

COMPETITION, MARKET STRUCTURE, AND MARKET IMPERFECTIONS:
AN EXAMINATION OF THE NASDAQ STOCK MARKET

by

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(Under the direction of James S. Linck)

ABSTRACT

This paper examines the relationship between competition, market structure and market imperfections. In particular, the discussion refers to critical institutional features of the Nasdaq dealer market and their efficiency in promoting a competitive environment that eliminates the possibility of collusive agreements. The discussion reveals that neither the presence of a large number of dealers for any given stock, nor Nasdaq's seemingly negligibly small entry barriers are sufficient conditions supporting a competitive market environment. I show that the SEC Order Handling Rules succeeded in improving market efficiency at the Nasdaq and even forced competition in the most actively traded issues i.e., in those securities with the highest prevailing degree of competition. In contrast, the expected benefits of the decimal pricing system have not completely been realized.

INDEX WORDS: Nasdaq Market Structure, Implicit Collusion, Second-Best Nash Equilibrium, Order Preferencing, Sanctions, Regulatory Penalties, SEC Order Handling Rules, Decimalization.

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PREFACE

“Among the plays which men perform in taking different parts in this magnificent world theater, the greatest comedy is played at the Exchange. There, ...hiding places, concealment of facts, quarrels, provocations, mockery, idle talk, violent desires, collusion, artful deceptions, betrayals, cheatings, and even tragic end are to be found.” — *Joseph de la Vega, Confusión de Confusiones (1688)*

Although this statement refers to the Amsterdam Stock Exchange during the 17th century, this paper relates to theoretical and empirical evidence which suggest that even among the advanced stock markets in the 21st century, market imperfections affecting the investor are an issue that cannot be ignored.

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CHAPTER 1

INTRODUCTION

This paper examines the relationship between competition, market structure, and market imperfections. In particular, the discussion concentrates on critical institutional features of the Nasdaq multiple dealer market structure and their efficiency in promoting a competitive environment that eliminates the possibility of collusive arrangements.

In 1994, William G. Christie and Paul H. Schultz presented strong empirical evidence that brokerage firms making markets in Nasdaq stocks (stocks that are traded through the National Association of Securities Dealers Automated Quotation system) implicitly collude. Thus, the self-regulatory organizational structure of the Nasdaq failed to prevent those market makers from quoting supracompetitive bid-ask spreads, and to protect investors from excessive trading costs. As a result, an investigation by the Antitrust Division of the U.S. Department of Justice (DOJ), an examination of the Securities and Exchange Commission (SEC), and a surveillance by the National Association of Securities Dealers (NASD) were initiated in order to examine these pricing practices.

Reviewing several studies that examine these irregular pricing patterns, the following discussion reveals that a collusive arrangement among the Nasdaq market makers is the most reasonable explanation. A large number of dealers for any given stock accompanied by relatively small entry barriers is not necessarily sufficient to support a competitive market environment that precludes collusive behavior.

Nasdaq's Preference Trade Rule that shifts competition for order flow to a different level (it is not competitive prices that guarantee order flow but rather maintaining good relationships with brokerage firms) as well as public limit orders are shown to be striking factors that strongly influence the efficiency of the Nasdaq Stock Market. Further, I show that Nasdaq's electronically supported and thus transparent trading environment facilitates the maintenance of collusive agreements.

In response to those observed market imperfections, numerous organizational reforms went into effect. The SEC Order Handling Rules succeeded in improving Nasdaq's competitive market environment. I provide empirical evidence that equilibrium spreads as well as effective spreads of Nasdaq securities with the highest prevailing degree of competition narrowed upon implementation of the new rules. In contrast, the expected benefits of the decimal pricing system have not completely been realized.

The paper is structured as follows: Chapter 2 introduces the main characteristics of the Nasdaq market system. Chapter 3 refers to anecdotal evidence of market imperfections at the Nasdaq as examined by Christie and Schultz [8] and Christie, Harris and Schultz [9]. Additionally, further empirical evidence about the supra-competitive pricing patterns as well as different reasons than an implicit collusive agreement are examined. The beginning of Chapter 4 reviews a game-theoretical model by Dutta and Madhavan [12] focusing on the explanation of the observed market imperfections at the Nasdaq. At the end of Chapter 4, I extend the general model for some important aspects. Chapter 5 refers to the organizational reforms and their efficiency in improving Nasdaq's market quality with the main focus being on the SEC Order Handling Rules. Chapter 6 draws the main conclusions.

CHAPTER 2

THE NASDAQ MARKET STRUCTURE

The Nasdaq Stock Market is a major national and international stock market that makes use of computer and telecommunication technology for the trading procedure and surveillance of the listed securities. As a dealer market with a decentralized nature, the market makers (or equivalently, dealers) are geographically dispersed. The Nasdaq stock market is built on a unique system in which dealers compete for order flow through prices. The dealers communicate through a computer network and post quotes at which they are willing to buy and to sell the securities in which they make markets. Dealers with the greatest demand to buy a specific security will post the highest bid-price whereas dealers with the greatest incentive to sell a security will post the lowest ask-price. This rational pricing behavior implies that a dealer will not simultaneously post the best bid and the best ask. The difference between the highest bid and the lowest ask price is known as the inside spread, which is influenced by several components. These components are discussed in Section 3.2 in greater detail.

Until 1997, an incoming order by an investor could only be executed through the market maker rather than through an opposed order by an investor. Strictly speaking, incoming market orders trade with the best bid or ask offered by the dealers. In contrast to the organized exchanges, Nasdaq limit orders are executed only if the inside spread reaches the limit price. Hence, the investors cannot use limit orders to compete with Nasdaq dealers. Consequently, Nasdaq market makers

do not face any competition but from other Nasdaq market makers. Schwartz [33] summarizes the organizational structure utilized by Nasdaq as follows:

Dealers compete with each other, and have been reluctant to accept additional competition from the public order flow. The NASD depends on this interdealer competition to keep markets fair, orderly and liquid. . . . Competing dealers face fewer regulatory restrictions than NYSE specialists because the NASD relies more on the constraints of a competitive environment to discipline dealer firms.

As a result of the new SEC Order Handling Rules in 1997, the allowance of limit orders that initially were not an integral part of the Nasdaq system enabled direct trading with other investors.

In order to avoid a monopolistic dealer position, at least two dealers per stock are required before the firm can trade on Nasdaq. On average 10 - 20 dealers compete for order flow of a stock. And actively traded stocks even attract as many as 60 market makers.

A further structural feature of Nasdaq is the 'Preferencing' and 'Internalization' of order flow. Order Preferencing is generally considered to be the practice for which dealers pay brokers for order flow. It may take the form of an independent market maker paying an institutional or retail broker under a formal or informal agreement for the allocation of order flow in the stocks in which the dealer makes the market. The dealer is then obliged to execute the orders at prices no worse than the best bid or best ask as required by Nasdaq rules. Internalization is the practice when a vertically integrated dealer directly channels order flow from his brokerage division.

At the time of the irregular pricing patterns reviewed in Chapter 2, the price frictions for bid and ask quotes were required to be multiples of one-eighth of a dollar for all stocks with a bid price exceeding \$10. Thus, dealers could either quote

in even-eighth $(0, 2/8, 4/8, 6/8)$ or in odd-eighth $(1/8, 3/8, 5/8, 7/8)$. Hence, the narrowest possible spread was one-eighth of a dollar.

CHAPTER 3

MARKET IMPERFECTIONS

As discussed in Section 2, the Nasdaq market structure has the unique feature that market makers compete for order flow through prices. Further, in the absence of virtually any entry and exit barriers, the number of market makers per stock ranges from 2 to 60. Regarding these characteristics, competitive spreads i.e., spreads close to the minimum price increment, can be assumed to be a natural outcome.

However, the following section refers to an empirical analysis that contradicts the premise of narrow spreads in the Nasdaq market. The case reveals that the multiple dealer market structure of Nasdaq failed to maintain competitive spreads.

3.1 ANECDOTAL EVIDENCE FOR THE NASDAQ STOCK MARKET

In May 1994, William G. Christie and Paul H. Schultz examined the entire distribution of inside bid and inside ask quotes for 100 of the most actively traded Nasdaq stocks in 1991 and found that spreads of one-eighth are virtually non-existent. The absence of one-eighth spreads can be contributed to the lack of either inside bid or inside ask quotes ending in odd-eighths i.e., ($1/8$, $3/8$, $5/8$, and $7/8$) for 70% of the total sample. Thus, if odd-eighth quotes are never used, the minimum inside spread equals one-fourth or equivalently \$0.25.

The authors compared the bizarre findings with a matched sample of stocks listed at the New York Stock Exchange (NYSE) and the American Stock Exchange (Amex). In contrast, for the NYSE/Amex sample the observed inside spreads range

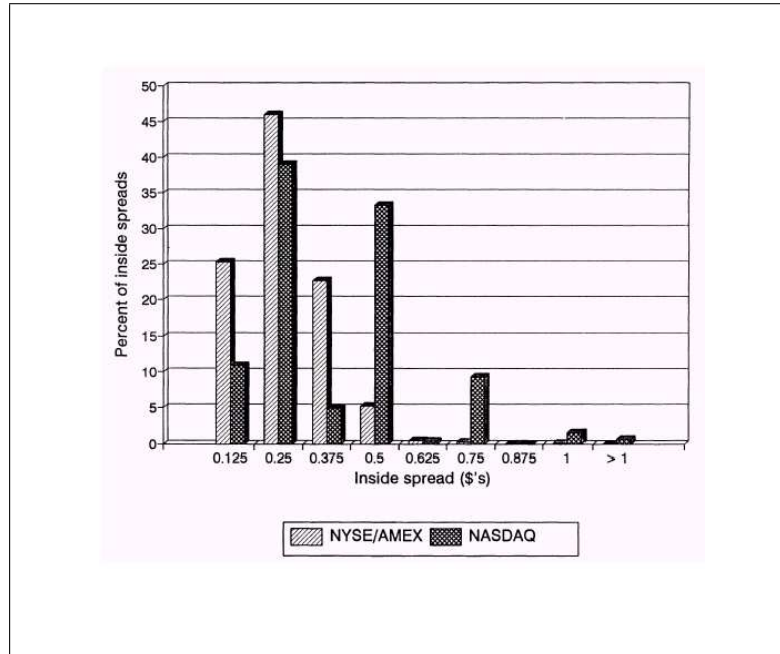


Figure 3.1: The distribution of inside spreads (in dollars) for 100 Nasdaq and 100 NYSE/Amex securities of similar price and end-of-year market capitalization. Source: Christie and Schultz [8]

over the whole spectrum of eighths. Hence, these differences suggests that the organizational structures of Nasdaq and NYSE/Amex differ in their efficiency in maintaining narrow and competitive spreads.

