Trading Rules, Competition for Order Flow and Market Fragmentation

Law Working Paper N° 256/2014
April 2014

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ECGI Working Paper Series in Law

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We especially wish to thank an anonymous referee and Michael Aitken, James Angel, Laura Cadella, Tarun Chordia, Carole Comerton-Forde, Hubert De Jesus, Alex Frino, Amit Goyal, Frank Hatheway, Michael McCorry, Vikram Nanda, Mahendrarajah Nimalendran, Valentyn Panchenko, Talis Putnins, Sugata Ray, Jeff Smith, Peter Swan, James Upson and seminar participants at the Capital Markets Co-operative Research Centre (CMCRC), the University of Sydney, 'The Market Microstructure Effects of the Rise of Dark Pools' conference at the University of South Australia, the 2012 FMA Doctoral Consortium and the 2013 Symposium on Financial Econometrics and Market Microstructure at Deakin University for helpful comments and suggestions. The views expressed herein are strictly those of the authors. Amy Kwan acknowledges financial support from the CMCRC and The University of Memphis for facilitating her work in the U.S. We recognize that there may be alternate views to those expressed in this research. Any errors or omissions are the responsibility of the authors alone.

Abstract

We investigate competition between traditional stock exchanges and new 'dark' trading venues using an important difference in regulatory treatment. SEC required minimum pricing increments constrain some stock spreads, causing large limit order queues. Dark pools allow some traders to by-pass existing limit order queues with minimal price improvement. Using a regression discontinuity design, we find spread constraints significantly weaken exchanges' competitiveness. As more orders migrate to dark pools, the probability of subsequent order execution there increases, raising liquidity. The ability to circumvent time priority of displayed limit orders is one cause of the rapid rise in U.S. equity market fragmentation.

Keywords: Market Fragmentation; Regression Discontinuity; Dark Pools; Trade Reporting Facility

JEL Classifications: G24, G28, G12

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Current Version: April 23 2014

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We especially wish to thank an anonymous referee and Michael Aitken, James Angel, Laura Cadella, Tarun Chordia, Carole Comerton-Forde, Hubert De Jesus, Alex Frino, Amit Goyal, Frank Hatheway, Michael McCorry, Vikram Nanda, Mahendrarajah Nimalendran, Valentyn Panchenko, Talis Putnins, Sugata Ray, Jeff Smith, Peter Swan, James Upson and seminar participants at the Capital Markets Co-operative Research Centre (CMCRC), the University of Sydney, 'The Market Microstructure Effects of the Rise of Dark Pools' conference at the University of South Australia, the 2012 FMA Doctoral Consortium and the 2013 Symposium on Financial Econometrics and Market Microstructure at Deakin University for helpful comments and suggestions. The views expressed herein are strictly those of the authors. Amy Kwan acknowledges financial support from the CMCRC and The University of Memphis for facilitating her work in the U.S. We recognize that there may be alternate views to those expressed in this research. Any errors or omissions are the responsibility of the authors alone.

1. Introduction

Competition between trading venues for order flow is changing the structure of financial markets. Dark trading venues are introducing new trading systems with potentially faster execution, greater anonymity, lower costs of trading, and more liquidity. By early 2014, more than a third of all U.S. stock trading volume takes place on dark trading venues. This reflects the rapid growth in importance of off-exchange trading systems for U.S. equity trades following adoption of Regulation National Market System (Reg NMS) in 2005. Much of this growth is concentrated in 'dark pools', which doubled in market share from about 7% in early 2008 to an average of 14.54% in 2013, according to Rosenblatt Securities. Given this rapid growth of competing trading systems, which comes at the expense of traditional stock exchanges,[1] it is important to more clearly understand the competitive advantages of both dark venues and traditional exchanges.

In this study, we investigate the effects of the minimum pricing increment regulation on trading venue competition. Imposing on exchanges a minimum pricing increment, or tick size, which is currently one penny, creates artificial constraints on the quoted bid-ask spread. When the spread is constrained, additional trading interest is reflected in a buildup of depth in the exchange's limit order book, which results in long queues at the best bid and ask prices, with time priority on each trading venue for the earliest limit order entering the book. We explore how traders can use dark pools to trade ahead of exchange displayed limit orders, while providing little or no price improvement.[2] As traders begin to migrate their order flow to dark venues, the

[1] The recent NYSE Euronext takeover by the electronic exchange ICE highlights this sea change in share trading.

[2] Dark pools operate much like traditional exchanges with the additional benefit of pre-trade opacity. Reg NMS is designed to protect top of the book quotes that are part of the National Best Bid and Offer (NBBO) from trade throughs. An exchange that receives an order must either execute it at the NBBO or forward it to a market currently

probability of trade execution there rises, which in turn attracts more trades to dark pools. This positive feedback loop in trading, initially triggered by minimum pricing requirements, is a potentially important cause of the rapid growth in dark pools.

We use regression discontinuity analysis as one method to isolate the marginal effects of the minimum pricing increment regulation on intermarket competition. Specifically, we examine whether tick size constraints give dark venues a competitive advantage over traditional stock exchanges by enabling faster executions at lower cost, as explained below. For this investigation, unlike previous studies, we use a dataset of off-exchange trading classified into five dark venues: dark electronic communication networks (DARK-ECN), block crossing networks (BLOCK), ping destinations (PING), retail market makers (INTERNALIZE) and others (OTHER).[3] Our primary focus is on trading activity on DARK-ECNs relative to traditional exchanges.

The SEC adoption of Reg NMS Rule 612 in 2005 offers an informative natural experiment. Rule 612 prohibits displaying, ranking, or accepting orders priced at more than two decimal places for stocks priced at or above $1.00 by broker-dealers and exchanges. When stock prices fall below $1.00, the required minimum pricing increment for exchange trades decreases from a penny, or $0.01, to $0.0001. Thus, there is a discrete change in the minimum spread for orders on exchanges when stock prices fluctuate around $1.00.

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displaying the NBBO unless there is an exception to SEC Rule 611, the Order Protection Rule. However, Reg NMS does not protect time priority, so dark pools can enable queue jumping off exchanges.

[3] Note that DARK-ECN and BLOCK venues constitute dark pools, while PING venues offer services that are analogous to those offered by dark pools (see SEC Concept Release No. 34-61358). We refer to retail market makers more generally as 'INTERNALIZE' as some broker-dealers that internalize orders also fall into this category.

