses and do not make futile bids and offers, yet do quite well in market simulations. Ten trade probability profiles are summarized in Table II. By setting all probabilities equal to one, all trades within sequences are given equal weight. In state 5, for example, zero profit trades never occur, while high profit trades (a total surplus of 2 on the trade) occur with probability .95; positive, but lower profit, trades are completed 50% of the time. The trade probability profile and the trading institution define a stochastic mapping of the 720 sequences into scenarios. This mapping is simulated by Monte Carlo.

Table III contains results for floor trading scenarios. The quantities reported are the average percentage of outcomes relative to the Walrasian benchmark, based on 50 Monte Carlo trials. This includes price, quantity, and surplus. The last row contains the average surplus per trade, which is a common efficiency measure in other experimental market settings. The same information is summarized for Globex in Table IV.[22]

In terms of average performance across all market states and Monte Carlo trials, Globex performs slightly better than the floor. Differences

[22] There are two possible ways of "missing a trade" in Globex. The first is simply to fail to enter the trade into the system, which is completely analogous to failing to make a trade based on profitability considerations. Table IV is constructed based on this assumption. It also is possible to have entered the trade into the computer system, but miss execution because the offer entry was not timely. This case also was investigated. Total surplus is greater under this last interpretation, because medium profit trades (i.e., a surplus of one) often are *eventually* executed. Surplus per trade is approximately the same as reported in Table IV, however.

TABLE III
FLOOR TRADING SUMMARY[a]

	Market state									
Average %	1	2	3	4	5	6	7	8	9	10
Price	71	60	57	64	57	56	53	47	43	40
	(3.8)	(2.6)	(3.0)	(2.0)	(1.8)	(1.4)	(0.9)	(1.4)	(1.6)	—
Quantity	11	10	9	18	17	15	21	34	46	71
	(1.1)	(1.1)	(1.5)	(1.5)	(1.1)	(1.1)	(0.8)	(1.5)	(1.6)	—
Surplus	77	82	83	63	69	71	60	54	48	41
	(1.9)	(1.5)	(1.4)	(1.3)	(1.6)	(1.5)	(0.9)	(1.6)	(1.4)	—
Surplus per trade	1.6	1.7	1.7	1.4	1.4	1.5	1.3	1.0	0.8	0.5
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	—

[a] Quantities reported are average percentage of outcomes relative to the Walrasian benchmark, with the exception of the last row, which is the average surplus per trade, all based on 50 Monte Carlo trials. Standard deviations are in parentheses.

can be small, but all differences are statistically different from zero based on commonly accepted levels of statistical significance. The average surplus-per-trade differential is only 0.10, with a standard error of 0.03. Globex achieves the benchmark of Walrasian surplus in 70.0% of all scenarios studied across all trade probability profiles and Monte Carlo trials. Floor trading as modeled here produces the Walrasian surplus outcome in 64.8% of the scenarios. The difference between these performance averages is 5.2% with a standard deviation of 1.94. In other words,

TABLE IV
GLOBEX TRADING SUMMARY[a]

	Market state									
Average %	1	2	3	4	5	6	7	8	9	10
Price	78	65	63	74	66	64	64	58	55	54
	(4.1)	(3.3)	(3.0)	(2.1)	(2.0)	(1.7)	(1.3)	(1.9)	(7.5)	—
Quantity	16	14	13	25	23	22	29	38	47	66
	(1.6)	(1.5)	(1.6)	(1.6)	(1.4)	(1.4)	(0.9)	(1.5)	(1.7)	—
Surplus	81	86	87	70	76	77	68	60	52	43
	(1.8)	(1.4)	(1.3)	(1.7)	(1.4)	(1.4)	(1.0)	(1.1)	(1.3)	—
Surplus per trade	1.6	1.6	1.7	1.4	1.4	1.5	1.3	0.9	0.7	0.5
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.02)	—

[a] Quantities reported are average percentage of outcomes relative to the Walrasian benchmark, with the exception of the last row, which is the average surplus per trade, all based on 50 Monte Carlo trials. Standard deviations are in parentheses.

out of every 100 trading scenarios possible, Globex reaches the Walrasian benchmark in 5.2 cases more than achieved on the floor on average. Similarly, the differences in the average percentage of outcomes relative to Walrasian clearing for price and quantity are 9.3 and 4.1%, with standard deviation of 3.93 and 1.86, respectively.

