Crossed Markets: Arbitrage Opportunities in Nasdaq Stocks

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Abstract

We examine how crossed markets create potential arbitrage opportunities in Nasdaq stocks. On average, actively traded Nasdaq listed stocks are crossed approximately 0.5% of the trading day. The incidence of crosses is higher in more fragmented markets. When crosses occur, the mean duration is three seconds, the value of the cross is around one cent, and the offer side has approximately 2,000 shares available for trading. Our simulated trading analysis shows that institutional traders, who act fast and pay little in transaction costs, can potentially exploit the arbitrage opportunities presented by market crosses.

Keywords: Locks and crosses, Nasdaq, arbitrage, trading strategy.

JEL Codes: G14, G19

Nasdaq listed stocks are traded in multiple trading venues. For example, during May 2005, only 42% of all trades occurred on Nasdaq; the remaining 58% of trades occurred in non-linked market centers.[1] Quotes in these non-linked markets often lock or cross each other. A locked market occurs when the best bid price, across all markets, equals the best offer price in one or more of the markets. A crossed market occurs when the national best bid price is greater than the best offer price in one or more of the markets. Locks and crosses do not generally occur in the same market because internal trading systems will immediately execute the initiating lock or cross order against the opposite side quotes. Moreover, locks and crosses seldom occur on New York Stock Exchange (NYSE) listed stocks since the NYSE executes approximately 80% of all the volume traded in their stocks.[2] According to Nasdaq [2003], locks and crosses mainly occur on heavily traded Nasdaq stocks.

The issue of locked and crossed markets is an area of concern for market professionals. Locks and crosses are an important market quality characteristic and their occurrences have been on the rise. A locked or crossed market quote may cause problems ranging from general confusion in the marketplace to possible system errors on trading desks (Schmerken [2003]). According to the Security and Exchange Commission [2004]:

> "Lock/cross markets indicate one of the following: one of the two quotes is not valid, brokers are not diligently representing their clients, or inefficiencies exist that deter trading with the quoting market. The result is confusion regarding the reliability of displayed quote and increased difficulty for market participants seeking best execution for customer orders" (p. 11158).

This is the reason the SEC discourages market participants from locking and crossing the overall market in their recently adopted Regulation NMS (National Market System).[3] If Regulation NMS does get fully implemented,[4] the precise impact of the new rules on the increasing number of locks and crosses is still uncertain. The Commission notes that locks and crosses have to be tolerated to a certain extent in the existing market environment.

While many seem to portray locks and crosses as a problem, academics have not shared this view. For example, Cao, Ghysels, and Hatheway [2000] examine locked and crossed markets during the Nasdaq pre-opening trading period (9:00 a.m. to 9:30 a.m.). They suggest that Nasdaq dealers often lock and cross the market in order to signal information. The ability of market participants to engage in price discovery through locks and crosses is also observed during the trading day (9:30 a.m. to 4:00 p.m.) in Shkilko, Van Ness, and Van Ness [2005]. In addition, Shkilko et al. [2005] suggest that locking and crossing quotes are used to avoid stale quotes and prevent liquidity shortages on electronic limit order books.[5] These positive attributes lead Shkilko et al. [2005] to view locks and crosses as a "natural mechanism that allows traders to cope with today's increasingly competitive and fragmented market environment" (p. 5).

While academics, practitioners, and regulators continue to debate the positive and negative effects of locked and crossed markets, many interesting questions remain unanswered. In particular, do crossed markets present arbitrage opportunities? Suppose the national best bid price is $10.02 and the best offer price is $10.01. Then, a trader could go short (sell) at the market center quoting $10.02 and cover (buy) at the competing market center quoting $10.01. In theory, this strategy would generate a 1 cent gross profit

per share, if the orders were filled at these prices. Of course, this is often difficult to do because crosses are fleeting and prices adjust rapidly as shown in Figure 1 below.

In this paper we examine the arbitrage opportunities (if any) presented by crossed quotes. In order to do this, we interviewed a large National Securities Dealer who has experimented with trading strategies that take advantage of crossed prices. The firm claims that their arbitrage strategies are quite profitable. While we were not given details of the firm's actual trades, we obtained a list of the firm's ten most actively traded stocks for the year and proprietary information on what it cost the firm to operate their trading desk. Using this proprietary information and intraday quote data provided by Nasdaq, we were able to examine the profitability of this sort of arbitrage. To the best of our knowledge, our study is unique in focusing on this aspect of crossed quotes. Our results suggest that institutional traders, who act fast and pay little in trading costs, should be able to profitably exploit the arbitrage opportunities presented by market crosses. On the other hand, retail traders, who try to exploit crossed markets, are unlikely to cover their trading costs.

The Origin of Locks and Crosses

The incidence of locked and crossed markets is a relatively new issue confronting market participants and security regulators. Three factors have significantly increased the incidence of locked and crossed markets. The first factor is the switch from quoting prices for Nasdaq stocks in fractions of a dollar (generally one-sixteenth of a dollar or 6 and one-fourth cent for large capitalization stocks) to quoting in cents and the reduction of the minimum price increment / tick size to one cent.