Figure 3.1 reveals that dollar spreads for Nasdaq stocks are mainly multiples of \$0.25. Spreads of \$0.125 and \$0.375 represent only 10 percent and 5 percent of all observed Nasdaq spreads, respectively. Spreads of \$0.5 are more common than spreads of \$0.375 and even large spreads of \$0.75 are more common than spreads of \$0.625 and \$0.375. In contrast, with negligible exceptions NYSE/Amex spreads do not exceed \$0.5. The whole distribution of spreads for NYSE/Amex stocks is mainly concentrated on spreads of \$0.125, \$0.25, and \$0.375, which suggests that

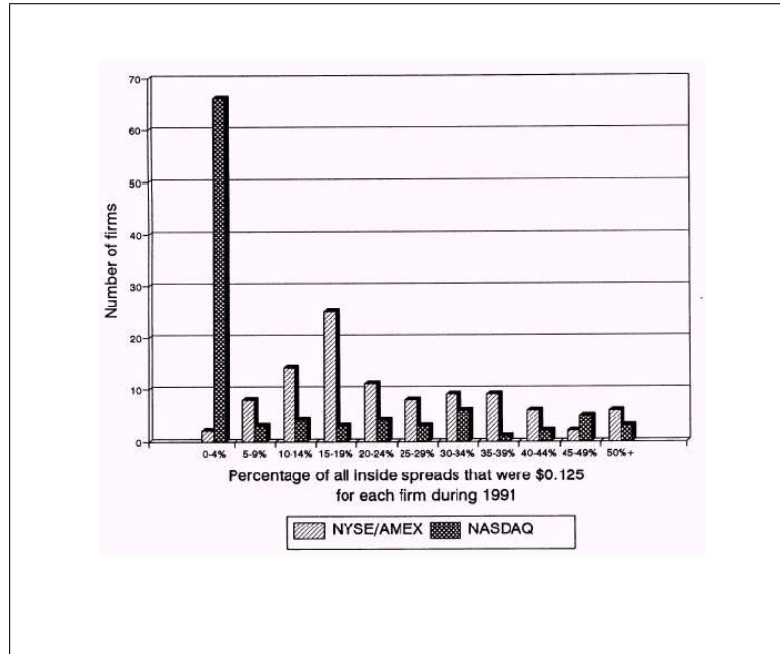


Figure 3.2: The percentage of inside spreads that are \$0.125 for 100 Nasdaq and 100 NYSE/Amex securities of similar price and end-of-year market capitalization. Source: Christie and Schultz [8]

the organizational structure utilized by the NYSE/Amex is more effective in promoting competitive spreads. Figure 3.2 illustrates how rare spreads of \$0.125 are for some Nasdaq stocks. Strictly speaking, for approximately 65 firms, fewer than 4 percent of all observed spreads are as small as one-eighth. In contrast, for most listed stocks, between five and 40 percent of all inside spreads equal \$0.125. Even for actively traded Nasdaq issues like Apple Computer and Lotus Development spreads of \$0.125 can only be observed in fewer than 2 percent of all cases. Further, a spread of \$0.50 accounts for almost half of the spreads for Apple Computer and Lotus Communication. Thus, these observations are everything but consistent with the premise of the organizational structure utilized by Nasdaq, which assumes that the

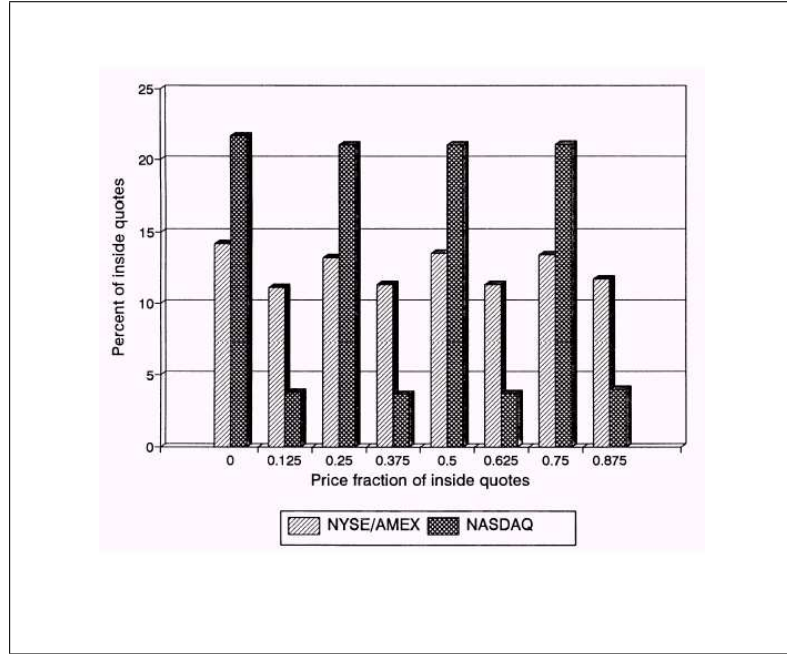


Figure 3.3: The distribution of price fractions across all inside quotes for 100 Nasdaq and 100 NYSE/Amex securities of similar price and end-of-year market capitalization. Source: Christie and Schultz [8]

more dealers are making a market in a certain issue the more they are faced with competition and consequently the narrower and more competitive are the spreads.

As indicated above, the lack of spreads of \$0.125, \$0.375, \$0.625, and \$0.875 suggests that most Nasdaq stocks are quoted in even-eighths i.e., in multiples of \$0.25. Hence, this quoting behavior ensures a minimum spread of \$0.25. Figure 3.3 highlights the different quotations of Nasdaq and listed stocks.

Although inside quotes in even-eighths are more frequent than in odd-eighths for the sample of the listed stocks – which is consistent with the findings reported by Harris [22] – all odd-eighth quotes ($1/8$, $3/8$, $5/8$, and $7/8$) cumulatively account for

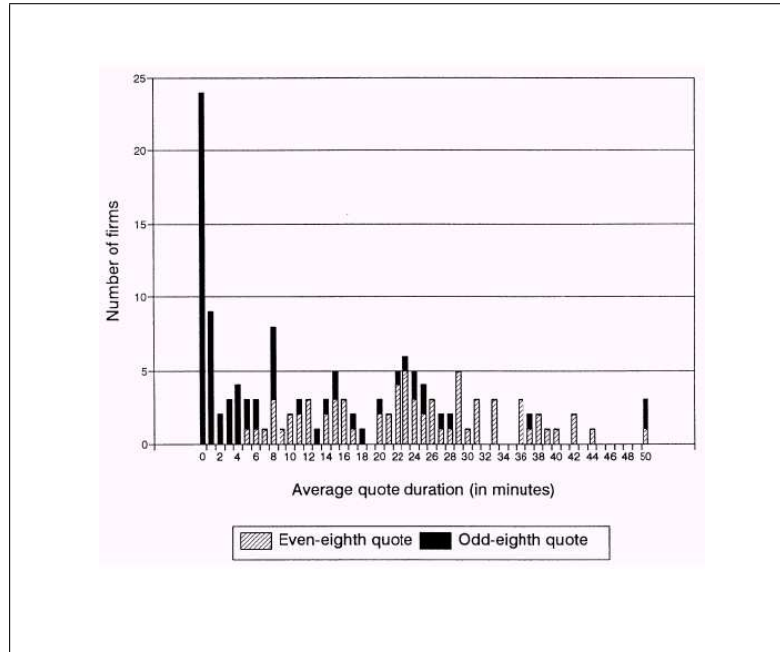


Figure 3.4: The distribution of the average duration of standing quotes for the sample of 70 Nasdaq stocks, whose market makers rarely use odd-eighth quotes. Source: Christie and Schultz [8]

more than 40 percent of all quotes. In contrast, fewer than 16 percent of all Nasdaq quotes are in odd-eighths.

In addition, Christie and Schultz [8] found that for the 70 stocks whose dealers rarely make use of odd-eighth quotes, the average duration for an odd-eighth quote is less than two minutes. On the contrary, even eighth quotes are effective between 20 and 35 minutes. This means that the results illustrated in Figure 3.3 even understate the small possibility to transact at odd-eighth quotes. These findings are summarized in Figure 3.4. Figure 3.4 reveals the average duration for even-eighth and odd-eighth quotes for issues whose market makers routinely use odd-eighths. It shows that the mean length of effective even-eighth and effective odd-eighth quotes is balanced.

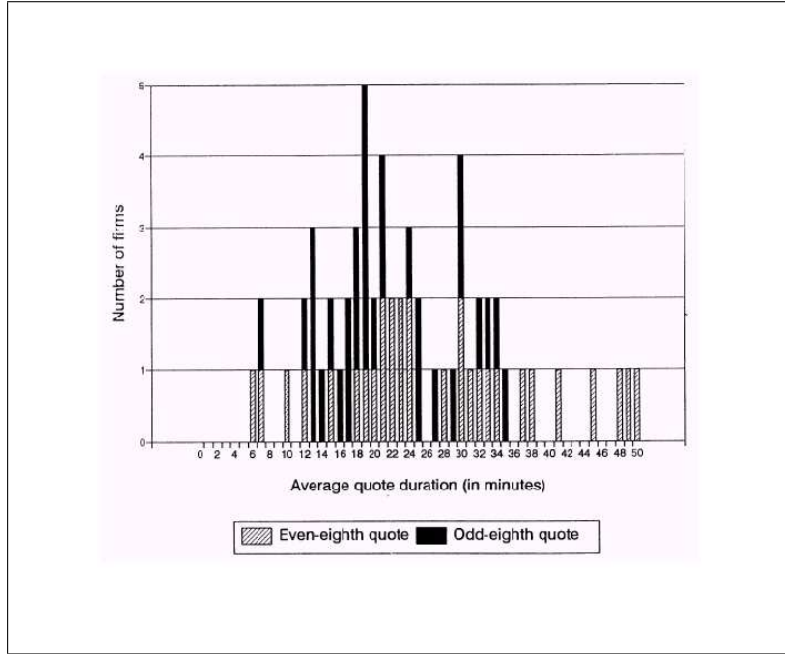


Figure 3.5: The distribution of the average duration of standing quotes for the sample of 30 Nasdaq stocks, whose market makers routinely use odd-eighth quotes. Source: Christie and Schultz [8]

3.2 ECONOMIC DETERMINANTS OF BID-ASK SPREADS

While the presented findings in Section 3.1 imply that the Nasdaq market structure failed to promote competitive spreads, the question of interest is whether tacit collusion among the market makers or economic determinants affecting the quoted spread were responsible for these observed patterns. These determinants include volume, volatility, market capitalization, and the stock price.

A high volume helps the market makers to adjust their inventory and therefore to reduce the risk they are faced with, which implies a negative correlation. In contrast, the higher the volatility, the higher is the inventory risk for the market maker. Thus, volatility and the bid-ask spread are positively correlated. Concerning the market

capitalization, Harris [24] argues that the higher the market capitalization, the more popularity the specific firm is exposed to. Consequently, market makers have to cope with fewer insider information and thus the asymmetric information component of the bid-ask spread that compensates them for this sort of risk is smaller.

Christie and Schultz [8], however, show that these economic determinants of the bid-ask spread are limited to explain the observed pricing behavior and that a major part of these patterns can be contributed to the fact whether a stock in the past was quoted in odd-eighths or not¹.

3.3 THE QUOTING BEHAVIOR AFTER THE PUBLIC DISSEMINATION

In response to the publication of the observed pricing patterns by several major newspapers on May 26 and 27, 1994, Christie, Schultz, and Harris [9] examined the inside and effective quotes of five of the ten most actively traded Nasdaq stocks (Amgen, Cisco Systems, Microsoft, Apple Computer, and Intel) after the announcement day. The effective spread is important to consider, since the inside spread does not necessarily reflect the trading costs for the investors. It is possible that – as a result of price negotiations – a trade is executed in between or outside the quoted spread. The effective spread relates the trade price to the ‘optimal’ price, which is defined as the midpoint of the quoted bid and ask. It is computed as follows:

$$ES = 2 \left| P_{Trade} - \left(\frac{P_{Ask} + P_{Bid}}{2} \right) \right| \quad (3.1)$$

The smallest quoted spread for each of these issues did not fall below \$0.25 between the beginning of 1993 and May 26, 1994. Moreover, these firms were also in the

¹The authors apply a logistic regression model that predicts the probability of a stock quoted in odd-eighths. The probabilities are derived from the maximum likelihood estimates of the coefficients for the independent variables included in the model. Taking a cut-off point of 50 percent, a stock with an estimated probability greater than 0.5 is classified into the category of stocks that are quoted in odd-eighths and a stock with an estimated probability less than 0.5 is classified into the group of stocks that are not quoted in odd-eighths.

sample of the 70 Nasdaq securities whose market makers rarely quoted in odd-eighths in 1991 as described in Section 3.1.

The authors found that the dealers in Amgen, Microsoft, and Cisco Systems began quoting in odd-eighths on the trading days subsequent to the public dissemination². As a result, the quoted spreads for these three firms decrease from 30 to 15 cents. The effective spreads decline from 17 to 10 cents for trades between 1,001 and 5,000 shares and from 30 to 16 cents for 100 share trades. Hence, the actual trading costs borne by an investor decline in correspondence to the decline in the width of the inside spread.

Since economic determinants could be excluded to be attributable to the abrupt narrowing of quoted spreads, the collapse of an implicit pricing agreement among the market makers remains the most possible explanation.

Further, since the number of dealers for any of the analyzed stocks remains constant after the collapse, the hypothesis that the ‘high’ spreads prior to the public dissemination have been competitive, must be rejected.

