Island Goes Dark: Transparency, Fragmentation, and Regulation

Terrence Hendershott
University of California at Berkeley

Charles M. Jones
Columbia University

Responding to a September 2002 regulatory enforcement, the Island electronic communications network stopped displaying its limit order book in the three most active exchange-traded funds (ETFs) where it was the dominant venue. Island's share of trading activity and price discovery fell, fragmenting the market. ETF prices adjust more slowly when Island goes dark, and there is substantial price discovery movement from ETFs to the futures market. Trading costs increase on Island and decrease off Island, with higher trading costs overall. When Island later redisplays its orders, market quality improves, with transparency and the reduction in fragmentation both playing important roles.

As they have for decades, financial market regulators and researchers are currently wrestling with a fundamental issue: how to facilitate competition between securities markets without destroying the externalities (in the form of more efficient prices) that arise when traders come together in space and time. Since directed by Congress in 1975 to create a national market system for financial securities, the U.S. Securities and Exchange Commission (SEC) has mandated a certain degree of integration, as well as public reporting of the terms of trade (quoted and transacted prices) at various venues. With the advent of electronic stock exchanges, the national market system needed updating, and in 1998 the SEC implemented Regulation ATS in an attempt to integrate these new automated markets into the existing linkages between venues.[1]

We thank Maureen O'Hara, two anonymous referees, Mike Barclay, Ekkehart Boehmer, Larry Harris, Marc Lipson, Venky Panchapagesan, Gideon Saar, Patrik Sandås, and seminar participants at the Courant Institute Mathematical Finance Seminar, the Federal Reserve Bank of New York, HEC Montreal, the New York Stock Exchange, the University of California at Irvine, the University of Southern California, the University of Wisconsin, and the 2004 American Finance Association meetings for helpful comments and suggestions. We are especially grateful to Brian Nigito for helping us understand Island operations and technology. This research began while Jones was the visiting economist at the New York Stock Exchange. The comments and opinions expressed in this article are the authors' and do not necessarily reflect those of the directors, members, or officers of the New York Stock Exchange, Inc. Terrence Hendershott gratefully acknowledges financial support from the National Science Foundation. Any errors or omissions are the responsibility of the authors alone. Address correspondence to Terrence Hendershott, Haas School of Business, University of California at Berkeley, Berkeley, CA 94720-1900, or e-mail: hender@haas.berkeley.edu.

[1] Since the original writing of this paper, the SEC has proposed Regulation NMS as part of its reexamination of the national market system. We discuss this in detail in the Conclusion.

doi:10.1093/rfs/hhi013 Advance Access publication January 5, 2005

On September 23, 2002, the SEC required the Island electronic communications network (ECN) to comply with Regulation ATS' display requirements in several of the highest-volume exchange-traded funds (ETFs) where Island dominated trading and price discovery.[2] Rather than participate in existing linkages, Island chose to comply by going "dark," no longer displaying its automated limit order book to *any* market participant. Trading and price discovery continue on Island after it goes dark, but at much lower levels, and the repercussions are observable across other markets. Over one year later, on October 31, 2003, Island redisplayed its quotes, this time in compliance with Regulation ATS' display requirements. The regulatory enforcement and the later restoration of quotes provide excellent experiments to examine quote transparency,[3] liquidity externalities, market fragmentation, and the adequacy of theoretical models in describing actual multimarket trading.

Our results show that when Island goes dark, the ETF market worsens in terms of price discovery and trading costs. By the time Island redisplays its order book, it no longer dominates trading, which means that the second event is more modest and is not a simple reversal of going dark. Nevertheless, the two events have consistent effects. Price discovery improves with the quote redisplay, and trading costs fall on Island and on some other venues as well.

Efficient prices are a public good and their production is a central role of markets. While the time horizons studied in this article are short, the degree of price efficiency at these horizons may affect the resources devoted to information production. When Island goes dark, ETF prices become less efficient and are slower to adjust to new information than the corresponding futures prices. This has implications well beyond ETFs. To our knowledge, this article demonstrates for the first time that a reduction in transparency and/or the migration of order flow away from the dominant market worsens overall price discovery. The main challenge is disentangling these two effects, because both result from the same event. However, it is important to try to separate these two, because the reduction in ETF trading concentration raises the possibility that Island going dark harms the ETF market by reducing liquidity externalities.

Liquidity externalities are network effects that arise when traders are able to come together either physically or virtually in space and time,

[2] As discussed further below, Regulation ATS requires an alternative trading system such as an ECN to join the national market system for a security if its trading volume in that security exceeds 5% in four of the past six months.

[3] The word transparency has a number of meanings. It sometimes refers to announcing trading intentions in advance [Admati and Pfleiderer (1991)], but the term usually refers either to pre-trade transparency, the availability of quotes and other information about trading interest, or to post-trade transparency, defined as the disclosure of executed trades. In this article, the term transparency alone refers to quote transparency.

reducing trading/search costs and enhancing price discovery. This in turn attracts more traders, further reducing trading costs and improving price discovery. The mechanism underpinning liquidity externalities is often somewhat vague, but competition between liquidity providers is one natural explanation. If competition across markets is not perfect, then a fragmented (less concentrated) trading arrangement may result in weaker competition among liquidity providers. Lack of transparency and integration are the main reasons for imperfect competition among securities markets. If traders cannot see the relative state of different markets and instantly choose the best one, it matters where trading occurs.

Transparency can also affect market quality directly. For example, Milgrom and Weber (1982) show that bid transparency increases competition in a static common value auction. Glosten (1999) writes that "transparency should lead to greater commonality of information. Greater commonality of information means that adverse selection becomes less of an issue." We find evidence to support both these ideas. When Island goes dark, both Island trading costs and overall ETF trading costs rise. Based on a simple Glosten (1987) spread decomposition, we find that Island liquidity providers earn more, and Island trades move prices more, when there are no displayed quotes. The former indicates a reduction in competition within Island, while the latter is consistent with greater adverse selection there.

While liquidity externalities are one of the most important issues in market design [Madhavan (2000)] and market regulation [Macey and O'Hara (1999)], it has been difficult to document their importance in practice.[4] We find evidence that liquidity externalities are important. To disentangle the effect of liquidity externalities versus transparency, we focus on venues other than Island. If markets are completely segmented, then a change in one market's transparency should not by itself directly affect price discovery and trading costs in other markets. In fact, if order flow is segmented but other markets rely on information in Island's book, a reduction in transparency on Island could harm price discovery and increase trading costs elsewhere. In contrast, if liquidity externalities are important, then these other markets should become more competitive as they gain order flow when Island goes dark. We find that trading costs (effective spreads) in all ETFs decline in non-Island markets that pick up market share, which are the other electronic systems (mainly Archipelago and Instinet). Realized spreads, which proxy for revenue to liquidity providers, decline off Island, indicating that these other markets become

[4] See Barclay and Hendershott (2004) for evidence on liquidity externalities arising from traders consolidating their activity in time, and Amihud, Lauterbach, and Mendelson (2003) for evidence on benefits of consolidation of trading of shares and deep-in-the-money warrants (on that same stock) that convert to shares.

more competitive as they obtain more order flow. Thus, order flow migration and liquidity externalities must be an important part of the story.

It turns out that the second event is also useful in disentangling liquidity externalities and transparency. When Island redisplays its quotes, there are cross-sectional differences in order flow migration. Even when there is no change in the concentration of trading, more transparency is associated with better market quality. This indicates that transparency is itself important. At the same time, the ETF with the biggest increase in trading concentration also exhibits the biggest improvement in trading costs and price discovery. Therefore, both transparency and consolidation of trading explain the improvement in market quality.

Securities markets compete along dimensions other than just price.[5] For example, ECNs and floor-based exchanges differ in their speed of execution, anonymity, and transparency. Surprisingly, we find that about half of Island's trading volume remains after it goes dark. This suggests that there are different clienteles with different preferences. We hope future research will develop richer models of multidimensional market competition with heterogeneous traders.

The presence of such multidimensionality and heterogeneity among traders and trading systems makes the regulator's task much harder. The Island event highlights the real-world difficulties of facilitating multimarket competition without damaging liquidity externalities [see Harris (1993) for further discussion]. We believe that improved linkages between markets are an important part of the solution, and we provide specific suggestions at the end of the article.

The article proceeds as follows. Section 1 reviews some related literature. Section 2 provides an overview of ETFs, the Island ECN, and Island's decision to go dark. Section 3 describes our data. Section 4 explores the effect going dark had on Island's market share and role in price discovery. Section 5 studies the impact on the efficiency of price discovery within the ETF market. Section 6 analyzes price discovery across the ETF and futures markets. Section 7 investigates the effect of Island going dark on trading costs across markets. Section 8 examines the effect of Island going dark on private information on Island and other markets. Section 9 investigates Island's later decision to redisplay its quotes. Section 10 concludes the article.

[5] In Pagano (1989a, 1989b), where markets compete on price, multiple equilibria are possible because traders face a coordination problem [see Morris and Shin (2003) for a discussion of equilibrium refinements which provide unique equilibria in such games with strategic complementarities], but trading often concentrates in a single market. Our results could depend on the particular equilibrium the market was in before and after the event, although we think this unlikely.

1. Related Literature

There is a great deal of related research on multimarket regulation, multimarket trading, and transparency.[6] For example, nearly every regulatory change that increases competition across markets improves market quality. Recent examples include the Nasdaq order handling rules [Barclay et al. (1999)] and the cross-listing of equity options [de Fontnouvelle, Fishe, and Harris (2003), Battalio, Hatch, and Jennings (2004)]. Island's going dark represents a substantially different event, in that robust competition exists before the regulatory change and the change harms market quality. Thus, this article provides evidence that care and caution are needed in crafting a national market system.

Theoretical research on multimarket trading typically assumes similar market structures to focus on traders' choice of venue [e.g., Pagano (1989a, 1989b) and Chowdhry and Nanda (1991)]. Similarly, Glosten (1994) examines whether competing liquidity suppliers in multiple markets can coexist. However, there are a few models of different competing market structures, including Parlour and Seppi (2003), who study competition between a specialist/limit order market and a pure limit order market, and Hendershott and Mendelson (2000), who analyze the effect of a crossing network on a dealer market.

There is also theoretical work on the display of limit orders. Harris (1996) notes that exposing a limit order may reveal private information and this may allow others to front-run the order. Madhavan, Porter, and Weaver (2000) develop a model where liquidity traders use limit orders and they conclude that greater order book transparency can reduce liquidity. In contrast, Baruch (2004) develops a model where liquidity is supplied by smart limit order traders and a specialist. An open limit order book improves liquidity in his model.

In terms of the empirical literature on limit order display, two directly relevant articles come to opposite conclusions. Boehmer, Saar, and Yu (2005) study the 2002 introduction of OpenBook, a real-time NYSE limit order book data feed, and find that the resulting increase in quote transparency is associated with lower trading costs and more aggressive limit order submission. In contrast, Madhavan, Porter, and Weaver (2000) examine the April 1990 decision by the Toronto Stock Exchange to provide the top five prices on either side rather than just the top of the book. They find wider spreads post-event. Both these articles examine decisions by markets to increase transparency to off-exchange traders,

[6] There are a number of models that assess the impact of revealing or suppressing security price information. Most pre-trade transparency articles contrast quote disclosure with negotiation in a multiple dealer market [Bloomfield and O'Hara (1999), Flood et al. (1999), and de Frutos and Manzano (2002)]. Madhavan (1992, 1995), Biais (1993), Pagano and Roell (1996), and Rindi (2002) study the disclosure of trade information following trades under different market structures.

rather than the regulatory shock that results in a complete loss of transparency that we study here. We find no support for the Madhavan, Porter, and Weaver (2000) results, although the Island event is not directly comparable because it involves the complete loss of transparency at one of many trading venues, and significant order flow migration occurs.[7]

There are also several articles that focus on the role and impact of ECNs on Nasdaq trading. Barclay et al. (1999) analyze the impact of Nasdaq's order-handling rules and show that ECN quotes play an important role in reducing trading costs. Simaan, Weaver, and Whitcomb (2003) show that ECN quotes are more likely to be on an odd tick than market-maker quotes and how quote anonymity affects market-makers' quotes. Huang (2002) finds that ECN quote updates are more informative than market-maker quote updates. Barclay, Hendershott, and McCormick (2003) find that more informed traders choose to trade on ECNs and are willing to pay higher effective spreads to do so. Biais, Bisiere, and Spatt (2002) study quote competition between Nasdaq and Island and the profitability of limit order strategies.

2. An Overview of Island's Decision to Go "Dark"

Before discussing Island and its decision to go dark, some background on ETFs is useful. ETFs are registered investment companies under the Investment Company Act of 1940. Like open-end index funds, they hold portfolios designed to track a particular stock or bond index. However, they differ from open-end index funds in two important ways. First, ETF shares can be traded continuously on major stock markets during the day. Second, at the end of every trading day, ETF shares can be created or redeemed by exchanging ETF shares (typically in multiples of 50,000 shares) for the appropriate number of shares of the underlying stocks. This ability to conduct arbitrage ensures that the ETF closely tracks its corresponding index. The first ETF, the S&P 500 Trust Series I (SPY), listed on AMEX in 1993. The success of SPY has led to related products for the Nasdaq-100 (QQQ), Dow Jones Industrial Average (DIA), sector-specific indexes, and value and growth-oriented indexes.[8] ETFs typically charge a management fee that is lower than that of a comparable open-end index mutual fund, though investors must also pay brokerage commissions to buy or sell ETFs.

[7] Foucault, Moinas, and Theissen (2002) also study a decline in quote transparency that is less closely related to the Island event. They examine Euronext's decision to stop displaying the identities of limit order traders. They find that average quoted spreads decline significantly while the average quoted depth increases significantly.

[8] SPY, QQQ, and DIA are sponsored by an affiliate of AMEX. Other major ETF sponsors include Merrill Lynch, which sponsors holding company depository receipts (HOLDRS), and Barclays Global Investors, which markets and manages iShares.

The three most active ETFs — DIA, SPY, and QQQ — are all listed on AMEX, but they trade in many other places as well. They are traded at the NYSE, most of the regional stock exchanges, third market dealers such as Madoff and Knight, and also at most ECNs. In fact, by the middle of 2002, the leading venue for the major ETFs was the Island ECN.

Island essentially operates a very fast, automated limit order book. This agency market accepts only priced limit orders. An order at a limit price that meets or crosses the best opposing price (a marketable limit order) executes immediately. If an incoming limit order does not cross an existing order, it goes into the book until a matching order is received or the limit order is canceled. For most securities, order submitters can choose to have an unmatched order displayed in the limit order book or remain hidden from view. At the end of each day all outstanding limit orders in the book expire.

Island matches orders based on strict price–display-time priority. This means that displayed orders have priority over undisplayed orders for orders at the same price. Island automatically executes matching orders on its system without regard to quotes posted by other market participants. Hence, Island does not guarantee the best price in the market, and the responsibility of ensuring best execution falls on the subscriber.

Island subscribers submit limit orders without charge. To encourage depth in the limit order book, if a limit order on Island does not execute immediately and subsequently executes against an incoming order, the subscriber receives a rebate per executed share. The incoming order executing against Island's book is charged a fee per executed share. In August 2002, the rebate was 0.11 cents per share and the fee 0.19 cents per share for these ETFs.[9]

Like other ECNs, Island displays the price and the number of shares available to the market, but not the identities of the investors or the brokers. Hence, in addition to immediate execution, Island and other ECNs offer anonymity. Both these features appeal to investors who may have short-lived information about future price changes. Furthermore, Island subscribers are able to suppress the display of their limit orders in whole or in part. These hidden limit orders are an important fraction of the total liquidity available on Island. Together these differences suggest that Island may appeal to a clientele of investors that are not well-served by a slower, less anonymous floor-based exchange.