This switch, which occurred in March and April 2001, immediately cut quoted and effective bid-ask spreads. Bessembinder [2003] found that the most striking reduction in average quoted spreads occurred with large capitalization Nasdaq stocks. Average spreads on these stocks decreased, on a volume-weighted basis, from 5.2 to 1.6 cents per share. Decimalization also increased the number of quote updates. According to Nasdaq [2001], the average number of quote updates, after controlling for day-to-day fluctuations in trading activity, increased by between 12% and 20% in the two-week post-decimalization period. Smaller spreads and more frequent quote updates tend to increase the incidence of locks and crosses. In fact, the same study found that instances of locks and crosses, for the most active stocks, increased by more than 100% after the switch to decimalization. These findings were confirmed in interviews with market makers.

The second factor which contributed to a sharp increase in the number of locks and crosses was the launch of Supermontage, Nasdaq's new trading platform in mid October 2002. Supermontage was designed to centralize liquidity in Nasdaq listings. Market participants were given the option of participating in Supermontage or posting their quotes on a non-linked market center. Many ECNs decided to operate independently and post their quotes on regional exchanges.[6]

Prior to Supermontage, locks and crosses rarely occurred, because all the ECNs participated in Nasdaq's trading platform, and both market makers and ECN's were obliged to execute against all posted orders before they locked or crossed a market. Nasdaq [2003] reported a sharp increase in the number of locked and crossed quotes in the overall market with the implementation of Supermontage. Although locks and crosses never occur in the Nasdaq market center, the new trading platform fragmented the

market for Nasdaq stocks. Now, the majority of trades in Nasdaq stocks occur away from the Nasdaq, in non-linked market centers.

A third factor contributing to the rise in the incidence of locked and crossed markets are differential access fees and liquidity rebates. When several major market participants opted out of Supermontage, fierce competition for order flow between Nasdaq and rival market centers resulted. Markets began offering liquidity rebates to traders who provide liquidity. In addition, larger liquidity providers receive somewhat higher rebates and pay lower access fees.[7]

Differential access fees and liquidity rebates increase the incidence of locks and crosses precisely because they are not the same across all trading venues or for all market participants. As a result, what is a locked or a crossed quote for one market participant may not be a locked or crossed quote for another market participant.

Data

We used three datasets in our study. The first dataset is a transaction database provided by the National Securities Dealer we interviewed. We use this data to estimate institutional transaction costs. The data reveal what it cost the firm to execute their 1.3 million trades (2.5 billion shares) during the period June 2002 to May 2003. The firm runs several trading operations. The transaction data consists of all trades executed through their proprietary trading desk for the year.

For each trade, we know the size of the trade, the market where the trade was executed, the type of trade as well as the fixed and variable costs associated with each trade. Execution costs vary with the size of the trade, the market where the trade was

executed (Nasdaq, ARCA, etc.) and the type of trade (marketable vs. limit order). The firm also applies a fixed cost to each trade. This fixed cost consists of a market clearing charge for the trade and general overhead expenses incurred with operating a trading desk (e.g. trading technology, site expenses, etc.). It is usually around $0.50 per transaction. The total cost of a trade is just the sum of the fixed and variable costs.

The other two datasets – the October 2003 Nastraq and SIP (Security Information Processor) data provided by the Nasdaq Stock Market - are used to identify market crosses. Our analysis is based on quote data for twenty heavily traded Nasdaq listed stocks. When choosing our twenty stocks, we first selected the ten most actively traded stocks of our sample firm. We then added the ten largest market capitalization stocks - excluding the top ten firm stocks - from the Nasdaq 100 index. We used this selection process so that we could compare the stocks the firm actively traded with other actively traded stocks in the marketplace. The stocks chosen are shown in Exhibits 1 and 2.

We extracted intraday quote data from both Nastraq and SIP databases for our analysis. Basically, we recreated the aggregated Level II quotes for the entire market, which market professionals continuously monitor throughout the day. Nastraq contains detailed quote data for market participants in the Nasdaq stock market, while SIP data contains detailed quote data for market participants outside of the Nasdaq market center.

We used two Nastraq datasets. The first file gives the inside or NBBO quotes across all markets throughout the trading day. The second file gives the top of file quotes for all market participants in the Nasdaq stock market only. The SIP data, which is organized slightly differently from the Nastraq data, contains detailed quote and trade data for market participants outside of the Nasdaq Stock Market.

Our first step was to use the Nastraq dealer quote file to recreate the inside quotes and size originating from the Nasdaq market center for each second of the trading day. Each time a market participant changes their bid or offer quote and/or volume, a new entry was generated, which allowed us to calculate the inside price, spread and size throughout the day for the Nasdaq market. Whenever multiple quote change occurred during the same second, we used the last quote for that second.

Second, we used the SIP dataset, which records the inside quotes and sizes of non-Supermontage market participants, to create a file containing the inside quotes and size for each second of the trading day for the four non-Supermontage market centers which traded Nasdaq listed stocks in October 2003. These four centers are the American Stock Exchange, the Alternative Display Facility (ADF), the Cincinnati Stock Exchange, and the Archipelago Stock Exchange.[8]

Finally, we matched the inside quotes for each of the five market centers – (American, Cincinnati, ADF, Nasdaq, and Archipelago) to the Nastraq inside quote file and determined where the best quotes were coming from and what the corresponding size (if any) was in each market center. We had to use this tedious procedure because the Nastraq inside quote file does not reveal the size or origin of the NBBO quotes and we needed this information to identify locks and crosses.

Empirical Results

During the month of October 2003 there were 23 trading days. On each day and for all twenty stocks, we examined the quotes every second from 9.30 a.m. to 4 p.m. This gave us a total of 538,200 observations (seconds) per stock per market center. In

total we analyzed over 53.8 million quotes (538,200 seconds x 5 market centers x 20 stocks). Exhibits 1 and 2 display some summary statistics on when the inside ask price was equal to (market lock) or lower than (market cross) the inside bid price on our sample stocks.