3.4 CONTROVERSIAL EXPLANATIONS

In contrast to explicit collusion, implicit collusive behavior is highly difficult, maybe even impossible to prove. Thus, the hypothesis by Christie and Schultz [8] that the observed pricing patterns on the Nasdaq are most likely to be attributable to tacit collusion among the market makers is considered by several academic studies.

For the most part, these studies refer to the special market structure of the Nasdaq. Kleidon and Willig [28] as well as Furbush, *et al.* [16] argue that the minimal entry barriers do not allow market makers to collude. Market makers have to make

²For example, 41 of the 45 market makers of Microsoft quoted solely in even-eighths on the days prior to the announcement. On May 27, this number shrank to one market maker.

one payment of \$10,000 to become eligible Nasdaq dealers³. Further, market makers are permitted to start trading one day after having made the initial payment. These results, however, disregard that the *unique* Nasdaq market structure implies high implicit entry barriers, especially caused by the order preferencing system. Even if a market maker can easily register as a Nasdaq dealer, he does not realize any profits as long as the brokers do not channel any orders to him. Hence, building up reputation that guarantees executable orders can be considered as a major entry barrier. This is discussed in Section 4.3.4 in greater detail.

Grossman *et al.* [19] rely on the negotiation hypothesis by Harris [22] in order to explain the avoidance of odd-eighth quotes. The negotiation hypothesis says that the use of coarse price increments minimizes negotiation costs i.e., by using all available price increments the time it takes to agree on a price increases and so do the costs. Since Nasdaq transactions with a volume lower than 1,000 shares are in general executed automatically through the Small Order Execution System (SOES) and only ‘larger’ orders are subject to a negotiation process, the hypothesis implies that the likelihood of a trade executed in odd-eighths should be greater for smaller trades. However, Figures 3.5 and 3.6 reveal that the negotiation hypothesis is not able to explain the lack of add-eighths. For the 70 stocks whose market makers seldom use odd-eighth quotes, large trades are more likely to occur in odd-eighths than small trades. And for the 30 issues whose market makers routinely use odd-eighths, no interpretable pattern can be observed i.e., odd-eighths are as likely for large trades as they are for small trades. Therefore, the negotiation hypothesis can easily be rejected for this case.

Furbush *et al.* [16] also argue that the unique market structure of the Nasdaq does not permit any collusive pricing behavior. The authors refer to the small degree of heterogeneous dealers at the Nasdaq. However, section 4.3.3 shows that the lower

³In contrast, the fee at the NYSE equals approximately \$300,000.

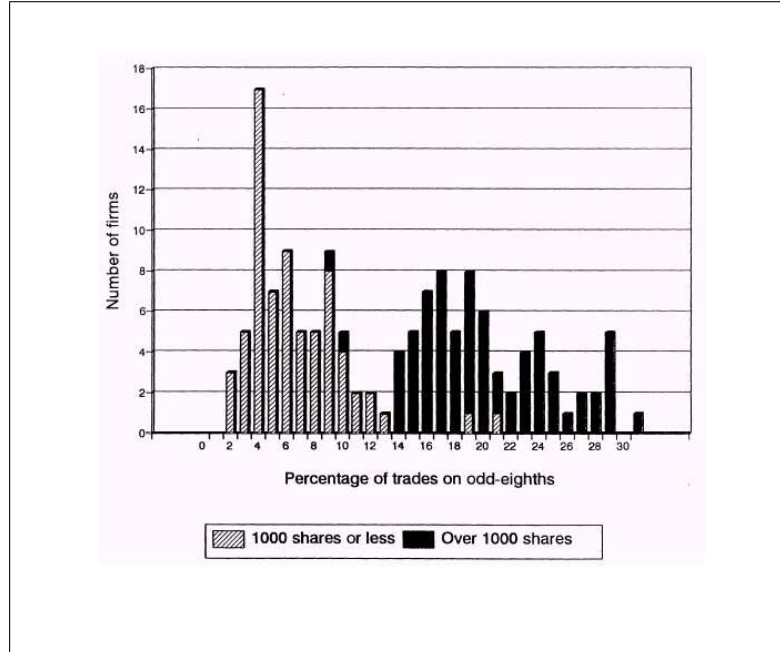


Figure 3.6: The distribution of the percentage of large and small trades executed on odd-eighths across the sample of 70 Nasdaq stocks, whose market makers routinely use odd-eighths. Source: Christie and Schultz [8]

the dealer concentration i.e., the degree of heterogeneous dealers, the more easily collusive prices can be maintained.

Kandel and Marx [27] acknowledge that the spreads are above competitive levels. However, they suggest that these patterns are mainly attributable to the discreteness of prices rather than to implicit collusion. This argument, however, is not in tune with the abrupt narrowing of spreads after the public dissemination as discussed in Section 3.3. As discussed in Chapter 4, narrower minimal price increments do not necessarily lead to a collapse of implicit pricing agreements. However, they reduce not only the range under which collusive prices are sustainable but also the dealers' excess profits.

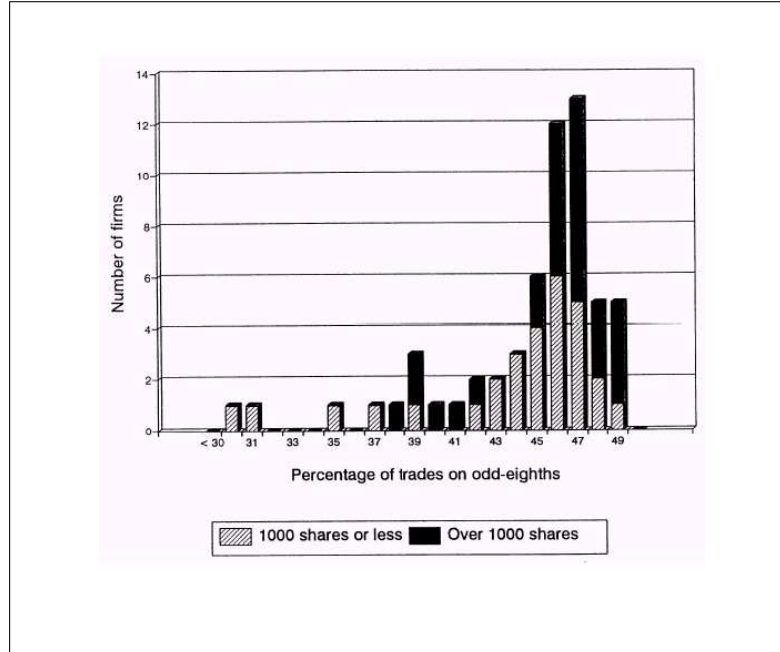


Figure 3.7: The distribution of the percentage of large and small trades executed on odd-eighths across the sample of 30 Nasdaq stocks, whose market makers rarely use odd-eighths. Source: Christie and Schultz [8]

Bessembinder [3] examines the relationship between trade execution costs and the frequency of quotation rounding to even-eighths for a sample of listed stocks at the NYSE and at the Nasdaq stock market. The objective is to uncover whether the observed pricing patterns are consistent with the collusion hypothesis by Christie and Schultz [8] or with the economic-cost hypothesis. The economic-cost hypothesis supported by Kleidon and Willig [28] states that the frequency of rounded quotations increases with the costs of market making. Thus, the hypothesis requires a positive relationship between trade execution costs and the frequency of quotation rounding at both the NYSE and the Nasdaq. While the sample of listed securities at the Nasdaq accounts for such a positive relationship, it is not observable for the

NYSE sample. Thus, the economic-cost hypothesis must be rejected. And since the requirement to display public limit orders excludes the possibility of anticompetitive pricing conventions for NYSE issues, the empirical results strongly support the hypothesis of a collusive pricing agreement among Nasdaq market makers.

Barclay [1] examines effective bid-ask spreads of Nasdaq listed securities that moved to the NYSE or Amex. The results show that stocks rarely quoted in odd-eighths decline substantially in spreads when moving to the NYSE or Amex. In contrast, effective spreads of issues whose market makers have routinely used odd-eighths, decline only slightly after the new exchange listing. Moreover, the author shows that differences in security specific costs of market making as well as different institutional market features do not adequately account for the substantial decline in effective spreads for those issues that were mainly quoted in even-eighths. Hence, the findings are consistent with the conclusion that an implicit pricing convention among Nasdaq market makers resulted in supracompetitive bid-ask spreads.

CHAPTER 4

A GAME-THEORETICAL MODEL

Considering the different opinions discussed above whether the pricing patterns are attributable to implicit collusion among the Nasdaq market makers or not, this chapter focuses on a game-theoretical model by Dutta and Madhavan [12] that helps to explain under which conditions collusive arrangements in a dealer market are feasible. In Section 4.4, I add some important features to the model that helps to explain the observed pricing patterns at the Nasdaq stock market.

In order to model the market makers' intertemporal pricing strategies, it is important to notice that the trading process in a market such as Nasdaq is exposed to deterministic or stochastic environmental changes (e.g. population of investors, supply and demand shocks, ...). Thus, a dynamic game rather than an infinite-horizon repeated game is the appropriate choice¹.

4.1 THE MODEL

The starting point is a risky stock traded in a dealer market. Since the focus is on intertemporal optimization strategies for dealers, transaction costs or adverse selection costs associated with insider trading are disregarded.

¹Christie and Schultz [8] consider the *folk-theorem* to support their view of implicit collusion among the market makers. However, the *folk-theorem* is based on a repeated game which does not consider the dynamic nature of a securities market. In a repeated game, the environment does not change from period to period i.e., if the market makers maintain the same bid and ask quotes, the profits would be unchanged for every trading round. However, this is an unrealistic assumption.

At the beginning of each trading round t ($t = 1, 2, \dots$) M dealers simultaneously determine their bid and ask prices. The ask and bid price quoted by dealer j in time t is denoted as a_t^j and b_t^j , respectively. The resulting inside spread equals

$$\lambda = a_t - b_t, \quad (4.1)$$

where $a_t = \min[a_t^1, \dots, a_t^M]$ denotes the best ask price and $b_t = \max[b_t^1, \dots, b_t^M]$ denotes the best bid price in time t . Further, it is assumed that the orders submitted by the traders are shared equally among all dealers who quote the inside spread.

The supply and demand functions for the risky stock are determined by three factors: (i) the best ask and bid prices, (ii) a volume shock, z_t , which represents the changing market environment² and is assumed to be an independent and identically distributed random variable, and (iii) unpredicted demand and supply shocks, denoted by ϵ_t and γ_t , respectively. Formally, the quantities demanded and supplied in period t equal

$$d_t \equiv d(a_t, z_t) + \epsilon_t \quad (4.2)$$

$$s_t \equiv s(b_t, z_t) + \gamma_t, \quad (4.3)$$

where $d(a_t, z_t)$ and $s(b_t, z_t)$ are the expected demand and supply, respectively. The error terms ϵ_t and γ_t are also assumed to be independent and identically distributed and have a mean of zero.

Assuming the market clearing price ν is independent of changes in the market environment z , the equilibrium is given by

$$s(\nu, z) = d(\nu, z) \quad (4.4)$$

for all z .

Thus, an increase in z shifts both the demand and the supply function, so that the market clearing price remains unchanged while the volume increases. Further, it

²Including the volume shock is necessary to obtain a dynamic game.

can be assumed that the market clearing price is the intrinsic value of the security, and that dealers observe the volume shock z_t just before they determine the quotes for period t . Additional restrictions imposed on the demand and supply functions can be found in Appendix A.

4.2 EQUILIBRIA

This section discusses possible equilibria under several market conditions i.e., under perfect competition, explicit collusion, and implicit collusion.

4.2.1 PERFECT COMPETITION

Assuming perfect price competition, the only Nash equilibrium in a single-period model is where market makers price noncooperatively and set both the bid and the ask equal to the market clearing price. No dealer has the incentive to deviate from the market clearing price. If a dealer undercuts the market clearing ask price or offers a higher bid price than the remaining market participants, he will receive all the order flow which in turn he will have to satisfy at a loss. In a multi-period model the “pricing at value” strategy remains a noncooperative Nash equilibrium.

4.2.2 EXPLICIT COLLUSION

Explicit collusion is the practice where market makers cooperate to maximize their joint profits i.e., the market makers act as a cartel³.