Island subscribers pay a fee for a complete real-time data feed, but for each security the top 15 orders on each side of the book are continuously displayed on Island's web site. For Nasdaq stocks, the top of Island's

[9] On October 21, 2002, the fees were equalized across Instinet and Island at a 0.2 cent rebate per executed share for providing liquidity and a 0.3 cent charge per executed share for demanding liquidity. This fee change at the end of our first event period has no discernible effect on any of our results.

book is displayed on and is accessible via Supermontage. For NYSE and AMEX stocks prior to October 2003, including the ETFs that are of interest here, Island transmits no quote information other than the web site and subscriber data feeds, and only subscribers can trade these listed stocks on Island.

In December 1998, the SEC adopted Regulation ATS to establish a regulatory framework for alternative trading systems to integrate them more fully into the national market system.[10] The goals of Regulation ATS are to provide investors with access to the best prices, facilitate competition, provide a complete audit trail and surveillance on alternative trading systems, and reduce the potential for market disruption due to system outages. An important section of Regulation ATS requires that if an alternative trading system executes more than 5% of the total volume in a given security in at least four of the past six months, it must do two things. First, if the alternative trading system displays quotes, it must display those quotes in the national market system (the Consolidated Quote system for stocks listed on the NYSE or AMEX). Second, it must allow participants at other venues to trade with these quotes. For listed stocks, this means that the alternative trading system must join the Inter-market Trading System (ITS).

ITS was developed in the late 1970s and early 1980s to electronically link together the NYSE, AMEX, Nasdaq, and regional stock exchanges. Its central purpose is to create a national market in NYSE and AMEX stocks, so that market participants can see and access the best bid and offer prices across all venues. A key requirement is that ITS members cannot trade through another venue. If a better price is offered in another market, the order must be sent to the other market via ITS. The market on the receiving end of an ITS order has up to 30 seconds to respond.

In effect, this means that the receiving market potentially has a 30-second option to execute the ITS order. Prices on the largest ETFs move so rapidly, and the securities have such narrow spreads, that this option is quite valuable to an ETF market-maker. This value to the market-maker is a cost to the investor whose order is sent over ITS. Thus, ITS has the potential to increase investor trading costs, a standard measure of market quality. Island was also concerned that the trade-through rules would greatly inhibit the speed of its ETF executions.

The SEC recognized this and tried to address these concerns about ITS by issuing an exemption to the trade-through rule on August 28, 2002, effective September 4, 2002. The exemption applied only to the three largest ETFs (DIA, QQQ, and SPY), and it allowed firms and trading

[10] Most ECNs, including Island, are subject to Regulation ATS. Archipelago is partially exempt from Regulation ATS because it is regulated as an exchange following the October 25, 2001, SEC approval to launch the Archipelago Exchange as a regulated facility of the Pacific Exchange.

venues to trade through the consolidated quote's national best bid offer (NBBO) by at most three cents.[11] Many market observers, including the SEC, expected Island to work to integrate its quote and orders into ITS. Beginning on September 23, 2002, the SEC required that Island comply with the display requirements of Regulation ATS. Island's market share was over the 5% threshold in DIA, QQQ, and SPY.[12]

However, Island surprised the market and found another way to comply with Regulation ATS. If an electronic trading system does not display quotes to subscribers at all, it is not required to post quotes or send and receive orders through ITS. Rather than post its quotes and participate in ITS, Island chose to go dark. It stopped displaying its limit order book completely in the affected ETFs. It did this by converting all affected orders to undisplayed status. For QQQ Figure 1 shows the state of Island's visible limit order after going dark and after redisplaying its order book. In an e-mail to its subscribers on September 19, 2002, Island explained, "We do not believe it would be possible for Island simultaneously to comply with these requirements and to maintain the system performance our subscribers expect."

ETF trading continued on Island, but with the limit order book not visible to any market participant. Island describes this as a continuous call market. Island knew this would hurt its trading volume in the affected securities. In an attempt to stem the expected loss of order flow, Island reduced its net fees for the first week after going dark. It increased its rebate for adding liquidity from 11 to 19 cents per hundred shares executed. The fee for removing liquidity (executing against an existing limit order) remained at 19 cents per hundred shares, so Island received no net revenue from trading in the affected ETFs for that week.

Why Island chose to comply with the display requirements of Regulation ATS in such a novel way is difficult to know for sure. It may be due to its stated reason that participating in the ITS made it unable to "maintain the system performance that our subscribers expect," although other electronic markets, such as Archipelago, function as part of ITS.

[11] While it is possible that the trade-through exemption could affect the examination of Island going dark, there is no evidence of significant changes occurring around September 4 [Hendershott and Jones (2005)].

[12] Island also exceeds the 5% percent threshold and stops displaying its quotes on September 23, 2002, in two other ETFs: MKH (Merrill Lynch Market 2000+ HOLDRs Index) and SMH (Merrill Lynch Semiconductor HOLDRs Index). MKH trades infrequently — fewer than 25 trades per day — and trading had left Island prior to doing dark, with an average of only four trades per day on Island prior to going dark and none afterward. SMH is more active, with a few thousand trades per day. However, Island is far from the dominant market in SMH, with a market share of only 8% pre-event and 2% post, so we would expect little change in SMH market quality when Island goes dark. In results not reported, we confirm that there is little change in overall SMH effective and realized spreads when Island goes dark. However, Island's effective and realized spreads increase significantly. Because Island's SMH market share fell below the 5% threshold after it went dark, on March 1, 2003, Island began displaying its limit order book in SMH again. With the reinstatement in March, Island's market share increases to a little less than 5%. Overall effective and realized spreads show little change, but Island's effective and realized spreads fall when its quotes return.

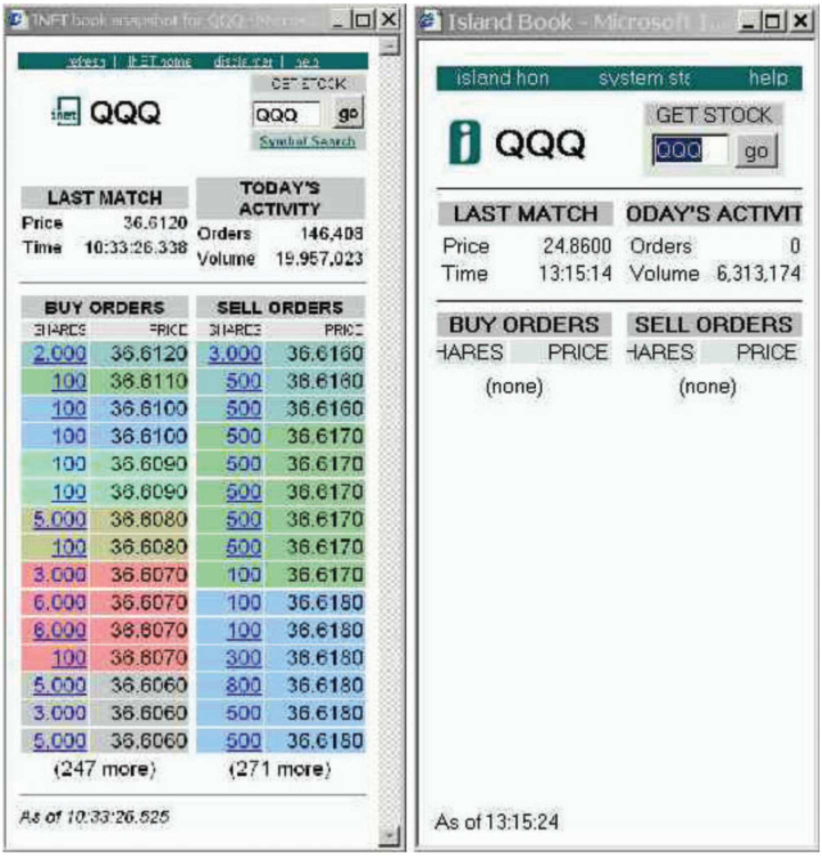


Figure 1
Island's limit order book
Two snapshots of Island's visible order book in QQQ, obtained from its web site. First screen: order book information was publicly available for all securities prior to Island's going dark and after Island redisplays its book. Second screen: while Island is dark (September 23, 2002, through October 30, 2003), only the last trade price and total daily volume are displayed for the affected ETFs.

When Island eventually redisplays quotes, it does not fully join ITS, but instead reprices or cancels orders so they do not trade through the existing quote by more than three cents (see Section 9 for details). Given that Island previously did not incorporate prices from any other venue in its systems, adding this functionality was a nontrivial undertaking contributing to the year delay in redisplaying its quotes. In going dark instead, Island presumably knew that it would lose some order flow. However, given that about half of Island's ETF trades execute against undisplayed limit orders prior to going dark, Island may have guessed that the clientele using hidden limit orders in the pre-dark period would remain when all limit orders became hidden.

More broadly, Island's actions can be viewed as a strenuous objection to regulations that force ECNs to accommodate slower traditional floor-based exchanges, for example, the 30-second option/delay for ITS orders. Once Island joined ITS, it probably felt that its business model would be permanently compromised, and perhaps avoiding that outcome was more valuable than the lost ETF market share. Given that Island's obligation is to its shareholders and not the market as a whole, it need not consider the market-wide negative consequences of going dark.

In contrast, the SEC's objective is to maximize the quality of the market as a whole. Given the current regulatory framework and the SEC's attempts to address Island's concerns with the three cent trade-through exemption discussed above, the SEC had little choice but to require Island to cease its clear violation of the display requirements of Regulations ATS. Unfortunately, we show that the application of existing regulation made the ETF market worse in terms of price discovery and trading costs. After presenting our results for Island going dark in detail, we analyze Island's decision to turn the lights back on, and we conclude by discussing regulatory approaches to integrating slower and faster markets.

3. Data and Descriptive Statistics

Our data consist of all the trades and quotes for three ETFs that went dark — DIA, QQQ, and SPY — during the normal trading hours from 9:30 A.M. to 4:00 P.M. from August 16, 2002 to October 31, 2002 (54 trading days, 25 in the pre period and 29 in the post period).[13] Data for non-Island trades and quotes are gathered from the NYSE's TAQ database. The TAQ data identify several different trading and quoting venues, including the NYSE, AMEX, Boston, Cincinnati, Midwest, Pacific, and Philadelphia exchanges. The Pacific Exchange trades using Archipelago's ECN technology, so it is essentially an automated limit order book. We group together the other regionals (Boston, Midwest, and Philadelphia, as well as non-Island Cincinnati trades) because their combined market share is fairly small, and their ETF business is fairly homogeneous. Other market-makers, such as Knight Securities and Madoff, and ECNs such as Instinet, print their trades on the so-called 3rd market. The TAQ data do not distinguish between 3rd-market participants, so all 3rd-market trades other than those matched to Island trades are treated as a single venue.[14]

The ITCH data from Island are identical to those supplied in real time to Island subscribers. The data consist of time-sequenced messages of trade and book activity. An arriving order executing against an existing

[13] August 16, 2002, was chosen as the beginning date because ARCA-Pacific began trading the three ETFs that day.

[14] Rule 11Ac1-5 reports show that about two-thirds of 3rd-market trading is Instinet, so we refer to this group as Instinet-3rd market.

order in the book generates an Order Execution message. If any part of the order does not execute, the system sends an Add Order message. Add Order messages have a unique identification number and describe whether the order is a buy or sell order, the number of shares, the limit price, the display condition (normal, subscriber-only, or invisible), and the buy–sell indicator. When an order executes, an Order Execution message reports its identification number. If an order is cancelled or reduced in size, a Cancel Order message is generated. We construct the visible book at each point in time by aggregating these messages from the start of the day up to that point in time. Although the arrival time and quantity of invisible orders are not available, special trade messages signal their execution.

To identify Island trades we match ITCH trades with TAQ trades in the markets where Island reports ETF executions (Cincinnati and the 3rd market). Due to timing delays in communicating across systems, the trade time in TAQ is usually slightly later than the ITCH trade time. We match trades on price and size using a sequence of time lags (2, 3, 1, 4, and 5 seconds). This approach identifies 99% of the Island trades in TAQ.

Because Island quotes are not in TAQ, it is more difficult to merge the ITCH data with the TAQ quotes. In constructing a consolidated NBBO our goal is to ensure accuracy, consistency, and comparability across the pre- and post-dark periods. There are two issues: there are no quotes in the ITCH data in the post-dark period and there is substantial post-dark order migration from Island to venues that participate in the TAQ consolidated quote.

Because there are no Island quotes in the post-dark period, one approach is to exclude the ITCH quote data in the pre-dark period. Unfortunately, this introduces several possible problems. First, it turns out that excluding the Island quotes could bias Island trading costs downward and non-Island trading costs upward.[15] Because this bias would appear only in the pre period, it would also bias estimates of changes in trading costs when Island goes dark. Specifically, this bias would falsely lead us to find an increase in Island spreads and a decrease in non-Island spreads when Island goes dark. This is exactly the result we expect from a

[15] A simple example illustrates this effect. Assume that the best non-Island bid is 100 and ask is 101. Buys and sells are equally likely. If Island is not at the inside, the issue of Island quotes is moot. Also, assume that if Island is tied at the inside of either quote, then the probability that Island gets the trade is .5. Finally, assume if Island is alone at the inside the probability of a trade occurring on Island is greater than .5, say .75. If Island's ask price is 100.9, then using a consolidated NBBO Island's trading cost as measured by the effective (half) spread—the absolute difference between the transaction price and the bid-ask midpoint—is 0.45. The non-Island trades will have an effective spread of 0.4833 $\left(\frac{1}{3} \times 0.55 + \frac{2}{3} \times 0.45\right)$. If the Island quotes are excluded then the Island effective spread is 0.44 $\left(\frac{2}{5} \times 0.5 + \frac{3}{5} \times 0.4\right)$ and the non-Island 0.5. Thus, the exclusion of the Island quotes biases the Island effective spread downward and the non-Island effective spread upward. If Island is alone at the inside at both the bid and the ask, this same bias exists as long as Island's improvement of the quotes is not symmetric and the quote that offers greater improvement over the non-Island quote is more likely to attract a trade.

reduction in transparency and the resulting order flow migration, and we want to ensure that this result is not artificially generated.

The second problem involves the migration of order flow when Island goes dark. If displayed liquidity moves from Island to, say, Archipelago, then that liquidity is in the consolidated quote post-event.[16] For consistency, that liquidity should also be in the consolidated quote pre-event. Based on these issues, we think it best to include the Island quotes in a consolidated NBBO for the pre-dark period. However, the results in this article on overall trading costs and non-Island trading costs are unaffected by the exclusion of the Island quotes from the NBBO in the pre period. When studying price discovery we present the pre-event period analysis both with and without the Island quotes and discuss the differences.

For the pre-dark period, we construct an Island inside quote of at least 100 shares from ITCH and merge that with quotes from TAQ to construct an NBBO. Because the differences in ITCH and TAQ times affect the construction of the NBBO, we perform the subsequent analysis using lags similar to those found between the ITCH and TAQ trade time. Using these different lags does not affect the results qualitatively. For example, an NBBO with Island quotes lagged two seconds provides somewhat stronger results than those in this article, for example, the increase in trading costs overall and on Island is larger. We also delete quotes that lock or cross the NBBO, although the results are not sensitive to the exclusion of these quotes. Finally, to ensure that our results are not sensitive to the rounding of quotes in TAQ to the nearest penny, we test (without reporting the details) that rounding the pre-period ITCH quotes does not affect the results.