--- Exhibits 1 and 2 ---

(a) The Incidence of Locks and Crosses

The incidence and duration of locks and crosses vary by stock. On average, the twenty stocks are locked far more often than they are crossed (14.7% of the time versus 0.5% of the time). For example, Microsoft was locked 25% of the time (approximately 133,400 seconds) during October, yet it was crossed only 1% of the time (approximately 5,200 seconds). When Microsoft was locked, the lock lasted 5 seconds on average before clearing, with an average offer size of about 7,500 shares. Crossed scenarios on Microsoft lasted 3 seconds on average with an average offer size of about 5,200 shares. Some stocks are locked or crossed far more often than others. For example, PALM is locked 4% of the time while JDSU is locked 26% of the time. However, JDSU is only crossed slightly more than PALM.

On average, the top 10 stocks traded by our firm are crossed less than the other 10 large cap Nasdaq stocks (0.3% of the time vs. 0.7% of the time). Why, then, didn't the firm simply concentrate on these other Nasdaq stocks that were crossed more frequently? There may be several reasons for this. First, the average duration of crosses for the firm stocks is 7 seconds vs. 3 seconds for the large capitalization Nasdaq stocks. In addition,

the average cross offer size for the firm stocks is 7,000 vs. 2,000 shares for the other Nasdaq stocks. Thus, at the level of the individual cross, the arbitrage opportunities provided by the 10 firm stocks appear to be better than those provided by the other Nasdaq stocks in our sample. Another reason may be the fact that the very large cap Nasdaq stocks are heavily traded stocks, with multiple market participants monitoring and trading them throughout the day, which make it more difficult to execute orders against crossed prices.

--- Figure 1 and Exhibit 3 ---

(b) The Duration and Value of Crosses

It is clear from Exhibit 2 that crosses are fleeting occurrences. Overall, the mean duration of crosses is only 1 second, whereas the median is 3 seconds. The corresponding figures are 4¾ and 2 seconds for the 10 firm stocks and 2½ and 1 second for the other large cap Nasdaq stocks. In Exhibit 3, we show that the value of crosses is not likely to exceed one cent. Stocks are usually crossed for 1 cent, with a weighted average cross price of 1.3 cents.[9] Figure 1 shows that average NBBO quotes adjust very quickly in the 60 seconds following an initial cross. The inside bid falls quickly, the inside ask rises and most of the difference between the initial best bid and current best ask is eroded within 10 seconds. It is clear that arbitrage opportunities are very short lived and need to be exploited quickly.

--- Exhibit 4 ---

(c) Who Initiates Crosses?

In Exhibit 4, we show who tends to initiate crossed markets. Nasdaq is the main culprit, which is consistent with existing research examining this issue (e.g., Shkilko et al. [2005]). This finding may be somewhat surprising to some in view of Nasdaq's strong public opposition to locked and crossed markets. For example, in a recent letter to the SEC, Nasdaq encouraged the SEC to establish and enforce rules prohibiting market participants from locking or crossing the overall market in their listed stocks.[10]

--- Exhibit 5---

(d) Market Fragmentation and the Incidence of Crosses

A priori, the incidence of crosses should rise when a stocks market share becomes less concentrated. In order to provide evidence of this, we examine the relationship between the incidence of crosses, volume, volatility and the degree of market fragmentation. Some OLS regression results are set out in Exhibit 5. The dependent variable is a logit transformation of the incidence of crosses i.e. logit p = ln(p / (1-p)) where p = incidence of crosses and ln denotes a natural log.[11] Volume and volatility are both measured as deviations from their group means (the monthly mean for each stock) in order to eliminate fixed effects. Volatility is measured as the square of $\ln(p^{hi}/p^{lo})$ where p^{hi} and p^{lo} are the daily high and low price respectively. We use an entropy measure E to measure market fragmentation. The entropy measure $E = -\sum_M s_m.\ln(s_m)$, where s_m is the share of market m and the summation is over all markets M, which is generally 5. E ranges from 0 (maximum concentration) to ln M (minimum concentration when market

shares are equal). As market concentration declines, E rises. We use an average of the inside bid and ask size to measure market share.

The regression results (with robust standard errors) in Exhibit 5 show that, as expected, the incidence of crosses rises with market fragmentation. The effect is highly significant. While the volume and volatility coefficients are positive, they are not significant. We checked that our results were robust to outliers using a least trimmed squares estimator and found that they were. We also looked at the Herfindahl index measure of concentration and got similar results.

--- Exhibit 6 ---

(e) Trading Costs and Arbitrage Opportunities

Since the value of crosses is one cent on average and crosses are fleeting, arbitrage opportunities are unlikely to exist if trade execution costs are high. Exhibit 6 shows what it cost our sample firm to execute their trades. We suspect that other institutions have similar transaction costs. The average costs in Exhibit 6, the sum of fixed and variable costs, are segregated by common trade sizes and order route.

The firm executes their marketable orders either by directly removing liquidity in a designated market center or by sending the orders to Knight Trading Group, the largest market maker of Nasdaq stocks. Many smaller dealers often send their orders to Knight for execution.[12] Knight either fills these orders from their inventory or works the orders in the open market. The advantage of going to Knight is that execution costs are cheaper. The disadvantage is a delay to execution. The median execution time for orders sent to

Knight was 16 seconds whereas the firm claims that it rarely takes longer than a second if they execute the order themselves (by directly removing liquidity in a designated market).