Denoting the expected profits for all dealers as $\pi_a(a_t; z_t) = (a_t - \nu)d(a_t; z_t)$ and $\pi_b(b_t; z_t) = (\nu - b_t)d(b_t; z_t)$ from selling and buying respectively, the corresponding

³Although explicit collusion is difficult to prove, and the Nasdaq market makers were only assumed to collude implicitly, it is important to consider the pricing strategies under explicit collusion, since as shown below in some circumstances the profits under explicit and implicit collusion are equal.

profit maximization problem in t equals:

$$\max_{a_t \leq \nu \leq b_t} [\pi_a(a_t; z_t) + \pi_b(b_t; z_t)] \quad (4.5)$$

Solving the maximization problem reveals that the optimal bid and ask prices change from period to period as the market environment z changes. For every z_t there exists only one profit maximizing price pair $\{a^c(z_t), b^c(z_t)\}$, known as monopoly or monopsony prices. Further, the spread is weakly monotone increasing in the volume shock (the bid is weakly decreasing and the ask is weakly increasing). Intuitively, since the volume shock, which can be regarded as the demand and supply elasticities of investors, increases demand for market making services, the cartel raises the price (spread) for providing more liquidity. Hence, the profit is also an increasing function of the volume shock.

4.2.3 IMPLICIT COLLUSION

Explicit collusion is not only difficult to prove but also difficult to sustain if there is a large number of heterogeneous dealers, especially in high-volume periods. Dealers with a small market share have a high incentive to undercut the supracompetitive spread in those periods in order to receive the total order flow.

Regarding the hypothesis that the observed pricing patterns at Nasdaq are attributable to implicit collusion, this section focuses on noncooperative pricing strategies that yield solutions at anticompetitive levels. The strategies are based on the intuition that in a dynamic game, dealers might consider quoting prices at supracompetitive levels if they believe that the remaining market makers behave similarly in the following trading rounds.

From the dealers' view the optimal prices would be those achievable under explicit collusion. However, this equilibrium is difficult to maintain in high-volume periods. As discussed in Section 4.2.2, the spread increases with the volume shock. Thus,

in high-volume periods the gain from undercutting the mutually maintained spread more than compensates the opportunity costs (present value of the lost gain from future cartel profits). Hence, as long as the volume shock is below a critical level the optimal prices under implicit collusion are equal to those under explicit collusion. If the threshold value is exceeded the spread must be narrowed in order to avoid dealers to undercut the spread. This is referred to as the second-best strategy.

Formally, the expected present value of future profits to all dealers under the second-best strategy and the known volume shock z' is as follows

$$J(z') = \max_{\{a', b'\}} \{\pi_a(a'; z') + \pi_b(b'; z') + \rho E[J(z)]\} \quad (4.6)$$

s.t.

$$(1/M)\{\pi_a(a'; z') + \pi_b(b'; z') + \rho E[J(z)]\} \geq \pi(a; z') + \pi(b; z') \quad (4.7)$$

for all $a \leq a'$ and $b \geq b'$, and where ρ is the appropriate discount factor.

Regarding the side-condition (4.7), a dealer who sets the prices equal to the prices (a', b') all dealers implicitly agreed on, will immediately receive $(1/M)[\pi_a(a'; z') + \pi_b(b'; z')]$ and can expect a future payoff equal to $E[J(z)]/M$ with z taking over all possible market environmental conditions. Alternatively, the dealer can deviate from the implicitly proposed prices by setting $a \leq a'$ and $b \geq b'$. The undercutting price pair (a, b) is chosen to maximize the right side of the constraint. Such a behavior would lead to a collapse of the implicit pricing agreement. This would happen if the profit from receiving the total order flow in one period (right side of the constraint) exceeds the expected profit share under the implicit pricing agreement (left side of the constraint). Concerning the function $J(z)$, the optimal solution would be to set the prices equal to the optimal prices under explicit collusion i.e., $(a', b') = (a^c(z'), b^c(z'))$. However, this solution is only sustainable if and only if

$$\frac{K}{M} \geq \left(1 - \frac{1}{M}\right) [\pi_a(a^c(z'); z') + \pi_b(b^c(z'); z')] \quad (4.8)$$

with $K \equiv \rho E[J(z)]$. Further, the value of K and equivalently every dealer's incentive to undercut the proposed prices is strongly dependent on the discount factor ρ . If the discount factor is large, which means that the dealer is patient, K is large and the likelihood to undercut the proposed prices is smaller than for a small discount factor.

Thus, the optimal strategy under implicit collusion for dealer i is therefore to set prices equal to the optimal prices under explicit collusion as long as the volume shock is below the critical value which itself depends on the discount factor i.e., $(a_t^i, b_t^i) = (a^c(z_t), b^c(z_t)) \forall z_t < z_c(\rho)$. According to constraint (R4), the optimal bid and ask prices for dealer i when the critical value is exceeded are marginal deviations from the collusive prices i.e., $(a_t^i, b_t^i) = (a^*(z_t), b^*(z_t))$ with $a^*(z_t) < a^c(z_t)$ and $b^*(z_t) > b^c(z_t) \forall z_t \geq z_c(\rho)$. Further, this strategy is only sustainable if the discount factor is large enough i.e., $\rho > \rho_0$ with $\rho_0 < 1$. In the event of a deviation from this strategy, the implicit agreement collapses and all dealers price at value i.e., $a_t = b_t = \nu$.

This noncooperative pricing strategy determines the so-called second-best Nash equilibrium. Strictly speaking this strategy yields the highest possible profit to all dealers when explicit pricing agreements (e.g. contracts, ...) are not possible. Considering the Nasdaq controversy, this strategy can be described as implicit collusion and shows that the equilibrium is sustainable even without any sanctions. This is because all dealers are best-off under this strategy and therefore do not have an incentive to deviate⁴.

⁴These conclusions also hold for the modification that the volume shock is time-dependent.

4.3 MARKET STRUCTURE AND IMPLICIT COLLUSION

In accordance with the derived noncooperative pricing strategy in Section 4.2.3 (implicit collusion), this section examines the fact whether this implicit pricing agreement is sustainable under several structural market features.

4.3.1 MARKET SIZE

The size of the market determines the number of buy and sell orders for any given price pair (a, b) and for any given market condition z . Thus, denoting the scale of the market as k , the expected demand and supply functions change as follows:

$$d^k(a; z) = kd(a; z) \quad (4.9)$$

$$s^k(b; z) = ks(b; z) \quad (4.10)$$

The modified functions show that market size affects both the supply and demand functions. Strictly speaking, both the quantities demanded and supplied change by k -times their initial values. This implies that in equilibrium the traded quantities change while the optimal bid and ask prices remain unaffected. Further, the market size does not influence the critical value z_c of the volume shock. Thus, implicit collusion is not affected by the size of the market.

4.3.2 TRADING FREQUENCY

Let n denote the number of trading rounds in a specified period. An increasing n implies that a dealer's profit from the prevailing implicit pricing agreement is nearer in the future. As a result, the discount rate $\rho \equiv \rho^{1/n}$ increases. In the limit, as $n \rightarrow \infty$, the discount rate approaches 1. Consequently, the critical value z_c , which determines the range under which the collusive pricing agreement is sustainable approaches infinity. Then, the optimal pricing strategy is reduced to setting all bid

and ask prices equal to the optimal prices under explicit collusion, regardless of the environment z_t .

The results imply that as trading frequency rises, the range under which market makers can quote monopoly prices (i.e. the optimal solution under explicit collusion) increases.

These conclusions are in tune with the findings of Christie, Harris and Schultz [9] that even actively traded stocks such as Apple Computer and Lotus Development are subject to collusion. It is important to notice, however, that the possibility to collude is not dependent on the volume of the stock. Thus, the possibility to collude is as high for low-volume issues as it is for high-volume issues if the trading frequencies are comparable.

4.3.3 HETEROGENEOUS DEALERS

The base model assumes that dealers who quote the inside spread, share the corresponding order flow equally. However, this is an assumption that is not representative for the Nasdaq, since brokers have the possibility to channel order flow to selected dealers. This is known as order preferencing. Moreover, differences in dealers' reputation and capacities determine differences in the received order flow. Thus, it is important to investigate whether unequal market shares among the dealers facilitate collusive behavior or not.

In the following, the fraction of order flow received by market maker i is denoted as ϕ_i with $\phi_i \geq 0$ when all dealers quote identical prices. The expected present value of future trading profits to dealer i equals

$$\phi_i K(\Phi) = \phi_i \rho E \left[\sum_{i=1}^M J_i(z; \Phi) \right], \quad (4.11)$$

where the expectation is taken over all future realizations of z . The equation reveals that the dealer with the smallest market share must be the first who to undercut the

prevailing collusive prices, since he receives the smallest profit under the collusive pricing agreement. Thus, if the dealer with the smallest profit share is willing to match the collusive prices, the collusive pricing agreement is sustainable.

This implies that the aggregate expected profit for all dealers increases with the profit share of the smallest dealer. Intuitively, the smaller the profit share of dealer i , the higher is the probability that dealer i is willing to undercut the prevailing prices. However, if the inside spread narrows, dealer i has less to gain by undercutting the spread. Thus, there exists a critical spread for which dealer i prefers to maintain the corresponding collusive prices. This critical spread increases with the profit share of the smallest dealer.

Grossman *et al.* [19] argue that the observed pricing patterns at Nasdaq are unlikely to be attributable to collusive behavior, since the measure of dealer concentration i.e., the degree of heterogeneous dealers is low. The analysis above, however, reveals that especially in a market environment with a large degree of homogeneous dealers, collusive prices are easier to maintain than in a market with a few dominant dealers. Further, the collusive profits in a homogeneous market are higher than in a heterogeneous market.

4.3.4 ENTRY BARRIERS

In reference to Kleidon and Willig [28] as well as Furbush *et al.* [16], the entry costs into the Nasdaq market are relatively low. With virtually no entry costs, the second-best Nash equilibrium is not sustainable, since new dealers will enter the market until expected profits equal zero. Under these circumstances, no collusion is possible and the only reasonable strategy is “pricing at value” i.e., $a_t = b_t = \nu_t$.

However, as suggested in Section 3.5, non-monetary and implicit entry costs, such as establishing reputation and forming long-term relationships with brokers

that channel the order flow to the dealers, have a major influence on the decision whether it is profitable to enter a market or not⁵.

Formally, explicit and implicit entry costs are denoted as $c > 0$. In reference to Section 4.3.3, expected future trading profits in the second-best Nash equilibrium are a function of the minimum order share. Assuming an equally distributed order share among the M market makers, the present value of expected future trading profits for all dealers is as follows:

$$K(\Phi) = \rho E[J(z)] \frac{1}{M} = K\left(\frac{1}{M}\right) \quad (4.12)$$

Intuitively, a new dealer is willing to enter the market as long as the aggregate explicit and implicit costs are below the share of the present value of expected future trading profits. Thus, the equation

$$\frac{1}{M} K\left(\frac{1}{M}\right) = c \quad (4.13)$$

determines the equilibrium number of dealers M^* . Since c can be assumed to be positive, the equation can be solved and the equilibrium number of dealers M^* is finite. Hence, implicit collusion is sustainable as long as at least implicit or explicit entry costs are positive. When the equilibrium number of dealers is reached, it is not profitable to enter the market. This is because K decreases with M .

The discussion above reveals that a competitive environment requires both the absence of implicit and explicit entry costs. So it is not appropriate to dismiss collusive behavior at the Nasdaq market by solely relying on the small explicit entry costs.

⁵In order to maintain these relationships, dealers offer monetary and non-monetary inducements to the brokers, such as research services, swaps, or assistance in the clearing and settlement process.

4.3.5 ORDER PREFERENCING

Order preferencing is a unique institutional characteristic of the Nasdaq stock market.

Let θ with $0 \leq \theta \leq 1$ be the fraction of order flow channeled by brokers to a group of N dealers. Each of these N dealers receives a proportion $\theta_i \geq 0$. Consequently, the remaining proportion of order flow $1 - \theta$ is partitioned equally by all M dealers. Thus, the total order flow received by dealer i who is in a preferencing arrangement and by dealer j who is not, equals $\phi_i = \theta_i + (1 - \theta)/M$ and $\phi_j = (1 - \theta)/M$, respectively. Recalling equations (4.12) and (4.13) reveal that the equilibrium number of dealers is smaller and bid-ask spreads are larger under preferencing arrangements than under an equally distributed order flow⁶.

