# Imperfect competition in financial markets:

# ISLAND vs NASDAQ

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**Abstract**

The Internet reduces the cost of exchanging information. Electronic markets exploit this opportunity to enable investors to place quotes at very little cost and compete with incumbent trading systems. Does this quasi–free entry situation lead to competitive liquidity supply? We analyze trades and order placement on Nasdaq and a competing electronic order book, Island. While Island traders often undercut Nasdaq quotes, they undercut each other much less frequently. The coarse tick size prevailing on Nasdaq in 2000 was considerably reduced in 2001, while the Island tick remained very thin. This resulted in tighter spreads on *both* markets. These findings are inconsistent with the perfect competition hypothesis, under which Island traders should undercut each others as much as Nasdaq quotes, and quote zero-profits spreads, unaffected by a drop in the Nasdaq tick. We also estimate and test a theoretical model of competition in limit orders, and find that Island limit orders earned rents in 2000, but not in 2001. Our findings suggest that perfect competition cannot be taken for granted, even in modern financial markets, and that competition among markets complements competition among traders.

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## 1  Introduction

Internet technology reduces communication and information processing costs. In turn, this reduces the cost of entry in financial markets. Thus, new market mechanisms can be created and compete with incumbent trading systems, and a larger population of investors and traders can access the market. In conjunction with this technological revolution, the regulatory change brought about by the 1997 SEC order display rule enhanced the ability of investors to post offers to trade stocks in the market. Electronic Communication Networks (hereafter ECNs) developed to exploit these opportunities. These changes in the structure of the market should foster competition to supply liquidity.

To study this point we focus on Island, one of the largest ECNs, which amounted to nearly 10% of the trading volume in Nasdaq stocks in 2002.[4] Island is operated as a fully transparent electronic limit order market, where all investors can anonymously post quotes. Its book is freely observable to all on the web in real time. Accessing this market is very inexpensive. In fact, Island grants a small rebate to limit orders when they are hit, to reward liquidity supply. We study the extent to which these features of the market foster competitive liquidity supply.

Stigler (1957) lists five conditions under which perfect competition obtains according to Adam Smith: "1) The rivals must act independently, not collusively. 2) The number of rivals, potential as well as present, must be sufficient to eliminate extraordinary gains. 3) The economic units possess tolerable knowledge of the market opportunities. 4) There must be freedom to act on this knowledge. 5) Sufficient time must elapse for resources to flow in the directions and quantities desired by their owners."

Christie and Schultz (1994) note that on Nasdaq dealers enjoy relatively free–entry and exit. Thus, the second of Stigler's conditions could hold, and the competitive outcome could be expected. However, Christie and Schultz (1994) showed empirically that Nasdaq dealers enforced implicit collusion, in violation of Stigler's first condition, which resulted in excessively large spreads.

Their analysis showed that competition in financial markets is imperfect when small groups of financial intermediaries have privileged access to the market and to information collection and dissemination

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[4]Island recently merged with Instinet, but its market model has not been altered.

(see e.g., also Chen and Ritter, 2000). Such privileges do not seem to exist on Island. Thus the competitive outcome is more likely on Island than it was on Nasdaq before the recent market reforms. Stigler's conditions 1) and 2) could hold on Island since there is open access to the market to many investors via the web. Also, the remarkable transparency of Island should ensure that condition 3) is satisfied. The 1997 Order–Handling Rule emphasized investors' right to place orders, hence condition 4) should hold also. Thus, after sufficient time (as required by condition 5), traders should devote resources to supply liquidity on Island, until a competitive situation is reached.

We test the hypothesis that liquidity supply on Island is competitive. We empirically analyze the strategies followed by liquidity suppliers on Island. We test if limit orders on Island are consistent with free-entry equilibrium, in line with the theoretical analysis of electronic order books by Glosten (1994). We also aim to shed light on the competition between Island, a relatively recent electronic marketplace, and the incumbent market, Nasdaq. Thus we tackle competition among liquidity suppliers within one trading mechanism *and* competition between trading mechanisms.

Our empirical strategy takes advantage of the difference in the pricing grids used in these two market places and of their changes. Before April 2001, the pricing grid on Nasdaq was relatively coarse, as the tick size was one-sixteenth, and quite thin on Island, where the tick size was 1/256. In April 2001, the Nasdaq pricing grid was decimalized. Prices on Nasdaq are now quoted in cents. At the same time the Island tick was reduced to one-thousandth of a dollar. While the change in tick size on Nasdaq is sizeable, the change in tick size on Island is negligible. We study if the pricing grids on the two markets and their changes had an impact on the strategies of liquidity suppliers. Did the rather coarse pricing grid prevailing on Nasdaq prior to decimalization constrain liquidity suppliers on this market? Did Island liquidity suppliers take advantage of the thinner grid prevailing on this ECN? How did the decimalization affect the competition between the two trading systems?

To conduct our analysis, we combine two sources of data for actively traded Nasdaq stocks. On the one hand we have downloaded the sequence of trades and order book dynamics from the Island site, on the other hand we have used the Nastraq dataset from Nasdaq. To study liquidity supply on Island and Nasdaq, we analyze the distribution of the best quotes on the Island limit order book and on the Nasdaq market (excluding Island quotes) as well as the placement of limit orders on Island and their profitability.[5]

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[5]Quotes in the Nastraq dataset are rounded to match the Nasdaq grid. This precludes observing situations where Island quotes are strictly better than Nasdaq quotes by less than one Nasdaq tick. In contrast, by using unrounded Island data, we can analyze the strategies of Island limit order traders who undercut Nasdaq quotes by using the finer pricing grid prevailing in this

In the pre–decimalization sample, the Nasdaq spread is equal to one tick more than 80% of the time. Thus the tick size was binding on Nasdaq and resulted in excessively large spreads. During this sample period, the most frequent values of the bid–ask spread on Island were one and two Nasdaq ticks. Note, however, that Island traders were not constrained to place their orders on this relatively coarse grid size. Indeed, we find that the second most frequent value of the Island spread corresponds to situations where the Nasdaq tick was undercut by just one (very thin) Island tick. This clustering of Island limit orders is not consistent with the perfect competition hypothesis. Under the latter, limit order schedules should mirror the marginal cost of liquidity provision (see Glosten, 1994, and Biais, Martimort and Rochet, 2000), which is unlikely to exhibit clustering.

In the post-decimalization sample, the coarse tick constraint is relaxed on Nasdaq, and accordingly, there is a marked decrease in the Nasdaq spread. While the change in the Island tick (from 1/256 to 1/1000) was negligible, we also observe a strong decrease in the Island spread. If Island quotes simply reflected the cost of supplying liquidity, as requested by competitive behavior, they would not be affected by a change in the tick size prevailing on the competing marketplace. Rather, our results suggest that Island limit order traders engaged in competition for order flow with the Nasdaq market makers more than among themselves. Facing a reduction in the Nasdaq spread, Island limit order traders had to tighten their quotes. That they were able to do so, and yet had not done it before, suggests they competed imperfectly and earned rents prior to decimalization.

Under this imperfect competition hypothesis, Island limit orders would be expected to undercut the current market best quotes more often when these quotes are set by Nasdaq market makers than when they are set by Island limit orders. To investigate this point we study the frequency of undercutting orders on Island. Undercutting orders are defined as (non-immediately marketable) limit orders placed within the best quotes (see Biais, Hillion and Spatt, 1995). We find that, when the best quote is set by an Island order, the probability that the next Island order will be undercutting is less than 10%. In stark contrast, when the best quote is set by other Nasdaq participants, the probability that the next Island order be undercutting is greater than 25%. Thus our findings suggest that Island limit order traders undercut Nasdaq quotes but compete less aggressively against one another to preserve their rents.

One might wonder how such behaviors could emerge in anonymous markets with potentially many participants. We learned from discussions with market participants that, while retail day–traders represent a significant fraction of the number of orders placed in the market, only a limited number of large

ECN.

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professional traders monitored Island and Nasdaq and strategically undercut Nasdaq quotes to earn trading profits. This induces a violation of the second of the five Stigler–Smith conditions listed above, thus raising the possibility of imperfectly competitive behavior.

To examine these points further, we study whether the gross profits earned by Island limit order traders exceed the cost they incur to supply liquidity. Using the generalized method of moments, we test restrictions imposed by theoretical models of competition in limit–order schedules (Glosten (1994) and Biais, Martimort and Rochet (2000)) and estimate the costs and the oligopoly rents of liquidity suppliers. The hypothesis that limit orders placed on Island face no adverse selection cost is rejected. Furthermore, our estimates are consistent with Island limit orders earning oligopoly rents when the Nasdaq spread was constrained by the coarse pricing grid prevailing on that market. In contrast, Island quotes observed after the decrease in the Nasdaq tick are consistent with competitive liquidity supply.

Our analysis sheds light on the way in which the Internet can enhance competition, and correspondingly, increase liquidity. It enables efficient modern market architectures to be established. These compete with the incumbent and force them to catch up. But, perfect competition should not be taken for granted, even on an Internet-based transparent easily accessible limit order book, although Adam Smith's conditions for perfect competition seem to hold. Competition between markets is necessary to complement competition among traders.[6]

Our emphasis on the competition between markets is in the line of Rust and Hall (2003). They model the competition between a trading mechanism where quotes are publicly posted by a market maker and another trading mechanism operated by middlemen. Their theoretical analysis sheds light on the likely effects of the reduction in search and transactions costs resulting from the information revolution and the advent of the World Wide Web. It also highlights the risk of undercutting faced by market makers publicly posting bid and ask prices. Our empirical investigation thus concurs with their theoretical analysis.