Exhibit 6 shows the costs incurred with executing limit orders. Since the firm places their limit orders in a range of financial markets, we present results aggregated for all markets. Trading costs for some limit orders is negative because the rebate for providing liquidity, on average, outweighed the cost of executing the trade.

(f) Possible Arbitrage Trading Strategies

We do not know the particular strategy used by our firm to exploit market crosses. However, we believe that traders must open up their position by submitting a marketable order to the market center first initiating the crossing price, since the mean (median) duration of a cross is only three (one) second. If the trader were successful in capturing the crossing price, then they could exit their position using several different strategies. For example, a trader might first try to exit their position by placing an aggressively placed limit order. Limit orders have the lowest transaction costs but take considerably longer to execute. If the limit order were not filled in a few seconds, perhaps the second option is to go to Knight with a marketable order. Transaction costs are much cheaper through Knight. Finally, traders could directly remove liquidity on both trades.

The potential net profit on each cross scenario is a function of the cross price (the difference between the opening best bid and the subsequent closing price), the trade size and the cost of trading. Therefore, an appropriate way of estimating the potential profits from capturing crossing prices is to simulate trading profits. We considered two simple

trading strategies. In both cases, we assume that trades are opened with a marketable order sent to the market center first initiating the crossing price. Under trading strategy A, we assume that trades are closed 3 seconds later with a marketable order. Under trading strategy B, we assume that trades are also closed 3 seconds later using a limit order (opposite side of the spread) at the inside ask. Of course, it is unreasonable to assume that all market crosses could be captured since almost ¾ of 17,663 crosses in our sample last for only one or two seconds. Therefore, we decided to confine our simulations to crosses that lasted three or more seconds (4,617 episodes). Of course, increased competition among arbitrage and other traders over time will reduce these durations (and any associated trading profits) even further.[13]

In our simulations, market prices throughout the day are determined from the intraday inside quote database. We used the firm's average variable cost of execution of marketable and limit orders in the prior year to estimate the variable costs of trading. In addition, we applied the firm's standard $0.50 per trade fixed cost to both the opening and closing trades.

--- Exhibit 7---

(g) Simulated Profits

Exhibit 7 presents summary statistics on the simulated trading profits. The mean and median net trading profits, under both trading strategies, are positive and statistically different from zero. The total net trading profits for 4,617 market crosses lasting 3 or more seconds in our sample is over $21,000 for trading strategy A and over $146,000 for trading strategy B.

--- Exhibit 8 ---

Another strategy could be to exit trades through a designated market maker, such as Knight. While this would lower the cost of executing, it would also delay execution times and bring on additional risk. In Exhibit 8, we examine profitability assuming it takes longer than three seconds to exit positions. Under both trading strategies, performance steadily declines with closing duration. Trading strategy A becomes highly unprofitable with longer holding times. This indicates that traders need to exit their positions as quickly as possible in order to profit from market crosses.

Our analysis is based on what it cost one National Securities Dealer to execute their trades. Of course, other market participants will pay varying rates and take varying times to execute their trades. Current market pricing schemes allow for more active trading firms to receive higher rebates when they provide liquidity and pay less to take liquidity. What may be an arbitrage opportunity for one trader may not be for another. Retail traders, who pay much higher trading fees than firms, would be less likely to take advantage of crossed scenarios. For example, Ameritrade, a typical large U.S. retail broker, charges their clients $10.99 per trade for market orders.[14] Traders paying these commissions would find it difficult to take advantage of crossed markets. In addition, most retail traders typically do not have direct access to the markets, which significantly delays execution times.

Conclusion

Recent U.S. market structure changes have led to increased competition and a significant reduction in the bid-ask spread. Because Nasdaq listed stocks trade in multiple trading venues, markets in these stocks are frequently locked or crossed during the trading day. A locked market occurs when the best bid price, across all markets, equals the best offer price in one or more of the markets. A crossed market occurs when the national best bid price is greater than the best offer price in one or more of the markets. While the recently adopted Regulation NMS discourages market participants from locking and crossing the overall market, locks and crosses are difficult to prevent in the current market environment.

Crossed markets are particularly interesting to study because they appear to represent arbitrage opportunities. Our study examines whether or not this is the case. In order to do so, we first consulted with a National Securities Dealer that runs an arbitrage operation in order to profit from crossing prices. We were provided with a list of the firm's ten most actively traded stocks for the year, as well as what it cost the firm to operate their proprietary trading desk. We then augmented these stocks with a sample of ten large market capitalization stocks.

We find actively traded stocks are crossed approximately 0.5% of the trading day in October 2003. The top 10 stocks traded by our firm were crossed less than the other 10 large cap Nasdaq stocks. However, crosses in the firm stocks were longer duration and had greater size available to trade.

Crossed markets are often initiated by Nasdaq, they are more frequent when market share is less concentrated, and they are fleeting in nature. Crossing prices last for

three seconds on average, although median duration is only one second. The average crossed amount is usually one cent. However, we find adequate size (an average of about 2,000 shares on the offer side) was available for some traders to take advantage of market crosses.

Based on our simulated trading analysis, we conclude that institutional traders, who act fast and pay little in trading costs, should be able to profitably exploit the arbitrage opportunities presented by market crosses. Retail traders, who try to exploit crossed markets, are unlikely to cover their trading costs. Identifying arbitrage opportunities in other markets and examining market crosses in international cross-listed stocks are interesting topics for future research.