While all trading venues must abide by the display, rank, and acceptance conditions of Rule 612, broker-dealers operating in alternative trading systems (ATSs) can offer price improvement in subpenny increments for all stocks regardless of price, which results in trades *executing* within a penny increment and potentially executing more quickly.[4] When spreads are constrained, long queues of orders at the best bids and offers are likely, creating strong incentives for some traders to shift their orders to alternative trading venues where they can trade immediately at or within the NBBO (see Buti, Rindi, Wen, and Werner, 2011). Thus, when stocks trade at prices above one dollar and exchange spreads are constrained, ATSs have a competitive advantage, which disappears at prices below one dollar, when the SEC mandated minimum pricing increment for exchanges abruptly falls to one hundredth of a penny. We propose that many traders take advantage of the faster executions and smaller spreads often available in dark pools to trade at or within the NBBO. Our initial empirical analysis uses regression discontinuity analysis around the $1.00 price threshold to test this dark pool competitive advantage.

The regression discontinuity (RD) approach is widely used in economics and is becoming common in corporate finance.[5] The central idea behind the RD method is that observations just below a cutoff point can be directly compared to observations just above the cutoff. In our application, we compare a dark venue's market share of trading in a stock priced just below $1.00 with trading in the same stock priced just above $1.00. By selecting events where stocks

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[4] Trades on exchanges can sometimes occur on the half penny through hidden limit orders that peg to the midpoint of the NBBO. In 2007 NYSE Arca was granted permission by the SEC to offer a midpoint order type that executes in half-penny increments.

[5] RD analysis is used in Rauh (2006), Chava and Roberts (2008), Roberts and Sufi (2009), Iliev (2010), and Bakke and Whited (2012). Also see the survey on methodology in corporate finance by Roberts and Whited (2012).

cross the $1.00 threshold, we can more accurately adjust for stock specific factors since each stock acts as its own control.

Our results indicate that the SEC's Minimum Pricing Increment Rule gives DARK-ECNs a competitive advantage that has persisted over time and provides one explanation for the rapid rise in dark pool market share. We find a discontinuity in the DARK-ECNs' market share of trades as the stock price rises just above $1.00; DARK-ECNs' market share of trades in stocks priced just above $1.00 is almost double that of stocks priced just below $1.00, which is robust to various measures of market share. The rise in DARK-ECN market share also corresponds to a discontinuous fall in the market share of trades of traditional exchanges.

The effects of the minimum pricing increment on intermarket competition are not limited to penny stocks. Minimum pricing increments also cause large buildups of liquidity demand for higher priced stocks constrained by tick size. When an exchange listed stock has a large order depth and a narrow spread, a newly submitted order must be priced more aggressively to gain time priority over existing orders in the order book (Buti, Rindi, and Werner, 2011a). Otherwise, the new order is relegated to the back of the limit order queue.

For a random sample of 116 stocks stratified by market capitalization, we estimate a predicted bid-ask spread for each stock in the absence of a minimum pricing increment using factors documented in the market microstructure literature to affect spreads. The strength of the spread constraint in a stock is estimated by the observed bid-ask spread minus its predicted value and has a lower bound of 0. We find that the market share of dark pools increases with the strength of the spread constraint. Using stock depth to measure the size of limit order queues, we find evidence that on trading days when stocks are severely constrained by the minimum pricing increment (exhibiting longer order queues), DARK-ECNs experience gains in market share.

One of the main disadvantages of trading in dark pools is the risk of nonexecution. Theoretical models argue for a tradeoff between potential price improvement and the probability of nonexecution (see Zhu, 2014; Ye, 2011). In these models, traders face two types of transaction costs: price impact and nonexecution risk. Informed traders have an incentive to trade in a dark pool because orders submitted to dark pools typically have a lower price impact compared to orders submitted to an exchange. This is because dark pools match orders at or within the midpoint of the exchange bid and ask prices. But, there is also no market maker to clear order imbalances, so buy and sell orders are often unbalanced, resulting in execution uncertainty. Spread constraints resulting from the minimum pricing increment encourage some traders, such as those with time sensitive information, to bypass exchanges' long limit order queues that can delay execution by submitting their orders to dark venues. As traders shift their order flow to dark venues, the risk of order nonexecution falls. Thus, there is a positive liquidity externality as traders are more likely to submit orders to dark pools when they perceive rising liquidity at this trading venue (Buti, Rindi, and Werner, 2011a). The positive feedback in trading is a potentially important driver of dark pool growth in recent years.

Our study is most closely related to theoretical papers examining the choice between exchange and dark pool trading venues. Zhu's (2014) model predicts that exchanges are more attractive to informed traders and dark pools are more attractive to uninformed traders. The rationale is that informed traders tend to cluster on one side of the market, and, thus, face higher execution risk in dark pools since they have no market makers to absorb excess order flow. On the other hand, liquidity traders are less likely to cluster on one side of the market, and, hence, have a higher probability of execution in a dark pool.

Buti, Rindi, and Werner (2011a) build a theoretical model of a limit order market where traders can choose to submit orders to the fully transparent limit order book or to a dark pool. For liquid stocks with high limit order book depth, they predict that tighter spreads in the dark pool foster price competition as traders can undercut the existing price in the limit order book, thus raising dark pool market share. When the limit order book has high depth and a narrow spread, new orders have to be more aggressively priced to gain priority over the existing orders in the book. Their model shows that dark pool market share is higher when tick size is larger. This is because with larger tick sizes, market orders on exchanges are more expensive and traders have an incentive to trade within the spread in the dark pool.

Buti, Rindi, Wen, and Werner (2011) model the intermarket competition between a public limit order book and an internalization pool dark venue, which offers a smaller tick size. Market orders sent to the public limit order book are intercepted by the internalization pool where better prices are available, resulting in a decline in liquidity demanded from the limit order book. Our study provides empirical support for many predictions of these theoretical models.

There is widespread concern that dark trading may be harming market quality. Studies investigating this issue examine the relation between dark trading, price discovery and transaction costs. Theoretical studies model an informed trader's choice between trading in a dark pool and a traditional exchange, but draw conflicting conclusions depending on the model parameters and type of private information assumed (see Hendershott and Mendelson, 2000; Buti, Rindi, and Werner, 2011a; Ye, 2011; and Zhu, 2014). Empirical studies investigate the impact of dark trading on market quality and they often arrive at conflicting assessments, depending on data quality and research methods used (see O'Hara and Ye, 2011; Weaver, 2011;

Buti, Rindi, and Werner, 2011b; Degryse, de Jong and van Kervel, 2011; Comerton-Forde and Putnins, 2012; Foley, Malinova, and Park, 2012; Gresse, 2012; and Nimalendran and Ray, 2014).