Our GMM analysis of limit-order schedules and adverse selection builds on the insightful structural econometric analysis of Sandas (2001), though we take a somewhat different viewpoint. In particular, while Sandas (2001) assumes competitive liquidity supply, we investigate market power. Thus, we simultaneously estimate adverse selection costs and the rents earned by Island liquidity suppliers. This relies in part on estimating the profits earned by limit orders. Thus our approach is related to the insightful analysis of the profitability of limit orders by Hasbrouck and Harris (1996), in particular to their

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[6]Thus our analysis adds to the debate on centralized vs. fragmented markets (e.g. Chowdhry and Nanda (1991) and Parlour and Seppi (2003)), and to the literature on the competition between markets (e.g. Barclay, Hendershott and McCormick (2003) and Bessembinder and Kaufman (1997)).

"ex–post performance measure," which computes the profitability of different types of orders, e.g., limit orders at the best quotes, when they are executed. Our focus differs from theirs, however. While they compare the performance of order placement strategies, we focus on the competition to supply liquidity and document undercutting strategies. Also, we take advantage in our identification strategy of the fact that we have two different samples, over which the order–handling cost is likely to remain constant, while other parameters, such as the oligopoly mark–up, are likely to change.

Interesting empirical analyses of ECNs are offered by Simaan, Weaver and Whitcomb (2003), Huang (2002), Barclay, Hendershott and McCormick (2003) and Hasbrouck and Saar (2001). Our focus on strategic liquidity supply and rents, differs from Huang (2002), who focuses mainly on price discovery, Hasbrouck and Saar (2001), who analyze the relationship between volatility and the order flow as well as fleeting orders, and Barclay, Hendershott and McCormick (2003), who shed light on the choice of trading venues by informed traders. Our result that Island limit orders undercut Nasdaq quotes by using the fine Island grid complements the finding by Simaan, Weaver and Whitcomb (2003) that Nasdaq market makers tend to quote on odd (Nasdaq) ticks on ECNs, thus narrowing the spread.[7] Another difference between our paper and the literature devoted to ECNs is that we develop a structural econometric approach to analyze quantitatively the trade–offs between adverse selection costs and oligopoly rents. A by–product of this analysis is to offer a new method to disentangle components of the spread without relying on parametric assumptions on distributions, while building directly from a standard microstructure model.[8]

The next section presents the institutional environment. Section 3 presents the data. Section 4 presents our empirical analysis of orders, quotes and spreads on Island and Nasdaq. Section 5 extends this analysis by offering a structural econometric investigation of profits and spreads on Island. Section 6 concludes.

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[7]The quotes data used by Simaan, Weaver and Whitcomb (2003) are rounded to the Nasdaq grid. Thus they could not observe undercutting quotes posted on the finer Island grid.

[8]Hasbrouck (1988) disentangles inventory costs from adverse selection costs by estimating the transient and permanent impacts of trades. Our approach does not enable us to estimate inventory costs, as it is based on a theoretical model where liquidity suppliers are risk neutral.

## 2 Institutional environment

### 2.1 ECNs

ECNs use web–based platforms, which collect limit and market orders, and match them or display them on internet–based order books. In 2002 they have been estimated to capture 39.3% of the dollar volume of trading in Nasdaq securities (source: Market Data).[9] The largest ECN, Instinet, was estimated to represent 12% of the trading volume on Nasdaq in February 2002, while Island amounted to 9.6%, RediBook to 6.5%, and Archipelago to 10.5%.[10]

While ECNs compete with the traditional source of liquidity on Nasdaq (i.e., market makers), they do not take proprietary positions, but simply handle and display their customer's orders. They cannot conduct trades away from the current best market prices and must allocate orders according to price priority. However, time priority is not enforced between ECNs and Nasdaq market makers.

Interestingly, empirical evidence so far does not suggest that the trading process managed by ECNs is systematically free riding on price discovery achieved by the traditional market participants (the Nasdaq dealers). To the contrary, Huang (2002) shows empirically that ECNs are important contributors to the price discovery process. In line with this result, Barclay, Hendershott and McCormick (2003) offer evidence of informed trades directed to ECNs and contributing to price discovery.

### 2.2 Island

Island is a web–based transparent limit order book.[11] Trades and the best 15 quotes on each side of the book can freely be viewed in real time through the internet. Island subscribers can freely place orders. Trades can take place from 7:00 a.m. to 8:00 p.m. Immediately executed orders are charged .25 cent per share traded. Non-marketable limit orders posted in the book receive .1 cent per share when executed, as compensation for supplying liquidity. When an order is transmitted to Island, if it is not immediately marketable, it is stored and displayed anonymously in the Island order book. If the order is marketable it is executed at the best market price.

Until April 2001, the Nasdaq tick size was 1/16 and the Island tick size was 1/256. Since April 2001, the Nasdaq tick size has been reduced to one cent ($0.01), while on Island prices are quoted with a three-digit precision, i.e., the tick size is one-thousandth of a dollar. The thinner price grid on Island

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[9]In March 2000, this proportion was 26.1% and in June 2001 it was 37.1% (McAndrews and Stefanadis, 2000).

[10]Island captured 6.4% of the trading in Nasdaq securities in March 2000, and 9.5% in June 2001.

[11]Hasbrouck and Saar (2001) offer a good description of the market structure.

makes it easier for traders placing orders on that ECN to undercut Nasdaq market makers' quotes.

Until October 2002 the best Island bid and ask quotes were displayed on the Nasdaq screen, along with the best quotes of ECNs and market makers.[12] Note, however, that Island quotes displayed and "advertised" on the Nasdaq screen were not shown at their actual price (quoted on a thin grid) but at rounded prices (from the Nasdaq grid). For example, when the Nasdaq tick was one-sixteenth, if the best ask for stock XYZ on Island was one dollar and 1/24, it was displayed on Nasdaq at one dollar and 1/16. Rounding the Island quotes enabled NASDAQ to avoid price priority constraints, and reduced the ability of the ECN to advertise good quotes and thus attract orders. This made it very important for Island to use another vehicle besides NASDAQ screens to disseminate information. This may be one of the reasons for the excellent and easily accessible website Island has developed.

Because of the display of the best Island bid and ask quotes on the Nasdaq screen, if the grid size was the same in the two market segments, the Nasdaq inside quote would, by construction always be at least as good as the Island spread. The grid is thinner on Island than on Nasdaq, however. This raises the possibility that Island quotes, placed on thin ticks inside the relatively coarse grid Nasdaq, could better the Nasdaq quote, at least on one side of the book.

## 3  Data

We acquired quotes and trades data from Nasdaq (including the Dealer Quotes (DQ) file, the Inside Quote (IQ) file, and the Trades (TR) file). We also downloaded a continuous record of the Island book from the Island website during 5 trading days in March 2000 (from March 8 to March 14) and 5 trading days in June 2001 (from June 18 to June 22). We collected this data for 7 stocks: COMS, Cisco, Dell, Intel, Microsoft, QCom, and Sun. One advantage of the Island data (downloaded from the Island website) is that it is not rounded to sixteenths (unlike the ECN quotes reported in the NASDAQ DQ file). Hence we can study the use of fine ticks by Island traders.

We consider data starting at the opening of NASDAQ (at 9:30 or a few minutes before) and ending at the NASDAQ close: 4:00 p.m. (Because of a data feed problem, for March 10, we have data only between 9:30 and 2:30).

Summary statistics on the Island data and the Nasdaq data are presented in Table 1. The Island data set includes 138432 trades for the March 2000 sample and 139966 trades for the June 2001 sample. The

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[12]In the fall of 2002 Nasdaq introduced its own order book, Super Montage. As briefly discussed in the conclusion below this led to changes in the interaction between Island and Nasdaq.

average trade size on Island in the March 2000 sample is 389 shares, while its counterpart for the June 2001 sample is 450 shares. The average trade size on Nasdaq is about twice as large (797 shares per trade in 2000 sample and 898 in 2001). While market activity was comparable in 2000 and 2001, prices fell dramatically; while the average transaction price is 99.14 in the March 2000 sample, it is 31.69 in the June 2001 sample. Volatility tends to be lower in the 2001 sample than in its 2000 counterpart.

## 4  Orders, quotes and spreads on Island and Nasdaq

### 4.1  Spreads and quotes

To document the market environment in which Island limit order traders operated, first consider the best quotes posted on Nasdaq by market makers and other ECNs than Island. In March 2000, the time-weighted average spread resulting from these quotes was 1.27 sixteenths, i.e., $.079.[13] The spread was exactly equal to one tick 81.5% of the time, while the two other most frequent values of the spread were 2 ticks (13.25% of the time) and 3 ticks (3.36% of the time). After decimalization, in June 2001, the Nasdaq tick was one cent and the time-weighted average spread was reduced to $.014. The spread was exactly equal to one tick 78.08% of the time, while the two other most frequent values of the spread were 2 ticks (12.26% of the time) and 3 ticks (4.23% of the time). Thus, decimalization led to a dramatic decrease in the average spread on Nasdaq, as well as a reduction in clustering. This is consistent with the view that the coarse tick size in 2000 constrained liquidity supply and led to artificially large spreads,[14] and that this constraint was relaxed by decimalization.

Now turn to the best quotes placed on Island. In 2000, the time-weighted average spread for our 7 stocks and our sample period was equal to $ 0.198.[15] Thus, the average Island spread was on average larger than the Nasdaq inside spread resulting from Island's competitors. Yet, Island limit order traders used the finer pricing grid prevailing on their market to often undercut the Nasdaq touch. Figure 1, Panel A, depicts the frequency of different values of the spread for the seven stocks in our sample, on Island and on Nasdaq in March 2000.[16] As illustrated in the figure there is marked clustering in the data. Clustering

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[13]Average spreads for each of the 7 stocks in our sample are presented in Table 1. Across all stocks, the mode and the median spreads were equal to exactly one-sixteenth ($.0625).