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Endnotes

[1] Source: www.nasdaqnews.com

[2] Source: www.nyse.com/pdfs/NYSEMarketQualityFeb2003.pdf

[3] The SEC commissioners voted 3-2 to implement Regulation NMS. Overall, this regulation should help to reduce the number and duration of locks and crosses. For example, Regulation NMS calls for a cap on market access fees. As we discuss, market access fees increase the number of lock and cross scenarios because they are not the same for all market participants. In addition, Regulation NMS requires markets to route the orders they receive to a competing market if it is providing a better price. This should pick off locking and crossing quotes more quickly.

[4] Some members of Congress are considering legislation to keep the rule from going into effect (http://online.wsj.com/article/SB111280765108399759-search.html).

[5] The logistic regression results in Shkilko et al. [2005], examining the relationship between locks and crosses, quote updates and liquidity, are rather heterogeneous across markets.

[6] ECNs are important markets for trading Nasdaq listed stocks. Both the quotes and trades in these markets are highly informative. See Huang [2002] and Barclay, Hendershott and McCormick [2003], *inter alia*.

[7] For example, the Nasdaq market center in April 2005 had the following pricing schedule. For liquidity providers, with a daily average of more than 20 million shares, the rebate is 0.25 cent per share. For liquidity providers, with a daily average between 2 and 20 million shares, the rebate is 0.22 per share. For all other liquidity providers, the rebate is 0.2 cents per share. Details of the tiered pricing schedules for traders taking liquidity can be found at:
http://www.nasdaqtrader.com/Trader/News/2005/headtraderalerts/hta2005-020.stm.

[8] Alternative Display Facility quotes mainly originated from the Instinet ECN, whereas the quotes on the Cincinnati Stock Exchange mainly originated from the Island ECN. The Boston Stock Exchange began trading Nasdaq listed stocks in December 2003.

[9] We calculate the weighted average cross price because there may be multiple crossed markets. For example, suppose that initially the best bid is $24.20 (ADF) for 3,000 shares and the best offer is $24.21 (Cincinnati) for 4,000 shares. The next best offer (Nasdaq) is $24.22 for 2,000 shares. If Nasdaq raises its bid price to $24.23, the overall market is now crossed in two market centers, which we count as one crossed market episode. The size of the cross is 6,000 shares. We calculate the size weighted average cross price for this scenario as 1⅓ cents = (4000/6000) * 1 cent + (2000/6000) * 2 cent.

[10] Nasdaq noted that during the week of March 29, 2004, markets for their 3,497 securities were locked or crossed an average of 509,018 times each day. The full letter is online at: http://www.sec.gov/rules/proposed/s71004/knight070504.pdf

[11] If the incidence of crosses equals 0, we replace it with 0.000001 since the log of zero is not defined.

[12] Larger dealers, such as Knight, will often pay for order flow or execute order flow relatively cheaply. Capturing order flow is important for firms like Knight, because it gives them an informational advantage, which they can use to generate trading profits (Ip [2000]).

[13] We also simulate trading profits using longer cross duration times of 4 and 5 seconds. This reduces the number of crosses to 3,311 and 2,512 respectively. The results are qualitatively the same as those reported in Exhibits 7 and 8.

[14] Source: www.ameritrade.com

Figure 1: The Average Change in the Best Bid and Best Ask in the 60 Seconds After an Initial Cross at Time t