Equally important to evaluating the effects of dark market fragmentation is an understanding of why markets fragment. Markets fragment for a variety of reasons. Upstairs brokers can screen and facilitate trades for large institutional clients, who may not otherwise trade (see Seppi, 1990; Grossman, 1992). Barclay, Hendershott, and McCormick (2003) find that ECNs offer the advantages of anonymity and speed of execution that attract informed traders away from Nasdaq market makers. We show that dark pools may increase the execution probability of limit orders placed relatively late. In general, limit order traders face a tradeoff between possible improvement in execution price and the risk of nonexecution (see Foucault, 1999). With a buildup of depth on the exchange, the risk of nonexecution of new exchange orders increases. Dark pools offer selected traders the ability to bypass long queues of orders on a traditional exchange and more quickly execute their trades at or within the NBBO. Note that this trading rule that gives a competitive advantage to dark pools is exogenously determined by the market regulator. Positive liquidity externalities resulting from this rule lead to increased market fragmentation, which is detrimental to market quality when one competitor is given a regulatory advantage over another.

Our findings also have implications for market transparency. The market share of trading in transparent markets has declined rapidly since the adoption of Reg NMS. Circumventing the time priority of displayed limit orders is likely to result in a withdrawal of liquidity providers from lit exchanges. Thus, to preserve market transparency, it is important to ensure that both transparent and opaque trading venues compete on an even playing field.

2. Institutional details

2.1. Exchanges versus dark venues

Dark venues offer several advantages over traditional exchanges: specifically pre-trade transparency, preferential access and subpenny price improvement.[6] Although off-exchange liquidity can come from either alternative trading systems (ATSs) or broker-dealer internalization,[7] we discuss both sources of liquidity together since broker-dealers can offer many services analogous to those offered by ATSs.

Our study primarily focuses on the third advantage, namely the potential for subpenny price improvement. The Minimum Pricing Increment Rule (Rule 612) prohibits exchanges, alternative trading systems, and broker-dealers from displaying, ranking, or accepting a bid or offer, an order, or an indication of interest in an increment smaller than a penny for NMS stocks that are priced above $1.00. While all trading venues must abide by the display, rank, and acceptance conditions of Rule 612, broker-dealers that operate ATSs and those internalizing orders can offer price improvement in subpenny increments, resulting in trade executions within a penny. Currently, there is no requirement for trading centers to route orders to venues setting

[6] Reg ATS allows two main exemptions for alternative trading systems that execute less than 5 percent of the average daily volume in a national market system (NMS) stock during at least 4 of the 6 preceding calendar months. First, ATSs under the 5 percent threshold are exempt from providing their best priced orders for inclusion in the consolidated quotation data for that security (Rule 301(b)(3)). Second, ATS that falls below the threshold can prohibit or limit any person from accessing the services offered by the ATS (Rule 301(b)(5)).

[7] See SEC Concept Release No. 34-61358.

the NBBO quotations.[8] This allows dark venues to trade ahead of displayed limit orders with little or no price improvement.

Thus, competing venues offer a range of services that cater to different investor clienteles. For example, some dark venues choose to offer limited pre-trade transparency to a select group of investors through Indications of Interests (IOIs), which inform recipients of trading interest in the dark pool at the best quoted price or better.[9] Other venues offer payments to retail brokers for order flow deemed to be uninformed or they limit access to investors considered uninformed. Dark ECNs, which operate much like exchanges, can compete on speed or subpenny executions when spreads on the exchanges are constrained at the penny increment. We focus on intermarket competition between trading venues when spreads are constrained.

While not the focus of this study, exchange venues can compete with other exchanges for order flow. A large number of studies investigate the competition for order flow between NYSE and Nasdaq (for example, see Christie and Huang, 1994; Huang and Stoll, 1996; Bessembinder and Kaufman, 1997). Similarly, Barclay, Hendershott, and McCormick (2003) and Huang (2002) investigate competition between Nasdaq market makers and electronic communication networks, which offer advantages of anonymity and execution speed.

2.2. Venue classifications

Non-exchange trading venues have a diverse range of operational structures (O'Hara and Ye, 2011). Mittal (2008) devises a 5-way categorization of dark pools based largely on ownership structure: public crossing networks, internalization pools, ping destinations,

[8] The SEC is debating a trade-at rule that will require incoming orders to be executed with significant price improvement or be routed to trading venues displaying the NBBO.

[9] The SEC has raised concerns that IOIs could be creating a two-tiered market if they are only displayed to selected market participants (see http://www.sec.gov/news/press/2009/2009-223-fs.htm).

exchange-based pools and consortium-based pools. Zhu (2014) uses a 3-way classification based on price discovery and order composition, namely pools that match at the NBBO price midpoint, nondisplayed limit order books (DARK-ECNs) and electronic market makers. Rosenblatt Securities provides trading statistics for dark pools, although classified differently into bulge bracket, market maker, independent/agency and consortium sponsored pools.

In our dataset, trades are classified into four main types: dark ECNs (DARK-ECN), block crossing networks (BLOCK), ping destinations (PING), and retail market makers (INTERNALIZE), which are described below. Similar to Zhu (2014), these categories are based on operational rather than ownership structures. Broker-to-broker negotiated trades and trades that cannot be categorized into any of the above four main types are classified as OTHER.[10] Thus, OTHER can include some trades that belong in the other four types.[11]

DARK-ECNs are operated by broker-dealers (Reg ATS Rule 301(b)(1)). The operator may act either as an agent, by crossing institutional agency flow provided by their customers, or as a principal, by contributing liquidity through its market making arm or proprietary trading desk. Additional liquidity is provided by external liquidity partners, who are typically high frequency trading firms. DARK-ECN operators are also permitted to exclude sell side firms from accessing the pool. DARK-ECNs operate much like nondisplayed limit order books and accept both limit and market orders. Limit orders submitted to DARK-ECNs can execute ahead of displayed orders on transparent exchanges as long as the price is at or within the NBBO. Orders can also be submitted with a level of price improvement, which reduces the spread. We

[10] Bessembinder and Venkataraman (2004), Booth, Lin, Martikainen, and Tse (2002), Fong, Swan, and Madhavan (2001), Madhavan and Cheng (1997) and Smith, Turnbull, and White (2001) study broker-to-broker negotiated trades in upstairs markets.