The superior performance of the Globex algorithm derives from the fact that the Globex book collects bids and offers and holds them at firm prices, thus exposing a higher percentage of potential trades to the market at any one time. The essential difference between Globex and the floor as modeled here is the placement of unanswered bids and offers in an electronic order book, potentially allowing for a higher rate of order execution. For example, if D_2 calls out a bid of 2 in Globex, immediately followed by D_3 bidding at 3, the bid of 2 is held in the order book, while on the floor, it is completely superseded by the higher bid. The results must be considered tentative due to the limitations of the analysis. Trading is continuous only within a scenario. The setup used here is similar to those used in experimental markets, in which players are assigned to be either suppliers, who begin the experiment with an inventory of contracts bought at different prices, or buyers with a fixed demand schedule for contracts. The experiment involves continuous tradng until players have exhausted inventory and bought as much as the demand schedules allow. The experiment then stops and is restarted again with new inventory values and individual demand schedules. Repetitions of such experiments are analogous to the Monte Carlo trials used for the scenarios induced from all trading sequences via the trading probability profiles. The collection of scenarios here is similar to an exhaustive sequence of double sealed-bid auctions. The market is symmetric in supply and demand and limited to six trades.[23] Nevertheless, these findings suggest that Globex may prove to be acceptable from the perspective of CFTC Regulation 1.38.

Trader Welfare in RAES and SOES

Preliminary investigation of the performance of RAES and SOES in Domowitz and Gardner (1990) treated the systems as though they operated without a concurrent floor market, i.e., as though all trading took

[23] Increasing the number of traders in the current setup quickly causes computational problems. Going from 6 to 10 traders increase the number of feasiable trading scenarios to 3,630,000, so that any comparison of floor with Globex requires 7.26 million simulation runs. Such a comparison was run once, for the case in which all probabilities were set to unity (the case of all possible combinations). Floor trading performance relative to Globex worsens substantially compared to the results reported in Tables III and IV. This may be misleading, however, due to the large number of zero-surplus trades possible in a 10-trader floor market as simulated here.

place on the automated system. Scenarios were constructed as in the last section in such a way as to mimic floor or Globex trading in the sense that a trading match resulted in the removal of both the supply-side trader and the bidder from the scenario. While Walrasian pricing occurred about as often as that reported here for floor trading, competitive surplus was achieved only 13% of the time.

The concurrent trading floor was integrated into the analysis in Domowitz (1990), and performance again was evaluated based on scenarios. Scenario analysis based on Fig. 1 was found to be degenerate, however. The best floor or NASDAQ-wide price requirement always resulted in too many contracts being traded at too low a price with zero surplus. If the market were modified in such a way as to make the floor or NASDAQ quote equal to the Walrasian equilibrium price, surplus still suffered relative to Walrasian clearing; the exact calculations depended on the order of rotation in RAES and whether or not the trader offering the best NASDAQ price also was trading on SOES.

These exercises show that correct price discovery in such systems is an accident, depending on equilibrium pricing on the floor. The nature of the surplus loss remains important and requires further investigation, however. In the context of floor or NASDAQ trading, market makers provide necessary liquidity to the market by their trading activity and willingness to post both a bid and an ask. Both SOES and RAES depend upon market maker participation by their very design. Market maker participation is mandated by law for certain classes of traders active on the floor or telephone network, but excessive losses on the automated system could possibly lead to decreased market activity and wider spreads in general. The Brady Commission report on the October 1987 market break cited problems with the SOES system, in particular. Several of NASDAQ's problems were traced to weaknesses in trading procedures and rules which were programmed into the automated execution system. Such problems were thought by the Brady Commission to have effectively closed down the automated systems, exacerbating the market's difficulties at the time. The performance of options small order execution systems was also scrutinized after the October break by the Division of Market Regulations, SEC, highlighting the unwillingness of individual market makers to participate voluntarily on a continuous basis in RAES during periods of unusual and unpredictable market volatility. The report pointed out that if market makers were to defect from an automated execution system, an exchange could be forced to discontinue its operation, thereby contributing to investor uncertainty. A different simulation methodology is proposed in this section to examine market maker losses on these systems.