[14]As illustrated in other contexts by Harris (1991, 1994).

[15]The mode and the median were 32/256, i.e., $.125. Average spreads on Island for the 7 stocks in our sample are presented in Table 1.

[16]Our graphical representation of the empirical frequency of different values of the spread is similar to Figure 1 in Christie and Schultz, 1994, and Figure 2 in Barclay et al, 1999. In the appendix, we provide additional information on the comparison

on one Nasdaq tick is less frequent for the Island spread than for the Nasdaq inside spread. Interestingly, the spread on Island was quite often just one Island tick below these levels, e.g., 15/256, 31/256, etc. This is likely to reflect undercutting, by a fine increment, of the Nasdaq spread by Island liquidity providers. By following this strategy, they acquire price priority relatively cheaply.[17]

In June 2001, the average spread on Island for our 7 stocks was $ 0.0648. This is definitely below the corresponding figures for March 2000. Figure 1, Panel B, presents the histogram of spread sizes on Island and Nasdaq for our June 2001 sample. As in the March 2000 case, there is a lot of clustering on the Nasdaq price grid. The Island spread and that of its competitors are most frequently equal to .01, .02 and .03, .04 or .05. There also is clustering for the Island spread just one tick below these values, reflecting undercutting of the Nasdaq quotes. Comparing the distribution of Island spreads in June 2001 to its March 2000 counterpart points to the stark reduction in spreads contemporaneous to the reduction in the Nasdaq tick from 1/16 to 1/100 and the practically negligible reduction in the Island tick during that period from 1/256 to 1/1000.

These preliminary results cast doubts on the hypothesis that Island limit order traders were perfectly competitive. Under perfect competition, Island best quotes would simply reflect the cost of supplying liquidity. In this case, they would not cluster at, or just one small Island tick within, the Nasdaq touch. Rather, they would be spread more diffusely on the very thin Island price grid. Furthermore, it's not clear why the change in tick size on the Nasdaq market would imply a decrease in the cost of supplying liquidity on the Island limit order book. Note that in that market the size was already extremely small in 2000 (as it equalled $ 1/256). Hence, the reduction to $ 1/1000, which took place in 2001, was not likely to have any direct effect on the best quotes on Island. Thus, it's difficult to reconcile the strong decrease in spreads on Island, between 2000 and 2001, with the perfect competition hypothesis. Rather, our results suggest that Island limit order traders engaged in competition for order flow with the Nasdaq market makers more than among themselves.

## 4.2   Order placement

The above discussion raised the possibility that Island limit order traders were imperfectly competitive. The goal of the present subsection is to shed more light on this point, using order flow data. Under the hypothesis that, while Island limit order traders compete market share away from Nasdaq, competi-

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between the Island and Nasdaq spreads, and on the instances where the Island quotes bettered their Nasdaq counterpart.

[17]Note however that, since Island prices were rounded before being represented on the Nasdaq system, the Island liquidity suppliers benefitted from this priority advantage only with respect to the Island order flow.

tion within Island is less strong, undercutting of the best quotes by Island limit orders should be more prevalent when the best quotes are set by Nasdaq than when they are set by the Island book.

To test this conjecture, we analyzed the Island order flow in more detail. In line with Biais, Hillion and Spatt (1995) we differentiated 12 categories of events:

- trades resulting from the placement of market orders to buy or sell;

- new buy or sell limit orders not immediately executed, placed within the best quotes, at the best quotes, or away from the best quotes;

- cancellations of orders, at or away from the best quotes, on the bid or the ask side;

Table 2 reports the frequency of each of these 12 events in ten different situations for the 2000 sample. Panel A reports the frequencies of events occurring on the ask side of the book (market or limit orders to sell), while Panel B reports the frequencies of events occurring on the bid side (market or limit orders to buy). In each panel, the first column reports the unconditional frequencies, while the 9 other columns, report the frequencies conditional on which market sets the best price, on the bid side and the ask side. For example, the second column corresponds to the instances where the best bid and the best ask quote were both quoted by Island, while the third column corresponds to the case where the best bid was quoted by Island and the best ask by Nasdaq market makers or other ECNs than Island. To conduct this conditional analysis we merged the Island data file and the Nasdaq IQ data file.[18] Inspecting the two panels of Table 2, we note that cancellations and order placement away from the best quotes are quite frequent. For example, their frequency is much higher than in the Paris Bourse (see Biais, Hillion and Spatt, 1995). This is consistent with the finding by Hasbrouck and Saar (2001) that a large fraction of the limit orders submitted to Island are "fleeting orders" which are rapidly cancelled.

Undercutting corresponds to the placement of limit sell orders within the quotes. The frequencies reported in Table 2, Panel A, show that undercutting of the best market ask by Island limit orders is more frequent when Nasdaq sets the best ask than when Island sets the best ask. When the best bid is set by Island, the frequency of undercutting by Island orders is 4.54% when the best ask is set by Island, and 26.55% when the best ask is set by Nasdaq. When the best bid is set by Nasdaq, the frequency of undercutting by Island orders is 7.99% when the best ask is set by Island, and 37.48% when the best ask

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[18]This was made difficult by synchronicity problems. The consequences of these non–synchronicity problems and the way we dealt with them are discussed in the appendix.

is set by Nasdaq. When the best bid is the same on Island and Nasdaq, the frequency of undercutting by Island orders is 4.39% when the best ask is set by Island, and 29.58% when the best ask is set by Nasdaq. To put these numbers in perspective, we can compare them to their counterparts in Panel B, which report the frequency of improvements of the best bid by Island limit orders. Whether Island or Nasdaq sets the best ask quote has less impact on the relative magnitude of these frequencies.[19]

A similar result holds on the bid side. Improvements of the best bid correspond to the placement of limit buy orders within the quotes. The frequencies reported in Table 2, Panel B, show that improvements of the best bid by Island limit orders are more frequent when Nasdaq sets the best bid than when Island sets the best bid. When the best ask is set by Island, the frequency of undercutting by Island orders is 4.78% when the best bid is set by Island, and 25.17% when the best bid is set by Nasdaq. When the best ask is set by Nasdaq, the frequency of bid improvements by Island orders is 9.40% when the best bid is set by Island, and 40.85% when the best bid is set by Nasdaq. When the best ask is the same on Island and Nasdaq, the frequency of improvements by Island orders is 5.15% when the best bid is set by Island, and 30.79% when the best bid is set by Nasdaq. Whether Island or Nasdaq sets the best bid quote has less impact on the relative magnitude of undercutting on the ask side.

Table 3 reports similar frequencies for the 2001 sample. Panel A focuses on the ask side of the book. Compare the frequencies of undercutting when Island sets the best ask and when Nasdaq sets the best ask: They are 5.25% and 14.10%, respectively, when Island sets the best bid; 8.89% and 29.97%, respectively, when Nasdaq sets the best bid; 4.55% and 21.64%, respectively, when the best bids are the same on Island and Nasdaq. Comparing these figures to their counterparts in Panel B, one observes that whether Island or Nasdaq sets the best ask quote has less impact on the relative magnitude of these frequencies. Inspecting Panel B, one can observe that similar results obtain for the bid side of the book.

These results are in line with the hypothesis that Island limit order traders compete more aggressively

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[19]For example, when the best bid is set by Island, the frequency of bid improvements by Island orders is 4.78% when the best ask is set by Island, and 9.40% when the best ask is set by Nasdaq. When the best bid is set by Nasdaq, the frequency of bid improvements by Island orders is 25.17% when the best ask is set by Island, and 40.85% when the best ask is set by Nasdaq. When the best bid is the same on Island and Nasdaq, the frequency of bid improvements by Island orders is 11.96% when the best ask is set by Island, and 23.35% when the best ask is set by Nasdaq. These pairs of frequencies are ordered in the same way as their counterpart for undercutting on the ask side, but the effect is less strong. This similarity might reflect the alternance of phases of activity and inactivity on Island. During the former, undercutting and improvements are frequent, and Island often establishes the best quotes, though not during the latter. That the identity of the market setting the best ask quote has much less impact on the frequency of bid improvements than on that of undercutting on the ask side is consistent with our imperfect competition hypothesis,

with Nasdaq than with one another, as the frequency of undercutting on the ask side is greater when the best ask is quoted by Nasdaq, while the frequency of improvements on the bid side is greater when the best bid is quoted by Nasdaq. The magnitude of this effect is more pronounced in 2000 than in 2001, suggesting that deviations from perfect competition were stronger in the former year than in the latter.

## 4.3 Conclusion

Putting together the above results, the following picture of the competition between Nasdaq and Island emerges: Before decimalization, liquidity supply on Nasdaq was constrained by the coarse tick size, resulting in large spreads. Island limit order traders took advantage of that situation by frequently undercutting the Nasdaq quote by just one thin Island tick. While they competed market share away from Nasdaq, they competed much less aggressively among themselves on Island.

The decrease in the Nasdaq tick brought about by decimalization led to a stark decrease in the Nasdaq spread. There was no significant contemporaneous change in the Island tick, which was already very thin before 2001, and unlikely to constrain order placement. Yet, the Island spread was strongly reduced by decimalization on Nasdaq. This reduction took place because the Island limit order traders had to react to the decrease of the spread of their Nasdaq competitors. That they were able to engage in this reduction, and yet had not done it before, is suggestive of imperfect competition among Island liquidity suppliers. The next section studies this point further.