Using the Lee and Ready (1991) algorithm, non-Island trades are classified as buyer initiated if the trade price is greater than the contemporaneous quote midpoint and seller initiated if the trade price is less than the quote midpoint. Trades executed at the midpoint are classified with the tick rule: midpoint trades on an uptick are classified as buyer initiated and midpoint trades on a downtick are classified as seller initiated. We represent the buy/sell indicator with the variable $x = +1$ for a buy order and $x = -1$ for a sell order. For Island trades we use the buy–sell indicator in the ITCH data. Using the ITCH buy–sell indicator only affects Island trades, and its primary benefit is to increase the precision of the estimates of Island's realized spreads and the price impact of Island trades in the pre period. The qualitative results are unchanged if we use the Lee and Ready (1991) algorithm for Island trades as well.

The data include almost 5 million trades for \$331 billion and a similar number of quote revisions. Table 1 provides daily trading activity, quoted

[16] This turns out be the case and causes the quote midpoints in the pre period to be less accurate. This mainly affects Island's trading costs by increasing the effective spreads and decreasing realized spreads in the pre period.

Table 1
Sample descriptive statistics

	DIA		QQQ		SPY	
Average daily	Pre	Post	Pre	Post	Pre	Post
Volume (M shares)	9.20	13.33	77.43	85.42	35.46	51.71
Volume (000 trades)	16.90	15.87	43.47	39.16	27.09	26.13
Price	85.72	79.90	23.59	22.38	91.22	85.18
Quoted spread (cents)	2.62	2.65	1.07	1.23	2.15	2.18
Market share (shares)						
AMEX	0.25	0.27	0.18	0.19	0.27	0.27
Island	0.36	0.16	0.36	0.22	0.21	0.12
NYSE	0.05	0.10	0.07	0.08	0.08	0.09
ARCA-Pacific	0.03	0.08	0.02	0.06	0.02	0.05
Other regionals	0.08	0.10	0.12	0.13	0.07	0.08
Instinet-3rd market	0.21	0.29	0.26	0.33	0.35	0.40
Herfindahl index	0.25	0.21	0.25	0.22	0.25	0.26
Market share (trades)						
AMEX	0.09	0.13	0.06	0.08	0.13	0.17
Island	0.61	0.29	0.59	0.37	0.56	0.30
NYSE	0.02	0.04	0.04	0.05	0.03	0.05
ARCA-Pacific	0.05	0.14	0.03	0.11	0.04	0.14
Other regionals	0.08	0.12	0.15	0.19	0.11	0.16
Instinet-3rd market	0.15	0.29	0.14	0.21	0.14	0.20
Herfindahl index	0.41	0.22	0.39	0.24	0.36	0.20
Fraction of Island volume executed against undisplayed orders						
Shares	0.45	1.00	0.50	1.00	0.50	1.00
Trades	0.54	1.00	0.55	1.00	0.56	1.00

Descriptive statistics based on TAQ and ITCH data for three exchange-traded funds—DIA, QQQ, and SPY — from August 16, 2002, to October 31, 2002. The pre period is August 16, 2002, to September 20, 2002, and the post period is September 23, 2002, to October 31, 2002. Descriptive statistics are calculated for each ETF each day and then averaged across days.

spreads, and market share in terms of shares and trades across markets for the three ETFs in both the pre- and post-dark periods. All three ETFs are very active, averaging two trades in three seconds for DIA and almost two trades per second for QQQ. Quoted spreads are narrow, ranging from 1.07 cents for QQQ up to 2.65 cents for DIA. Before going dark, Island is the dominant venue in share volume for DIA and QQQ. For SPY Island executes the majority of trades, but its smaller trade size results in it having only 21% of the share volume. In SPY both AMEX and Instinet-3rd market have greater share volume. One possible effect of Island going dark is that some traders exit or migrate to the futures market, but trading volume increases substantially in all three ETFs: 50% in DIA and SPY and 10% in QQQ. Relative to futures volume, ETF trading volume is essentially unchanged after Island goes dark (results available upon request).

Going dark reduces Island's market share by 40–55% in both share and trade terms. In the post period, Island does not have the highest share volume in any of the ETFs, although it still has the greatest number of trades. Most of the volume leaving Island moves to other electronic venues, with ARCA-Pacific and Instinet-3rd market gaining the majority of Island's lost market share (Rule 11Ac1-5 reports show that over half of the growth in 3rd market volume is due to Instinet).

A standard way of measuring market concentration is a Herfindahl index. For example, Ellis, Michaely, and O'Hara (2002) and Schultz (2003) use the Herfindahl index to measure the concentration of trading in Nasdaq stocks. The Herfindahl index is given by the sum of the squares of the percentage market share of each market. All trading being in a single market gives a Herfindahl index equal to one, while equally sized markets yield an index of one divided by the number of markets. Table 1 also provides the Herfindahl index in both share and trade terms. Note that due to data limitations, the third market is considered a single venue for this purpose. The average daily Herfindahl index shows that trading concentration decreases in the post-dark period. This change is significant at the .01 level, except for market share in share volume in SPY where the change is positive but not statistically significant. There is no single correct measure of concentration in financial markets, so later when we calculate a measure of price discovery across markets — information share — we will calculate another Herfindahl index measuring the concentration of price discovery. The price discovery concentration index exhibits larger declines than the trading concentration index presented here.

Undisplayed limit orders are often an important feature of automated trading systems, but hidden limit orders are particularly prominent in Island's ETF trading. Table 1 shows that prior to going dark, between 45 and 50% of Island's share volume executed against undisplayed liquidity. When Island goes dark and all executed volume is by definition against undisplayed liquidity, Island's overall market share also declines on the order of 50%. Thus, to a first approximation, the volume of hidden order executions on Island remains constant post-event. One possible explanation for Island's continued significant market share is that certain market participants value a hidden limit order book market and, by extension, value the absence of quote transparency. However, it does not necessarily follow that market quality improves when the dominant market becomes nontransparent, because the lack of transparency may impose costs on others. We return to trading cost measurement later, but first we examine price discovery, beginning with the information shares of various venues before and after Island goes dark.

4. Island Going Dark: Market Share and Information Share

The effects of Island going dark are immediate. Figure 2 provides the daily average market share for Island by share volume (Panel A of Figure 2) and number of trades (Panel B of Figure 2). Island's percentage of share volume in DIA and QQQ is about 35% through September 20, 2002, and then drops to about 20% the day it goes dark. For SPY, Island's percentage of share volume

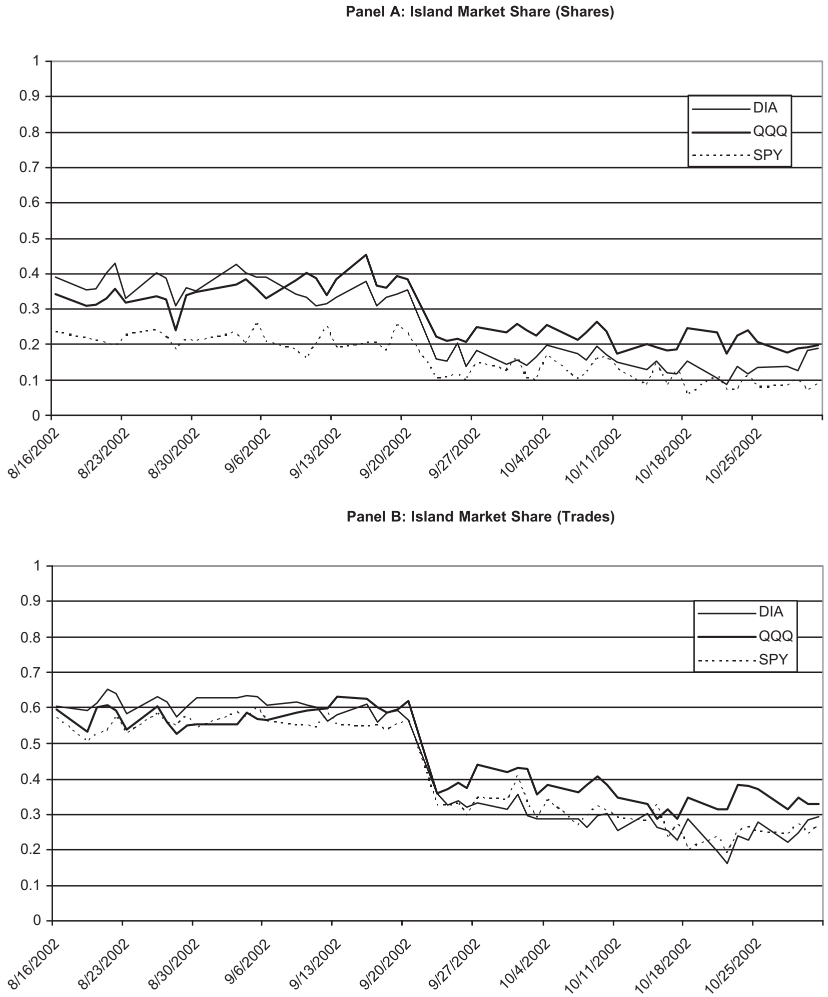


Figure 2
Island's daily market share in shares and trades
For the three ETFs this graph depicts Island's daily market share as a fraction of share volume (Panel A) and trades (Panel B) from August 16, 2002, to October 31, 2002.

drops from over 20% until September 20 to 10% on September 23. Island's market share of trades is much higher, making the drop more pronounced. Island's trade share is between 55 and 60% in all three ETFs prior to going dark. This drops to below 40% in QQQ and to just about 30% in DIA and SPY. Island's trade share continues to decline somewhat in all three.

Prior research shows that electronic markets' prices and quotes are more informative than their fraction of trading would suggest [e.g., Huang (2002) and Hasbrouck (2003)], and trading on ECNs is associated with more informed trading [Barclay, Hendershott, and McCormick (2003)]. Thus, the impact of Island going dark on the price formation process might be even greater than its precipitous decline in market share suggests. To examine this issue a framework for the price formation process across multiple markets must be laid out.

4.1 Information share

Our analysis follows the information share approach of Hasbrouck (1995), Huang (2002), and others. A more detailed overview of this and alternative procedures is provided by Baillie et al. (2002), de Jong (2002), Harris, McInish, and Wood (2002), Hasbrouck (2003), and Lehmann (2002). These methods focus on the random-walk component of security prices across markets — the latent efficient price. The random-walk innovation variance is decomposed into components that can be attributed to innovations in each market's price. The relative contribution of a given price to the overall random-walk variance is defined as that price's information share.

Let p_t be a $(n \times 1)$ vector of transaction prices from n markets. If the prices are nonstationary, their future time path depends on past effects. Although the prices are individually nonstationary, they are for the same underlying asset, so a linear combination of the prices may be stationary. If all prices follow a random walk, they are integrated of order one and Δp_t is a stationary process. Prices are cointegrated if there exists a nonzero cointegrating vector b such that $b'p_t = e_t$ is stationary. The vector e_t can be interpreted as a deviation from long-run equilibrium. When e_t is stationary, pricing errors are corrected over time.

Cointegrated variables can be equivalently represented as a vector autoregression (VAR) in levels, as a vector error correction model (VECM), or as a vector moving average (VMA) representation. Suppose p_t can be expressed as a VAR:

$$p_t = \phi_0 + \sum_{j=1}^{q} \phi_j p_{t-j} + \varepsilon_t, \tag{1}$$

where $E(\varepsilon_t) = 0$ and $E(\varepsilon_t\ \varepsilon_s') = \Omega$ if $s = t$ and 0 otherwise. Then there exists a VECM:

$$\Delta p_t = \theta_0 p_{t-1} + \sum_{j=1}^{q-1} \theta_j \Delta p_{t-j} + \varepsilon_t, \tag{2}$$

where $\theta_j = -\sum_{i=j+1}^{q} \phi_j$ for $j = 1, \ldots, q-1$ and $\theta_0 = -\left(I_n + \sum_{i=1}^{q} \phi_j\right)$.

Alternatively, the common trends representation proposed by Stock and Watson (1988) is

$$p_t = p_0 + \Lambda(1)\sum_{i=1}^{t} \varepsilon_i + \Lambda^*(L)\varepsilon_t, \tag{3}$$

where $\Lambda^*(L)$ is a polynomial matrix with elements which are scalar polynomials in the argument L, p_0 is the initial price, and the last term of Equation (3) is a stationary process. The middle right-hand term is the stochastic common trend to prices in all markets and captures the permanent impact of new information on prices. This impact excludes all transient price effects such as inventory adjustment and bid-ask bounce. Hasbrouck (1995) provides a measure of a market's contribution to price discovery using the total variance of the common stochastic trend, $\Lambda\Omega\Lambda'$, where Λ is a row in $\Lambda(1)$, and Ω is the $(n \times n)$ covariance matrix of the innovations. The share of this total variance attributed to market j is

$$I_j \equiv \frac{\Lambda_j^2\Omega_{jj}}{\Lambda\Omega\Lambda'}. \tag{4}$$

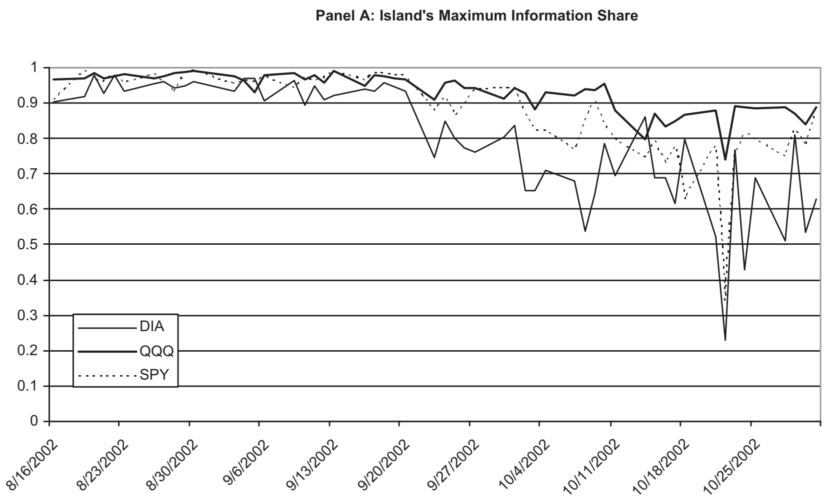
If the innovation covariance matrix (Ω) is not diagonal, the information share is not exactly identified. To bound the contribution of an innovation, the matrix is typically diagonalized by finding the Cholesky factorization of Ω: $\Omega = FF'$, where F is a triangular matrix. Using F so that $\varepsilon_t = Fu_t$, the innovations (u_t) are orthogonal to the preceding innovations in the ordering. Thus, the proportion of the information attributable to a market depends on the ordering. The upper and lower bounds of the information share of each market are calculated over all possible orderings of the markets.

In this case, with a vector of prices in six markets, the VECM specification (2) requires 36 estimated coefficients per lag. If prices are measured every second, then a two-minute maximum lag result requires estimation of $36 \times 120 = 4320$ coefficients. To reduce the number of estimated coefficients, we follow Hasbrouck (1995, 2003) and use polynomial distributed lags. The 6×6 coefficient matrices θ_j are constrained to be quadratic in the lag j. That is,

$$\theta_j = A_0 + A_1\, j + A_2\, j^2, \tag{5}$$

where the A_i are 6×6 estimated matrices. Separate quadratic polynomials are fit over various lag ranges and, at longer lags, the coefficient matrix θ_j is constrained to be constant over a pre-specified lag range.[17]

[17] Prices are measured at one-second intervals, and the maximum lag is two minutes for a total of 120 lags. Three separate second-degree polynomial distributed lags are imposed on lags 1–10, lags 11–20, and lags 21–30. VECM coefficients are constant for all lags 31–60. Similarly, the coefficient matrix is restricted to be constant over lags 61–90 and 91–120.