[11] Trading platforms have many different features (Nimalendran and Ray, 2014), so classifying all trades is difficult.

conjecture that traders use DARK-ECNs when spreads are constrained on major exchanges to enable them to jump the queue of existing displayed limit orders, while providing little or no price improvement.

BLOCK venues are the most traditional form of dark pool and are modelled widely in the finance literature (see Buti, Rindi, and Werner, 2011a; Ye, 2011; Zhu, 2014). Broker-dealers operating BLOCK venues act as an agent, with no proprietary order flow provided by the operator. Typically, these venues operate as continuous crossing networks matching buy and sell orders as they arrive at a price derived from the NBBO (usually at the midpoint) and charge a commission for this trading. The main advantage of BLOCK venues is the ability to execute large orders anonymously and with minimal price impact.

PING venues accept only immediate or cancel (IOC) orders from customers. IOC orders interact directly with the operator's proprietary order flow. The operator can accept incoming IOC orders, in which case the order trades against the operator's proprietary flow, or reject the order, in which case the order is cancelled. While PING destinations can attract order flow by providing price improvement, the amount of price improvement is unknown to the trader at the time the order is submitted. In contrast to DARK-ECNs, where the operator can act either as agent or principal, PING operators always trade as principals. Because PING operators actively choose which orders they trade against, we do not expect PING destinations to compete aggressively on the basis of queue jumping.

INTERNALIZE are retail market makers who internally match order flow coming from the customers of retail brokerage firms. Retail brokerages are often affiliated with a retail market maker who may pay these retail brokers for order flow.[12] Differences in market structures indicate that off-exchange venues compete among themselves and with exchanges in many ways.

2.3. Post-trade reporting

Off-exchange trades are reported first to a trade reporting facility (TRF), which then submits a report to the consolidated trade data feeds.[13] In 2011, only two TRFs, specifically, FINRA/Nasdaq and FINRA/NYSE TRF, are active for most stocks. FINRA rules require a reporting member to submit information on trades including symbol, number of shares, trade price, and execution time.[14] For most transactions, trade reporting must be completed within 30 seconds of trade execution.[15] The trade report is then disseminated to the public via the consolidated tapes under the generic participant identifier 'D'. Trades in NYSE- and AMEX-listed stocks are reported to the Consolidated Tape System (CTS) and trades in Nasdaq-listed stocks are reported to the Unlisted Trading Privileges (UTP) trade data feed.

3. Data and sample

We identify NYSE- and Nasdaq-listed stocks that cross the $1.00 threshold at least once over the period 1 January 2010 to 31 March 2011. To ensure variability in trade prices, we select an event window of 11 days: 5 days before the cross, the day of the cross, and 5 days after the cross. This event window allows us to differentiate between stocks that experience a permanent price decline/increase from stocks that fluctuate around one dollar.

[12] See SEC Concept Release No. 34-61358. Payment for retail order flow has been studied extensively in the literature (see Easley, Kiefer, and O'Hara, 1996; Bessembinder and Kaufman, 1997; and Battalio, 1997).

[13] The Consolidated Tape Association (Nasdaq OMX) manages the collection, processing and dissemination of trade and quote data for NYSE and AMEX (Nasdaq) listed securities.

[14] http://finra.complinet.com/en/display/display_main.html?rbid=2403&element_id=4392. Note that reporting party and contra party MPIDs are removed from our dataset.

[15] http://finra.complinet.com/en/display/display_viewall.html?rbid=2403&element_id=4439&record_id=5533

There are two trade reporting facilities (TRFs) active during our sample period – FINRA/Nasdaq and FINRA/NYSE. Detailed trade data are obtained from the FINRA/Nasdaq TRF. For each transaction, there is information on the stock symbol, execution date, trade report time, trade price and volume, and a field that identifies the type of dark venue (i.e. DARK-ECN, BLOCK, PING, INTERNALIZE or OTHER) on which the trade originated. Trade reports are time stamped to 10 milliseconds and represent the time at which the trade is reported to the TRF.

Dark trades reported to the FINRA/NYSE TRF are identified through the Securities Information Processor (SIP), which consolidates trade and quote data for public dissemination to trading participants. FINRA/NYSE TRF transactions are identified with participant identifier 'D' and submarket code 'N', but without further identification of the origin of the dark trade (see Weaver, 2011). Trading venues reporting to the FINRA/NYSE TRF are likely to operate as DARK-ECNs and we classify their trades accordingly.[16]

The trade data are processed to remove erroneous and irregular trades. Only regular trades executed between 9:30:30 and 16:00:00 are included. The 30 second delay from the opening time of 09:30 is to ensure that our sample is not contaminated by the opening call auction. Regular trades are identified with condition codes '@', '@F,' and 'F'. This filter eliminates Volume Weighted Average Price (VWAP) trades as these trades do not reflect how market participants respond to intraday market conditions. For reported trades, observations with account status codes B, C, D, E, I, K, N, X are deleted as these represent trade print backs,

[16] See http://www.goldmansachs.com/media-relations/comments-and-responses/archive/market-structure-folder/alt-trading-sys.html. When we separate out NYSE-TRF reported trades from DARK-ECN (not shown) we reach the same conclusions.

cancelled, and broken trades. Daily time weighted quoted spreads are calculated from SIP NBBO files and market capitalization values are calculated from CRSP.

Table 1 reports summary statistics for our sample of 1,060 events by 173 unique companies. *Mcap* is measured on day 0 of the event window and is expressed in millions of USD. All other variables are measured on a daily basis for trading days -5 to +5. The summary statistics show that we are dealing with a sample of small cap companies: the median stock has a *Mcap* of $26.01 million and trades 193,900 shares per day. However, large differences between mean and median values indicate that the data are highly skewed. The median *Qspread* is 1.6 pennies, indicating that many stocks in the sample may be constrained by the minimum pricing increment when the trade price is above a dollar.[17]

Table 1, Panel B, reports measures of trading activity for each of the trading venue types. Again, the data are skewed, indicated by differences between mean and median *Volume* and *Ntrades* values. Counter to our expectations, we find relatively large trade sizes for INTERNALIZE. This may be because retail orders, unlike institutional orders, are not sliced into smaller trade sizes by algorithms. Further, retail trading involves a large amount of activity by day traders and high net worth investors, both of whom may generate large orders. Less sophisticated retail traders are likely to be investing in stocks via mutual funds and pension fund accounts so that these trades would reflect typical institutional trading behavior.[18]

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[17] Furthermore, for trading days with an average price equal to or above $1.00, we find that 54.5% of days have a bid-ask spread of a penny occurring over a majority of the trading day. If we include the time when the bid-ask spread is at two pennies, the percentage of trading days increases to 74.7%.