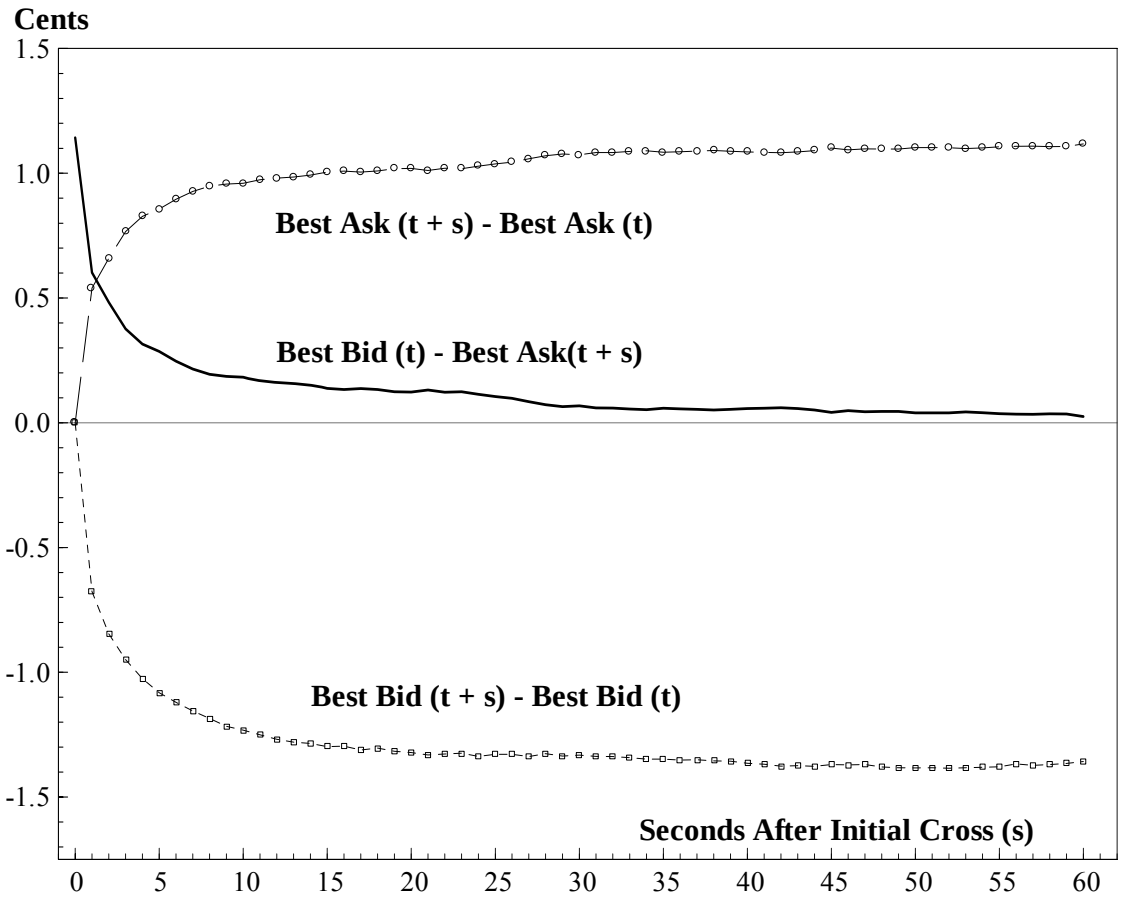

Exhibit 1: Market Locks

This Exhibit presents some summary statistics on the incidence, duration and size (volume) of locks across the five markets (American, Cincinnati, Alternative Display, Nasdaq, and Archipelago) for 20 Nasdaq stocks in Oct. 2003. When choosing our twenty stocks, we first selected the ten most actively traded stocks of a National Securities Dealer, who operates an arbitrage trading operation in order to profit from crossed markets. We then added the ten largest market capitalization stocks from the Nasdaq 100 index, ones that had not already been selected to our list. The statistics are based on the last recorded quotes for each stock in each of the 538,200 seconds between 9.30 a.m. and 4 p.m. on the 23 trading days in Oct. 2003. Episodes or runs of locks refer to sequences of locks that follow each other in time. Standard errors for the means are show in parentheses.

Stock	All Locks		Episodes / Runs of Locks					
				Duration (Seconds)		Offer Size (000's)		
	Total Seconds Locked (000's)	Incidence of Locks	No of Episodes (000's)	Mean	Median	Mean All Markets	Mean Locked Markets	Median Locked Markets
Firm Stocks								
ADCT	102.5	19.0%	2.4	43 *(2.5)*	9	47.1 *(0.8)*	26.3 *(0.7)*	14.7
CMGI	83.6	15.5%	1.4	60 *(3.9)*	12	22.0 *(0.5)*	9.3 *(0.3)*	5.6
CSCO	118.4	22.0%	18.7	6 *(0.1)*	3	18.5 *(0.1)*	6.1 *(0.7)*	2.8
ERICY	42.6	7.8%	3.0	14 *(0.7)*	2	3.3 *(0.1)*	2.4 *(0.1)*	0.5
JDSU	141.4	26.3%	3.1	46 *(1.8)*	13	84.3 *(1.5)*	41.8 *(1.1)*	24.9
NXTL	76.7	14.2%	15.9	5 *(0.1)*	2	3.4 *(0.03)*	1.7 *(0.2)*	0.9
ORCL	109.6	20.4%	11.5	10 *(0.2)*	4	29.0 *(0.02)*	9.7 *(0.1)*	5.0
PALM	23.6	4.4%	2.5	10 *(0.5)*	2	1.0 *(0.03)*	0.6 *(0.02)*	2.3
SUNW	102.4	19.0%	3.7	28 *(0.8)*	12	119.1 *(1.4)*	55.7 *(1.1)*	31.4
VTSS	73.6	13.7%	5.2	14 *(0.4)*	4	4.3 *(0.1)*	2.0 *(0.04)*	1.1
Nasdaq Stocks								
AMAT	117.0	21.7%	22.9	5 *(0.1)*	2	8.2 *(0.1)*	2.9 *(0.03)*	1.8
AMGN	32.2	6.0%	9.8	3 *(0.1)*	1	1.4 *(0.02)*	0.8 *(0.01)*	0.5
CMCSA	32.8	6.1%	7.7	4 *(0.1)*	1	1.3 *(0.03)*	0.7 *(0.02)*	0.3
DELL	64.8	15.8%	18.1	5 *(0.1)*	2	4.5 *(0.04)*	2.7 *(0.03)*	1.4
EBAY	49.5	9.2%	14.3	3 *(0.05)*	2	1.3 *(0.01)*	0.8 *(0.01)*	0.5
IACI	34.9	6.5%	6.3	6 *(0.1)*	2	1.3 *(0.02)*	0.8 *(0.01)*	0.4
INTC	120.0	22.3%	28.4	4 *(0.04)*	2	12.8 *(0.1)*	4.0 *(0.1)*	2.0
MSFT	133.4	24.8%	25.6	5 *(0.1)*	3	19.7 *(0.1)*	7.5 *(0.1)*	4.0
QCOM	42.5	7.9%	9.9	4 *(0.1)*	2	1.6 *(0.02)*	0.9 *(0.02)*	0.5
YHOO	66.0	12.3%	16.1	4 *(0.1)*	2	2.2 *(0.02)*	1.3 *(0.02)*	0.6
All 20 Stocks	1587.4	14.7%	226.5	7 *(0.9)*	2	12.6 *(0.1)*	5.1 *(0.03)*	1.2

Exhibit 2: Market Crosses

This Exhibit presents some summary statistics on the incidence, duration and size (volume) of crosses for 20 heavily traded Nasdaq stocks in Oct. 2003. See notes to Exhibit 1. Standard errors for the means are show in parentheses.