Simulation of the concurrent market (floor or NASDAQ) is based on the simulation model of Cohen *et al.* (1983), with modifications to allow for different bids and offers by different traders (instead of a single aggregate market best bid/offer) and for the monitoring of individual traders. The number of floor traders ranges from 20 to 80 in the experiments. New information arrives to the floor based on a Poisson process with average arrival rate A_f. The arrival of this information generates new bids and offers by each trader on the floor. The information is not differentiated as "good" or "bad" news. The arrival of information simply forces each trader to generate a new bid and offer according to a simple stochastic difference equation. Consider the generation of offers for an individual trader; the generation of bids is completely analogous. Upon the arrival of new information, the trader's offer is given according to log P = log (current best market bid) + x.[24] The innovation, x, is drawn from a distribution common to all traders and depends on the current market's best bid and ask quotations at the time of the offer generation.[25] The high bid and the low ask among the traders define the new market bid and ask. Thus, new bids and asks are generated for each participant as a random function of the market bid and ask. Trading on the floor or on NASDAQ is not modeled here. This part of the simulation simply generates a sequence of bids and offers for each trader and a market bid and market ask, which are transmitted to the RAES or SOES at each moment in time. Realized bids and offers fluctuated mainly in the range of \$8 to \$10 in the simulation reported here.

Traders on RAES and SOES are subsets of the floor/NASDAQ traders. The number of automated system traders is fixed at 20; variations in the number of floor traders are used to modify the ratio of floor to system traders. Customer orders arrive randomly according to a Poisson process with arrival rate A_s. The arrival of customer orders is exogenous; NASDAQ/floor activity and transactions prices on the automated system

[24] The bid price is given by P = (current best market ask) e^x, where x is drawn from a mirror image distribution. Given this method of bid/offer generation, there is no systematic drift in prices and trends are short lived.

[25] The Yawl density of Cohen *et al.* used to generate the offer innovations is given by

$$f(x) = \begin{cases} y + (y/c)x & \text{if } x \in (-c, 0) \\ (by/s)x & \text{if } x \in (0, s) \\ by - (by/a)[x - s] & \text{if } x \in (s, a + s) \\ 0 & \text{otherwise,} \end{cases}$$

where s is the difference between the log of the best bid and the log of the best offer. The bid distribution has zero mass at the market ask and the offer distribution has zero at the market bid. Simulations were run with $a = 2$, $b = 1$, $c = 2$; y is set by the requirement that the density integrate to unity. An explanation and defense of this particular structure in the context of financial markets is contained in Cohen *et al.* (1983). Among other things, use of this spread-varying distribution avoids negative serial correlation in returns and instability in the returns process, both of which result from a fixed distribution of prices.

do not affect the arrival rate. Each customer order is for 10 contracts and there is an equal probability of an order being a buy or a sell. The arrival of orders into the automated system is randomly interspersed with the arrival of news on the floor. Trader bid/ask generation and the generation of customer orders are independent processes. Further, trading activity on the automated system does not affect the arrival of news to the trading floor. Information is passed only from the floor to the automated system.

The simulation then proceeds as follows. Market bids and asks are transmitted to the automated system. When a customer order arrives, it is routed to the automated system and randomly assigned to be a buy or a sell order. It then is processed according to RAES or SOES rules.[26] The rules stipulate that one of the traders on the system automatically is assigned the trade at a price that depends on the market quotes. That price is compared to the trader's floor quote at the time of customer order entry (the price at which the trader desires to trade). The difference between the transaction price (the price at which the customer receives order execution) and the trader's floor quote is reached as the trader's net loss. This procedure corresponds to the fashion in which surplus was calculated in the last section.

Simulations were run for 10 trading "days," with 6 periods per day. At the beginning of each new day, the rotation within RAES is determined randomly and market prices are reinitialized, with initial values in the \$8–\$10 range. At the beginning of each new period within a day, draws are made from the Poisson arrival processes that govern the information arrival and trading within the period. Existing bids and offers are rolled over from the previous period, and the RAES rotation is unchanged from period to period within a day.