[18] It is also possible that some large broker-to-broker negotiated trades or BLOCK trades are misclassified as INTERNALIZE.

For each stock, we define *Mktshare* as the share volume occurring in the indicated venue type divided by the total share volume across all venue types. Of the dark venues, INTERNALIZE reports the highest *Mktshare*, which is consistent with the notion that retail investors are drawn to highly volatile, low priced stocks. BLOCK venues are inactive in dollar stocks, reflecting the low execution probabilities in these venues.

Table 1, Panels C and D, summarizes the venue characteristics for trading days when the average trade price is above and below $1.00, respectively. When stocks are priced above $1.00, we observe higher *Mktshare* for the dark trading venues and lower EXCH *Mktshare* compared to when the stocks are priced below $1.00. DARK-ECN shows the largest percentage change in *Mktshare*, indicating that this trading venue could offer some trading advantages at stock prices above $1.00. In the next section, we use changes in *Mktshare* to proxy for changes in trading venue competitiveness.

4. Empirical results

4.1.Trading around $1.00 threshold

Fig. 1 plots trading volume against price. All trades are classified such that $0.80 ≤ price < $0.81 are in the $0.80 price bin (*PriceBin*) and so forth. We show plots for each trading venue type for trades between $0.80 and $1.20. The vertical line in each plot indicates the $1.00 threshold at which the minimum pricing increment changes. In the absence of a discontinuity, we expect the distributions to appear as a smooth triangle, which peaks at $1.00. We expect lower trade activity at the ends of the price distribution because while all stocks cross the $1.00 threshold, not all stocks fall in price to $0.80 or rise to $1.20 over the 11 day sample period.

Our hypothesis predicts a sharp rise in volume for dark venues and a sharp decline in volume for traditional exchanges when the stock price crosses above $1.00. Consistent with our predictions, we observe an obvious decrease in EXCH volume and a positive jump in DARK-ECN and OTHER volume. We also observe a slight decrease in INTERNALIZE volume. In contrast, there are no visible discontinuities in plots for BLOCK and PING, indicating that trading in these venues does not exhibit sensitivity to the spread constraint.

To test for changes in relative competitiveness of trading venues, we investigate changes in *Mktshare* around the $1.00 threshold. Fig. 2 plots *Mktshare* against *PriceBin*. For each stock, we calculate *Mktshare* for every trading venue type at each *PriceBin* and find the cross-sectional mean. *Mktshare* is defined for a given stock as the share volume in a trading venue type divided by the total share volume in the *PriceBin* across all venues.[19] We present plots for each trading venue type for trades at prices between $0.80 and $1.20.

We predict a decline in *Mktshare* for EXCH and a rise in *Mktshare* for dark venues when the trade price crosses just above $1.00. Indeed, for EXCH (DARK-ECN) we observe a negative (positive) jump in *Mktshare* for trades just above $1.00 compared to trades just below $1.00. The plot shows a jump in DARK-ECN *Mktshare* from around 1.5% to over 2.5% when the price crosses above $1.00. We do not observe a discontinuity effect for BLOCK, PING, and INTERNALIZE, indicating that these venues are insensitive to this price threshold. There is a small discontinuity for OTHER, although the jump is less pronounced than for DARK-ECN, indicating that some trades in the OTHER category could be misclassified in terms of their trading venue. Similar plots are obtained if *Mktshare* is calculated based on number of trades, rather than share volume.

[19] To reduce the effects of outliers, we first remove the largest 1% of trades and require each trading bucket to have at least 20 trades.

Next, we perform a discontinuity design regression on a per stock basis to test the significance of jumps in *Mktshare* more formally. A major advantage of regression discontinuity (RD) designs is that only mild assumptions are required for causal inferences compared to other nonexperimental approaches (Lee and Lemieux, 2010). For RD analysis to be as credible as a randomized experiment, we only need to assume that the density function of the treatment variable is continuous across a known threshold point (Lee, 2008). Thus, causal inferences drawn from RD designs can be more credible than inferences drawn from other natural experiment designs, such as difference-in-differences or instrumental variable techniques, which require stronger assumptions to be valid. The validity of the RD experiment relies on the randomness of a stock price crossing above or below the \$1.00 threshold. We assume that traders cannot precisely manipulate the price around \$1.00, and, thus, stock prices cross the \$1.00 threshold randomly.[20]

As mentioned earlier, we create price bins by rounding each trading price *downward* to the nearest whole cent, so that all the trades with a price from \$0.80 to less than \$0.81 are in the \$0.80 price bin. We typically use a subset of these bins such that \$1.00 - $h \leq PriceBin \leq$ \$1.00 + h. For h = \$0.20 there are 41 bins ranging from \$0.80 to \$1.20. We estimate the following pooled regression around the \$1.00 threshold and bandwidth, h:

$$Mktshare_{i,k} = \beta_0 + \delta_0 DollarPrice_{i,k} + \beta_1\left(PriceBin_{i,k} - \$1.00\right) + \beta_2 DollarPrice_{i,k} \cdot (PriceBin_{i,k} - \$1.00) + \epsilon_{i,k}, \quad (1)$$

[20] We formally test this underlying assumption of our RD framework. Specifically, we test whether the number of trades across all trading venues changes around the \$1.00 threshold and find a statistically insignificant change.

where, for stock i and price bin k, $Mktshare_{i,k}$ is the share volume in the indicated trading venue divided by the total share volume across all trading venues, $DollarPrice_{i,k}$ is an indicator that takes the value of 1 if the price bin is equal to or greater than \$1.00 and a value of 0 if price bin is less than \$1.00, and ε is a random error term. δ_0 is the magnitude of the discontinuity at the \$1.00 threshold. Inferences are based on heteroskedasticity-consistent standard errors, clustered by individual stock.

Table 2, Panel A, reports regression estimates where h equals \$0.20. We find a statistically and economically significant 1.4% jump in Dark-ECN market share at the \$1.00 threshold. EXCH *Mktshare* declines by 2.2% when the stock price crosses above \$1.00.

The next step in regression discontinuity analysis is to choose the optimal bandwidth. The choice of bandwidth size is a tradeoff between precision and bias. A larger bandwidth yields more precise coefficient estimates because more observations are used. However, estimates using larger bandwidths are biased if the model specification is nonlinear. On the other hand, smaller bandwidths are more likely to produce unbiased estimates as a linear specification provides a close approximation even if the underlying model specification is nonlinear.