## 5 An econometric analysis of the costs and profits of Island limit order traders

### 5.1 Theoretical framework

In this section we examine econometrically the costs incurred by Island limit order traders and the profits they earn. Consider a limit order to sell, at time $t$, at the best quote in the Island limit order book: $A_t$. If this order is filled its profit is:

$$A_t - v - (c - f),$$

where $v$ is the fundamental value of the asset, $c$ is the order–handling cost incurred by the limit order trader, and $f$ is the compensation offered by Island to executed limit orders. Note that $f$ is not a parameter to be estimated, but an observable pricing rule set by Island.

Now consider a standard market microstructure model (as in Glosten, 1994): competitive risk neutral limit order traders face risk–averse investors privately informed about the underlying value of the stock and their own risk–sharing needs. In this case, the marginal limit order just breaks even on average. Denoting the expected profit $\pi$, this break-even condition can be written as:

$$\pi = E(A_t - v - (c - f)|H_t, Q_t \geq Q_{A_t}) = 0,$$

where $H_t$ is the information set of the liquidity suppliers just before receiving the order, $Q_t$ is the size of the market buy order hitting $A_t$, and $Q_{A_t}$ is the depth of the order book at the best quote.[20] As first emphasized by Rock (1990) and Glosten (1994), the conditioning set in this upper tail expectation reflects the workings of the limit order book: the marginal limit order at the best ask in the book is executed if and only if the total size of the market buy order is greater than or equal to the depth at the best ask price in the book.[21] The limit order reflects this informational content of trades. A symmetric equality holds on the bid side of the book.

On the other hand, if the limit order traders are strategic, as in Bernhardt and Hughson (1997), and Biais, Martimort and Rochet (2000), their expected profits are not equal to zero. In that case, the relevant condition is:

$$E(A_t - v - (c + \pi - f)|Q_t \geq Q_{A_t}) = 0,$$

where the expected profit ($\pi$) is not in general equal to 0, as long as the number of liquidity suppliers, $N$, is finite. As shown in Biais, Martimort and Rochet (2000), when $N$ goes to infinity, the oligopolistic mark–up $\pi$ goes to 0, and quotes go to their competitive level.

## 5.2 Econometric approach

In this subsection we show how the bid and ask equations above yield empirical restrictions which can be used to test the model and estimate its parameters. Subtracting the bid from the ask, the spread is:

$$A_t - B_t = \alpha + 2(c - f + \pi),$$

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[20]Traders also can place hidden orders, but these have no time priority over the visible orders. Hence, hidden orders do not affect the conditioning set for the conditional expectation of the value of the security relevant for the marginal visible order at the first level in the book.

[21]This differs from the information structure arising in the signaling trading game analyzed in Kyle (1985). In the latter, the transaction price is equal to the expectation of the value of the asset conditional on the exact size of the trade.

where:

$$\alpha = [E(v|Q_t \geq Q_{A_t}, H_t) - E(v|Q_t \leq -|Q_{B_t}|, H_t)]$$

denotes the informational component of the spread.

Some time after (say at time $t + \Delta t$), the liquidity suppliers have updated their expectation of the fundamental value of the asset to form:

$$E(v|H_{t+\Delta t}).$$

We proxy this expectation by the mid–quote observed half an hour after the trade:

$$m_{t+\Delta t} = E(v|H_{t+\Delta t}) + \epsilon_{t+\Delta t}.$$

For simplicity, we assume that $\epsilon_{t+\Delta t}$ is white noise. In this context, we obtain that:

$$m_{t+\Delta t} - A_t = [E(v|H_{t+\Delta t}) + \epsilon_{t+\Delta t}] - [E(v|Q_t \geq Q_{A_t}, H_t) + c - f + \pi].$$

Taking expectations conditional on the occurrence of the purchase at time $t$:

$$E(m_{t+\Delta t} - A_t|Q_t \geq Q_{A_t}, H_t) =$$
$$E([E(v|H_{t+\Delta t}) + \epsilon_{t+\Delta t}] - [E(v|Q_t \geq Q_{A_t}, H_t) + c - f + \pi_i]|Q_t \geq Q_{A_t}, H_t).$$

Applying the law of iterated expectations:

$$E([E(v|H_{t+\Delta t}) + \epsilon_{t+\Delta t}]|Q_t \geq Q_{A_t}, H_t) = E(v|Q_t \geq Q_{A_t}, H_t).$$

Hence, the expected difference between the ask price and the subsequent mid–quote simplifies to:

$$E(A_t - m_{t+\Delta t}|Q_t \geq Q_{A_t}, H_t) = c - f + \pi.$$

A similar equality holds for the bid side:

$$E(m_{t+\Delta t} - B_t|Q_t \leq -|Q_{B_t}|, H_t) = c - f + \pi.$$

The intuition is that, on average, the informational component of the spread differences out, so that the difference between the transaction price and the subsequent midquote, i.e., the gross trading profit of the liquidity supplier, is equal to his non–informational cost ($c$ net of the compensation offered by Island to liquidity supply, $f$) plus the oligopoly rent ($\pi$).

The above analysis yields two moment conditions, which can be used to estimate the parameters and test the model:

$$E(A_t - B_t - [\alpha + 2(c - f + \pi)]|H_t) = 0, \qquad (1)$$

and:

$$\begin{aligned} E([B_t - (m_{t+\Delta t} - (c - f + \pi))]I(Q_t &\leq -|Q_{B_t}|) \\ +[A_t - (m_{t+\Delta t} + (c - f + \pi))]I(Q_t &\geq Q_{A_t})|H_t) = 0. \qquad (2) \end{aligned}$$

where $I(.)$ is the indicator function equal to 1 when the condition in the argument holds and 0 otherwise.

The second moment condition enables one to identify $c + \pi$. Denote $\theta$ the sum of these two parameters. Given the estimate of $\theta$ (obtained from the second moment condition), $\alpha$ can be estimated, using the first moment condition. While in practice we estimate $\theta$ and $\alpha$ jointly, and thus do not follow this two-step procedure, this discussion indicates that $\alpha$ is identifiable. Unfortunately, we cannot identify separately the two components of $\theta$. Yet, we can rely on two approaches to obtain additional information about these components.

1. The descriptive statistics reported in the previous section suggest that Island liquidity suppliers exert strategic behavior by undercutting the Nasdaq touch by just one tick. Thus, we posit that such undercutting reflects strategic behavior. Under perfect competition, $\pi$ would be equal to 0, and the fact that Island traders just undercut the Nasdaq grid would be irrelevant for their profits. Under the alternative hypothesis that Island traders are strategic, this undercutting behavior should affect profits. To test the null hypothesis of perfect competition in our GMM framework, we will include in the instruments an indicator variable equal to one when the best quote is set by an undercutting order. Under the null hypothesis, this instrument should be irrelevant. Under the alternative hypothesis of strategic behavior including this instrument should lead to rejecting the model.

2. We observe data from two subperiods: period 1 before decimalization, and period 2 after. A priori there is no reason to expect $\alpha$ or $\pi$ to be constant across the two periods. Indeed, a change in the oligopoly mark–up $\pi$ is to be expected, since the market environments are different in the two samples, reflecting the change in the tick size on Nasdaq. The information content of trades $\alpha$

15

also might well have changed. Correspondingly, we carry the estimation separately over the two periods, which yields two sets of parameter estimates: $\{\alpha_1, \theta_1\}$ and $\{\alpha_2, \theta_2\}$. On the other hand, it is plausible that the order-handling cost $c$ is constant across our two subsamples. Under this assumption, we disentangle $\pi$ from $c$ by comparing the results obtained for the two periods. Since $\theta_1 = c + \pi_1$ and $\theta_2 = c + \pi_2$ we have that: $\theta_1 - \theta_2 = \pi_1 - \pi_2$. Thus, if we find that $\theta_1 - \theta_2 > 0$ and since $\pi_2$ must be non–negative, we know that $\pi_1 > 0$.

Finally note that our approach to decomposing the spread is robust and avoids relying upon auxiliary parametric assumptions, instead building directly upon a fundamental microstructure model.

## 5.3 Empirical results

### 5.3.1 Observations and instruments

As discussed above, if limit order traders are competitive and risk neutral, the marginal limit orders break even on average (in line with Glosten, 1994, and Sandas, 2001). In contrast, with a discrete pricing grid, infra-marginal orders can earn profits, even in the competitive case. Hence, to test the hypothesis that liquidity supply is competitive, we impose the moment conditions only on trades involving marginal limit orders in the book. For example, suppose that, at the best ask quote in the book, 500 shares are offered. A market buy order for 250 shares would not hit the marginal limit order. Hence it would not be included in the data we use to estimate the model and test the competitive hypothesis. In contrast, a market buy order for 500 shares or more would be included.

### 5.3.2 A first, simple, specification

First we estimate a simple specification, where it is assumed that the parameters are constant across market conditions. The instruments are the square of the change in the stock price during the last half–hour, to proxy for the volatility, and the sign of the last trade. The parameter estimates are presented in Table 4:

- As can be seen in the table, the estimates of $\alpha$ are significantly positive in both subperiods. Negative estimates of $\alpha$ would have contradicted the model. Significantly positive estimates lead to rejection of the hypothesis that there is no adverse selection.

- The estimate of $c + \pi$ is positive in 2000 for 6 stocks out of 7, and significantly so for 3 stocks. It is also significantly positive for the pooled data. Hence, we reject the hypothesis that there

is no order–handling cost or market power in that period. In contrast, the estimate of $c + \pi$ is significantly positive only for one stock out of seven after decimalization. For this period, it is not significantly different from 0 for the pooled data. Thus, overall, the result is that $c + \pi$ was positive before decimalization, but not after. Under the plausible assumption that $c$ did not vary between the two periods, this suggests that liquidity supply on Island was imperfectly competitive before decimalization and competitive afterwards, i.e., $\pi$ was significantly positive during the first period and not significantly different from zero in the second period.