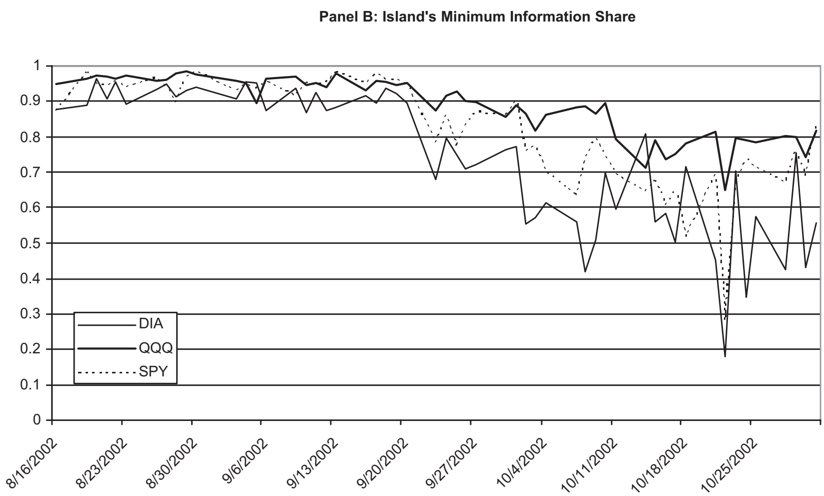


Figure 3
Island's daily information share
This graph depicts the bounds on Island's daily information share with (Panel A) being the maximum and (Panel B) being the minimum from August 16, 2002, to October 31, 2002.

Figure 3 shows Island's maximum (Panel A of Figure 3) and minimum (Panel B of Figure 3) information share each day. Island's maximum information share is between 94 and 97% prior to going dark and falls to 74, 91, and 88% for DIA, QQQ, and SPY, respectively. Its maximum information share continues to decline through the post period finishing at 60, 90, and 85% for DIA, QQQ, and SPY, respectively. The minimum information shares follow a similar pattern starting between 90 and 95%

and declining to 55–80%.[18] Note that the fragmentation of price discovery and the fragmentation of market share in the post-dark period are significantly different. Even though Island's share of trades falls to 30–40% in the post-dark period, its information share remains at 60–90%. This demonstrates that Island's higher price discovery is not simply generated by its higher trading activity. In fact, this divergence between information share and market share is consistent with Huang (2002), Hasbrouck (2003), and Barclay, Hendershott, and McCormick (2003), who find that electronic platforms have a ratio of price discovery to trades that is greater than one.

Just as trading activity shifts from Island to the other electronic markets, so does price discovery. Table 2 presents the daily averages of each market's maximum and minimum information share for the three ETFs in both the pre- and post-dark periods, and inference is conducted using the time series of daily information shares. The floor-based markets see some increases in price discovery that are significant at the .01 level, but these are small in economic terms, with none of AMEX, NYSE, or the regionals having a maximum information share of 5% in any of the ETFs. In contrast, all of the changes in information share for ARCA-Pacific and Instinet-3rd market are statistically significant. Island's going dark results in ARCA-Pacific's maximum information share increasing from about 1% to over 10% in all three ETFs. Instinet-3rd market's information share in DIA increases from less than 5% to over 20% when Island goes dark.

The final columns of Table 2 calculate a Herfindahl index for the concentration of price discovery across markets. As noted earlier, Instinet-3rd market is considered a single venue because TAQ does not provide data about the actual trading location within the third market. Because the maximum information shares add up to more than one and the minimum to less than one, each day we calculate the sum of the maximum and minimum information shares across markets and then divide each market's information share by the total. Another approach to deal with the contemporaneous component across markets would be to choose a particular orthogonalization. Because no orthogonalization is clearly preferable, we opt for our simpler approach. Given how tight the bounds on the information shares are, it is unlikely that the exact approach is important. The information share Herfindahl index decreases by roughly 40, 20, and 30% for DIA, QQQ, and SPY, respectively. These decreases are much bigger than the Herfindahl index decreases based on trading volume, indicating that price discovery fragments more than trading volume.

5. The Effect of Island Going Dark on the Efficiency of Price Discovery

An important benefit of concentrating trading in a single market is more efficient price discovery [Pagano (1989b)]. Thus, Island's going dark may

[18] For robustness, we also calculate information shares including non-Island quote midpoints in the vector of prices. This has almost no effect on Island's dominance.

Table 2
Information shares within the ETF market

	AMEX		Island		NYSE		ARCA-P		Regionals		Instinet-3rd		Herfindahl	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
DIA max														
Median	0.009	0.040	0.940	0.687	0.003	0.004	0.009	0.095	0.002	0.008	0.045	0.225	0.841	0.441
Mean	0.014	0.043*	0.941	0.679*	0.007	0.007	0.014	0.106*	0.006	0.012	0.045	0.257*	0.842	0.485*
SE	(0.002)	(0.004)	(0.005)	(0.026)	(0.002)	(0.001)	(0.003)	(0.015)	(0.002)	(0.003)	(0.004)	(0.026)	(0.010)	(0.018)
DIA min														
Median	0.008	0.034	0.918	0.584	0.002	0.002	0.005	0.056	0.001	0.004	0.026	0.164	0.887	0.497
Mean	0.012	0.036*	0.915	0.596*	0.006	0.004	0.010	0.065*	0.005	0.008	0.025	0.192*	0.888	0.532*
SE	(0.002)	(0.004)	(0.006)	(0.028)	(0.002)	(0.001)	(0.002)	(0.009)	(0.002)	(0.002)	(0.003)	(0.024)	(0.009)	(0.021)
QQQ max														
Median	0.004	0.005	0.973	0.888	0.004	0.008	0.007	0.093	0.001	0.003	0.017	0.053	0.921	0.693
Mean	0.006	0.006	0.973	0.893*	0.008	0.013	0.008	0.107*	0.002	0.005*	0.020	0.054*	0.918	0.710*
SE	(0.001)	(0.001)	(0.003)	(0.009)	(0.002)	(0.002)	(0.002)	(0.012)	(0.001)	(0.001)	(0.003)	(0.005)	(0.007)	(0.017)
QQQ min														
Median	0.003	0.004	0.960	0.817	0.003	0.005	0.004	0.049	0.001	0.001	0.006	0.026	0.948	0.788
Mean	0.005	0.005	0.957	0.823*	0.007	0.009	0.005	0.056*	0.001	0.003*	0.009	0.029*	0.947	0.800*
SE	(0.001)	(0.001)	(0.004)	(0.013)	(0.002)	(0.002)	(0.001)	(0.008)	(0.000)	(0.001)	(0.002)	(0.004)	(0.005)	(0.016)
SPY max														
Median	0.005	0.028	0.971	0.822	0.003	0.015	0.005	0.168	0.002	0.008	0.025	0.051	0.903	0.593
Mean	0.007	0.034*	0.968	0.809*	0.006	0.020*	0.011	0.159*	0.004	0.013*	0.026	0.066*	0.901	0.592*
SE	(0.001)	(0.006)	(0.004)	(0.021)	(0.001)	(0.004)	(0.003)	(0.021)	(0.001)	(0.003)	(0.003)	(0.009)	(0.009)	(0.023)
SPY min														
Median	0.003	0.019	0.951	0.739	0.002	0.011	0.004	0.098	0.001	0.005	0.008	0.029	0.943	0.666
Mean	0.005	0.026*	0.949	0.719*	0.005	0.015*	0.008	0.098*	0.003	0.009*	0.011	0.036*	0.938	0.671*
SE	(0.001)	(0.005)	(0.005)	(0.023)	(0.001)	(0.003)	(0.003)	(0.014)	(0.001)	(0.002)	(0.002)	(0.005)	(0.007)	(0.026)

Statistics are based on a vector error correction model (described in Section 4) of transaction prices estimated at a one-second resolution. Estimates are calculated for each ETF each day and then averaged across days. The pre period is August 16, 2002, to September 20, 2002, and the post period is September 23, 2002, to October 31, 2002. An asterisk (*) represents a statistically significant difference between the pre and post period at the .01 level, based on the daily time series of information share estimates.

hamper the incorporation of information into prices. This could occur for several reasons. First, having a dominant market for price discovery could simplify the process of determining the efficient price. Prior to going dark, the information share analysis in Table 2 suggests that traders could simply look at Island to obtain the efficient price. Once Island goes dark, traders may need to look at Island, ARCA-Pacific, Instinet, and AMEX and decide how to weigh each venue. This process alone could slow price discovery over short horizons. Another possibility is that if trading costs increase when Island goes dark (and they do; see below), information that was profitable before might no longer yield a profitable trade. As a result, prices may adjust more slowly. To measure effects on the efficiency of price discovery beyond the increase in bid-ask bounce, we examine quote midpoints and measure the autocorrelation of their changes.

Table 3 shows the average daily autocorrelation of quote midpoint returns over 15-, 30-, and 60-second intervals by ETF for the pre and post periods. In the pre-dark period, we calculate the NBBO in two ways: using all market center quotes and using only non-Island quotes. We do this to determine whether changes in price discovery are driven by the change in transparency on Island or the resulting order flow migration. However, we first focus on overall price efficiency using all market center quotes.

The autocorrelations in Table 3 are all positive, signifying lagged adjustment to information. The quote change autocorrelations increase from the pre period to the post period in all ETFs for all time intervals, indicating a reduction in the efficiency of price discovery in the post-dark period. Seven of the nine increases in quote autocorrelation are significant

Table 3
Quote return autocorrelations

	DIA			QQQ			SPY		
Interval	Pre	Non-Island Pre	Post	Pre	Non-Island Pre	Post	Pre	Non-Island Pre	Post
15 seconds	0.00	0.06	0.08*	0.01	0.08	0.09*	0.09	0.18	0.12*†
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
30 seconds	0.07	0.14	0.18*†	0.04	0.16	0.14*	0.10	0.19	0.14†
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)
60 seconds	0.06	0.10	0.13*	0.04	0.14	0.11*	0.04	0.09	0.05†
	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)

The first-order autocorrelation of quote midpoint returns is calculated over 15-, 30-, and 60-second intervals for each ETF each day and then averaged across days. The pre period is August 16, 2002, to September 20, 2002, and the post period is September 23, 2002, to October 31, 2002. The NBBO pre period uses quotes from all market centers and the non-Island pre period uses quotes from all markets except Island. Standard errors are in parentheses. An asterisk (*) represents a statistically significant difference between the pre and post period at the .01 level, based on the daily time series. A dagger (†) represents a statistically significant difference between the non-Island pre and post periods at the .01 level.

at the .01 level. For example, autocorrelations for one-minute quote returns in QQQ increase markedly from 0.04 before September 23 to 0.11 afterward. Autocorrelations over five-minute and longer intervals are not reported, but are indistinguishable from zero in both the pre and post periods.

Given that Island's going dark is a change in transparency that leads to order flow migration, it is difficult to completely disentangle the two effects. However, examining the non-Island markets provides some insight. If order flow moving from Island to other markets results in improved price discovery in these markets, the fragmentation results in a more efficient price on these markets. Table 3 shows that this appears to be the case for SPY at all intervals.

Alternatively, given Island's dominant role in price discovery in the pre period, it is possible that traders off Island watch and benefit from the Island quotes. If this effect is stronger than the benefits from increased order flow, it could result in less efficient prices off Island in the post period. This does not seem to be the case for SPY, where off-Island quotes are more efficient when Island goes dark. However, the transparency effect appears stronger for DIA, as non-Island quote autocorrelations increase in the post period at all intervals. For QQQ, the transparency and order flow effects appear to cancel out, with none of the changes in the quote autocorrelation being statistically significant. Together these results indicate that both the externalities of order flow and the ability to observe prices in a dominant market center contribute to the efficiency of price discovery.

For all three ETFs studied here, there are also futures traded on the same underlying securities. Changes in the ETF market may also affect the linkages between the ETF and futures markets. Hasbrouck (2003) shows that almost all price discovery in the Nasdaq-100 and S&P 500 futures markets occurs in the E-minis. E-minis are variants of the standard index futures contracts, with a smaller contract size and electronic trading rather than open outcry. We have data from the Chicago Mercantile Exchange for NQ, the Nasdaq-100 contract, and ES, the S&P 500 contract. To look at price discovery in the ETF and futures markets, we begin by calculating first-order cross-correlations of returns in the two markets. We use E-mini transaction price data and ETF quote midpoints.[19] If price discovery is fully efficient across the ETF and futures markets, these cross-correlations should be zero.

Table 4 shows the average daily first-order cross-autocorrelation of ETF quote midpoint returns and E-mini futures transaction price returns

[19] Historical quotes for Globex trading are not available from the Chicago Mercantile Exchange, so transaction prices are used. ETF transaction prices provide the same qualitative results, but the bid-ask bounce increases the variance of ETF returns, reducing the autocorrelations toward zero in both the pre and post periods.

Table 4
ETF and futures return cross-autocorrelations

	Nasdaq-100			S&P 500		
Interval	Pre	Non-Island Pre	Post	Pre	Non-Island Pre	Post
Panel A: ETF(t) − E-mini(t − 1)						
15 seconds	0.12	0.34	0.41*†	0.18	0.38	0.35*†
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
30 seconds	0.09	0.41	0.40*	0.16	0.35	0.28*†
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
60 seconds	0.06	0.33	0.28*†	0.08	0.21	0.13*†
	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)
Panel B: ETF (t − 1) − E-mini(t)						
15 seconds	0.04	−0.02	0.00*	0.06	0.04	0.03*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
30 seconds	0.00	−0.02	−0.01	0.04	0.02	0.01*
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
60 seconds	−0.01	−0.02	−0.03	−0.01	−0.03	−0.03
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)

The first-order cross-autocorrelation of ETF quote midpoint returns and E-mini future transaction price returns are calculated over 15-, 30-, and 60-second intervals for each index each day and then averaged across days. The pre period is August 16, 2002, to September 20, 2002, and the post period is September 23, 2002, to October 31, 2002. Standard errors are in parentheses. The pre period uses quotes from all market centers and the non-Island pre period uses quotes from all markets except Island. An asterisk (*) represents a statistically significant difference between the pre and post periods at the .01 level, based on the daily time series. A dagger (†) represents a statistically significant difference between the non-Island pre and post periods at the .01 level.

for 15-, 30-, and 60-second intervals. Again, we calculate the ETF quote returns in the pre-dark period both using our NBBO of all market centers' quotes and using an NBBO of all market centers except Island. The cross-autocorrelation of ETF NBBO returns with lagged E-mini returns is positive, while the lagged ETF returns provide little predictive power for current E-mini returns. These imply that ETF prices lag futures prices. This is consistent with Hasbrouck (2003), who finds that price discovery in these indexes is concentrated in the E-mini futures market.[20] When Island goes dark, the lag in ETF prices increases and the cross-autocorrelation of ETF returns with lagged E-mini returns goes up significantly. This is true for both the Nasdaq-100 and the S&P 500, and it is true for 15-, 30-, and 60-second returns. For example, the cross-autocorrelation in 15-second Nasdaq-100 returns goes from 0.12 pre-event to 0.41 post-event.

[20] This could also be due to difficulties in reconciling the times across both markets. The discussion of merging the TAQ and ITCH data notes the several second lags between the ITCH time stamps and the TAQ time stamps. The changes between the pre- and post-dark periods in the cross-autocorrelations here are not sensitive to this—similar results are found when ETF returns are calculated using ETF transaction prices and when ETF returns are calculated using Island transaction prices with the ITCH time stamps, but how much the futures prices lead the ETF prices may be sensitive to these timing issues. We explore this in the next section.