Table 2, Panel B, uses a bandwidth of \$0.10. Overall, the results are qualitatively similar to those in Panel A, although the precision of the estimate declines as bandwidth size declines. Specifically, we find that EXCH *Mktshare* declines while DARK-ECN *Mktshare* increases as soon as the stock price crosses above \$1.00. Our results are robust to the addition of higher order terms in the regression model and to subsamples based on listing market.

Taken together, these results show that circumventing the time priority of displayed limit orders is one way DARK-ECNs compete for order flow. Broker-dealers operating DARK-ECNs can act both as agents and principals. When the broker-dealer is acting solely as an agent, DARK-ECNs function much like hidden limit order books offering faster executions of orders.

We claim that any differences in market share on either side of the cutoff should be due only to the effects of spread constraints and the ability to trade within the NBBO. This claim relies on several identification assumptions. First, as we approach \$1.00 from either side, any differences in stock characteristics are assumed to be random, which is supported by the fact that a stock trading just above \$1.00 has similar risk characteristics as the same stock trading just below \$1.00. Second, we assume that there is no significant change in trader types around \$1.00. The SEC defines penny stocks as speculative securities of very small companies priced below \$5,[21] and thus, changes in institutional trading interest should occur at \$5.00, rather than \$1.00. Indeed, some mutual funds are restricted from investing in penny stocks. Third, it is costly to short sell stocks priced under \$5.00 per share. For stocks priced under \$5.00, FINRA Rule 4210 requires a maintenance margin, which is the greater of \$2.50 per share or 100 percent of the stock's current market value. This means that the level of short selling or institutional interest is unlikely to change around the dollar threshold.[22] As further robustness, we include controls for total number of trades and trade size. The coefficient estimates reported in Table 3 are largely

[21] http://www.sec.gov/answers/penny.htm

[22] As further tests, we compare institutional ownership for stock quarters with a closing price between \$0.80 and \$1.00 and stock quarters with a closing price between \$1.00 and \$1.20, using Form 13F filings. We do not find a significant difference between the levels of institutional ownership (p-value = 0.232), nor is there a difference in the percentage of stocks with no institutional ownership (p-value = 0.768). We also compare changes in quarterly institutional ownership for stocks that rise in price from below \$1.00 to above \$1.00 (Risers), and stocks that decline in price from above \$1.00 to below \$1.00 (Decliners). Again, we find no significant difference in the percentage change in institutional ownership for Risers and Decliners (p-value = 0.526).

consistent in magnitudes and significance with those in Table 2. Again, we find after controlling for trading characteristics, a discrete jump in DARK-ECN *Mktshare* as stock price crosses above \$1.00.[23]

4.2. First-differenced analysis

We repeat the prior experiment using a first-differenced approach based on daily data. In our experiment, first-differencing has some advantages over regression discontinuity analysis. First, matching quotes and trades using intraday data introduces some timing issues, which can be overcome by using daily values. Estimating the average daily bid-ask spread allows us to compare stocks that on average are more spread constrained with stocks that are less spread constrained. Using daily data, we can also identify stocks that show a permanent change in price (i.e., remain above or below \$1.00 for an extended period of time).

For the daily analysis, we estimate the following first-differenced equation:

$$\Delta Mktshare_i = \delta_0 + \beta_1 \Delta \log(Ntrades_i) + \beta_2 \Delta + \beta_3 \Delta Volatility_i + \epsilon_i, \qquad (2)$$

where $Mktshare_i$ is the daily share volume for each trading venue type divided by the total share volume for pricing event i, $Ntrades_i$ is the daily number of trades, $Tradesize_i$ is the average daily trade size, and $Volatility_i$ is the difference between the log of the intraday high ask price and the log of the intraday low bid price. All variables are first measured on a daily basis. Next, we average the daily variables across the 5 trading days -5 to -1 in the pre-event window and the 5 trading days 0 to +4 in the post-event window.

Our analysis consists of two types of pricing events, events with prices that cross above \$1.00 and events with prices that cross below \$1.00. To account for the two scenarios, we

[23] In results shown in the Internet Appendix, we also find an increase in dark trading when a stock undergoes a reverse split from a pre-split price of less than \$1.00.

subtract the mean value for the trading days where the closing price is below \$1.00 from the mean value for the trading days where it is above \$1.00, which ensures consistency in our interpretation of δ_0. This means that we subtract the post-event mean from the pre-event mean for events where the stock price crosses below the \$1.00 threshold.

Table 4, Panel A, shows the results for the full sample of events. Consistent with our main analysis, we find that δ_0 is negative and significant for EXCH, indicating that traditional exchanges lose market share on days when the stock trades above \$1.00. In contrast, δ_0 is positive and significant for DARK-ECN and OTHER, meaning that these trading venue types are more competitive when the price is above \$1.00.

The full sample results presented in Table 4, Panel A, use all event windows formed over the sample period. However, there could be overlapping events if stocks fluctuate around \$1.00 over short time periods. Additionally, we expect the strongest results when stock prices are constrained. We form subsamples for single events and constrained single events. The single event subsample contains events where a stock crosses the \$1.00 threshold once within the event window. The constrained single events subsample also requires that *Qspread* is below 1.1 pennies on trading days when the average daily stock price is above \$1.00.[24]

Table 4, Panels B and C, present the results for the single event subsample and constrained single event subsample, respectively. Supporting our predictions, we find that δ_0 is consistently positive and significant for DARK-ECN and OTHER, and negative and significant for EXCH across all panels. Importantly, the economic significance of our findings is largest for our subsample of constrained single events. This finding supports our prediction that DARK-

[24] We use 1.1 pennies rather than 1 penny to allow for minimal variations in *Qspread* throughout the trading day. Otherwise, a single trade that walked the book could eliminate that stock from our sample.

ECNs are most beneficial to traders when exchange trading is constrained by minimum pricing increments as these venues can offer traders narrower tick sizes and higher time priorities.

5. Additional robustness and alternative explanations

We detail additional robustness tests and alternative explanations for our findings. For brevity, we report the tabulated results in the online Internet Appendix.

5.1. Placebo tests for alternative price thresholds

In U.S. markets, there is only one regulatory mandated change to the minimum pricing increment in our sample period, which occurs at $1.00. Thus, we should not observe a sharp decrease in EXCH trading corresponding to a sharp increase in DARK-ECN trading for other price cutoff points. We test for trading activity discontinuities around several alternative price thresholds, namely at $2.00, $5.00 and $50.00.[25] We fail to observe a similar drop in EXCH trading at these alternative price cutoffs, further supporting our hypothesis.