The results imply that order preferencing arrangements create additional entry barriers. Intuitively, new dealers receive a smaller fraction of order flow when some existing dealers receive preferred orders. Thus, the expected present value of future trading profits for new dealers is smaller than in the absence of preferencing arrangements. Formally, equations 4.12 and 4.13 change to

$$K(\Phi) - K(\theta) = \rho E[J(z)] \frac{1 - \theta}{M} = K\left(\frac{1 - \theta}{M}\right) \quad (4.14)$$

and

$$\frac{1 - \theta}{M} K\left(\frac{1 - \theta}{M}\right) = c, \quad (4.15)$$

respectively. Equation 4.15 reveals that the equilibrium number of dealers M^* remains finite if $c > 0$. However, since

$$\frac{1 - \theta}{M} K\left(\frac{1 - \theta}{M}\right) \leq \frac{1}{M} K\left(\frac{1}{M}\right), \quad (4.16)$$

the equilibrium number of dealers under preferencing arrangements is smaller than under equally distributed order flow.

⁶The notation of equations 4.12 and 4.13 assume that the order flow is equally distributed among all M dealers.

This is a striking insight regarding the anticompetitive pricing patterns at the Nasdaq stock market. Although a second-best equilibrium is sustainable in the absence of preferencing arrangements, those arrangements further reduce the competitiveness of the market by creating additional entry barriers.

4.3.6 NASDAQ'S PREFERENCE TRADE RULE

The discussed issues in Section 4.3.5 assume that dealers must quote the best bid and ask before any orders can be channeled to them. However, the 'Preference Trade Rule' utilized by Nasdaq, does not require dealers to post the inside spread in order to receive preferenced order flow. They have the possibility to post a spread different from the inside spread. The preferenced orders, however, must be executed for the best intermarket prices. This rule has a large impact on the dealers' incentive to undercut the prevailing collusive prices, since in contrast to the discussion in Sections 4.2.3 and 4.3.3 a dealer who is willing to undercut the inside spread does not necessarily receive the total order flow. Most of the dealers will have (best price) preferencing arrangements that 'reserve' a certain market share regardless of their quoted prices⁷. In other words, under Nasdaq's Preference Trade Rule, any dealer who undercuts the prevailing prices will only get those orders that are not preferenced by other market makers. As a result, the incentive to post better prices is strongly restricted by this rule.

Technically, the smallest investor who has the highest incentive to undercut the prices, becomes more patient under the Preference Trade Rule, which is reflected in a higher discount factor ρ . Hence, equation (4.8) holds under a wider range of market environmental observations z_t than in the base case which excludes best price order

⁷As argued in Section 4.3.3, typically the dealer with the smallest market share should have the highest incentive to undercut the prevailing prices.

preferencing⁸. To sum up, Nasdaq's Preference Trade Rule increases the probability for dealers to realize monopoly prices⁹.

4.3.7 DISCRETE PRICES

At the time of the observed pricing patterns by Christie and Schultz [8], the minimum tick equaled one-eighth for all issues with a price greater than \$10. In reference to Kandel and Marx [27] the anticompetitive prices at this time are attributable to those discrete prices.

Price discreteness restricts any dealer's pricing set driven by the minimum price increment. Let us assume two market conditions: (i) the minimum price increment equals \$1/8, (ii) the minimum price increment equals \$1/16. Under scenario (i), the prevailing collusive prices $(a^c(z), b^c(z))$ can be undercut at a minimum of \$1/8. Thus, the resulting profit equals $\Pi_{1/8} = [\pi_a(a^c(z) - \$1/8; z) + \pi_b(b^c(z) + \$1/8; z)]$, assuming all order flow is received. Under scenario (ii) the collusive prices can be undercut at a minimum of \$1/16, resulting in a profit of $\Pi_{1/16} = [\pi_a(a^c(z) - \$1/16; z) + \pi_b(b^c(z) + \$1/16; z)]$. Since the profit under scenario (ii) is larger than under scenario (i), it follows that coarsening the minimum tick size reduces any investor's incentive to undercut the prevailing collusive prices. Conversely, the size of sustainable bid-ask spreads as well as the expected future trading profits of the implicit pricing agreement increase with the minimum tick size.

Hence, reducing the minimum price increment does not necessarily make implicit collusion impossible, but it does increase a dealer's incentive to undercut the collusive

⁸The value of the volume shock z_t must be below the critical value $z(\rho)$ for equation (4.8) to hold. The critical value, however, is positively dependent on the discount factor ρ , which implies that the more patient the smallest dealer is the higher are the discount factor and the critical value.

⁹In accordance to Section 4.2.3, these are the profit maximizing prices set under explicit collusion.

prices. A possible result would be a narrowing of bid-ask spreads. The following chapter examines this issue in greater detail.

4.4 MODEL EXTENSION AND IMPLICATIONS

The following discussion adjusts the model by Dutta and Madhavan [12] for some striking aspects that help to explain the observed Nasdaq pricing patterns prior and after the public dissemination.

4.4.1 SANCTIONS BY DEALERS

Although Dutta and Madhavan [12] show that implicit collusion is sustainable without any sanctions, it is justified to modify the model through the inclusion of a variable accounting for the threat of possible sanctions. The Nasdaq is based on an electronically supported trading mechanism and dealers can easily uncover violators of the pricing agreement. Possible sanctions that are consistent with the market structure at the Nasdaq are as follows:

- In the case of any order preferencing arrangements, a violator might receive orders unbalancing his inventory, e.g. he only receives sell-orders.
- The remaining dealers might refuse to trade directly with the violator.
- Brokers might channel orders to the violator that are assumed to originate from superior informed investors.
- The violator might receive fewer orders from the brokers.

The argument by Dutta and Madhavan [12] is based on the aspect that a dealer is not willing to undercut the collusive prices as long as the present value of expected future cartel profits exceeds the onetime profit from undercutting the collusive prices.

In order to account for the threat of possible sanctions in the case of violating the implicit pricing agreement, the only necessary modification is to introduce a variable ξ_t that reflects the dealers' perceptions of possible sanctions in time t .

Intuitively, if the perceived degree of possible sanctions is high, a dealer is more patient in terms of undercutting the collusive prices. Hence, the discount factor ρ is positively dependent on the perceived degree of possible sanctions i.e., $\rho = \rho(r, \xi)$, where r denotes the required rate of return. If $\xi = 0$, sanctions are perceived as virtually non-existent and the implications from the previous sections apply. If $\xi > 0$, the following proposition characterizes the second-best Nash equilibrium.

Proposition 1 *If the market environment is below a unique critical level i.e., $z_t < z_c(\rho(r, \xi))$, the optimal solution for dealer i is equal to the solution under explicit collusion i.e., $\{a_t^i(z_t), b_t^i(z_t)\} = \{a^c(z_t), b^c(z_t)\}$. If the market environment is above a unique critical level i.e., $z_t > z_c(\rho(r, \xi))$, the bid and ask prices for dealer i are marginal deviations from the solution under explicit collusion i.e., $\{a_t^i(z_t), b_t^i(z_t)\} = \{a^*(z_t), b^*(z_t)\}$ with $a^*(z_t) < a^c(z_t)$ and $b^*(z_t) > b^c(z_t)$. If $\xi \rightarrow \infty$, then $\rho(r, \xi) \rightarrow 1$, and as a result, collusive prices are sustainable in all environments:*

$$\lim_{\rho(r, \xi) \rightarrow 1} z_c(\rho(r, \xi)) = \infty \quad (4.17)$$

Proposition 1 implies that the presence of possible sanctions faced by violators of the implicit pricing agreement even increase the range under which optimal (collusive) prices are sustainable. Intuitively, comparable dealers who only distinguish in the perceived degree of future sanctions will differ in their willingness to undercut the prevailing collusive prices. In other words, the higher the perceived impact of future sanctions, the smaller is a dealer's incentive to violate the implicit pricing agreement, *ceteris paribus*.

This is an important insight, since Nasdaq's electronically supported trading mechanism provides the necessary transparency for sanctions among market makers.

4.4.2 PENALTIES BY REGULATORS

The game-theoretical model by Dutta and Madhavan [12] does not consider factors that reduce the likelihood of collusive behavior. These factors, however, can be assumed to influence the decision process of dealers, especially after the public dissemination of the anticompetitive pricing practices observed by Christie and Schultz [8]. For this reason, I modify the model by accounting for anticipated penalties imposed by regulators in response to collusive pricing practices.

Equivalently to the modifications in Section 4.4.1, a variable accounting for the effects of anticipated penalties has to be included. Let κ_i denote the set of possible penalties imposed by regulators for dealer i . For instance, these penalties might differ for the frequency as well as for the magnitude of anticompetitive spreads. If we assume that all dealers can rationally determine the true impact of those penalties depending on the frequency and magnitude of anticompetitive spreads, this implies that the longer dealers maintain collusive behavior and the higher their anticompetitive trading profits are, the more likely they are to undercut the prevailing collusive prices, *ceteris paribus*.

Further, this decision is also dependent on the regulators' historical success in uncovering collusive arrangements. This is a striking issue, since spreads at the Nasdaq during the investigation of the SEC and the Antitrust Division of the DOJ abruptly narrowed¹⁰. Formally, let

$$\varphi_t = \sum_{k=1}^{\tau} \frac{\varphi_{t-k}}{\tau} \quad (4.18)$$

denote the recent success rate of regulators of uncovering collusive behavior, with $\tau \geq 1$ as a reasonable time frame. Thus, the expected penalties for anticompetitive pricing practices for dealer i are as follows:

$$E(\kappa_i) = \varphi_t \cdot \kappa(d_i, m_i), \quad (4.19)$$

¹⁰See Barclay *et al.* [2].

where d_i and m_i denote the frequency and the magnitude of collusive prices for dealer i , respectively.

The second-best equilibrium in the presence of expected penalties is characterized by the following proposition.

Proposition 2 *The discount rate is negatively dependent on the expected penalties i.e., $\rho = \rho(E(\kappa_i))$ with $\frac{d\rho}{dE(\kappa)} < 0$. If the market environment is below a unique critical level i.e., $z_t < z_c(\rho(\varphi_t \cdot \kappa(d_i, m_i)))$, the optimal solution for dealer i is equal to the solution under explicit collusion i.e., $\{a_t^i(z_t), b_t^i(z_t)\} = \{a^c(z_t), b^c(z_t)\}$. If the market environment is below a unique critical level i.e., $z_t > z_c(\rho(\varphi_t \cdot \kappa(d_i, m_i)))$, the bid and ask prices for dealer i are marginal deviations from the solution under explicit collusion i.e., $\{a_t^i(z_t), b_t^i(z_t)\} = \{a^*(z_t), b^*(z_t)\}$ with $a^*(z_t) < a^c(z_t)$ and $b^*(z_t) > b^c(z_t)$.*

Proposition 2 implies that the higher a dealer's expected penalties are, the more impatient he is in maintaining the collusive prices. In accordance to the model by Dutta and Madhavan [12], there exists a critical discount factor $\rho_0 < 1$ that determines the degree of necessary patience for any given dealer i . If any dealer's discount factor is below this constant, the second-best equilibrium is not sustainable and the only possible strategy is “pricing at value”. Hence, Proposition 2 implies that there exists a critical degree of expected penalties $E(\kappa)^*$, so that dealers are not sufficiently patient and not willing to maintain the second-best strategy.

This might explain the abrupt narrowing of spreads after the public dissemination by Christie and Schultz [8]. In anticipation of a rigorous investigation by the SEC and the Antitrust Division of the DOJ, dealers possibly became more aware of future penalties and consequently narrowed their quoted spreads. Moreover, Barclay *et al.* [2] found that trading costs strongly declined during periods of governmental investigations.

CHAPTER 5

EFFECTS OF RECENT MARKET REFORMS ON THE NASDAQ STOCK MARKET

The public dissemination of the Christie and Schultz [8] results initiated a wave of reconsiderations whether the the Nasdaq market structure is efficient in promoting a competitive environment. As a result of several regulatory investigations by the Securities and Exchange Commission (U.S. SEC [39]) and Department of Justice (U.S. DOJ [38]), numerous reforms went into effect.