If we perform the same analysis using only non-Island quotes in the pre-dark period, the results are consistent with the autocorrelation results of Table 3. For the Nasdaq-100, the cross-autocorrelations using non-Island quotes in the pre period are similar to the post period, with the cross-autocorrelations higher in post period at 15 seconds, similar at 30 seconds, and lower at 60 seconds. For the S&P 500, E-mini futures lead the non-Island ETF quotes less in the post period than in the pre period.

Another way to assess price efficiency is to look at the intraday variability in the basis between futures and ETFs, as discussed in Hasbrouck (2003). While the basis varies over time depending on interest rates, dividend yields, and accrued but unpaid dividends on the ETF, the basis should be constant within a trading day if the ETF perfectly tracks the E-mini or vice versa. Thus, for each trading day we examine deviations from the mean basis for that day. We use all ETF and E-mini transaction prices at 60-second intervals based on TAQ time stamps, but the results are virtually identical for other sampling intervals. When Island goes dark, the two markets become less tightly linked. For the Nasdaq-100, the average absolute deviation rises from 5.52 basis points pre-dark to 5.91 basis points afterward. Similarly, when Island goes dark, the average absolute deviation for the S&P 500 rises from 1.69 to 2.54 basis points. Both these changes are statistically significant at the .01 level, where inference is conducted using the daily time series of average absolute deviations.

Thus, quote autocorrelations, quote cross-autocorrelations, and deviations between ETF and futures prices all yield similar results. When Island goes dark, prices become less efficient both within the ETF market and across markets for related securities.

6. The Effect of Island Going Dark on Price Discovery Across Securities

Hasbrouck (2003) finds that the E-mini futures prices dominate intraday price discovery in the Nasdaq-100 and S&P 500 indexes in March through May of 2000. However, two years later spreads on the ETF have fallen by an order of magnitude—spreads are 1–2 cents in our sample versus 20 cents in Hasbrouck (2003). Also, ETF trading volume has increased substantially to 40,000 and 27,000 daily trades in QQQ and SPY versus 10,000 and 1700 daily trades in Hasbrouck's 2000 sample. These statistics suggest that ETFs' role in index price discovery may have increased since 2000. If this is the case, then Island going dark may have important effects on price discovery between ETFs and futures.

To measure price discovery between the ETFs and futures we return to the information share analysis from Section 4 [and in Hasbrouck (2003)].

We estimate each VECM using ETF and associated E-mini prices at one-second resolutions. Table 5 presents the daily averages of the ETF and E-mini

Table 5
Information shares across the EFT and futures markets

	All ETF trades (TAQ times)				Island ETF trades (ITCH times)			
	E-mini		ETF		E-mini		ETF	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Nasdaq-100 max								
Median	0.947	0.986	0.077	0.022	0.371	0.755	0.785	0.433
Mean	0.858	0.985*	0.167	0.023*	0.335	0.757*	0.802	0.415*
SE	(0.038)	(0.002)	(0.039)	(0.002)	(0.035)	(0.008)	(0.023)	(0.011)
Nasdaq-100 min								
Median	0.923	0.978	0.053	0.014	0.215	0.567	0.629	0.245
Mean	0.833	0.977*	0.142	0.015*	0.198	0.585*	0.665	0.243*
SE	(0.039)	(0.002)	(0.038)	(0.002)	(0.023)	(0.011)	(0.035)	(0.008)
S&P 500 max								
Median	0.989	0.997	0.019	0.006	0.730	0.922	0.463	0.191
Mean	0.970	0.994	0.040	0.010	0.710	0.918*	0.481	0.183*
SE	(0.018)	(0.001)	(0.020)	(0.002)	(0.028)	(0.009)	(0.023)	(0.017)
S&P 500 min								
Median	0.981	0.994	0.011	0.003	0.537	0.809	0.270	0.078
Mean	0.960	0.990	0.030	0.006	0.519	0.817*	0.290	0.082*
SE	(0.020)	(0.002)	(0.018)	(0.001)	(0.023)	(0.017)	(0.028)	(0.009)

Statistics are based on a vector correction model (described in Section 4) of prices estimated at a one-second resolution. Estimates are calculated for each index each day and then averaged across days. Statistics are calculated using all ETF transaction prices with their TAQ time stamps and Island transaction prices with their ITCH time stamps. The pre period is August 16, 2002, to September 20, 2002, and the post period is September 23, 2002, to October 31, 2002. An asterisk (*) represents a statistically significant difference between the pre and post period at the .01 level, based on the daily time series.

maximum and minimum information share for the Nasdaq-100 and S&P 500 in both the pre- and post-dark periods. Using all ETF trade prices with the TAQ time stamps shows E-mini dominance similar to Hasbrouck (2003), although the 14–17% information share for ETFs in the Nasdaq-100 is higher than the 5–7% in Hasbrouck (2003). The post-dark increase in the E-mini information share and decrease in the ETF information share is significant in the Nasdaq-100, with the ETF losing almost its entire role in price discovery. For the S&P 500, the ETF information share is only 3 or 4% in the pre period and declines to 1% or less after Island goes dark.

From matching Island trades to their corresponding TAQ prints, we know that there is a lag of at least a second or two between the ITCH time stamp and the TAQ time stamp. This lag may bias downward the price discovery attributable to ETFs. To test this, we redo the analysis using just the Island trades and the ITCH time stamps to calculate the ETF information share. Table 5 shows that this makes a significant difference, with ETFs commanding 60–80% of the price discovery in the pre period in the Nasdaq-100 and 30–50% in the S&P 500. These numbers indicate that Island is responsible for a substantial fraction of price discovery pre-event. When we use ITCH time stamps, ETF information shares drop by about one-half to two-thirds in the post period; price discovery is moving to the futures.[21]

When ITCH data are used, there is a large difference between maximum and minimum information shares. This implies that significant contemporaneous price discovery is occurring across the E-mini and ETF markets. This also explains why using the less informative non-Island ETF trades reduces the ETF information share. Calculating the information shares with only Island trades (details not presented), but with their TAQ time stamps shows that about one-third of the increase in ETF information shares when using the ITCH data is due to using only Island trades and the other two-thirds is due to the lagged time stamps in TAQ.[22]

Figure 4 shows the daily maximum information shares for ETF and E-mini futures prices using only the ITCH ETF transaction prices. As with the other figures in this article, Figure 4 shows that the date Island went dark, September 23, 2002, was a shift in regime. When Island goes dark, index price discovery migrates substantially from ETFs on Island to E-mini futures on Globex.

7. The Effect of Island Going Dark on Trading Costs

We know that the elimination of quote transparency on Island reduces the information available to limit order providers. This may result in higher trading costs on Island due to greater adverse selection and/or less aggressive competition in liquidity provision. However, a change in one market's transparency should not by itself directly affect trading costs in other markets. Instead, changes in other markets are most likely due to order flow migration. If liquidity externalities are important, then fragmentation of the order flow away from Island should increase the liquidity externalities in the markets that pick up order flow and decrease trading costs in those markets.

7.1 Effective and realized spreads on Island

Panel A of Figure 5 shows Island's average daily effective half-spreads — measured as the absolute difference between the transaction price and the contemporaneous bid-ask midpoint of our consolidated NBBO — by ETF

[21] One possible explanation for this is that a group of informed traders moves from trading ETFs to E-mini futures. When Island goes dark E-mini volume increases in both NQ and ES, but Table 1 shows that ETF trading volume increases in both QQQ and SPY as well. While it may be that some group of traders switched from ETFs to E-minis, the changes in trading volume do not clearly indicate it.

[22] There is a significant difference between our sample period and that of Hasbrouck (2003). He shows that E-minis continue to dominate price discovery even if they are lagged by 10–15 seconds, while we find a more developed ETF market where price discovery findings are sensitive to much smaller changes in time stamps.

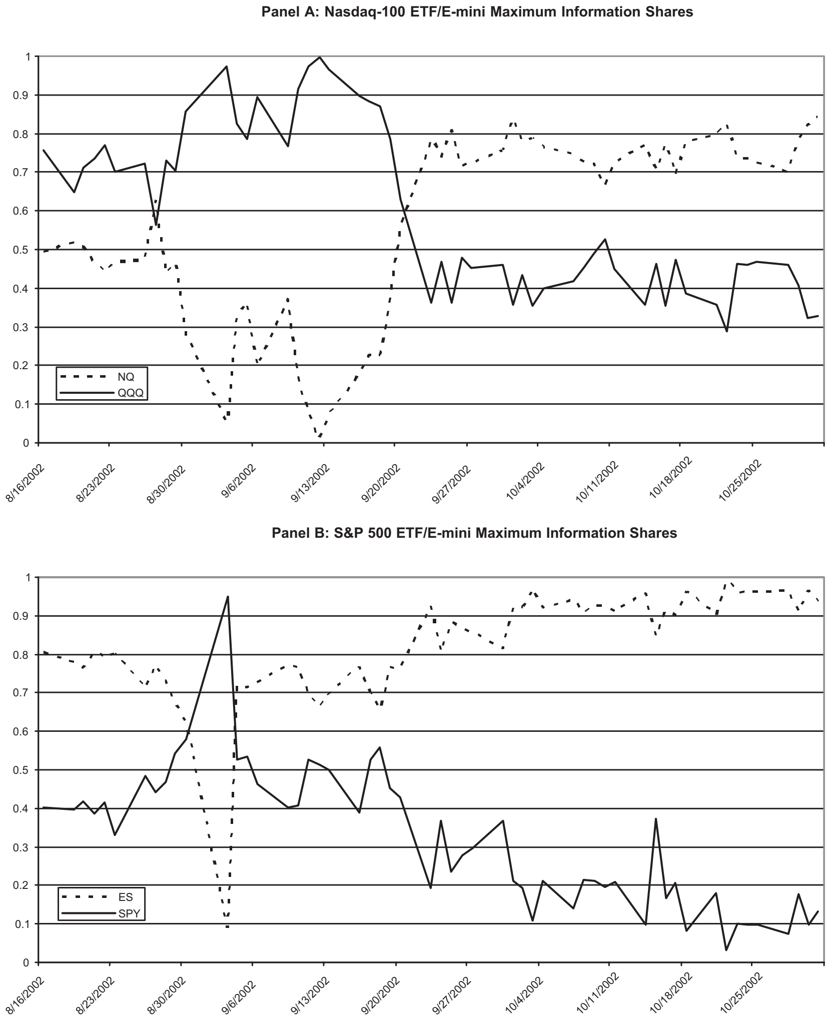


Figure 4
Daily futures and ETF information shares
This graph depicts the maximum daily information share for ETF and E-mini transaction prices. ETF prices are Island transactions using ITCH time stamps. The Nasdaq-100 index is shown in (Panel A) and the S&P 500 index is shown in (Panel B). Data extend from August 16, 2002, to October 31, 2002.

over the sample period.[23] Island's effective spreads are low, less than 2 cents for all three major ETFs and close to half a cent in QQQ. Island's effective spreads double in DIA and QQQ and go up by 50% in SPY after going dark.

[23] All trading cost measures are calculated on a share-weighted basis throughout. Daily averages are reported and used for statistical inference, assuming independence over time.

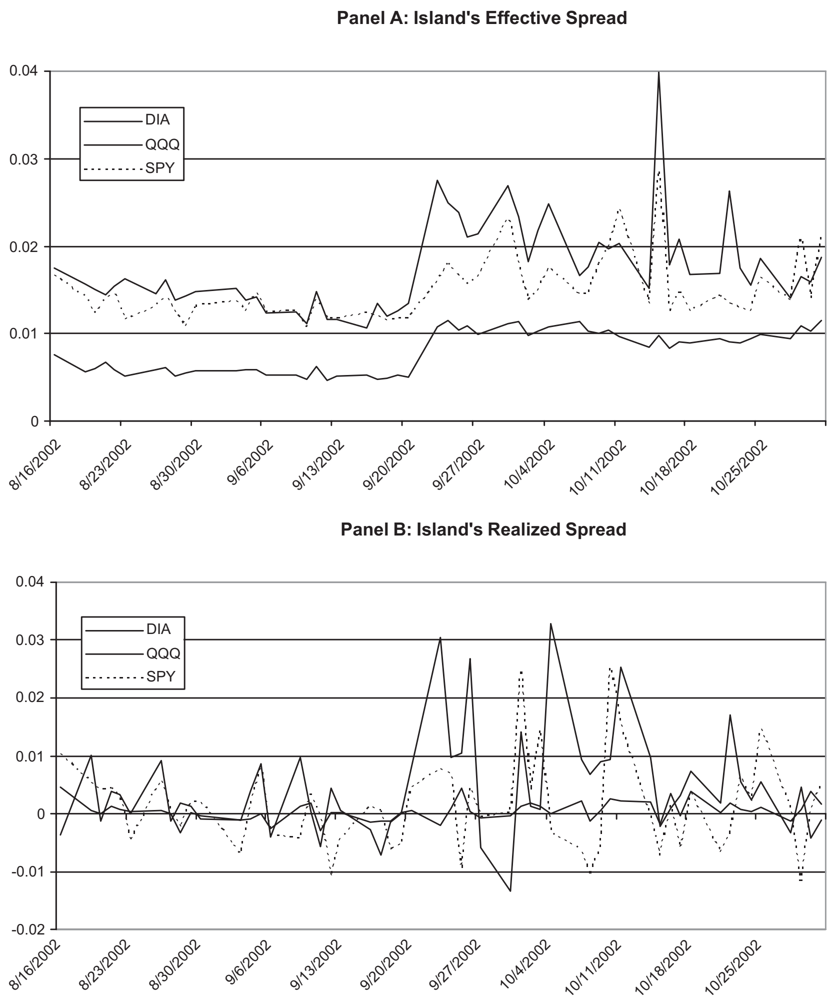


Figure 5
Daily effective and realized half-spreads on Island
For the three ETFs this graph depicts Island's daily average effective (Panel A) and realized half-spreads (Panel B) from August 16, 2002, to October 31, 2002. Daily averages are calculated on a per share basis.

If the reason for the increase in Island's effective spreads is that the reduction in transparency on Island reduces competition for liquidity provision, then profits from providing liquidity on Island should go up post-event. Realized spreads — the difference between the transaction price and the quote midpoint five minutes after the trade signed by the direction of the trade — provide an ex post measure of trading cost to the demander of liquidity and an ex post measure of profitability for the provider of liquidity. Panel B of Figure 5 shows Island's average daily realized half-spread by ETF over the sample period. The realized spreads on Island are small both before and after the ECN goes dark, but they increase after Island goes dark, indicating that competition for liquidity provision on Island declines. However, the increase in realized spread is not as obvious or large as the increase in effective spreads, suggesting that prices move more in the direction of a trade after Island goes dark. That is, going dark may have increased adverse selection on Island. We return to these issues in a moment, but first we examine the effect of Island's going dark on trading costs in other markets.