The base simulation was run with 40 floor traders and 20 system traders. The expected arrival rate of new floor quotes to new customer orders was 2 to 1, and there were 20 RAES trades per period on average. The calculation of losses is based on approximately 1200 trades through RAES and 2400 new floor quotes for each trader. The average loss per trader on RAES was calculated to be 0.79 with a standard deviation of about 0.02. Measured against an average price of (bid + ask)/2 in the floor market of about 9, such a loss is 8.8% of the desired trading price. The average loss to a SOES trader was 0.58, also with a standard deviation of 0.02, which is 6.4% of the trading price. The average losses in SOES are lower due to the difference in the rules of rotation between RAES and SOES. SOES trades are executed against the market maker on the automated system

[26] Preferencing is ignored here. Such prearrangements were the primary focus in Domowitz and Gardner (1990) and Domowitz (1990). The large number of traders in the simulations precludes an examination of preferencing arrangements in the present context. See footnote 23.

TABLE V
VARIATIONS IN THE RATIO OF FLOOR TO SYSTEM TRADERS[a]

	Average loss per trader	
Ratio	RAES	SOES
1	0.74	0.0
	(0.02)	—
1.5	0.73	0.03
	(0.02)	(0.02)
2	0.79	0.58
	(0.02)	(0.02)
2.5	0.78	0.63
	(0.02)	(0.02)
3	0.79	0.63
	(0.02)	(0.02)
4	0.82	0.61
	(0.02)	(0.02)

[a] Standard deviations are in parentheses. Figures are based on approximately 1200 RAES or SOES trades and 2400 floor quote changes per trader. Average trading price is $9.

who is posting bids and offers closest to the best quotes in the NASDAQ system, minimizing welfare loss relative to RAES, in which execution assignments are purely random.

The robustness of these results can be checked with respect to two parameters of interest in this model. The first is the ratio of the number of floor traders to the number of system traders. Given the institutional rules of RAES and SOES assignments, it is natural to fix the number of traders on the system (20) and to vary the number of traders on the floor (20 to 80). The results are reported in Table V for both RAES and SOES. As the number of traders on the floor is increased relative to the number of RAES, market maker losses increase, but not very much. Percentage losses relative to average floor prices range from 8.2 to 9.1% as the ratio increases from unity to 4. This increase is the expected outcome, because a higher ratio makes it more likely that the next RAES trader in rotation will not have a personal bid or ask close to the best floor quote. Quotes in this simulated market are not far apart, however, as is the case in real floor markets, mitigating this effect. Average losses with a ratio of 2 to 1 are not statistically significantly different from the average loss with a ratio of 3 to 1, for example. The situation is similar in SOES, but with a twist. Average losses are zero at a one-to-one ratio, because the trader with the best floor quote also is on the system and will be assigned the trade. The odds that this situation persists remain good for small increases in the ratio; average loss is only 0.3% of the average trading price at a ratio of 1.5. Once the ratio reaches 2, percentage losses rise to about 6.4% and remain relatively flat, not exceeding 7%.

The second parameter is the ratio of the arrival rate of floor information (new floor quotes) to the arrival rate of new customer orders. Losses based on variations in this ratio are given in Table VI. In RAES, once the ratio rises above unity, losses are about 9% of the average trading price up to a ratio of 5. There is no detectable pattern of variation and that which exists is small. The same story is true for SOES, in which losses remain constant at about 6.5% of the price on average.

In summary, the RAES and SOES rules allow trades that would not occur on the trading floor or in Globex. In the context of the simple measure of welfare used here, such trades are detrimental to market makers participating in the system. The market makers certainly realized this before the writing of this paper; they fled the system during the October 1987 market correction, and RAES participation was generally inadequate just prior to any expiration date, especially in the index options such as the S&P 500 contract.