First, in accordance with the DOJ settlement, market makers agreed to end their convention of solely quoting in even-eighths. Second, the NASD Regulation Inc. was formed in order to separate the regulatory responsibilities of the National Association of Securities Dealers (NASD) from the operation and ownership of the Nasdaq stock market. Third, in 1997 the SEC implemented new order handling rules with the main focus being on an improved competitive market environment¹. Fourth, on April 9, 2001, the Nasdaq stock market finally switched to decimal pricing. The following discussion examines the impact of the *SEC Order Handling Rules* with the main focus being on securities facing a high prevailing degree of competition, and it provides an outlook of the effects of the implementation of the decimal pricing system.

¹See Nasdaq (1997), Integrating the SEC Order Handling Rules.

5.1 SEC ORDER HANDLING RULES

The SEC Order Handling Rules applied to the first fifty stocks on January 20, 1997, and to a subsequent group of fifty securities on February 10, 1997. On October 13, 1997 all remaining Nasdaq issues were subject to the new rules.

5.1.1 REGULATORY CHANGES

The new SEC Order Handling Rules include the following market structural changes².

(i) *Limit Order Display Rule*

As described in Chapter 2, the public was traditionally not able to compete with the Nasdaq market makers through limit orders. Public competition was considered unnecessary, since Nasdaq's multiple dealer market environment was assumed to be sufficiently effective in supporting competitive bid-ask spreads. However, the game-theoretical model discussed in Chapter 4 reveals that a large number of dealers accompanied with small entry barriers do not necessarily result in competitive pricing behavior.

Under the new SEC rules, a dealer receiving a public limit order is required to either (i) execute it directly against his own inventory, (ii) post the order as his own quote, or forward the order (iii) to another dealer, or (iv) to a proprietary trading system. Thus, a limit order that lies in between the prevailing inside spread reduces the spread when being displayed. As a result, all market makers are required to trade with their own customers at the limit order price. Hence, under this rule public limit orders directly compete with dealer quotes.

²See Barclay *et al.* [2].

(ii) *Display of Quotes on Electronic Communication Networks*

Electronic communication networks (ECNs) are proprietary trading systems, like Instinet or Island, that are mainly used by market makers and large institutional investors. In recent years, ECNs have gained a large market share, since this form of trading circumvents traditional intermediaries (market maker and specialist). In 1999, ECNs accounted for almost 30% of Nasdaq's total trading volume.

Prior to the SEC Order Handling Rules, market makers were able to post different quotes on Nasdaq and on an ECN. Since ECNs directly match anonymous sell and buy orders without any intermediaries, spreads could usually be observed to be narrower than at the Nasdaq. Hence, Nasdaq dealers had the privilege to trade at more favorable prices than the public investor³.

Under the SEC Order Handling Rules, a market maker posting quotes on an ECN has to comply with one of the following two options: Either his quote with its total depth is shown anonymously to the public, or the quote is posted on Nasdaq with the minimum required depth while revealing the dealer's identity. Hence, by eliminating price fragmentation across trading alternatives, competition can be expected to increase.

(iii) *Reduction in the Minimum Depth*

Prior to the SEC Order Handling Rules, the minimum required depth for the most Nasdaq issues equaled 1,000 shares⁴. Since the public is allowed to place limit orders with a minimum depth of 100 shares, Nasdaq market makers would obviously be opposed to a disadvantage by requiring a depth of 1,000 shares.

Therefore, under a pilot program the minimum required quote size was reduced

³Due to the emergence of online-brokerage accounts utilizing ECNs, the number of private investors making use of these proprietary trading systems steadily increases.

⁴For some issues, the minimum depth equaled 500 shares.

to 100 shares for all Nasdaq issues that were subject to the new SEC rules on January 10, 1997. All issues that were phased in on February 10, 1997 still require a minimum depth of 1,000 shares per order.

(iv) *Relaxation of the Excess Spread Rule*

The initial Excess Spread Rule required every Nasdaq market maker's spread not to deviate more than 125 percent from the average of the three narrowest individual spreads for each issue⁵. As argued by Kandel and Marx [27], this requirement strongly reduces each dealer's independency to change the spread width, since it has to fall in a restricted range conditional on the other market makers' spread widths.

The new Excess Spread Rule allows Nasdaq market makers to exceed the average of the three lowest dealer spreads by 150 percent at a maximum. In contrast to the initial excess spread requirements, a dealer has to comply with the critical 150 percent on a monthly basis rather than continuously i.e., individual spreads within a month are permitted to exceed the critical 150 percent as long as the monthly average complies.

Thus, the SEC Order Handling Rules introduced auction-like characteristics into the traditionally pure Nasdaq dealer market.

5.1.2 EFFECTS

Regarding the SEC Order Handling Rules, it is striking to examine their efficiency in improving the competitive environment of the Nasdaq stock market. If this is true, then dealers should be forced to reduce bid-ask spreads.

Barclay *et al.* [2] find that quoted and effective spreads narrowed by approximately 30 percent after the implementation of the SEC Order Handling Rules. They

⁵Nasdaq continuously calculates this average for each stock.

further concluded that the significant decrease in trading costs on the Nasdaq was mainly attributable to the display of limit orders and to the display of quotes on proprietary trading systems.

Weston [40] primarily focuses on the question whether the SEC Order Handling Rules increased competition among the Nasdaq market makers. According to microstructure theory, the quoted spread typically has four components:

(a) *Order-Processing Costs*

These costs are attributable to the order clearing process i.e., they include the fixed cost of holding a seat on the exchange, paperwork, and administrative costs⁶.

(b) *Inventory-Holding Costs*

In general, every dealer on the Nasdaq holds a personal position in those issues he is making the market. Thus, a dealer bears the risk of a non-diversified portfolio. Consequently, a part of the spread compensates this sort of risk for the dealer.

(c) *Adverse-Selection Costs*

In theory, market makers trade with two different types of investors: (1) informed investors, and (2) liquidity investors. Informed investors trade due to insider information i.e., information that is typically not available to market makers and to the general public. Since informed traders can be assumed to know the true value of the security, they are only willing to buy (sell) if the quoted ask-price (bid-price) is too low (high). Thus, market makers constantly lose money when they trade with informed investors. In order to offset this loss, they typically widen the bid-ask spread and thus gain profits from trading with liquidity investors.

⁶See Demsetz [10].

Since this component is dependent on the frequency of information events (e.g. merger announcements, dividend policy changes, ...), it is unlikely to be affected by the new SEC rules.

(d) *Market Maker Rents*

This is the fraction of the spread that does not offset any costs. It is simply the economic profit for a market maker.

Using the empirical spread decomposition model by Huang and Stoll [25], Weston [40] find that, on average, the fraction of the spread representing order-processing costs and market maker rents decreased from \$0.271 to \$0.171, whereas the adverse-information costs and the inventory-holding costs remained unchanged after the implementation of the SEC Order Handling Rules. And since the new SEC rules did not change any factors determining the order-processing costs, it can be concluded that the spread reduction is attributable to reduced market maker rents. Hence, the results show that the new SEC Order Handling Rules succeeded in forcing competition among Nasdaq market makers.

The subsequent analysis focuses on the effects of the SEC Order Handling Rule on Nasdaq issues whose spreads were already very tight (i.e. close to one-eighth of a dollar, on average) prior to the new rules. The main question is whether the introduction of the new rules resulted in further spread reductions and in a different quoting behavior for issues facing the highest degree of competition among all Nasdaq stocks.

In order to address this question, TAQ data for Microsoft Corporation and Cisco Systems Inc. has been selected for a time frame surrounding January 20, 1997, the date when these issues were phased in under the new rules. According to NASD [31], Microsoft Corporation and Cisco Systems Inc. ranked second and third as far as total market value in 1996 is concerned, respectively. Moreover, Cisco Systems

Inc. was the second most actively traded issue among all Nasdaq firms, whereas Microsoft ranked fourth⁷.

DATA

The data used for this examination are supplied by the *NYSE TAQ Database*, and consist of intraday inside quotes and trades for the period from January 1, 1997, through February 15, 1997, for Microsoft Corporation and Cisco Systems Inc. I exclude all quotes before 9.30 a.m. and after 4.00 p.m. Moreover, I eliminate all locked or crossed quotes (where the bid either equaled or exceeded the ask), since they are not sustainable.

INSIDE SPREADS

The impact of the SEC Order Handling Rules on the issues of Microsoft Corporation and Cisco Systems Inc. is tested by computing a daily time-weighted average inside spread, and averaging the daily values for the days prior and after the new SEC rules. The statistical significance of univariate differences in means across the days prior and after the new rules is determined using standard two-sample t-tests.

Table 5.1 shows that the average of the time-weighted daily inside spreads for both Microsoft Corporation and Cisco System Inc. is relatively small for the days prior to the new SEC Order Handling Rules. Barclay *et al.* [2] calculate the average inside spreads categorized for total dollar volume for a comparable period. There, the average inside spread for the top twenty issues by dollar volume equals \$0.183. Thus, the issues of Microsoft Corporation and Cisco Systems Inc., whose average spreads are narrower than the average spread of the top twenty issues, ranked by dollar

⁷Share volume and market value (both in thousands) for Microsoft Corporation: 1,205,766 and \$98,752,409, respectively. Share volume and market value (both in thousands) for Cisco Systems Inc.: 1,789,884 and \$41,308,277, respectively.

Table 5.1: Quoted Inside Spreads Surrounding the Introduction of the SEC Order Handling Rules

Date	01/02/1997 - 01/19/1997	01/20/1997 - 02/14/1997
<u>Company</u>		
Microsoft Corporation (US-\$)	0.1564	0.1365**
Cisco Systems Inc. (US-\$)	0.1490	0.1301**

** The value is statistically different at the 1 percent level from the preceding value.

A detailed summary of the t-Test can be found in Appendix B.

volume, can be considered as representative choices for stocks facing the highest degree of competition.

Table 5.1 shows a decline in the average of the time-weighted daily inside spread for both Microsoft Corporation and Cisco Systems, once the SEC rules are implemented. The inside spread for Microsoft declines from \$0.1564 to \$0.1365, while Cisco's inside spread narrows from \$0.1490 to \$0.1301. Both changes are statistically significant at the 1 percent confidence level. Hence, for both stocks the inside spread declines by more than 12 percent after the introduction of the new SEC rules⁸.

Figures 5.1 and 5.2 plot the time-series of time-weighted average inside spreads for both Microsoft Corporation and Cisco Systems Inc. in order to examine if the significant decline in quoted spreads is attributable to the SEC Order Handling Rules. Figure 5.1 reveals that the average daily inside spread for Microsoft is highly volatile prior to the implementation of the new SEC rules. However, it can be seen

⁸The calculated inside spreads prior to the new SEC rules coincide with those calculated by Christie, Harris and Schultz [9] for Microsoft Corporation and Cisco Systems Inc. after the public dissemination of their results.

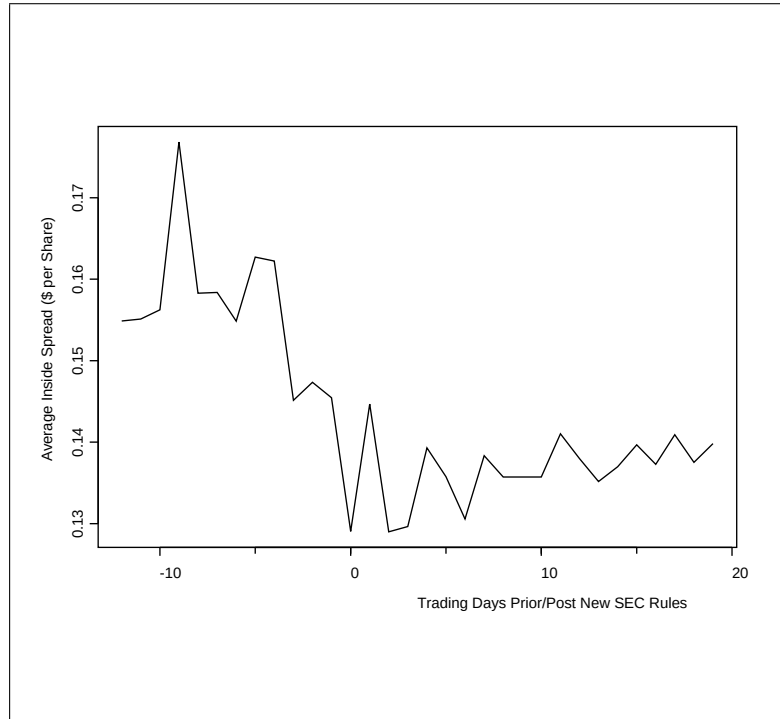


Figure 5.1: Time-series for time-weighted average inside spreads for Microsoft Corporation.

that the daily inside spreads fluctuate between \$0.176 and \$0.145. Immediately upon introduction of the new SEC rules, average inside spreads collapse to \$0.129, and fluctuate between \$0.129 and \$0.145 for the rest of the sample period. For Cisco Systems Inc. a similar trend can be observed in Figure 5.2. Daily average inside spreads are exposed to a fluctuation between \$0.163 and \$0.14 prior to the implementation of the SEC Order Rules, while immediately collapsing to \$0.126 on the day when the new rules went into effect. In the subsequent days, inside spreads fluctuate between \$0.137 and \$0.126. Hence, the decline in average spreads coincides with the date when the SEC Order Handling Rules were implemented, confirming that the spread reduction is attributable to the SEC rule change.