7.2 Effective and realized spreads across markets

While reducing liquidity on Island raises trading costs there, the migration of liquidity should lower trading costs in the markets where the liquidity moves. The net overall effect of rising costs on Island and falling costs elsewhere is ambiguous. To confirm that any change in spreads is not due to a market-wide change in liquidity, Figure 6 compares overall ETF spreads to spreads in similarly active individual stocks. Effective half-spreads are

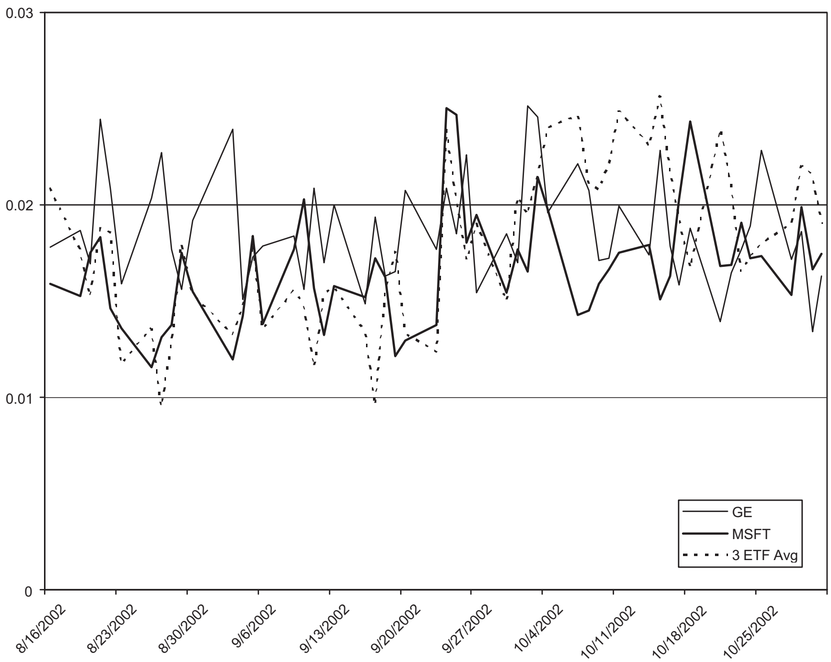


Figure 6
Daily effective half-spreads
This graphs depicts the daily average effective half-spreads from August 16, 2002, to October 31, 2002, for one of the most active NYSE-listed stocks (GE) and one of the most active Nasdaq stocks (MSFT), and for the average across the three ETFs. Daily averages are calculated on a per share basis.

calculated for the average across DIA, QQQ, and SPY, as well as two highly active stocks, General Electric (GE) and Microsoft (MSFT), which are listed on the NYSE and Nasdaq, respectively. Figure 6 shows that in the pre period, trading costs in cents per share are similar for the ETFs and the stocks. Because the average ETF share price of $70 is higher — GE is about $25 and MSFT is $50 — the ETF costs are lower in percentage terms. GE and MSFT spreads stay roughly constant throughout the sample period, while the ETFs increase when Island goes dark. The increase in overall ETF effective spreads in Figure 6 is less pronounced than the increase in Island effective spreads in Figure 5, suggesting that effective spreads off Island fall when Island goes dark.

To test the statistical significance of the increase in ETF effective spreads in Figure 6 and to examine the effects across markets, Table 6 reports average daily effective half-spreads by ETF and market for the pre and post periods. Because Island's going dark resulted in an increase in average trade size, to examine market-wide costs we classify trades by size, 1000 shares or less (small), 1001–9999 shares (medium), or 10,000 shares or more (large). The effective half-spreads are quite small, averaging between half a cent and 6 cents depending on trade size and trading venue. For DIA and QQQ, overall non-Island trading costs decrease, with most of the decreases statistically significant at the .01 level. In SPY, only ARCA-Pacific shows a statistically significant spread decline, and Instinet-3rd market effective spreads increase significantly. This increase for Instinet-3rd market is presumably due to Instinet's October 1, 2002, decision to stop trading SPY, as its market share was also exceeding the 5% trigger for the display requirements of Regulation ATS. Instinet began trading SPY again on November 1, 2002.

Prior to going dark, Island has the lowest effective spreads. Going dark raises spreads on Island and shifts trading to higher cost markets. Therefore, even though effective spreads generally fall in markets other than Island, the net effect is an increase in effective spreads. The increase is almost 10% for DIA and QQQ and over 20% in SPY. Therefore, we find no support for the Madhavan, Porter, and Weaver (2000) result that better transparency increases trading costs, although our event is not directly comparable because we study the complete loss of transparency at one of many trading venues, and significant order flow migration occurs.

The evidence indicates that going dark increases Island's realized spreads. This implies a decrease in competition for providing liquidity on Island. If this decrease in competition is due to the loss of order flow on Island, there could be a corresponding increase in competition in the markets where liquidity moves. To explore this, Table 7 reports average daily realized half-spreads by ETF, trade size, and market for the pre and post periods. As noted earlier, realized spreads on Island increase and the increase is significant in DIA and QQQ. The realized spreads on ARCA-Pacific decrease sharply in all ETFs, indicating that the shift in

Table 6
Effective half-spreads

		Overall		AMEX		Island		NYSE		ARCA-P		Regionals		Instinet-3rd	
ETF	Trade Size	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
DIA	Small	1.95	2.23*	3.61	3.35*	1.36	1.86*	3.30	2.47*	1.55	1.37*	3.15	3.04	2.11	2.12
	Medium	3.61	3.39	4.43	4.10*	1.49	2.61*	4.05	3.11*	2.09	1.61	4.13	3.87	4.04	2.98*
	Large	5.20	4.95	5.78	5.00*	1.61	3.77*	5.56	4.50*	1.42	1.20	6.27	4.39*	5.30	5.42
	Overall	3.16	3.39*	4.72	4.30*	1.39	2.07*	4.43	3.63*	1.63	1.42*	3.66	3.42	4.04	3.72
QQQ	Small	0.84	1.06*	1.35	1.20*	0.54	0.98*	1.21	1.16*	0.72	0.74	1.45	1.21*	1.11	1.11
	Medium	0.98	1.16*	1.58	1.37*	0.57	1.02*	1.34	1.33	0.84	0.76*	1.85	1.53	1.27	1.20*
	Large	2.07	2.01	1.88	1.62*	0.61	1.05*	2.32	2.15	0.96	0.76	2.13	2.05	2.22	2.25
	Overall	1.41	1.53*	1.77	1.52*	0.56	1.01*	1.97	1.85	0.78	0.75	1.81	1.58*	1.95	1.91
SPY	Small	1.73	2.09*	2.71	2.63	1.24	1.56*	2.55	2.17*	1.62	1.28*	2.83	2.86	1.81	2.27*
	Medium	2.49	2.55	3.18	3.05	1.36	1.74*	3.07	2.84*	1.78	1.34*	3.32	3.41	2.37	2.79*
	Large	4.32	5.10*	3.82	4.13	1.46	1.83*	3.48	3.32	1.18	1.70	5.35	5.28	4.76	6.00*
	Overall	3.25	3.97*	3.47	3.65	1.28	1.67*	3.35	3.14	1.68	1.32*	3.58	3.73	4.24	5.39*

Effective spreads, the absolute difference between the transaction price and the quote midpoint, are calculated (in cents) for each ETF each day and then averaged across days. Daily averages are calculated on a per share basis. The pre period is August 16, 2002, to September 20, 2002, and the post period is September 23, 2002, to October 31, 2002. Trade-sizes are 100–1000 shares (small), 1001–9999 shares (medium), and greater than or equal to 10,000 shares (large). An asterisk (*) represents a statistically significant difference between the pre and post period at the .01 level, based on the time series of daily averages.

Table 7
Realized half-spreads

ETF	Trade size	Overall		AMEX		Island		NYSE		ARCA-P		Regionals		Instinet-3rd	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
DIA	Small	0.92	1.10	2.85	2.85	0.08	0.51*	2.94	1.85*	1.46	0.30*	2.63	2.38	1.12	0.64*
	Medium	2.92	2.71	4.10	3.56	0.48	1.84	2.92	2.57	1.92	0.77	3.51	3.62	2.70	1.94
	Large	4.74	4.74	3.86	4.97	−0.76	−1.00	4.44	4.29	2.22	2.71	5.82	4.80	6.15	4.85
	Overall	2.32	2.73*	3.63	4.02	0.15	0.74*	3.42	3.34	1.52	0.45*	3.05	3.31	3.94	2.83
QQQ	Small	0.39	0.49*	1.03	0.95	0.01	0.07	0.97	0.69*	0.55	0.09*	1.13	1.08	0.67	0.54
	Medium	0.53	0.56	1.31	1.17	−0.01	0.11*	1.01	0.91	0.91	0.01*	1.58	1.65	0.94	0.44*
	Large	1.70	1.84	1.38	1.47	−0.17	0.01	2.28	1.51*	−0.08	−0.20	2.44	2.03	1.79	2.21
	Overall	0.99	1.13	1.35	1.34	−0.01	0.11*	1.85	1.28*	0.70	0.00*	1.64	1.58	1.53	1.67
SPY	Small	0.68	1.14*	2.23	2.07	0.00	0.39*	1.91	1.16*	1.04	0.34*	1.96	2.32	0.64	1.16*
	Medium	1.70	1.57	2.73	2.46	0.12	0.19	2.61	1.50*	0.60	0.53	2.70	2.93	1.42	1.68
	Large	3.41	4.57*	2.64	3.76*	0.68	0.63	2.35	2.22	−1.31	−3.50	5.42	3.77	4.04	5.71*
	Overall	2.33	3.25*	2.66	3.16*	0.03	0.24	2.30	2.05	0.75	0.40	2.93	2.78	3.45	4.99*

Realized spreads, the difference between the transaction price and the quote midpoint five minutes after the trade signed by the direction of the trade, are calculated (in cents) for each ETF each day and then averaged across days. Daily averages are calculated on a per share basis. The pre period is August 16, 2002, to September 20,2002, and the post period is September 23, 2002, to October 31, 2002. Trade sizes are 100–1000 shares (small), 1001–9999 shares (medium), and greater than or equal to 10,000 shares (large). An asterisk (*) represents a statistically significant difference between the pre and post period at the .01 level, based on the time series of daily averages.

volume increases competition in providing liquidity there. Aggregated across all markets, realized spreads increase and the effect is significant in DIA and SPY. As with effective spreads, the increase in SPY realized spreads in Instinet-3rd market is probably due to Instinet stopping trading in SPY in October.

Tables 6 and 7 demonstrate that trading costs on Island increase when it goes dark, particularly relative to other markets. The fall in costs in other markets mitigates the overall impact, and it is possible that some other market-wide effect is responsible for the overall increase in effective spreads. To account for this, we include as controls both a volatility measure and a measure of spreads in other stocks. ETF spreads should be positively related to both of these. We use the contemporaneous day's transaction price range (the day's high minus the day's low) in the given ETF as the volatility measure. To measure changes in other stocks' bid-ask spreads, we construct a market-wide liquidity factor based on the dollar volume-weighted daily average effective spread for all NYSE-listed common stocks. Table 8 regresses average daily ETF percentage effective and realized spreads for all trades, Island trades, and non-Island trades on ETF dummies, a dummy for the dark period, trade size dummies, the dark dummy interacted with the trade size dummies, volatility, and the market liquidity factor.

The first column of Table 8 shows that Island's going dark increases overall effective spreads by 0.60 basis points. The mean effective spread for the entire sample period in the regression is 4.8 basis points, implying that the effective spread increases by more than 10%. Similarly, overall realized spreads increase in both relative and absolute terms, by 0.79 basis points on an average of 3.7 basis points. That is, after controlling for differences in volatility and market-wide liquidity, overall trading costs rise and overall competitiveness of liquidity provision declines.

While we are attempting to measure changes in trading costs, it is important to acknowledge that the total expected trading costs include implicit, explicit, and opportunity costs. Because we do not have order submission data or a complete breakdown of commissions, we focus on the implicit trading costs as indicated by measures of the spread. One possible change in explicit trading costs is the liquidity fee that Island charges to demanders of liquidity that most other markets do not. Island's net fee is 0.08 cents per share, which corresponds to about 0.1 basis points for DIA and SPY and 0.3 basis points for QQQ. Table 1 shows that going dark reduces Island's market share (in shares) by 20, 14, and 9% respectively, so the overall increase in effective and realized spreads in Table 8 is more than 20 times the possible savings in liquidity fees for overall trading.

As in Tables 6 and 7, the increase in overall trading costs in Table 8 is driven by the increase in trading costs on Island, and the next two columns of Table 8 confirm the Island increase in the presence of volatility and

Table 8
Overall, Island, and non-Island spread regressions controlling for market-wide changes in liquidity

	All trades		Island trades		Non-Island trades			
Variable	Effective spread	Realized spread	Effective spread	Realized spread	Effective spread		Realized spread	
Dark	0.60	0.79	1.12	0.55	−0.46		−0.30	
	(4.93)	(3.53)	(10.31)	(3.06)	(−3.31)		(−1.07)	
Dark*Small						−0.50		−0.82
						(−3.43)		(−2.71)
Dark*Medium						−0.76		−1.14
						(−5.19)		(−3.73)
Dark*Large						−0.10		0.39
						(−0.71)		(1.29)
Medium						1.15		1.35
						(8.22)		(4.63)
Large						2.77		2.72
						(19.75)		(9.32)
DIA	1.95	1.52	0.86	0.50	3.08	1.88	2.55	1.14
	(4.55)	(1.92)	(2.24)	(0.78)	(6.26)	(5.40)	(2.61)	(1.57)
QQQ	4.38	3.07	2.24	0.14	6.06	3.93	4.93	2.49
	(10.21)	(3.86)	(5.80)	(0.22)	(12.29)	(11.28)	(5.04)	(3.44)
SPY	2.10	1.65	0.42	0.07	2.19	0.72	1.46	−0.15
	(4.89)	(2.08)	(1.08)	(0.12)	(4.44)	(2.07)	(1.49)	(−0.21)
Volatility	1.54	0.33	1.46	0.12	2.01	1.70	1.44	1.38
	(1.22)	(0.14)	(1.28)	(0.06)	(1.38)	(1.70)	(0.50)	(0.66)
Market liquidity	8.62	5.90	3.27	−0.05	9.29	8.66	8.16	8.83
	(3.72)	(1.38)	(1.57)	(−0.31)	(3.49)	(4.73)	(1.54)	(2.32)

Effective spreads, the absolute difference between the transaction price and the quote midpoint, and realized spreads, the difference between the transaction price and the quote midpoint five minutes after the trade signed by the direction of the trade, are calculated (in basis points) for each ETF each day for all trades, Island trades, and non-Island trades. Daily averages are calculated on a per share basis. The pre period is August 16, 2002, to September 20, 2002, and the post period is September 23, 2002, to October 31, 2002. The dummy variable for the dark period is Dark. Dummy variables for the medium and large trade sizes are Medium and Large. The dark period dummy interacted with trade size dummies are Dark*Small, Dark*Medium, and Dark*Large. The three dummy variables for the ETFs are DIA, QQQ, and SPY. The daily percentage difference between the highest and lowest transaction price in that ETF is volatility. The share-weighted daily average effective spread for all NYSE-listed stocks is market liquidity. *T*-statistics are given in parentheses.

market liquidity controls. The increase in effective spreads for Island trades is 1.12 basis points on an average of 2.5 basis points. Because realized spreads on Island are quite close to zero before going dark, the increase in realized spreads of 0.55 basis points is actually greater than the average realized spread of 0.3 basis points.

Tables 6 and 7 show a decrease in trading costs off Island, particularly on ARCA. The rightmost columns of Table 8 aggregate all non-Island trading together to test whether or not there is a significant decrease in trading costs in other markets when order flow leaves Island.[24] The overall decrease in effective and realized spreads for non-Island trades is

[24] The cessation of SPY trading on Instinet on October 1, 2002, complicates the measuring of non-Island trading costs in SPY. In Table 8 non-Island spreads are calculated excluding all Instinet-3rd market trades throughout the sample period. The analysis in Table 8 is qualitatively unchanged if SPY is excluded entirely.

0.46 and 0.30 basis points on means of 5.4 and 4.5 basis points. While the decrease if effective spreads is statistically significant, the fall in realized spreads for non-Island trades is not. There are several possible explanations. Realized spreads are noisier than effective spreads, which reduces statistical power. There is also a change in the composition of the order flow, as average trade sizes rise when Island goes dark. Finally, Island is dominated by relatively small trades, so we do not expect migration of these trades to affect realized spreads for large trades. To control for these, we disaggregate the trades by trade size and include trade size dummies. For both the small and medium trade sizes, the non-Island effective and realized spreads decline significantly. For large trades the changes in spreads are not significant.