Stock	All Crosses		Episodes / Runs of Crosses					
				Duration (Seconds)		Offer Size (000's)		
	Seconds Crossed (000's)	Incidence of Crosses	No of Episodes (000's)	Mean	Median	Mean All Markets	Mean Crossed Markets	Median Crossed Markets
Firm Stocks								
ADCT	0.7	0.1%	0.1	10 *(2.3)*	3	23.1 *(3.0)*	10.1*(2.3)*	4.1
CMGI	0.01	0.0%	0.01	2 *(0.7)*	1	10.5 *(4.6)*	4.2 *(2.7)*	1.2
CSCO	2.1	0.4%	0.6	4 *(0.2)*	2	15.9 *(0.8)*	3.4 *(0.3)*	0.9
ERICY	3.5	0.6%	0.4	9 *(1.5)*	2	4.6 *(0.1)*	3.8 *(0.7)*	0.6
JDSU	1.5	0.3%	0.1	17 *(3.0)*	8	44.6 *(0.9)*	18.0 *(2.7)*	5.5
NXTL	3.3	0.6%	1.3	2 *(0.1)*	1	3.1 *(0.1)*	1.4 *(0.1)*	0.6
ORCL	2.0	0.4%	0.3	6 *(0.6)*	2	21.1 *(1.1)*	6.0 *(0.6)*	1.5
PALM	1.1	0.2%	0.3	4 *(0.4)*	1	0.9 *(0.1)*	0.6 *(0.1)*	0.2
SUNW	1.1	0.2%	0.1	10 *(1.4)*	4	63.8 *(5.5)*	24.4 *(3.7)*	3.7
VTSS	0.7	0.1%	0.2	4 *(0.4)*	2	3.3 *(0.4)*	1.6 *(0.3)*	0.5
Nasdaq Stocks								
AMAT	3.6	0.7%	1.0	4 *(0.3)*	2	8.0 *(0.2)*	2.2 *(0.1)*	1.0
AMGN	3.3	0.6%	1.6	2 *(0.2)*	1	1.5 *(0.04)*	0.9*(0.04)*	0.5
CMCSA	1.9	0.3%	0.8	2 *(0.1)*	1	1.4 *(0.1)*	0.7 *(0.1)*	0.3
DELL	5.7	1.1%	1.8	3 *(0.2)*	1	4.7 *(0.1)*	2.8 *(0.1)*	1.0
EBAY	5.4	1.0%	2.9	2 *(0.1)*	1	1.4 *(0.03)*	0.9 *(0.03)*	0.5
IACI	2.2	0.4%	0.8	3 *(0.2)*	1	1.3 *(0.1)*	0.8 *(0.1)*	0.3
INTC	3.4	0.6%	1.1	3 *(0.2)*	2	12.1 *(0.5)*	3.3 *(0.4)*	1.1
MSFT	5.2	1.0%	1.6	3 *(0.1)*	2	15.6 *(0.4)*	5.2 *(0.2)*	1.6
QCOM	2.2	0.4%	0.9	3 *(0.1)*	1	1.9 *(0.1)*	0.9 *(0.1)*	0.4
YHOO	4.3	0.8%	1.9	2 *(0.1)*	1	2.1 *(0.1)*	1.1 *(0.1)*	0.4
All 20 Stocks	53.1	0.5%	17.6	3 *(0.1)*	1	5.9 *(0.1)*	2.2 *(0.1)*	0.6

Exhibit 3: Distribution of Crossed Amounts (in Cents)

This Exhibit shows the distribution of the weighted crossed amounts when prices are crossed. The crossed amounts (if any) in each of five market are weighted using the relative size at the inside ask in crossed markets as a weight. The sample size is 53.1 thousand, after a few anomalous observations were dropped.

	Crossed Amounts (cents)
Mean	1.3
Standard Deviation	1.5
Median	1
25% Percentile	1
50% Percentile	1
75% Percentile	1
80% Percentile	1
90% Percentile	2
95% Percentile	3

Exhibit 4: The Incidence of All and New Crosses by Market

This Exhibit shows the incidence of crosses in the five markets. New crosses refer to the first observation in a run of crosses respectively. The percentages sum across columns to more than 100%, since crosses can occur simultaneously in a number of markets.

	American	Cincinnati	Alternative Display	Nasdaq	Archipelago	Number (000's)
All Crosses	11.7%	15.5%	25.3%	45.6%	34.1%	53.1
New Crosses	7.3%	13.1%	22.3%	41.9%	35.9%	17.7

Exhibit 5: The Incidence of Crosses and the Degree of Market Fragmentation

This Exhibit reports OLS regression results (with robust standard errors) examining the relationship between the incidence of crosses, volume, volatility and the degree of market fragmentation. The dependent variable is a logit transformation of the incidence of crosses i.e. logit p = ln (p / (1-p)) where p = incidence of crosses and ln denotes a natural log. Volume and volatility are both measured as deviations from their group means (the monthly mean for each stock) in order to eliminate fixed effects. Volatility is measured as the square of $\ln(p^{hi}/p^{lo})$ where p^{hi} and p^{lo} are the daily high and low price respectively. We use an entropy measure E to measure market fragmentation. The entropy measure $E = -\sum_M s_m.\ln(sm)$ where s_m is the share of market m and the summation is over all markets M, which is generally 5. E ranges from 0 (maximum concentration) to ln M (minimum concentration when market shares are equal). Market size is measured by the average of the inside bid and ask sizes. The number of observations is 460 (20 stocks by 23 trading days). Absolute t statistics, based on heteroscedastic robust standard errors, are shown in parentheses. The robustness of the OLS results to outliers has been checked using LMS (least median of squares) regressions.