### 5.3.3  A more flexible specification

While the assumption that $c$ is constant through time and market conditions is reasonable, adverse selection and rent-earning opportunities are likely to vary. Consequently, we estimate a more flexible specification allowing the parameters to vary with market conditions. In this specification the adverse selection cost parameter for stock $k$ at time $t$ ($\alpha_t^k$) is specified as:

$$\alpha_t^k = \beta^{\alpha^k} X_t^k,$$

where $\beta^{\alpha^k}$ is a vector of parameters and $X_t^k$ is a vector of variables including:

- the constant,

- the depth at the best ask quote for observations corresponding to purchases, and depth at the best bid for observations corresponding to sales,

- the square of the change in the stock price during the last half–hour, to proxy for the volatility.

Similarly, $\theta_t^k = \beta^{\theta^k} X_t^k$. The instruments used to carry out the estimation are the variables in $X_t^k$, to which we add the sign of the last trade.

The parameter estimates and the p–values for this more flexible specification are presented in Table 5. Both in 2000 and in 2001 the null hypothesis that the model is correct is not rejected at the 5% level for 4 stocks out of 7. This suggests reasonable adequacy of the model to the data.[22] The p–level is much smaller when the model is estimated with the pooled data suggesting that parameters do differ across stocks.

For the adverse selection component of the spread, the constant (i.e., the first element of $\beta^\alpha$) is significantly positive for 5 stocks out of seven and for the pooled data, both in 2000 and in 2001. This

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[22]This reasonable fit of our structural model with a flexible specification is not unlike that obtained in Sandas (2001).

reinforces our previous finding that Island liquidity suppliers face significant adverse selection costs. Regarding depth and volatility there is no clear pattern in the parameter estimates. Neither is there any clear pattern either in the parameter estimates relative to $\theta$, except that in 2000 the order-handling cost/market power parameter is increasing in volatility.

### 5.3.4 The role of undercutting

Under perfect competition, Island limit orders' expected profits should be zero, irrespective of whether they undercut Nasdaq or not. Thus, the indicator variable equal to one when the Nasdaq grid is undercut by just one tick should be unrelated to the profit of Island orders. Hence, to test the null hypothesis of perfect competition, we include this indicator variable in the instruments.

The p–level and parameter estimates obtained when undercutting is included in the set of instruments are presented in Table 6. The model is now rejected at the 5% level in 5 cases out of 7 in 2000 and 6 cases out of 7 in 2001. This contrasts with the results obtained when undercutting was not included in the instruments (in that case the model was rejected in for 3 stocks only in 2000 and in 2001). These results point to the relevance of undercutting for the profits of Island limit order traders. While this would be expected to arise with strategic limit order placement, this contradicts the perfect competition hypothesis.

This suggests to explore further the determinants of liquidity suppliers' rents by including the indicator of undercutting in the variables in the flexible model. Table 7 presents the parameter estimates and p–values obtained in this specification. As in Table 5, the null hypothesis that the model is correct is not rejected at the 5% level for 4 stocks out of 7. Parameter estimates for the constant, volatility and depth are similar to those reported in the previous table, which speaks in favor of the robustness of the model. For the market power/order-handling costs parameter, the estimate corresponding to the undercutting variable is positive for 5 stocks out of 7. While this is significant for only 2 stocks in 2000 and one stock in 2001, this is broadly consistent with the hypothesis that Island limit order traders earn rents by undercutting the Nasdaq grid.

## 6  Conclusion

This paper is a study in the industrial organization of financial markets. We examine the competition between limit order traders as well as the competition between markets. We find that, before decimalization, Nasdaq spreads were constrained by the tick size, and were correspondingly excessively wide. Reacting to this situation, limit order traders used Island as a platform to compete for the supply of liquid-

ity. To do so they often undercut the Nasdaq inside quotes, by using the finer Island grid. Undercutting on Island did not lead to competitive liquidity supply, however. In contrast with zero–profit free–entry equilibrium, limit orders placed on Island, before the Nasdaq decimalization, earned positive profits (net of transactions costs). After the Nasdaq decimalization, the Island spread became much tighter. In this context, the rents earned by Island limit orders virtually disappeared.

Our results suggest that the wide dissemination of information and the reduction in the costs of accessing markets brought about by the internet technology are important but not sufficient to eliminate market power in financial markets, in particular in the supply of liquidity. In addition to the competition between liquidity suppliers within a marketplace, competition between trading mechanisms plays an important role.

In the fall of 2002, Nasdaq introduced a new trading mechanism, Super Montage, enabling the display of orders in an electronic book. While this made Nasdaq more similar to Island, it did not reduce the competition between the two markets. Island does not participate in Super Montage. While it continues to run its electronic limit order book, its orders are represented on the Cincinnati Stock Exchange and appear on the Nasdaq level 1 and 2 screens under the heading "Cinn". Analyzing the evolution of the competition between the electronic limit order books of the incumbent (Nasdaq) and the new entrants (the ECNs) is an interesting avenue of further research.

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**Table 1: Summary statistics on daily activity**

The table reports the average daily number of trades, the average trade size (in terms of number of shares per trade), the average $ spread, the average difference between the highest and the lowest transaction price of the day, the average transaction price, and the average daily return. The statistics are given for each stock in the sample and also when pooling all stocks.

**Panel A: 2000 Sample**

| Stock | # trades | | Trade size | | Spread (in $) | | Hi-Low | Price (in $) | Return |
|---|---|---|---|---|---|---|---|---|---|
| | Nasdaq | Island | Nasdaq | Island | Nasdaq | Island | | | |
| COMS | 20,585 | 2,829 | 659 | 393 | .080 | .218 | 5.85 | 64.6 | -.045 |
| CSCO | 39,831 | 5,141 | 655 | 338 | .076 | .178 | 6.15 | 136.1 | -.003 |
| DELL | 52,255 | 5,879 | 1,185 | 478 | .064 | .092 | 3.33 | 52.8 | .029 |
| INTC | 31,521 | 3,929 | 779 | 392 | .075 | .211 | 5.69 | 119.5 | .006 |
| MSFT | 41,279 | 5,157 | 942 | 416 | .071 | .147 | 3.99 | 97.6 | .010 |
| QCOM | 37,713 | 4,834 | 463 | 331 | .106 | .282 | 10.50 | 131.0 | .007 |
| SUNW | 21,897 | 2,611 | 583 | 331 | .083 | .256 | 5.18 | 94.0 | -.010 |
| All | 35,012 | 4,340 | 797 | 389 | .079 | .198 | 5.81 | 99.1 | -.001 |

**Panel B: 2001 Sample**

| Stock | # trades | | Trade size | | Spread (in $) | | Hi-Low | Price (in $) | Return |
|---|---|---|---|---|---|---|---|---|---|
| | Nasdaq | Island | Nasdaq | Island | Nasdaq | Island | | | |
| COMS | 2,596 | 278 | 1,271 | 326 | .015 | .072 | 0.27 | 4.62 | -.0008 |
| CSCO | 53,569 | 6,599 | 1,121 | 603 | .011 | .030 | 1.16 | 17.16 | -.0072 |
| DELL | 26,655 | 3,174 | 869 | 447 | .012 | .060 | 1.22 | 23.73 | -.0100 |
| INTC | 45,518 | 5,922 | 848 | 482 | .011 | .046 | 1.46 | 27.48 | -.007 |
| MSFT | 39,750 | 5,472 | 713 | 372 | .013 | .086 | 2.02 | 68.55 | -.0001 |
| QCOM | 25,312 | 4,157 | 481 | 258 | .028 | .126 | 3.17 | 51.06 | .0055 |
| SUNW | 40,694 | 5,420 | 1,092 | 464 | .011 | .034 | 1.05 | 14.61 | -.022 |
| All | 33,442 | 4,432 | 898 | 450 | .014 | .065 | 1.48 | 31.69 | -.0059 |

**Table 2: Frequency of different types of orders on Island in 2000**

We identify 6 categories of orders on each side of the book (buy and sell), differentiating them by execution status (immediate in the case of market orders, delayed for new quotes placed in the book, prevented in the case of cancellations) and location in the book (at, within or away from the best quotes). Pooling all stocks, we compute the relative frequency of each of these events on each side of the book. The first column reports unconditional frequencies, while the 9 remaining columns report frequencies conditional on 9 different situations: 1) when the best bid and ask quotes are set by Island, 2) when the best bid is set by Island but the best ask is set by Nasdaq, 3) when the best bid is set by Island and the ask is the same on Island and Nasdaq, 4) when the best bid is set by Nasdaq while the best ask is set by Island, 5) when the best bid and ask are set by Nasdaq, 6) when the best bid is set by Nasdaq and the ask is the same on Island and Nasdaq, 7) when the bid is the same on Nasdaq and Island and the best ask is set by Island, 8) when the bid is the same on Nasdaq and Island and the best ask is set by Nasdaq, and 9) when the bid and the ask are the same on Island and Nasdaq. Panel A focuses on the ask side of the book (orders to sell), while Panel B focuses on the bid side (orders to buy). Each column within each panel is a vector of relative frequencies adding up to 100%.