5.2. Constrained and unconstrained stocks

If the spread constraint is an important factor driving trading venue competition, we should see the strongest results in stocks that are tightly constrained by the minimum pricing increment. We divide our sample into constrained and unconstrained stocks. A constrained stock has a *Qspread* below 1.1 pennies on days with an average trade price above $1.00 and experiences a reduction in the spread when the average trade price falls below $1.00. This means that the spreads of these stocks are tightly constrained when the price is above $1.00 and becomes unconstrained when the price falls below $1.00. On the other hand, the minimum pricing increment should have no impact on trading in unconstrained stocks, which we define as

[25] For this analysis, we use TAQ data, which contains a generic identifier for TRF reported trades. TRF represent aggregate trades of DARK-ECN, BLOCK, PING, INTERNALIZE and OTHER.

a stock that has a *Qspread* above 1.1 pennies, regardless of price. We expect the changes in *Mktshare* to only hold for the constrained stock sample and the evidence supports our hypothesis. Specifically, we find for the constrained stocks that EXCH *Mktshare* significantly falls and DARK-ECN *Mktshare* significantly rises when the price crosses above the dollar threshold. For the unconstrained stock sample these *Mktshare* changes are statistically insignificant.

5.3. Alternative measures of market share

In our main results, we calculate *Mktshare* for every stock and price bin combination and test for regression discontinuities using pooled OLS regressions with stock fixed effects. Our summary statistics in Table 1 show that the data are highly skewed. As a robustness test, we construct volume-weighted measures of market share. For each *PriceBin*, we sum the share volume for each trading venue type and divide by the total share volume within the price bin. The results show a significant decrease (increase) in EXCH (DARK-ECN) market share when the stock price crosses above the $1.00 threshold.

Our results so far are based on market shares expressed in share volumes to capture trading venue competition. As an alternative measure of trading venue competition, we calculate market shares based on the number of trades, which captures a trader's decision on whether to trade in a particular venue, in contrast to trading volume, which captures a trader's decision on how much to trade. Again, we obtain qualitatively similar results to our main findings.

5.4. Logit regressions

An alternative methodology for testing trading venue competitiveness is to estimate the likelihood of a trade taking place in a particular trading venue type. We estimate a multinomial logit model where the dependent variable, *Venue*, takes a value from 0 to 5, depending on the venue type in which the trade is executed, where 0 to 5 represents EXCH, DARK-ECN, BLOCK, PING, INTERNALIZE and OTHER, respectively. The independent variable is $DollarPrice$, an indicator that takes a value of 1 if the trade price is at or above \$1.00 and we also control for $Tradesize$ and $Price$. Our results are consistent with a migration of order flow away from EXCH when trading is constrained by minimum pricing increments to take advantage of queue jumping on DARK-ECNs. Furthermore, splitting trades into those that are constrained (i.e. prevailing bid-ask spread is at the minimum pricing increment) and unconstrained, we find that the results are driven by our sample of constrained trades.

5.5. Changes in a stock's risk (e.g. probability of delisting)

Stocks that fall below the \$1.00 price level and remain at this level for a period of time risk being delisted from the exchange.[26] In our regression discontinuity design, we assume that a stock trading at \$1.01 has essentially the same risk of delisting as a stock trading at \$0.99. To further investigate the validity of this assumption, we split our events into stocks that fluctuate around \$1.00 and stocks that consistently remain below (above) \$1.00 for five consecutive days and then stay above (below) \$1.00 for the next five days. We label these stocks permanent risers and decliners. While permanent risers (decliners) could experience a decrease (increase) in the probability of delisting, stocks persistently fluctuating around \$1.00 are likely to experience a negligible change in their probability of delisting. The results show that a rise in delisting risk is unlikely to be driving our results. Specifically, we find that across the three subsamples, *DollarPrice* is positive and significant for DARK-ECN and negative and significant for EXCH,

[26] Under Nasdaq listing rules, stocks are subject to delisting if the bid price remains below \$1.00 for 30 consecutive days. The company then has a period of 180 calendar days to re-achieve compliance (see Equity Rules Section 5810 Notification of deficiency by the Listing Qualifications Department).

which is consistent with the results from our main tests.

As an additional test, we identify NYSE- and Nasdaq-listed stocks having a minimum closing daily price between $0.80 and $1.00 (62 stocks) and $1.00 and $1.20 (64 stocks) during 2010. We then compare the number of exchange delistings that occur over the subsequent two year period for the paired samples. Using a Chi-square test, we find no significant difference in the number of delistings between the two samples (p-value = 0.203). This is further evidence that the risk of stock delisting is not a key factor driving our results.

5.6. Maker-taker fee structure

Our results are unlikely to be driven by changes in exchange maker-taker fee structures around the $1.00 threshold. Across the main exchanges, the rebate for posting liquidity falls when a stock price drops below $1.00, discouraging liquidity providers from providing liquidity on the exchange, which should reduce exchange order flow. At prices immediately below the $1.00 threshold, there is also an increase in taker fees on the NYSE and Nasdaq for absorbing liquidity. For example, the taker fee on the NYSE is $0.0025 per share for stocks priced at or above $1.00 and rises to 0.3% for stocks priced below $1.00. Thus, when a stock price falls below $1.00, this fee structure should lead order flow to migrate away from more expensive exchange venues. Our empirical evidence shows just the opposite effect; we find order flow migrates to the exchange when the stock is priced below $1.00. In contrast, dark pools vary by venue and by investors in their pricing policies, though some venues make no change in fees around the $1.00 threshold (Harris, 2013).[27]

[27] Dark pools typically have lower fees than exchanges. Some midsized dark pools may have a change in fee structures for selected clients around the $1.00 threshold but this reduction in dark pool fees is likely to be more than offset by a reduction in exchange rebates as the stock price falls below $1.00.

6. Further tests of venue competitiveness

The prior evidence indicates that dark venues have an advantage when the NBBO is constrained by minimum pricing requirements. While the change in minimum pricing increment provides a very clear exogenous event to test changes in dark venue market share, the behaviour of dollar stocks may not be representative of the universe of stocks. To address this issue, we next study higher priced stocks and consider whether dark venues are used more actively when trading is constrained. If queue jumping is a significant competitive factor, then we expect to find a larger dark pool market share when the bid-ask spread is constrained at its penny minimum and the best bid and ask prices have sizable depth.