TABLE VI
VARIATIONS IN THE RATIO OF ARRIVAL RATE OF FLOOR INFORMATION TO ARRIVAL OF SYSTEM ORDERS[a]

	Average loss per trader	
Ratio (A_f/A_s)	RAES	SOES
1	0.60	0.54
	(0.02)	(0.02)
2	0.79	0.58
	(0.02)	(0.02)
3	0.84	0.59
	(0.02)	(0.02)
4	0.82	0.58
	(0.02)	(0.02)
5	0.81	0.60
	(0.02)	(0.02)

[a] Standard deviations are in parentheses. Figures are based on approximately 40 floor traders and 20 system traders. Average trading price is $9.

Market maker participation now is mandatory in SOES for NASD members dealing in National Market System securities. In the options market, participation is mandated in two circumstances. The CBOE Market Performance Committee is authorized to designate option classes in which any market maker who logs onto RAES in that class during an expiration month is required to participate in RAES whenever present on the trading floor, until the next expiration date. The Committee is further empowered to require market makers on the floor to sign onto RAES "absent reasonable justification or excuse for nonparticipation." It is interesting to note that the SEC explicitly stated that the problem of participation was properly addressed by such rule changes in 1988, and did not require a change in the technology of the system.[27] This may have reflected the opinion that customer service is the appropriate thing to maximize in an automated market designed for retail customer orders. It is clear that customer surplus is maximized, albeit at the expense of market makers who provide liquidity to the system.

4. CONCLUDING REMARKS

Descriptions of the automated trade execution systems and their associated computerized trading rules have generated a great deal of technical detail from the institutional perspective. It is useful to summarize differences in systems' characteristics. This is done in Table 7. The most important difference relates to whether or not automated execution is carried out in tandem with a regular floor trading operation. NASDAQ is characterized as having the analogue of a regular floor in the form of telephone and terminal connections; the operative concept is a concurrent market that allows human interaction. Market orders are priced based on floor activity. Globex operates after regular floor trading hours and accepts limit orders only. This system exposes orders to the entire market, while the exposure rules in RAES and SOES are such as to maximize customer surplus at the expense of resident market makers. Economic efficiency in the large was never a consideration in the design.[28]

The secondary order option in Globex seems to be an attempt to encourage the trading of large orders on the computer, while the systems operating with a floor market leave the large-order handling to concurrent market. Traders and policy makers tend to agree that the main obstacle to

[27] See Securities and Exchange Commission Release No. 34-25995, August 19, 1988, for the proposed rule changes concerning participation and the Commission's response.

[28] This was confirmed in part by Alden Adkins, Special Counsel to David Ruder, former Chairman of the Securities and Exchange Commission, in personal communication.

TABLE VII
SYSTEMS CHARACTERISTIC SUMMARY

	Globex	RAES	SOES
Concurrent floor	No	Yes	(Yes)
Market orders	No	Yes	Yes
Limit orders	Yes	No	Yes
Secondary orders	Yes	No	No
Preferenced orders	No	No	Yes
Order size limits	No	Yes	Yes
Execute against multiple standing orders	Yes	No	No
Rotation	No	Random	Yes
Time priority	Yes	No	First in/first out
Cross within spread	Yes	N/A	No

the widespread adoption of automated trade execution systems is large-order processing. Traders will be unwilling to leave large orders exposed on the book in an automated system for fear of being badly hurt during adverse market moves. Further, a trader does not like to publicize a large order for fear of adverse price movement upon disclosure.

Analysis of system performance using the secondary order option is important for these reasons, but beyond the scope of the present paper. A preliminary look at the problem is contained in Domowitz (1989). Outcomes in efficiency terms depend critically on the distribution of standing orders in the book relative to outstanding demand in the market. Competitive surplus is obtained roughly half the time relative to the outcomes reported in Table VI, dropping as low as 20% in some market configurations. Incoming orders under the secondary quantity option are not necessarily exposed to all standing quantities as they are when only primary quantities are traded. The percentage of residual standing orders that is potentially unexecutable increases relative to total residual demand as the reservation price associated with the secondary quantity increases. Realized surplus declines, and correct price discovery is distorted as well.

More work on this problem, as well as on the design of other systems in operation, is needed. The constructive critique of existing systems and the design of new ones critically depend on our ability to understand their properties in terms of price discovery, quantity determination, and welfare.

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