**Panel A: Ask side**

| Best Bid set by: | All | Isld | Isld | Isld | Nasdaq | Nasdaq | Nasdaq | Same | Same | Same |
|---|---|---|---|---|---|---|---|---|---|---|
| Best Ask set by: | All | Isld | Nasdaq | Same | Isld | Nasdaq | Same | Isld | Nasdaq | Same |
| Cancel ask at best quotes | 13.66 | 14.71 | 12.25 | 18.16 | 9.84 | 12.91 | 16.55 | 12.25 | 13.58 | 17.09 |
| Cancel ask away from best quotes | 24.44 | 27.36 | 12.74 | 17.71 | 35.74 | 21.69 | 25.89 | 30.51 | 18.17 | 21.45 |
| New ask at best quotes | 12.96 | 5.76 | 9.92 | 22.27 | 6.43 | 9.02 | 26.08 | 5.44 | 8.32 | 20.76 |
| New ask away from best quotes | 22.34 | 32.06 | 16.45 | 17.41 | 36.82 | 15.80 | 15.81 | 31.79 | 14.62 | 14.79 |
| New ask within best quotes | 15.82 | 4.54 | 26.55 | 7.80 | 7.99 | 37.48 | 12.53 | 4.39 | 29.58 | 8.27 |
| Sale | 10.78 | 15.58 | 22.09 | 16.65 | 3.18 | 3.11 | 3.14 | 15.61 | 15.73 | 17.66 |

**Panel B: Bid Side**

| Best Bid set by: | All | Isld | Isld | Isld | Nasdaq | Nasdaq | Nasdaq | Same | Same | Same |
|---|---|---|---|---|---|---|---|---|---|---|
| Best Ask set by: | All | Isld | Nasdaq | Same | Isld | Nasdaq | Same | Isld | Nasdaq | Same |
| Cancel bid at best quotes | 13.90 | 17.00 | 13.12 | 17.69 | 12.44 | 12.61 | 13.96 | 14.60 | 12.74 | 13.59 |
| Cancel bid away from best quotes | 23.78 | 26.10 | 34.46 | 27.79 | 12.39 | 19.43 | 15.36 | 18.45 | 23.62 | 18.86 |
| New bid at best quotes | 8.96 | 5.88 | 7.33 | 5.74 | 7.47 | 7.20 | 7.40 | 16.50 | 16.99 | 15.16 |
| New bid away from best quotes | 21.82 | 25.28 | 31.95 | 25.19 | 13.44 | 16.17 | 14.16 | 17.21 | 19.14 | 17.69 |
| New bid within best quotes | 18.41 | 4.78 | 9.40 | 5.15 | 25.17 | 40.85 | 30.79 | 11.96 | 23.35 | 14.71 |
| Purchase | 13.13 | 20.96 | 3.74 | 18.43 | 29.09 | 3.75 | 18.33 | 21.28 | 4.15 | 20.00 |

**Table 3: Frequency of different types of orders on Island in 2001**

We identify 6 categories of orders on each side of the book (buy and sell), differentiating them by execution status (immediate in the case of market orders, delayed for new quotes placed in the book, prevented in the case of cancellations) and location in the book (at, within or away from the best quotes). Pooling all stocks, we compute the relative frequency of each of these events on each side of the book. The first column reports unconditional frequencies, while the 9 remaining columns report frequencies conditional on 9 different situations: 1) when the best bid and ask quotes are set by Island, 2) when the best bid is set by Island but the best ask is set by Nasdaq, 3) when the best bid is set by Island and the ask is the same on Island and Nasdaq, 4) when the best bid is set by Nasdaq while the best ask is set by Island, 5) when the best bid and ask are set by Nasdaq, 6) when the best bid is set by Nasdaq and the ask is the same on Island and Nasdaq, 7) when the bid is the same on Nasdaq and Island and the best ask is set by Island, 8) when the bid is the same on Nasdaq and Island and the best ask is set by Nasdaq, and 9) when the bid and the ask are the same on Island and Nasdaq. Panel A focuses on the ask side of the book (orders to sell), while Panel B focuses on the bid side (orders to buy). Each column within each panel is a vector of relative frequencies adding up to 100%.

**Panel A: Ask side**

| Best Bid set by: | All | Isld | Isld | Isld | Nasdaq | Nasdaq | Nasdaq | Same | Same | Same |
|---|---|---|---|---|---|---|---|---|---|---|
| Best Ask set by: | All | Isld | Nasdaq | Same | Isld | Nasdaq | Same | Isld | Nasdaq | Same |
| Cancel ask at best quotes | 10.09 | 13.42 | 8.28 | 12.04 | 10.26 | 9.69 | 10.82 | 13.11 | 9.70 | 12.35 |
| Cancel ask away from best quotes | 29.56 | 29.07 | 24.19 | 25.54 | 34.53 | 29.95 | 30.16 | 29.74 | 26.82 | 25.77 |
| New ask at best quotes | 7.63 | 6.21 | 3.87 | 9.81 | 8.94 | 3.65 | 14.65 | 7.63 | 3.76 | 13.66 |
| New ask away from best quotes | 26.73 | 28.67 | 24.77 | 25.61 | 33.33 | 23.50 | 23.76 | 27.53 | 24.55 | 22.91 |
| New ask within best quotes | 15.83 | 5.25 | 14.10 | 5.75 | 8.89 | 29.97 | 16.55 | 4.55 | 21.64 | 6.90 |
| Sale | 10.16 | 17.37 | 24.79 | 21.25 | 4.05 | 3.25 | 4.06 | 17.43 | 13.53 | 18.40 |

**Panel B: Bid Side**

| Best Bid set by: | All | Isld | Isld | Isld | Nasdaq | Nasdaq | Nasdaq | Same | Same | Same |
|---|---|---|---|---|---|---|---|---|---|---|
| Best Ask set by: | All | Isld | Nasdaq | Same | Isld | Nasdaq | Same | Isld | Nasdaq | Same |
| Cancel bid at best quotes | 9.79 | 14.22 | 10.14 | 13.23 | 8.20 | 8.81 | 9.57 | 10.07 | 10.62 | 11.87 |
| Cancel bid away from best quotes | 29.52 | 27.21 | 33.83 | 27.83 | 22.81 | 30.68 | 27.12 | 25.00 | 30.43 | 24.69 |
| New bid at best quotes | 6.68 | 5.75 | 9.05 | 7.27 | 3.55 | 3.31 | 4.00 | 8.48 | 10.73 | 10.00 |
| New bid away from best quotes | 28.15 | 28.16 | 33.12 | 28.11 | 25.32 | 25.77 | 26.43 | 26.36 | 26.17 | 25.07 |
| New bid within best quotes | 15.73 | 5.28 | 9.60 | 4.82 | 12.96 | 28.45 | 19.83 | 6.08 | 18.21 | 7.15 |
| Purchase | 10.14 | 19.38 | 4.25 | 18.74 | 27.16 | 2.98 | 13.05 | 24.01 | 3.83 | 21.22 |

**Table 4: GMM estimates when the parameters are assumed to be constant across market conditions**

The adverse selection cost parameter for stock $k$: $\alpha^k$, and the order-handling cost/market power parameter: $\theta^k$, are estimated from the 2 moment conditions given in equations (1) and (2). The instruments are the square of the change in the stock price during the last half–hour, to proxy for the volatility, as well as the sign of last trade. t-statistics are given in italics below the corresponding parameter values.

**Panel A: 2000 Sample**

|       | $\alpha$ | $\theta = c + \pi$ |
|-------|------|-------|
| COMS  | .14  | .01   |
|       | *2.84* | *.28* |
| CSCO  | .18  | -.02  |
|       | *4.95* | *-1.38* |
| DELL  | .06  | .00   |
|       | *4.42* | *0.08* |
| INTC  | .03  | .05   |
|       | *.80* | *2.79* |
| MSFT  | .09  | .00   |
|       | *2.96* | *.29* |
| QCOM  | .03  | .08   |
|       | *.63* | *2.98* |
| SUNW  | .08  | .05   |
|       | *1.97* | *2.14* |
| All   | .09  | .02   |
|       | *5.54* | *2.49* |

**Panel B: 2001 Sample**

|  | $\alpha$ | $\theta = c + \pi$ |
|---|---|---|
| COMS | .04 | .00 |
|  | *3.92* | *.85* |
| CSCO | .02 | .00 |
|  | *3.50* | *.08* |
| DELL | .04 | .00 |
|  | *4.63* | *.12* |
| INTC | .03 | .00 |
|  | *3.65* | *.38* |
| MSFT | .03 | .01 |
|  | *2.74* | *2.56* |
| QCOM | .07 | .01 |
|  | *3.80* | *.58* |
| SUNW | .02 | .00 |
|  | *5.87* | *.30* |
| All | .04 | .00 |
|  | *7.88* | *1.53* |

# Table 5: GMM estimates of the flexible model

The adverse selection cost parameter for stock $k$ at time $t$ ($\alpha_{1,t}^k$) is specified as: $\alpha_{1,t}^k = \beta^{\alpha^k} X_t^k$, where $\beta^{\alpha^k}$ is a vector of parameters and $X_t^k$ is a vector of variables equal to: the constant, the depth at the best ask quote for observations corresponding to purchases, and the depth at the best bid for observations corresponding to sales, as well as the square of the change in the stock price during the last half–hour, to proxy for the volatility. Similarly, the order–handling–cost/market power parameter is specified as: $\theta_{1,t}^k = \beta^{\theta^k} X_t^k$. The set of instruments includes the variables as well as the sign of last trade. t-statistics are given in italics below the corresponding parameter values.