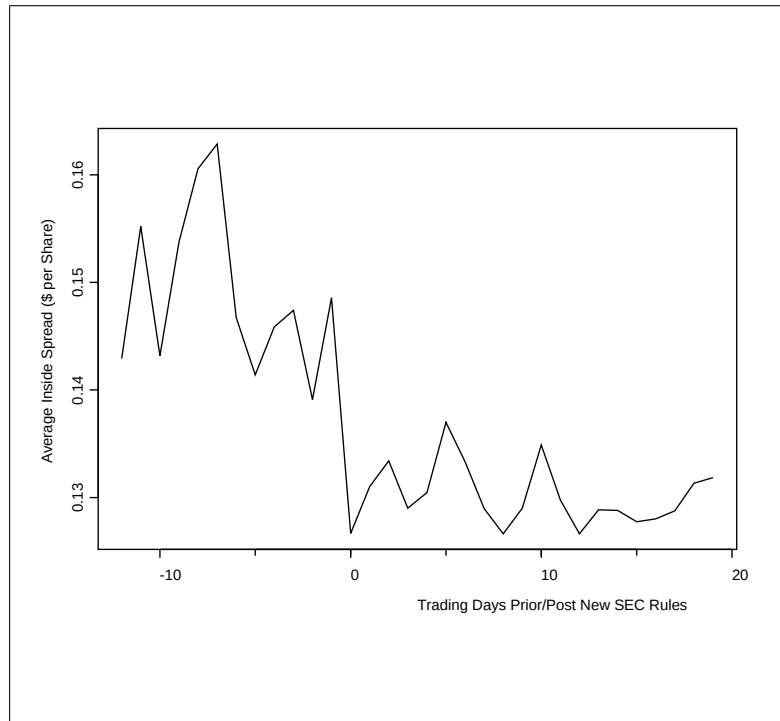


Figure 5.2: Time-series for time-weighted average inside spreads for Cisco Systems Inc.

Figures 5.3 and 5.4 show the distribution of time-weighted average inside spreads for Microsoft Corporation and Cisco Systems Inc. conditional on the presence of the SEC Order Handling Rules. During the period prior to the rule change, spreads of \$0.125 and \$0.25 account for 73 percent and 26 percent of the time for Microsoft Corporation, respectively⁹. Subsequent to the new rules, the fraction of spreads of \$0.125 increases to 91 percent, whereas spreads of \$0.25 occur only 9 percent of time. A similar pattern can be observed for Cisco Systems Inc. During the period prior to

⁹Christie, Harris, and Schultz [9] calculate the distribution of inside spreads for Microsoft around the public dissemination of the odd-eighths avoidance. The occurrence of a \$0.125 inside spread after the public dissemination is comparable to the 73 percent prior to the new SEC rules. This suggests that the quoting behavior has not been changed during this time.

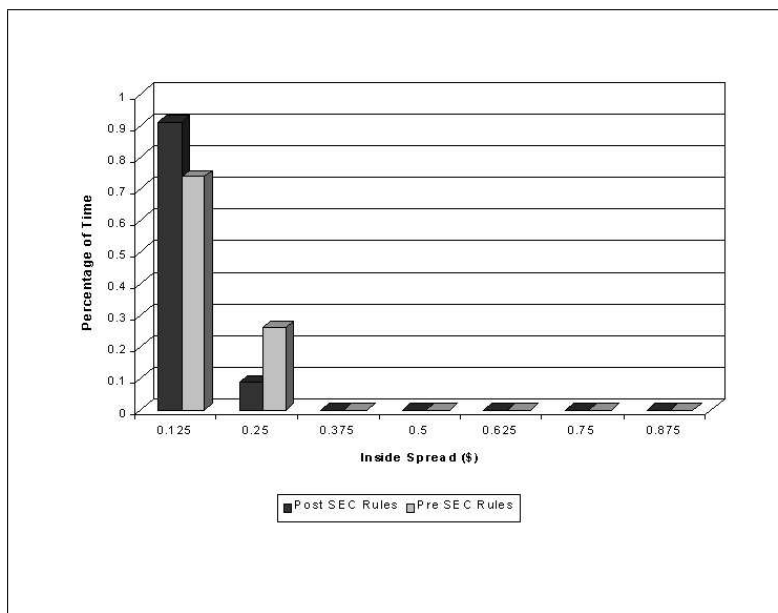


Figure 5.3: Distribution of time-weighted average inside spreads for Microsoft Corporation conditional on the presence of the SEC order handling rules introduced on January 20, 1997.

the rule changes, spreads of \$0.125 and \$0.25 comprise 80 percent and 19 percent of all quotes, respectively. Once the new rules are implemented, the spread width of \$0.125 accounts for 95 percent of time, while the occurrence of spreads equal to \$0.25 reduces to 4 percent of total sample time.

Interestingly, during the total sample period spreads of \$0.375 and greater could almost never be observed for both issues. In reference to Barclay *et al.* [2] who calculate a comparable distribution as an average for a large sample of Nasdaq issues, spreads greater than \$0.375 comprise, on average, approximately 42 percent of all quotes until the new rules are implemented. Furthermore, during the period proceeding the new rules, inside spreads of \$0.25 are more likely to occur than spreads of \$0.125. Hence, comparing these patterns with the distributions for Microsoft and

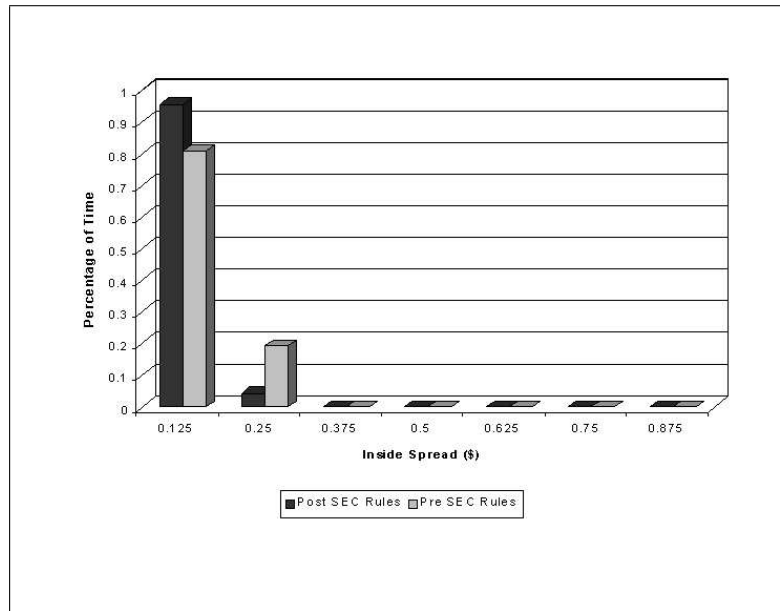


Figure 5.4: Distribution of time-weighted average inside spreads for Cisco Systems Inc. conditional on the presence of the SEC order handling rules introduced on January 20, 1997.

Cisco Systems Inc. supports the premise that both issues have already faced a high degree of competition.

Thus, assuming Microsoft Corporation and Cisco Systems Inc. are representative for issues facing the highest degree of competition among all Nasdaq securities, the results suggest that the introduction of auction-like market features increased competition even for stocks that have already been exposed to a high degree of competition.

TRADE EXECUTIONS

The preceding discussion reveals that quoted bid-ask spreads narrowed following the implementation of the new SEC Order Handling Rules. However, since trades

must not necessarily be executed at the quoted inside spread i.e., they can also be executed either inside or outside the quoted spread, a reduced average of quoted inside spreads does not necessarily imply reduced trading costs for investors.

In order to assess the reliability of the quoted inside spread as a measure of actual trading costs, it has to be determined whether the impact of trade executions outside and inside the quoted spreads is negligible for the issues of Microsoft Corporation and Cisco Systems.

For these purposes, the percentage of trades executed at, inside, and outside the quoted spread are calculated for the period before and after the implementation of the new rules. Figures 5.5 and 5.6 illustrate that trades executed either outside or inside the quoted spread cumulatively account for approximately 15 to 20 percent for Microsoft and Cisco¹⁰. Thus, solely relying on the quoted spread could be misleading in order to determine the impact of the new SEC rules on the actual trading costs. A detailed summary of the distribution of trade executions can be found in Exhibit D.

EFFECTIVE SPREADS

The finding that trades executed at prices better or worse than the quotes account for a non-negligible part of total trades implies that changes in actual trading costs could be smaller or greater than changes in quoted spreads. As discussed in Section 3.3, the effective spread is a more precise measure for actual trading costs borne by an investor.

In accordance with equation (3.1), effective spreads are calculated as twice the absolute difference between the trade price and the midpoint of the contemporaneous bid and ask quotes. Although some authors (e.g. Lee and Ready [30]) recommend

¹⁰In addition, the fractions of trades executed at, inside, and outside the spread remain unaffected by the new rules for both Microsoft Corporation and Cisco Systems.

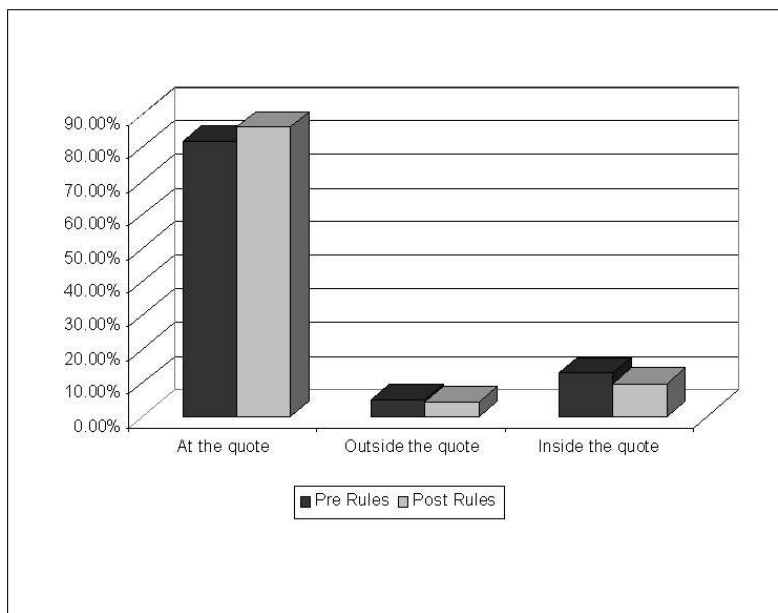


Figure 5.5: Trade executions at, inside, and outside the quotations for Cisco Systems Inc.

adjusting the trade and quote matching procedure with time stamps in order to account for trade reporting lags, recent evidence by Peterson and Sirri [32] as well as Ellis, Michaely, and O'Hara [15] suggests that contemporaneous matching algorithms provide more accurate results.