Tables 6,7, and 8 demonstrate that the reduction in transparency on Island diminishes the liquidity externalities and related competition for providing liquidity on Island and increases them in the markets where order flow moves. When Island goes dark, it costs more to trade there and liquidity providers earn more. When order flow moves elsewhere, the result in other markets is lower trading costs and lower profits for providing liquidity. Because Island is the dominant market with the lowest trading costs prior to going dark, the overall effect is a loss of liquidity externalities and higher trading costs. If Island were not the dominant market, the overall impact might be quite different.

Because Boehmer and Boehmer (2003) study the ETF market about a year prior to Island going dark, it is interesting to contrast our results to theirs. They find that while the NYSE's entry results in less concentrated trading, it significantly reduces spreads in all markets. Prior to the NYSE entry the ETF market appears relatively uncompetitive, with quoted spreads of 8.3, 2.7, and 6.4 cents for DIA, QQQ, and SPY, respectively. These narrow by 20–50% with NYSE entry and narrow in all markets. These results are not inconsistent with ours. The NYSE entry improved competition, and this competitive effect most likely swamped any loss of liquidity externalities that might have occurred when trading became spread across more venues. By August 2002 quoted spreads decline even further, indicating a quite competitive market, and Island has captured significant volume.[25] Thus, Island's going dark represents a substantially different event in that robust competition exists before the change.

An alternative approach to trading cost measurement is to use SEC Rule 11Ac1-5 (Dash5) filings by various market centers. Under Dash5,

[25] Comparing our effective and realized spreads to those in Boehmer and Boehmer (2003) is somewhat difficult because they calculate spread on a trade-weighted basis and in different trade size categories. However, it appears that effective spreads decrease similarly to quoted spreads from the end of their time period to the beginning of our time period. Boehmer and Boehmer (2003) report a Nasdaq market share of 20–40% after NYSE entry whereas by our 2002 time period Island and Instinet-3rd market represent about 60% of volume in all three ETFs.

each market center must report monthly aggregate execution costs (including effective spreads and realized spreads) by stock for market orders and marketable limit orders of less than 10,000 shares. There are two main advantages to Dash5. First, there is no error in inferring whether a given trade was buyer or seller initiated. Second, execution costs are calculated based on the prevailing quotes at the time the order is received at the market center, not at the time the order is executed. In results not reported, we examine Dash5 filings from August 2002, the month before Island goes dark, and October 2002, the month after. We find roughly the same ordering and qualitative changes in trading costs for the non-ECN venues. In contrast, the ECN numbers are unreasonably large. For example, during August 2002 Island's average effective spread on marketable limits in DIA is more than 12 cents in every order size category. This is about four times the effective (whole) spread estimates in Table 6. Because we have the entire ITCH data feed, we have tried to reconstruct the Island Dash5 numbers but are unable to come anywhere close to these spread estimates. Others have encountered similar problems, and so many practitioners simply ignore the Dash5 numbers for Island and Instinet. In addition, Dash5 requires the use of the NBBO from the consolidated quote, thus excluding Island quotes in the pre-dark period. As we note above, because most price discovery occurs on Island, Dash5 trading costs are less useful if they are based on a less informative quote. Finally, Dash5 ignores the largest trades of more than 10,000 shares, which are quite common in these ETF markets. For all these reasons, we do not use Dash5 effective spread estimates in our main analysis.

8. The Effect of Island Going Dark on Private Information

Uninformed traders are likely to value transparency more than informed traders, and they would tend to migrate to transparent venues where they know the likely terms of trade in advance. If liquidity traders no longer congregate at the dominant market, this implies that those who remain on Island post-dark are more informed, resulting in higher costs of trading on Island. The expected effect on other markets is less clear. We know that the information share of non-Island markets goes up, which indicates that these other markets are picking up informed traders as well as liquidity traders. Thus, the net effect on adverse selection in other markets is ambiguous.

The simplest measure of the amount of information in trades is the difference between the gross cost of the trade (the effective spread) and an ex post measure of net cost (the realized spread), or equivalently the change in the quote midpoint five minutes after the trade signed by the trade direction, often referred to as the price impact of the trade. The more information trades contain, the more prices will move in the direction of the trade (up following purchases and down following sales), reducing the ex post trading costs.

The difference between the effective spread in Table 6 and the realized spread in Table 7 is the average daily five-minute price impact by ETF, trade size, and market for the pre and post periods. Island price impacts generally increase. This implies that liquidity traders are leaving Island more than informed traders. With the exception of ARCA-Pacific, price impacts for non-Island markets do not show many significant changes. The significant increase in the price impact of trades on ARCA-Pacific suggests that the volume moving to it from Island is informative, whereas for the other markets it is less so.

The simple price impact of a trade is biased if trades are serially correlated, and in our data, the trade direction is persistent—buys are more likely to follow buys and sells are more likely to follow sells. For example, if a series of buys occurs in rapid succession, then each buy order is credited with the aggregate price impact of the entire series, and the price impact of any individual trade is overstated. Because trades are small and frequent on Island, the potential bias in the simple price impact is possibly significant.

To isolate the price impact of an individual trade, we construct a VAR with a quote equation, an Island trade equation, and a non-Island trade equation. Define x_t^{n} to be the sum of the signed non-Island trades (+1 for buys, −1 for sells) during the five-second interval t. Similarly, define x_t^{I} to be the sum of the signed Island trades during interval t, and define r_t to be the percentage change (log return) in the quote midpoint during interval t. The VAR using 10 lags consists of three equations, two trade equations and a quote return equation:[26]

$$x_t^{\mathrm{I}} = \sum_{i=1}^{10} \varphi_i r_{t-i} + \sum_{i=1}^{10} k_i x_{t-i}^{\mathrm{I}} + \sum_{i=1}^{10} \lambda_i x_{t-i}^{\mathrm{n}} + \varepsilon_{3,t}, \tag{6}$$

$$x_t^{\mathrm{n}} = \sum_{i=1}^{10} \delta_i r_{t-i} + \sum_{i=1}^{10} \phi_i x_{t-i}^{\mathrm{I}} \sum_{i=1}^{10} \gamma_i x_{t-i}^{\mathrm{n}} + \varepsilon_{2,t} \tag{7}$$

and

$$r_t = \sum_{i=1}^{10} \alpha_i r_{t-i} + \sum_{i=1}^{10} \beta_i x_{t-i}^{\mathrm{I}} + \sum_{i=1}^{10} \zeta_i x_{t-i}^{\mathrm{n}} + \varepsilon_{1,t}. \tag{8}$$

The VAR is inverted to get the VMA representation, and impulse response functions measure the permanent price impacts from a shock to each trade equation. As discussed in Hasbrouck (1991), this method is

[26] Estimating the VAR with 3- to 20-second time intervals and five to 20 lags provides qualitatively similar results. VARs with orthogonalized residuals also provide qualitatively similar results.

Table 9
Impulse response (permanent price impact)

	DIA				QQQ				SPY			
	Non-Island		Island		Non-Island		Island		Non-Island		Island	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Median	0.086	0.104	0.192	0.285	0.047	0.116	0.239	0.381	0.046	0.056	0.109	0.144
Mean	0.091	0.103	0.185	0.276*	0.037	0.107*	0.242	0.401*	0.054	0.055	0.113	0.157*
SE	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)

The permanent price impact of a trade (in basis points) is based on the VAR/VMA model (described in Section 8) of prices estimated with 10 lags of the signed net number of Island and non-Island trades over 10-second intervals. Estimates are calculated for each ETF each day and then averaged across days. The pre period is August 16, 2002, to September 20, 2002, and the post period is September 23, 2002, to October 31, 2002. An asterisk (*) represents a statistically significant difference between the pre and post period at the .01 level, based on the daily time series of the estimated permanent price impact.

robust to price discreteness, lagged adjustment to information, and lagged adjustment to trades.

Table 9 shows the average daily permanent price impacts of Island and non-Island trades by ETF for the pre and post periods. As with the simple price impacts, the impulse response shows a significant increase in the information in Island trades, but there is no such increase in information for non-Island trades. Before September 23, 2002, the impulse response to a trade on Island is between 100 and 550% greater than the response to a non-Island trade. When Island goes dark, the impulse response to an Island trade increases by 49, 66, and 40% in DIA, QQQ, and SPY, respectively. These percentage increases are similar or somewhat higher than the simple price impact that can be calculated from the differences in effective and realized spreads in Tables 6 and 7. The price impacts in Table 9 suggest that Island appeals to traders with relatively better information about short-run price changes. Traders with this type of information are more likely to remain on Island after it goes dark.

Table 9 shows that adverse selection increases for both Island and non-Island trades in the post-dark period, although the increase in permanent price impact for non-Island trades is small and not statistically significant in DIA and SPY. To test if this is caused by a market-wide change in adverse selection in the post period, we estimate (details not reported) a VAR with trades from all markets aggregated in a single trade equation and find little difference across periods. Similarly, the difference between the coefficient on the dark period dummy in the effective and realized spread regressions represents the change in the simple price impact. For all trades, the dark coefficient is larger in the realized spread regression, implying that the overall average simple price impact falls slightly in the dark period.

At first glance, it may seem odd that adverse selection increases on Island, does not change off Island, but does not increase overall. The explanation lies in the fact that adverse selection is significantly higher on Island. When some of the less informed traders leave Island, these traders in aggregate are still more informed than the average traders in the other markets. Therefore, adverse selection can increase on Island without an increase in adverse selection overall. To see this in our results, look at SPY in Table 9. If Island had two equal-sized groups of traders in the pre period with price impacts of 0.06 and 0.16, respectively, then the average price impact for an Island trade in the pre period would be 0.11. If the group with the smaller price impact left Island when it went dark, then the price impact of an Island trade would be 0.16 in the post period. Because non-Island trades in the pre period have a price impact of about 0.06 as well, the price impact of non-Island trades would remain unchanged in the post period.

9. Island Redisplays Quotes

On Friday, October 31, 2003, Island (subsequently renamed INET ATS, Inc.) resumed the display of its limit order book in DIA, QQQ, and SPY. Island's subscribers and web site visitors can now view all displayed limit orders in these ETFs, and the top of the book is now represented in the Consolidated Quote through the Cincinnati Stock Exchange (subsequently renamed the National Stock Exchange). To ensure fast response times, Island does not send orders outbound over ITS.[27] To comply with the 3-cent de minimis exemption to the trade-through rule without routing orders elsewhere, the Island/INET system now performs price checking at the time of order entry and afterward. Upon order entry, every order is checked to ensure that it does not cross the market by more than 3 cents. If an order crosses the market by more than 3 cents, it is repriced to exactly 3 cents above the offer (for buys) or below the bid (for sells). Orders entered for display are not impacted by the trade-through rule after acceptance. However, Island cancels non-displayed orders when the NBBO crosses them by more than 3 cents.

Island reinstating its quotes would seem to be the mirror image of it going dark. Unfortunately, this is not exactly the reverse event because there were other changes in the competitive landscape in the interim. In particular, conversations with INET employees indicate that Archipelago became a more formidable competitor during the interim period. Archipelago decreased its fees, improved its technology, and discontinued subpenny trading, all of which improved its market share in these ETFs. Island's merger with Instinet may have also had an effect, as the gradual integration of the two platforms changed how orders were routed to Island and Instinet.

[27] Island claims its average response time from order submission to execution is less than one millisecond.

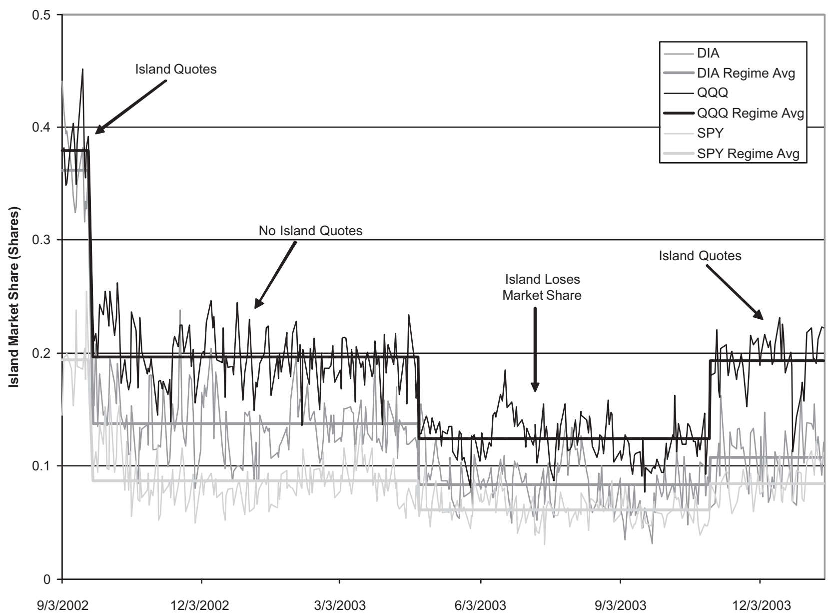


Figure 7
Island's daily market share
For the three ERFs this graph depicts Island's daily market share as a fraction of share volume from September 3, 2002, to January 4, 2004. Source: INET ATS.

As a result, trading migrates from Island to Archipelago, especially during April and May 2003. Figure 7 shows the Island market share (as a fraction of total share volume) for each ETF from September 3, 2002, through January 4, 2004. There appear to be four regimes, with break-points when Island goes dark on September 23, 2002, in late April 2003, and when Island redisplays quotes on October 31, 2003.[28] A thicker line shows Island's average market share in each regime.

As in Panel A of Figure 2, Island's market share in September 2002 is around 40% in DIA and QQQ and 20% in SPY and falls immediately when Island goes dark. Island's market share in the three ETFs remains fairly constant until late April 2003, when it falls again. When Island redisplays its quotes, its market share improves immediately but remains far below September 2002 levels. For example, in October 2003 Island's market share (in shares) is 9, 12, and 6% for DIA, QQQ, and SPY, respectively. In November 2003 these increase to 11, 18, and 8%. By October 2003, most of Island's lost market share had moved to Archipelago and Instinet—which

[28] An extensive literature search and private conversations with INET employees did not identify a single cause of the change in ETF market share in April 2003.

each have between 20 and 25% market share in each ETF—while AMEX and the NYSE have also lost market share relative to 2002. What market share Island recaptures comes from Archipelago and Instinet, but does not change the concentration of trading, as the Herfindahl index in trade and share terms remains essentially unchanged after Island redisplays its quotes.

Because Island is no longer the dominant market, the redisplay of Island quotes has less of an impact on market quality and price discovery. However, the qualitative effects of the redisplay are consistent with our prior analysis. ETF prices tend to become more efficient once Island redisplays its quotes, and trading costs (both overall and on Island) tend to go down. Because the quote reinstatement has a smaller effect, we highlight the changes in price discovery and trading costs, but do not provide a complete replication of the going dark analysis.[29] Throughout, we employ the same methodology as above and compare the 22 days before the redisplay (October 1–October 30) to the 20 days after (October 31–November 28).

9.1 Price discovery

For the second event, Table 10 provides the maximum information shares analogous to those in Table 2 (the minimum information shares are qualitatively similar). By October 2003 Archipelago is the dominant venue in terms of price discovery in DIA and SPY, with an information share around 60% in each. Island's corresponding maximum information shares are only 16 and 35%, respectively. In contrast, Island maintains its dominance in QQQ, with an 80% information share compared to Archipelago's 20%. Island's information share increases with the redisplay of its quotes, but it does not regain its dominance in DIA or SPY. Archipelago and Instinet-3rd market lose information share in all three ETFs, but the loss is statistically significant only for Instinet. The concentration of price discovery as measured by the Herfindahl index decreases in DIA and SPY, but the change is not statistically significant. However, price discovery concentration increases from 0.56 to 0.63 in QQQ. Because quote transparency returns to all three ETFs while order flow migration differs across ETFs, it may be possible to use this second event to separately identify the effects of transparency and fragmentation. We return to this issue below.