### Panel A: 2000 Sample

|  | COMS | CSCO | DELL | INTC | MSFT | QCOM | SUNW | All |
|---|---|---|---|---|---|---|---|---|
| Obs | 3709 | 7293 | 5557 | 5634 | 6971 | 5343 | 3847 | 38354 |
| **alpha** | | | | | | | | |
| constant | 0.22 | 0.13 | 0.08 | 0.10 | 0.10 | 0.05 | 0.19 | 0.12 |
|  | *2.91* | *2.23* | *3.15* | *1.87* | *2.19* | *0.53* | *2.46* | *5.65* |
| depth | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
|  | *-0.37* | *0.38* | *1.15* | *-1.56* | *0.23* | *-3.31* | *-1.01* | *-1.24* |
| volat | -0.05 | 0.04 | -0.04 | -0.01 | -0.03 | 0.04 | -0.09 | -0.01 |
|  | *-2.17* | *1.29* | *-1.81* | *-1.20* | *-1.51* | *1.88* | *-1.40* | *-1.87* |
| **theta** | | | | | | | | |
| constant | -0.03 | -0.01 | -0.01 | 0.01 | 0.00 | 0.07 | -0.02 | 0.00 |
|  | *-0.92* | *-0.42* | *-0.85* | *0.50* | *-0.10* | *1.58* | *-0.42* | *0.27* |
| depth | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
|  | *0.39* | *-0.11* | *-0.99* | *1.82* | *0.08* | *3.53* | *1.50* | *1.46* |
| volat | 0.03 | -0.01 | 0.02 | 0.00 | 0.02 | -0.02 | 0.05 | 0.01 |
|  | *2.31* | *-0.61* | *1.94* | *1.57* | *1.96* | *-1.69* | *1.41* | *3.02* |
| **p-value** | 0.00 | 0.16 | 0.00 | 0.00 | 0.63 | 0.05 | 0.56 | 0.00 |

**Panel B: 2001 Sample**

|          | COMS  | CSCO  | DELL  | INTC  | MSFT  | QCOM  | SUNW  | All   |
|----------|-------|-------|-------|-------|-------|-------|-------|-------|
| Obs      | 221   | 8178  | 4819  | 8775  | 8750  | 7547  | 8219  | 46509 |
| **alpha** |      |       |       |       |       |       |       |       |
| constant | 0.04  | 0.01  | 0.05  | 0.03  | 0.05  | 0.06  | 0.03  | 0.04  |
|          | *4.03* | *1.18* | *4.16* | *2.52* | *3.81* | *2.33* | *5.79* | *6.95* |
| depth    | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
|          | *-0.79* | *0.86* | *-1.26* | *1.05* | *-2.41* | *1.45* | *-2.01* | *-1.32* |
| volat    | -0.91 | 0.34  | -0.03 | -0.03 | -0.03 | -0.01 | -0.07 | -0.01 |
|          | *-0.80* | *2.43* | *-0.30* | *-0.67* | *-1.01* | *-1.29* | *-1.07* | *-0.76* |
| **theta** |      |       |       |       |       |       |       |       |
| constant | 0.00  | 0.01  | 0.00  | 0.00  | 0.00  | 0.01  | 0.00  | 0.00  |
|          | *0.20* | *1.50* | *-0.81* | *0.26* | *0.56* | *1.10* | *-1.26* | *1.01* |
| depth    | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
|          | *1.09* | *-0.77* | *1.27* | *-1.07* | *2.24* | *-1.56* | *2.03* | *-0.17* |
| volat    | 0.50  | -0.17 | 0.01  | 0.02  | 0.01  | 0.01  | 0.04  | 0.01  |
|          | *0.84* | *-2.46* | *0.30* | *0.90* | *0.63* | *1.13* | *1.15* | *1.36* |
| **p-value** | 0.12 | 0.53 | 0.00 | 0.00 | 0.25 | 0.06 | 0.00 | 0.04 |

**Table 6: Flexible model when undercutting is included in the instruments but not in the variables**

The adverse selection cost parameter at time $t$ ($\alpha_{1,t}$) is specified as: $\alpha_{1,t} = \beta^\alpha X_t$, where $\beta^\alpha$ is a vector of parameters and $X_t$ is a vector of variables equal to: the constant, the depth at the best ask quote for purchases and at the best bid for sales, as well as the square of the change in the stock price during the last half–hour to proxy for volatility. The order–handling–cost/market power parameter is specified as: $\theta_{1,t} = \beta^\theta X_t$. Instruments include the variables, the sign of last trade, and the indicator variable equal to one if the Island limit order which has been hit bettered the Nasdaq grid by just one Island tick. t-statistics are given in italics below the corresponding parameter values.

| | | | | Panel A: 2000 Sample | | | | |
|---|---|---|---|---|---|---|---|---|
| | COMS | CSCO | DELL | INTC | MSFT | QCOM | SUNW | All |
| Obs | 3709 | 7293 | 5557 | 5634 | 6971 | 5343 | 3847 | 38354 |
| **alpha** | | | | | | | | |
| constant | 0.22 | 0.12 | 0.08 | 0.10 | 0.09 | 0.04 | 0.19 | 0.11 |
| | *2.96* | *2.03* | *3.26* | *1.98* | *2.17* | *0.46* | *2.49* | *5.44* |
| depth | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *-0.39* | *0.39* | *1.13* | *-1.69* | *0.23* | *-3.31* | *-1.11* | *-1.09* |
| volat | -0.05 | 0.04 | -0.03 | -0.01 | -0.03 | 0.05 | -0.09 | -0.01 |
| | *-2.16* | *1.33* | *-1.74* | *-1.20* | *-1.53* | *2.06* | *-1.47* | *-1.87* |
| **theta** | | | | | | | | |
| constant | -0.04 | -0.01 | -0.01 | 0.01 | 0.00 | 0.07 | -0.02 | 0.01 |
| | *-0.97* | *-0.22* | *-0.97* | *0.44* | *-0.06* | *1.63* | *-0.51* | *0.48* |
| depth | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *0.40* | *-0.12* | *-0.97* | *1.93* | *0.08* | *3.50* | *1.67* | *1.50* |
| volat | 0.03 | -0.01 | 0.02 | 0.00 | 0.02 | -0.02 | 0.05 | 0.01 |
| | *2.32* | *-0.66* | *1.86* | *1.57* | *1.98* | *-1.76* | *1.47* | *3.02* |
| **p-value** | 0.00 | 0.02 | 0.00 | 0.00 | 0.90 | 0.00 | 0.09 | 0.00 |

**Panel B: 2001 Sample**

|          | COMS    | CSCO    | DELL    | INTC    | MSFT    | QCOM    | SUNW    | All      |
|----------|---------|---------|---------|---------|---------|---------|---------|----------|
| Obs      | 221.00  | 8178.00 | 4819.00 | 8775.00 | 8750.00 | 7547.00 | 8219.00 | 46509.00 |
| **alpha** |         |         |         |         |         |         |         |          |
| constant | 0.04    | 0.01    | 0.05    | 0.03    | 0.05    | 0.06    | 0.03    | 0.04     |
|          | *3.71*  | *1.13*  | *4.11*  | *2.61*  | *3.80*  | *2.30*  | *5.72*  | *6.83*   |
| depth    | 0.00    | 0.00    | 0.00    | 0.00    | 0.00    | 0.00    | 0.00    | 0.00     |
|          | *-0.77* | *0.62*  | *-1.31* | *1.06*  | *-2.44* | *1.41*  | *-2.03* | *-1.26*  |
| volat    | -1.01   | 0.36    | -0.04   | -0.03   | -0.03   | -0.01   | -0.08   | -0.01    |
|          | *-0.89* | *2.55*  | *-0.42* | *-0.80* | *-0.92* | *-1.24* | *-1.14* | *-0.69*  |
| **theta** |         |         |         |         |         |         |         |          |
| constant | 0.00    | 0.01    | 0.00    | 0.00    | 0.00    | 0.01    | 0.00    | 0.00     |
|          | *0.69*  | *1.55*  | *-0.79* | *0.16*  | *0.41*  | *1.09*  | *-1.20* | *1.14*   |
| depth    | 0.00    | 0.00    | 0.00    | 0.00    | 0.00    | 0.00    | 0.00    | 0.00     |
|          | *1.03*  | *-0.57* | *1.32*  | *-1.11* | *2.34*  | *-1.50* | *2.03*  | *-0.23*  |
| volat    | 0.58    | -0.18   | 0.02    | 0.02    | 0.01    | 0.01    | 0.04    | 0.01     |
|          | *0.98*  | *-2.61* | *0.45*  | *1.00*  | *0.53*  | *1.08*  | *1.23*  | *1.28*   |
| **p-value** | 0.13 | 0.00    | 0.00    | 0.00    | 0.00    | 0.00    | 0.00    | 0.00     |

**Table 7: Flexible model when undercutting is included in the instruments and the variables**

Adverse selection at time $t$ is $\alpha_{1,t} = \beta^{\alpha} X_t$, where $X_t$ is a vector of variables: the constant, the depth at the best ask for purchases and at the best bid for sales, the square of the change in the stock price during the last half–hour to proxy for volatility, and the indicator variable equal to one if the Island limit order which has been hit bettered the Nasdaq grid by just one Island tick. The order–handling–cost/market power parameter is: $\theta_{1,t}^k = \beta^{\theta^k} X_t^k$. Instruments include the variables and the sign of last trade. t-statistics are given in italics below the corresponding parameter values.