Explanatory Variables	I	II	III
Constant	-15.06 (11.4)	-15.02 (11.0)	-15.02 (11.0)
Log Volume (dev. from group mean)	-	0.47 (1.5)	0.36 (1.3)
Volatility (dev. from group mean)	-	-	26.58 (0.9)
Fragmentation (entropy E)	6.78 (7.3)	6.76 (7.3)	6.76 (8.4)
Mean of dependent variable		5.45	
Standard deviation of dependent variable		2.20	
Standard error	2.05	2.04	2.04
Adjusted R^2	13.1%	13.6%	13.6%
Ramsey Reset Test (P Value)	0.29	0.41	0.53

Exhibit 6: An Example of Actual Institutional Trading Costs in 2002-3

This Exhibit sets out some details of the trading costs incurred by our sample NSD firm. The sample is based on 1.3 million trades executed by the firm during the period June 2002 to May 2003. Trades are segregated by common trade sizes and order type. Marketable orders were executed by either sending the order directly to a market center or by routing the order to Knight Trading Group for execution.

Trade Size	Trading Costs			
	Marketable Orders			Limit Orders
	Sent to Market	Sent to Knight	All	
Mean				
≤ 100	$1.23	$0.98	$1.17	$0.85
101-500	$2.37	$1.15	$1.83	$0.73
501-1000	$3.70	$1.26	$2.47	$0.58
1001-2000	$6.33	$1.38	$3.65	$0.29
2001-3000	$8.97	$1.73	$5.06	$0.09
3001-4000	$11.44	$2.22	$5.61	-$0.35
> 5000	$13.07	$3.55	$7.15	-$0.47
Median				
≤ 100	$1.20	$1.00	$1.20	$0.90
101-500	$2.00	$1.00	$1.95	$1.00
501-1000	$3.00	$1.00	$2.00	$1.00
1001-2000	$5.00	$1.00	$2.00	$1.00
2001-3000	$7.00	$1.00	$2.50	$1.00
3001-4000	$9.00	$1.00	$3.00	$1.00
> 5000	$11.00	$1.00	$3.50	$1.00
All trade sizes				
Mean	$4.92	$1.74	$3.59	$0.05
Median	$2.80	$1.00	$1.70	$0.95
Std. dev.	$6.09	$2.31	$5.03	$2.34

Exhibit 7: Simulated Trading Profits

This Exhibit shows the simulated trading profits on all 4.6 thousand market crosses which lasted a minimum of 3 seconds (approximately 25% of all cross episodes) on our twenty stocks during October 2003. We assume a trader enters their position with a marketable order and then exits their position 3 seconds later. Trading strategy A assumes the position is closed with a marketable order while strategy B assumes the trade is closed with a limit order. NBBO market prices are compiled from the Nastraq and SIP databases. Trading costs are based on the costs set out in Exhibit 6.

	Trading Strategy A	Trading Strategy B
All 20 Stocks (4617 Crosses)		
Mean profit	\$4.59*	\$31.69*
Median profit	\$0.84*	\$2.09*
25th percentile	-\$14.48	-\$8.71
75th percentile	\$20.21	\$32.70
Total profits	\$21,171	\$146,350
Number of profitable round-trips	53%	56%
10 Firm Stocks (1254 Crosses)		
Mean profit	\$4.24*	\$52.14*
Median profit	\$2.27*	\$4.41*
25th percentile	-\$18.01	-\$10.51
75th percentile	\$39.22	\$64.13
Total profits	\$5,322	\$65,380
Number of profitable round-trips	56%	60%
Other 10 Nasdaq Stocks (3363 Crosses)		
Mean profit	\$4.71*	\$24.08*
Median profit	\$0.84*	\$2.09*
25th percentile	-\$13.32	-\$8.36
75th percentile	\$16.52	\$25.60
Total profits	\$15,849	\$80,971
Number of profitable round-trips	52%	54%

* Indicates significance at the 1% level.

Exhibit 8: Total Trading Profits for Varying Exit Times

This Exhibit shows how the total trading profits in Exhibit 7 vary with the duration of the trade. The closing times range from 3 to 19 seconds. .

Duration of Trade	Trading Strategy A ($000's)	Trading Strategy B ($000's)
Close after (seconds)		
3	$21.2	$146.4
4	-$4.6	$120.6
5	-$30.9	$94.3
6	-$51.0	$74.2
7	-$70.0	$55.2
8	-$80.1	$45.1
9	-$94.2	$31.0
10	-$103.3	$21.9
11	-$110.2	$15.0
12	-$116.9	$8.3
13	-$122.4	$2.7
14	-$128.0	-$2.9
15	-$129.7	-$4.6
16	-$133.8	-$8.7
17	-$137.3	-$12.1
18	-$146.6	-$21.5
19	-$147.9	-$22.7