We first summarize some price efficiency measures rather than report them in tables. When Island redisplays quotes, most of the ETF quote return autocorrelations, as in Table 3, do not change significantly. The exception is QQQ, where 60-second quote return autocorrelations decline from 0.12 to 0.08, a significant change at the .05 level. Compared to futures, ETF prices

[29] The complete analysis for Island redisplaying its quotes (corresponding to Tables 1–9 and Figures 2–5) is available from the authors upon request.

Table 10
Maximum information shares within the ETF market when Island quotes are redisplayed

	AMEX		Island		NYSE		ARCA-P		Regionals		Instinet-3rd		Herfindahl	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
DIA														
Median	0.056	0.036	0.141	0.277	0.021	0.011	0.608	0.584	0.045	0.081	0.227	0.161	0.366	0.353
Mean	0.061	0.047	0.159	0.263*	0.023	0.012*	0.579	0.574	0.066	0.091	0.230	0.150*	0.361	0.350
SE	(0.008)	(0.009)	(0.015)	(0.016)	(0.004)	(0.003)	(0.024)	(0.018)	(0.012)	(0.011)	(0.016)	(0.018)	(0.017)	(0.013)
QQQ														
Median	0.002	0.005	0.829	0.863	0.014	0.011	0.172	0.147	0.009	0.020	0.103	0.056	0.553	0.628
Mean	0.006	0.008	0.792	0.859*	0.018	0.013	0.208	0.147	0.012	0.020*	0.105	0.057*	0.557	0.634*
SE	(0.002)	(0.002)	(0.022)	(0.009)	(0.005)	(0.002)	(0.030)	(0.016)	(0.002)	(0.002)	(0.009)	(0.006)	(0.025)	(0.014)
SPY														
Median	0.021	0.034	0.347	0.393	0.011	0.015	0.647	0.570	0.011	0.029	0.124	0.103	0.416	0.380
Mean	0.023	0.037*	0.345	0.385	0.015	0.018	0.616	0.576	0.014	0.030*	0.136	0.109*	0.423	0.384
SE	(0.003)	(0.006)	(0.028)	(0.020)	(0.003)	(0.003)	(0.031)	(0.020)	(0.002)	(0.004)	(0.011)	(0.007)	(0.025)	(0.018)

Statistics are based on a vector error correction model (described in Section 4) of transaction prices estimated at a one-second resolution. Estimates are calculated for each ETF each day and then averaged across days. The pre period is October 1, 2003, to October 30, 2003, and the post period is October 31, 2003, to November 28, 2003. An asterisk (*) represents a statistically significant difference between the pre and post period at the .01 level, based on the daily time series of information share estimates.

adjust more quickly when Island redisplays quotes. Using cross-autocorrelations for 15-second returns as in Panel A of Table 4, the futures price lead falls from 0.40 to 0.17 for the Nasdaq-100 and from 0.29 to 0.21 for the S&P 500. This change is similar in magnitude to the results in Table 4.

A more direct measure of the link between price efficiency in the futures and ETF markets is the intraday variability in the basis between futures and ETFs. When Island reinstates its quotes, the two markets become more tightly linked. For the Nasdaq-100, the average absolute deviation falls from 2.85 basis points while dark to 2.69 basis points post dark. Similarly, when Island redisplays quotes, the average absolute deviation for the S&P 500 falls from 1.72 to 1.61 basis points. Both of these changes are statistically significant at the .01 level, where inference is conducted using the daily time series of average absolute deviations.

Table 11 replicates some of the analysis in Table 5, studying the relative magnitude of price discovery in the ETF and futures markets. Just before Island redisplays quotes, the maximum ETF information share is 10% for the Nasdaq-100 and 7% for the S&P 500 using TAQ trade times. The ETF information shares almost double when Island redisplays its quotes.

Because there are different order flow effects across ETFs, the second event is useful in separating the effects of transparency and fragmentation. For DIA and SPY, Island's redisplay has little effect on order flow and information share concentration. However, price discovery improves in SPY, especially relative to the futures.[30] This indicates that improved

Table 11
Information shares across the ETF and futures markets when Island quotes are redisplayed

	Nasdaq-100				S&P 500			
	E-mini		ETF		E-mini		ETF	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Maximum								
Median	0.924	0.859	0.104	0.178	0.954	0.919	0.070	0.109
Mean	0.921	0.846*	0.105	0.188*	0.951	0.893*	0.071	0.135*
SE	(0.006)	(0.023)	(0.007)	(0.024)	(0.004)	(0.024)	(0.005)	(0.025)
Minimum								
Median	0.896	0.822	0.076	0.141	0.930	0.891	0.046	0.081
Mean	0.895	0.812*	0.079	0.154*	0.929	0.865*	0.049	0.107*
SE	(0.007)	(0.024)	(0.006)	(0.023)	(0.005)	(0.025)	(0.004)	(0.024)

Statistics are based on a vector error correction model (described in Section 4) of prices estimated at a one-second resolution. Estimates are calculated for each index each day and then averaged across days. Statistics are calculated using all ETF transaction prices with their TAQ time stamps. The pre period is October 1, 2003, to October 30, 2003, and the post period is October 31, 2003, to November 28, 2003. An asterisk (*) represents a statistically significant difference between the pre and post period at the .01 level, based on the daily time series.

[30] Recall that we do not have futures data corresponding to DIA, so we focus on the S&P 500 results.

quote transparency itself must be an important source of the improvement. Fragmentation also plays a role. The order flow and information share concentration effects are bigger for QQQ, and the autocorrelation evidence in particular indicates that QQQ price discovery improves the most. Thus, both increased quote transparency and increased trading concentration are associated with more efficient price discovery.

9.2 Trading costs

Given the earlier results from Island going dark, we expect trading costs on Island to fall when quotes are redisplayed. Table 12 calculates effective and realized spreads overall and by market for each ETF. For brevity we do not show spreads by trade size. Effective spreads on Island narrow substantially, with the biggest effect on QQQ. For example, DIA spreads go from 1.03 to 0.78 cents, while QQQ effective spreads decline from 0.82 to 0.36 cents. Realized spreads show a statistically significant decrease on Island for DIA and QQQ. This indicates that competition on Island increases with the redisplay of quotes.

Spreads at other venues can help distinguish the effects of transparency and fragmentation. Archipelago loses market share when Island redisplays quotes, which would suggest an increase in Archipelago spreads if order flow concentration is the only determinant of market quality. However, effective spreads on Archipelago decline significantly in all three ETFs. This indicates that improved quote transparency at one venue can reduce spreads elsewhere. These two automated platforms may be close substitutes, enhancing the cross-market effect of the improved transparency.

Interestingly, this effect does not always extend to other venues. Aggregating across all venues, overall effective half-spreads decrease from 1.11 to 0.97 cents in QQQ, but DIA spreads are unchanged at 1.67 cents, and SPY effective spreads change little, going from 1.96 to 1.92 cents. Because concentration increases in QQQ but changes little for DIA and SPY, this indicates that fragmentation is also part of the story. To summarize, in price discovery and in trading costs, both transparency and increases in concentration account for the market quality improvement when Island again displays its order book.

10. Conclusions

Recent experience with Nasdaq order handling rules [Barclay et al. (1999)], cross-listing of options contracts [Battalio, Hatch, and Jennings (2004)] and de Fontnouvelle, Fishe, and Harris (2003)], and entry in ETF trading by the NYSE [Boehmer and Boehmer (2003)] demonstrate the substantial benefits of increasing competition between trading venues. Through Regulation ATS the SEC is attempting to bring these benefits to investors. In response to the SEC enforcing the display requirements of

Table 12
Effective and realized half-spreads when Island quotes are redisplayed

	Overall		AMEX		Island		NYSE		ARCA-P		Regionals		Instinet-3rd	
ETF	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Panel A: Effective spreads														
DIA	1.67	1.67	2.46	2.51	1.03	0.78*	2.03	2.09	0.82	0.76*	1.80	1.60*	1.84	2.21*
	(0.05)	(0.06)	(0.06)	(0.09)	(0.07)	(0.02)	(0.09)	(0.10)	(0.02)	(0.01)	(0.09)	(0.05)	(0.12)	(0.14)
QQQ	1.11	0.97*	1.26	1.27	0.82	0.36*	1.16	0.99*	0.70	0.55*	1.12	1.02*	1.38	1.35
	(0.03)	(0.03)	(0.03)	(0.05)	(0.02)	(0.00)	(0.04)	(0.05)	(0.01)	(0.02)	(0.03)	(0.03)	(0.07)	(0.06)
SPY	1.96	1.92	2.00	1.75*	1.14	0.84*	1.65	1.74	0.93	0.84*	1.91	1.36*	2.59	2.80
	(0.11)	(0.12)	(0.05)	(0.06)	(0.07)	(0.01)	(0.06)	(0.07)	(0.03)	(0.02)	(0.07)	(0.05)	(0.22)	(0.30)
Panel B: Realized spreads														
DIA	1.08	1.39	2.22	2.41	0.50	−0.19*	1.45	2.19	0.26	0.19	0.98	1.89*	1.28	1.90
	(0.12)	(0.12)	(0.21)	(0.29)	(0.14)	(0.11)	(0.36)	(0.49)	(0.10)	(0.08)	(0.31)	(0.28)	(0.35)	(0.31)
QQQ	0.71	0.71	1.11	0.92	0.04	−0.05*	0.88	0.67	0.11	0.12	0.93	0.78	1.04	1.26
	(0.06)	(0.05)	(0.13)	(0.09)	(0.04)	(0.02)	(0.15)	(0.18)	(0.04)	(0.08)	(0.10)	(0.08)	(0.14)	(0.10)
SPY	1.49	1.61	1.70	1.75	0.26	0.28	1.47	1.73	0.36	0.22	1.55	0.91*	2.08	2.45
	(0.13)	(0.20)	(0.22)	(0.22)	(0.14)	(0.14)	(0.33)	(0.31)	(0.13)	(0.12)	(0.25)	(0.20)	(0.28)	(0.42)

Effective spreads, the absolute difference between the transaction price and the quote midpoint, and realized spreads, the difference between the transaction price and the quote midpoint five minutes after the trade signed by the direction of the trade, are calculated (in cents) for each ETF each day and then averaged across days. Daily averages are calculated on a per share basis. The pre period is October 1, 2003, to October 30, 2003, and the post period is October 31, 2003, to November 28, 2003. Standard errors are in parentheses. An asterisk (*) represents a statistically significant difference between the pre and post period at the .01 level, based on the time series of daily averages.

Regulation ATS, the Island ECN stopped displaying its limit order book completely in several of the highest volume ETFs beginning on September 23, 2002. Island was the dominant market in these securities, so this event has a significant effect on the ETF trading environment. Although the majority of price discovery still occurs on Island, and it remains the most active ETF trading venue after going dark, it loses substantial market share. ETF trading becomes significantly less concentrated than it was before Island went dark.

After Island goes dark, price discovery becomes less efficient both within the ETF market and between the ETF and futures markets. Substantial price discovery also moves from the ETF market to the futures market. We also find that trading costs, measured by effective and realized spreads, increase on Island and decrease on other venues. The net effect is a substantial increase in overall effective and realized spreads. This indicates that competition on and off Island is significantly altered by this event, with the provision of liquidity becoming less competitive on Island and more competitive in the markets that pick up order flow. Overall, ETF market quality worsens when Island goes dark.

The going-dark event also provides evidence on the importance of liquidity externalities and their relationship to competition within and among markets. A key finding is the decrease in realized spreads off Island. This indicates that these other markets become more competitive as they obtain more order flow. The conventional wisdom is that liquidity begets liquidity. The evidence here refines that virtuous cycle: liquidity (order flow) begets competition, which improves price discovery and reduces trading costs, which attracts additional order flow, which begets more competition. These results suggest that competition across markets is not perfect and a less concentrated trading arrangement results in weaker competition among liquidity providers. Competition among markets is imperfect because of a lack of complete transparency and integration.

When Island redisplays its quotes about a year later, it is no longer a dominant player. Nevertheless, the second event improves ETF price discovery, and it reduces trading costs on Island and also on Archipelago, a close substitute. Most importantly, there are cross-sectional differences in order flow migration and we use these to disentangle the effects of transparency and fragmentation. It turns out that both effects are important. Even when there is no change in trading concentration, market quality improves. But the improvement is bigger when trading concentration increases.

Even with the externalities associated with consolidation, a monopolistic trading arrangement is not necessarily optimal. If there is heterogeneity across traders, multiple venues can be optimal, with competition keeping them responsive to their customers. Thus, we would argue instead that virtual consolidation is better than actual consolidation.

Improving the speed and transparency of linkages between market centers may be the best approach to maintaining the benefits of competition across venues without destroying liquidity externalities.

Regulation ATS tries to accomplish some of this. In this case, however, the regulatory enforcement reduced market quality. Throughout this article, we avoid attributing the decline in market quality to either the SEC or Island, but clearly the SEC bears final responsibility for its rules and their effect on market quality. One solution is to modify Regulation ATS, but the broader questions are how and whether market centers should be linked together. The SEC recently proposed Regulation NMS to address these issues, among others.

In the lead-up to Regulation NMS, some markets, including Island, have argued that the existing linkages are so antiquated that ITS trade-through prohibitions should be repealed. However, the ability to trade through could increase agency problems between brokers and customers, and the SEC's proposal does not contemplate repeal. In an earlier version of the article, we argued that one natural possibility was to modify ITS or the ITS rules. We suggested a second tier be added to ITS for those seeking an immediate execution. With such a setup, market integration could be achieved for venues offering faster execution. Slower markets could choose to modify their internal systems to offer immediate execution for some orders or simply not participate in the faster tier of ITS. In submitting an order, investors could explicitly choose faster execution, or slower execution with the possibility of a better price. Trade-through rules would continue to apply, but orders designated for faster execution would only need to avoid trading through venues that meet the speed criteria. At first glance, this proposal might seem to disadvantage floor-based systems by relegating the NYSE and AMEX to the slower tier. However, the NYSE has an automated execution facility, Direct+, which would probably qualify for the faster ITS tier. Presumably AMEX could respond similarly.

The current version of Regulation NMS (as proposed on December 16, 2004) adopts this general approach by giving trade-through protection only to automated markets. And, as predicted, the NYSE is making fundamental changes, moving to a hybrid automated and floor-based system to ensure that it qualifies for trade-through protection.

In a previous version, we also wrote about the dangers of mandating a specific linkage mechanism. Stoll (2001) also argues that publicly-provided linkages would impair "innovation and competition," that "no market would have an incentive to improve or update the [linking] mechanism," and that ITS "is a good example of linking that has not kept pace with technology." The Reg NMS proposal attempts to respond to these concerns by requiring open, non-discriminatory access between trading venues without mandating a specific linkage.

Overall, based on the evidence here and elsewhere, we favor a regulatory arrangement that encourages greater transparency and enables vigorous competition between venues without endangering liquidity externalities. The current SEC proposal moves in this direction. But we would advocate mandatory disclosure of trade-throughs as an attractive alternative to trade-through prohibitions. When brokers make order-routing decisions, brokers would be required to disclose all trade-throughs to the customer. Without hindering technological innovation, such disclosure should help ensure that brokers get their customers the best possible execution.

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