<div align="center">

**Panel A: 2000 Sample**

</div>

|  | COMS | CSCO | DELL | INTC | MSFT | QCOM | SUNW | All |
|---|---|---|---|---|---|---|---|---|
| Obs | 3709 | 7293 | 5557 | 5634 | 6971 | 5343 | 3847 | 38354 |
| **alpha** |  |  |  |  |  |  |  |  |
| constant | 0.20 | 0.16 | 0.10 | 0.09 | 0.10 | 0.05 | 0.19 | 0.13 |
|  | *2.56* | *2.62* | *3.56* | *1.65* | *2.17* | *0.60* | *2.43* | *5.63* |
| undercut | 0.14 | -0.24 | -0.09 | 0.05 | -0.03 | -0.15 | 0.01 | -0.05 |
|  | *1.21* | *-2.66* | *-1.93* | *0.55* | *-0.36* | *-0.62* | *0.05* | *-1.28* |
| depth | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
|  | *-0.43* | *0.61* | *1.02* | *-1.59* | *0.25* | *-3.31* | *-1.00* | *-1.19* |
| volat | -0.05 | 0.04 | -0.04 | -0.01 | -0.03 | 0.04 | -0.09 | -0.01 |
|  | *-2.15* | *1.28* | *-1.81* | *-1.16* | *-1.53* | *1.88* | *-1.40* | *-1.91* |
| **theta** |  |  |  |  |  |  |  |  |
| constant | -0.03 | -0.03 | -0.02 | 0.02 | 0.00 | 0.06 | -0.02 | 0.00 |
|  | *-0.67* | *-0.86* | *-1.41* | *0.56* | *-0.18* | *1.47* | *-0.45* | *-0.01* |
| undercut | -0.06 | 0.12 | 0.05 | -0.02 | 0.01 | 0.10 | 0.02 | 0.02 |
|  | *-1.04* | *2.62* | *2.07* | *-0.36* | *0.36* | *0.81* | *0.25* | *1.37* |
| depth | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
|  | *0.44* | *-0.34* | *-0.85* | *1.84* | *0.06* | *3.52* | *1.45* | *1.41* |
| volat | 0.03 | -0.01 | 0.02 | 0.00 | 0.02 | -0.02 | 0.05 | 0.01 |
|  | *2.30* | *-0.59* | *1.95* | *1.54* | *1.99* | *-1.69* | *1.40* | *3.06* |
| **p-value** | 0.00 | 0.15 | 0.00 | 0.00 | 0.63 | 0.05 | 0.55 | 0.00 |

**Panel B: 2001 Sample**

| | COMS | CSCO | DELL | INTC | MSFT | QCOM | SUNW | All |
|---|---|---|---|---|---|---|---|---|
| Obs | 221 | 8178 | 4819 | 8775 | 8750 | 7547 | 8219 | 46509 |
| **alpha** | | | | | | | | |
| constant | 0.05 | 0.02 | 0.04 | 0.03 | 0.05 | 0.06 | 0.03 | 0.04 |
| | *4.08* | *2.75* | *3.04* | *2.92* | *3.62* | *2.19* | *5.67* | *6.80* |
| undercut | -0.04 | -0.07 | 0.05 | -0.03 | 0.00 | 0.02 | -0.01 | -0.01 |
| | *-1.65* | *-4.44* | *2.71* | *-1.46* | *0.02* | *0.33* | *-0.77* | *-1.11* |
| depth | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *-1.00* | *0.60* | *-1.25* | *0.99* | *-2.41* | *1.43* | *-2.05* | *-1.35* |
| volat | -0.75 | 0.35 | -0.03 | -0.03 | -0.03 | -0.01 | -0.07 | -0.01 |
| | *-0.67* | *2.48* | *-0.39* | *-0.65* | *-1.01* | *-1.29* | *-1.09* | *-0.77* |
| **theta** | | | | | | | | |
| constant | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 |
| | *-0.40* | *-0.31* | *0.04* | *-0.39* | *0.37* | *1.09* | *-1.62* | *0.50* |
| undercut | 0.02 | 0.04 | -0.02 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 |
| | *1.77* | *4.68* | *-2.42* | *1.73* | *0.54* | *-0.10* | *1.16* | *1.39* |
| depth | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | *1.34* | *-0.50* | *1.26* | *-1.00* | *2.26* | *-1.55* | *2.08* | *-0.13* |
| volat | 0.41 | -0.18 | 0.02 | 0.02 | 0.01 | 0.01 | 0.04 | 0.01 |
| | *0.70* | *-2.52* | *0.39* | *0.87* | *0.63* | *1.14* | *1.18* | *1.37* |
| **p-value** | 0.13 | 0.60 | 0.00 | 0.00 | 0.25 | 0.06 | 0.00 | 0.04 |

## Appendix: Additional statistical information

**Comparing the Island and Nasdaq spreads**    Using the merged Island and Nasdaq dataset, we compared the best Island bid quote and the best bid posted on Nasdaq by its competitors. 35.89% of the time the Island bid was strictly higher than its Nasdaq counterpart, 43.16% of the time it was lower, and 20.94% of the time the two bid quotes were equal. On the ask side, the best Island quote was better than that of its competitors 26.71% of the time, it was higher 43.43% of the time, and the two quotes were equal 29.87% of the time.

These results are consistent with the findings by Simaan, Weaver and Whitcomb (2003), that ECNs often establish the inside market. Our results differ from, and complement theirs because we analyze data on unrounded Island quotes, downloaded from their site, rather than rounded quotes from the Nasdaq DQ file. Hence, we find more frequent occurrences of the situation where Island beats the Nasdaq market makers quotes, and we document undercutting by Island orders on a finer grid than the sixteenth grid.

**The consequences of rounding**    To better document the impact of the rounding procedure on the quotes observed on the Nasdaq system, we conducted the following experiment. Using the Island data for March 2000 (from the NASTRAQ DQ file), we computed the mean spread on Island. It was equal to $59.26/256, which is greater than its Island data counterpart, $50.70/256. This shows that the rounding procedure made the Island quotes much less attractive than they were actually. This confirms our remark above that Island traders relied on other ticks than sixteenths to quote to a large extent.

**Synchronicity problems**    Since the Island quotes are incorporated in the Nastraq IQ quotes, the former can be better than the latter only when they are on a finer price grid than the Nasdaq grid. This offers an opportunity to assess the magnitude of the problems induced by synchronicity. When the best Island bid (resp. ask) is better than the best Nasdaq bid (resp. ask), it should be on a finer tick than the Nasdaq grid. In our data this is the case for DELL 84.60% (resp. 84.63%) of the time. This suggests that in 15% of the cases synchronicity problems induce mistakes in our best quotes comparisons.

Figure 1, Panel A: Frequency of different values of the spread on Island and Nasdaq (excluding Island) in March 2000 for the 7 stocks in our sample

Note: graph zooms on 0 to 2 Nasdaq ticks. 46% of the time Island spread was greater than 32/256.
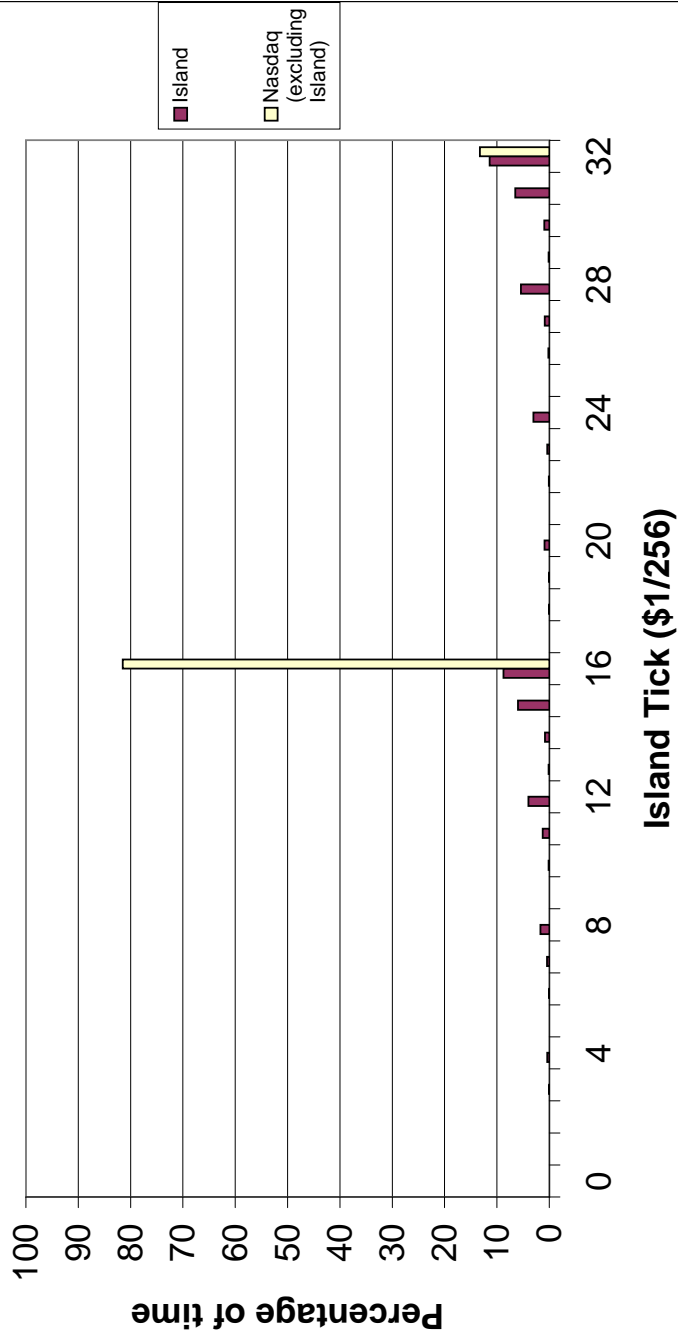
**Figure 1, Panel B: Frequency of different values of the spread on Island and Nasdaq (excluding Island) in June 2001 for the 7 stocks in our sample**

Note: graph zooms on 0 to 5 Nasdaq ticks. 39% of the time Island spread was greater than 50/1000.