Table 5.2 reports on average effective bid-ask spreads for Microsoft Corporation and Cisco Systems Inc. measured in cents per share. The results are obtained by computing an equally weighted effective spread for each trading day and then averaging across the days before and after the implementation of the new rules¹¹. Once the new SEC rules are introduced, average effective bid-ask spreads decline for both Microsoft Corporation and Cisco Systems. The effective spread for Microsoft

¹¹Another approach is to calculate a volume-weighted average for each day and then averaging across the days.

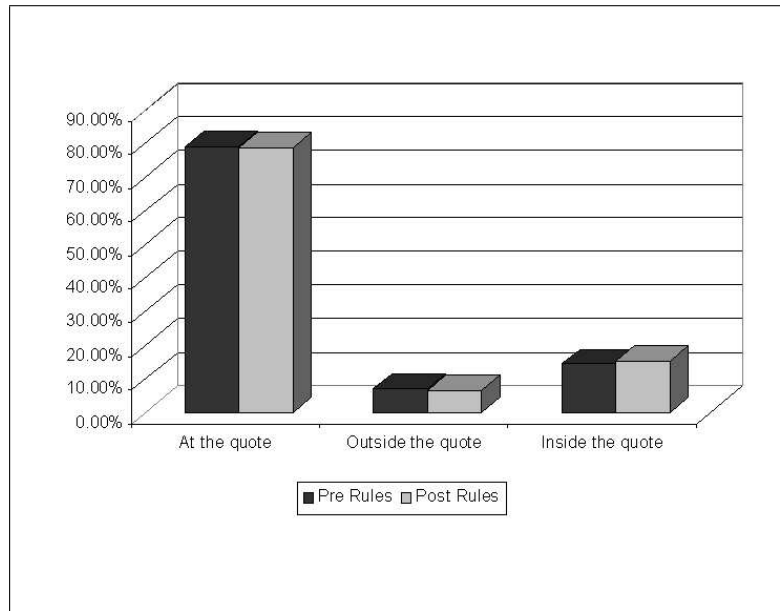


Figure 5.6: Trade executions at, inside, and outside the quotations for Microsoft Corporation.

declines from \$0.1581 to \$0.1482, while Cisco's effective spread narrows from \$0.1424 to \$0.1331. While Microsoft's spread change is statistically significant at the 5 percent confidence level, the post-rule effective spread for Cisco is statistically different from its preceding value at the 1 percent confidence level.

Comparing these results with the quoted spreads as reported in Table 5.1 reveals a striking insight: Quoted spreads declined by 12 percent while effective spreads only declined by 6 percent once the new SEC rules are implemented. Hence, actual trading costs borne by an investor decreased but price deteriorations became more apparent in the wake of the SEC Order Handling Rules.

Table 5.2: Effective Spreads Surrounding the Introduction of the SEC Order Handling Rules

Date	01/02/1997 - 01/19/1997	01/20/1997 - 02/14/1997
<u>Company</u>		
Microsoft Corporation (US-\$)	0.1581	0.1482*
Cisco Systems Inc. (US-\$)	0.1424	0.1331**

*/** The value is statistically different at the 5 percent (1 percent) level from the preceding value. A detailed summary of the t-Tests can be found in Appendix C.

5.2 DECIMALIZATION

The Nasdaq stock market replaced the system of fractional pricing in favor of decimal pricing on April 9, 2001¹². Bessembinder [4] examines the impact of the decimal pricing system by calculating trading cost measures and market quality measures surrounding the periods of implementation. His results show that quoted bid-ask spreads sharply decline upon implementation while effective spreads are statistically indistinguishable from the corresponding pre-decimalization Nasdaq measure. This observation is attributable to both the increasing number outside the quote executions and the decreasing number of inside the quote executions¹³. The increasing number of outside the quote executions is partly due to a newly adopted practice of brokerage firms to add (subtract) a fee (equivalent to a commission) to buy (sell) orders¹⁴. These commission-equivalent payments are assumed to originate from the

¹²Some pilot issues were subject to the decimalization at an earlier date. For 14 Nasdaq securities the decimal pricing system was adopted on March 12, 2001. On March 25, 2001 another 197 securities were subject to the decimalization.

¹³This trend is mostly observable for actively traded issues.

¹⁴See Chapman [7].

narrowing bid-ask spreads. In addition, the Nasdaq stock market does not prevent investors from trades executed at prices outside the quotations, even if the desired trade size is below the posted quotation size. In reference to Smith, Selway, and McCormick [34], Nasdaq only requires “any transaction with a customer be at a price that is favorable relative to the best prevailing inter-dealer market, subject to market conditions and the nature of the transactions”. Hence, the additionally required margins by Nasdaq market makers legitimately drive the actual trading costs out of the quoted spread.

Furthermore, the most substantial decline in quoted spreads can be observed for the most actively traded Nasdaq issues. A reasonable explanation for this observation is that actively traded stocks face a high degree of competition. Therefore, equilibrium spreads can be assumed to be narrower and more likely to be restricted by the minimum price increment than those for less actively traded issues. Thus, by reducing the minimum tick to one penny, the degree of competition of each stock determines the magnitude of the spread decrease.

As far as quotation sizes are concerned, the empirical results by Bessembinder [4] show a substantial decrease for all Nasdaq issues. This observation might be attributable to a decrease in liquidity supply. Harris [23] argues that a smaller tick size can restrain incentives to provide liquidity and thus reduce market quality¹⁵.

To sum up, the adoption of the decimal pricing system forced quoted spreads to decline. However, since trades outside the quoted spread substantially increased, which is partly due to the commission-equivalent fees charged by brokerage firms, actual trading costs as measured in effective spreads remained unchanged in the wake of decimalization. In contrast to the NYSE, the regulatory environment at the Nasdaq does not prevent investors from receiving inferior prices i.e., prices outside

¹⁵These findings are consistent with those by Jones and Lipson [26].

the quoted spread¹⁶. Thus, in the absence of regulations restricting Nasdaq market makers to execute trades with a size equal or below the quoted size outside the best bid and ask prices, the potential benefits of the decimal pricing system could not be realized by the investor.

¹⁶The ITS agreement requires trades for exchange-listed securities to be executed inside or at the given quotes, if the trade size equals or is less than the quotation size.

CHAPTER 6

CONCLUSION

The preceding discussion reveals that the pricing practices at the Nasdaq Stock Market observed by Christie and Schultz [8] are most likely to be attributable to an implicit pricing convention among Nasdaq market makers. Prior to the SEC Order Handling Rules Nasdaq's unique dealer market structure failed to promote a competitive market environment that eliminates the possibility collusive arrangements. Reviewing the game-theoretical model by Dutta and Madhavan [12] reveals that the presence of a large number of (homogeneous) market makers accompanied with small explicit entry barriers is not a sufficient condition for a market environment under which the only strategy is "pricing at value". To be more precise, Nasdaq's Preference Trade Rule is a major determinant in restricting price competition among market makers i.e., potentially new dealers are less willing to enter a market whose order flow is already reserved. Moreover, my extension of the base model shows that Nasdaq's electronically supported and thus transparent trading mechanism even facilitates the maintenance of anticompetitive pricing conventions.

Acknowledging Nasdaq's susceptibility for anticompetitive pricing conventions, the SEC began phasing in new trading rules on January 20, 1997 with the main focus being on an improvement of the competitive market environment. Among the most crucial modifications are that public limit orders are required to be either executed immediately or exposed to the market, as well as that orders on proprietary trading systems have to be made available to all market participants. This paper

provides empirical evidence that the objective of an improved competitive and efficient trading system has been met even for securities with the highest prevailing degree of competition. Recent research has only concentrated on the efficiency of the new rules regarding large samples of Nasdaq securities grouped by volume. Heavily traded large capitalization securities can be expected to be exposed to the highest degree of competition and thus to have the smallest equilibrium spreads¹. Hence, simply focussing on the averaged effects of the top-twenty Nasdaq securities ranked by dollar-volume, does not necessarily answer the question whether securities facing the highest degree of competition i.e., with equilibrium spreads close to one-eighth of a dollar, were affected by the new SEC rules.

I show that quoted spreads for the issues of Microsoft Corporation as well as Cisco Systems Inc. narrowed by more than 12 percent once the new SEC rules went into effect. Acknowledging the fact that an integral fraction of those securities' trades are executed either inside or outside the quoted spread, thereby affecting the actual trading costs borne by an investor, effective spreads are also calculated. For both issues effective spreads declined by more than 6 percent. Hence, actual trading costs could be reduced but price deteriorations became more perceptible for these issues in the wake of the SEC Order Handling Rules.

In contrast, the expected benefits of the decimal pricing system have not yet been fully realized. According to Bessembinder [4] the benefits of declined quoted spreads are offset by a significant increase in outside-the-quote executions. A non-negligible part of these price deteriorations is attributable to the commission-equivalent fees charged by brokerage firms. Ironically, the regulatory environment at the Nasdaq does not prevent investors from receiving inferior prices if the trade size is below or equals the quoted size. Hence, this regulatory gap enables brokerage firms to realize

¹This premise only holds in the absence of collusive pricing arrangements (see Section 4.3.2).

additional profits and obviously undermines the potential benefits of the adopted decimal pricing system.

APPENDIX A

RESTRICTIONS ON DEMAND AND SUPPLY FUNCTIONS¹

- (R1) *Symmetry*: Demand and supply functions are symmetric around the mean i.e., every restriction imposed on one of the functions is also true for the other one.
- (R2) *Monotonicity*: Given a volume shock z , demand (supply) a decreasing (increasing) function of the price. And for every fixed ask (bid), demand (supply) is increasing in z .
- (R3) *Monotone Demand Ratio*: Given $a' \leq a$, the ratio of the expected demands $d(a', z)/d(a, z)$ is decreasing in z . This holds under multiplicative separability i.e., $d(a, z) \equiv d_1(a) \cdot d_2(z)$ as well as under additive separability i.e., $d(a, z) \equiv d_1(a) + d_2(z)$.
- (R4) *Concavity*: For every z , the expected profit function, $(a - \nu)d(a, z)$, is a strictly concave function of the ask price.

¹See Dutta and Madhavan [12].

APPENDIX B

STANDARD TWO-SAMPLE T-TESTS – QUOTED INSIDE SPREADS

B.1 T-TEST RESULTS FOR MICROSOFT CORPORATION

data: prior and post

$t = 8.7346$, $df = 30$, $p\text{-value} < 0.01$

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval:

0.01529360 0.02462783

sample estimates:

mean of x mean of y

0.1564558 0.1364951

B.2 T-TEST RESULTS FOR CISCO SYSTEMS INC.

data: prior and post

$t = 10.1115$, $df = 30$, $p\text{-value} < 0.01$

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval:

0.01504611 0.02266224

sample estimates:

mean of x mean of y

0.14896 0.1301059

APPENDIX C

STANDARD TWO-SAMPLE T-TESTS – EFFECTIVE SPREADS

C.1 T-TEST RESULTS FOR MICROSOFT CORPORATION

data: prior and post

$t = 2.4005$, $df = 30$, $p\text{-value} = 0.0228$

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval:

0.00146674 0.01819291

sample estimates:

mean of x mean of y

0.1580583 0.1482285

C.2 T-TEST RESULTS FOR CISCO SYSTEMS INC.

data: prior and post

$t = 2.8027$, $df = 30$, $p\text{-value} = 0.0088$

alternative hypothesis: true difference in means is not equal to 0

95 percent confidence interval:

0.002533682 0.016142758

sample estimates:

mean of x mean of y

0.142401 0.1330628

APPENDIX D

TRADE EXECUTIONS

Table D.1: Trade Executions Surrounding the Introduction of the SEC Order Handling Rules for Microsoft Corporation.

	At the quote	Outside the quote	Inside the quote
<u>Pre SEC Rules</u>			
Trades	66,655	5,811	11,991
Percentage of Trades	78.92	6.88	14.20
<u>Post SEC Rules</u>			
Trades	181,137	14,263	35,127
Percentage of Trades	78.58	6.19	15.24

Table D.2: Trade Executions Surrounding the Introduction of the SEC Order Handling Rules for Cisco Systems Inc.

	At the quote	Outside the quote	Inside the quote
<u>Pre SEC Rules</u>			
Trades	48,698	2,965	7,684
Percentage of Trades	82.06	5.00	12.95
<u>Post SEC Rules</u>			
Trades	213,046	10,509	24,008
Percentage of Trades	86.06	4.24	9.70

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