Due to data availability, the initial sample comprises the 120 stocks used in the stratified sample analyzed by Brogaard, Hendershott, and Riordan (2013), which is chosen to include a wide range of market capitalizations and liquidity levels. Our sample period is 3 January 2011 to 31 March 2011. Three stocks are delisted before the sample period (BARE, CHTT, and KTII) and another stock is delisted during the sample period (BW), leaving a final sample of 116 stocks, which are presented in the Internet Appendix. Of these stocks, 59 are listed on the NYSE and 57 on Nasdaq. We obtain trade and quote data for this sample following the same procedures used for the dollar stock sample. Table 5 presents summary statistics for our stratified sample of stocks and shows that it contains a broad mix of spread constrained and unconstrained stocks. Compared to our dollar stock sample, we observe in our higher priced stocks larger EXCH, DARK-ECN and BLOCK market shares, reflecting greater levels of institutional interest in these stocks.[28] INTERNALIZE market share, which comprises mostly retail trading interest, is much lower for the higher priced stocks, which is consistent with the Barber and Odean (2000) finding that households invest more heavily in small, high-beta stocks.

As discussed earlier, dark venues are likely to be more attractive for highly spread constrained stocks. Our analysis proceeds in two stages. In the first stage, we estimate a daily measure of the spread constraint (*Constrain*) based on stock and trade characteristics and in the second stage, we relate *Constrain* to *Mktshare*. In the cross section, we expect relatively more trading in dark venues for stocks more constrained by the minimum pricing requirement, while in time series, we expect relatively more dark venue trading on more spread constrained days.

We estimate a predicted spread for each sample stock using factors shown in the literature to influence spreads including price, trade activity, and return volatility (see McInish and Wood, 1992; Stoll, 2000; Bessembinder, 2003). This is formalized in the statistical model below.

$$Ln(Qspread_{it}) = \beta_0 + \beta_1 \text{Ln}(Mcap_{it}) + \beta_2 \text{Ln}(Price_{it}) + \beta_3 \text{Ln}(Ntrades_{it}) + \beta_4 \text{Ln}(Tradesize_{it}) + \beta_5 Volatility_{it} + \epsilon_i, \quad (3)$$

where $Qspread_{it}$ is the daily time-weighted quoted spread, $Mcap_{it}$ is the stock's market capitalization and $Volatility_{it}$ is the natural log of the stock's daily high price divided by daily low price, measured over our three month sample period.[29] We estimate the equation using Tobit and OLS regressions. The Tobit regression model is bounded below at -4.6, which represents the natural log of the minimum allowed spread (0.01). The OLS regression uses all stock days that

[28] In contrast, PING venues, also used by institutional traders, show a fall in market share, possibly due to more competition by BLOCK and DARK-ECN venues as the probability of trade execution in these venues increases for larger, more liquid stocks.

[29] These results remain unchanged if the first-stage model is estimated out-of-sample using two months of data prior to the sample period.

are unconstrained. Based on prior studies, we expect $Qspread_{it}$ to be positively correlated with $Price_{it}$ and $Volatility_{it}$ and negatively correlated with $Mcap_{it}$ and $Ntrades_{it}$. In untabulated results, we find that the two statistical models have good explanatory power (*pseudo-*R^2 = 0.68; R^2 = 0.81) and have estimates consistent with the findings of prior studies.

Next, we use the estimated coefficients and the observed daily control variable levels to predict $Ln(\widehat{Qspread_{it}})$ for the sample of 116 stocks on each day over our sample period. Using this predicted spread, we estimate the size of the spread constraint as: [30]

$$Constrain_{it} = \begin{cases} Ln(Qspread_{it}) - Ln(\widehat{Qspread_{it}}) & for\ Ln(Qspread_{it}) > Ln(\widehat{Qspread_{it}}) \\ 0 & Otherwise \end{cases}. \quad (4)$$

Positive values of $Constrain_{it}$ indicate that trading in the stock is spread constrained as the observed spread exceeds its predicted value. This recognizes that stocks trading at a spread wider than a penny can also be constrained by minimum tick size requirements. For example, if the true spread is $0.015 but the observed spread is $0.02, trading in this stock is also considered spread constrained. In these circumstances, traders have the incentive to migrate their order flow to dark venues to benefit from the tighter pricing grids. Table 5, Panel C, reports summary statistics for *Constrain*. For an observed quoted spread of a penny, the mean *Constrain* corresponds to a predicted spread of 0.69 pennies (ln(0.01) – ln(0.0069) = 0.371).

We hypothesize that dark venues are more attractive to traders as stocks become more spread constrained. Table 6 estimates the relation between *Constrain* and dark venue *Mktshare* in the cross-section. Given that we only have three consecutive months of trading data, there is

[30] Truncating *Constrain* at 0 may introduce a bias into our estimates. We repeat our analysis without truncating the data and find similar results. In our second stage regressions, we use *Constrain* as an independent variable. Because Constrain is derived from the residuals, rather than predictions, from the first-stage model, it is unnecessary to adjust our standard errors in the second stage regression (see Pagan, 1984, Model 4).

unlikely to be much intra-stock variation. For our cross-sectional tests, we average *Mktshare* and *Constrain* over the sample period so that we have one observation per stock. Consistent with our hypothesis, we find that *Constrain* is correlated with lower *Mktshare* on exchange trading venues and higher *Mktshare* in all dark venues except for BLOCK. Panels A and B show similar results, so in the subsequent regressions we only present results based on Tobit estimates of *Constrain*.

Despite limited time-series variation in the data, Table 7 estimates in time series the relation between *Constrain* and dark venue *Mktshare*. In Table 7, Panel A, we establish that for trading days when a stock is more spread constrained, dark venue market share is higher, after controlling for stock and day fixed effects. We find a higher market share in DARK-ECN, BLOCK and OTHER venues. But, the largest difference is within DARK-ECN venues. Our regression results show an average market share of 3.0% for unconstrained stocks (i.e. *Constrain* = 0), which rises by 1.3% when the actual spread is constrained at its mean level (i.e. 0.371). Given average daily turnover of $190 million, this translates to a mean $2.53 million ($190 x 1.3%) shift in daily order flow from traditional exchanges to DARK-ECN venues for our sample.

In Table 7, Panels B and C, we investigate the relation between limit order book queue size and dark venue market share for spread constrained and unconstrained stocks.[31] If long queues exist in the limit order book, a trader must submit a more aggressive quote to execute sooner. Hence, there are strong incentives to shift order flow towards dark venues where trades can occur at or within the NBBO. We use the depth at the best bid and ask prices on the exchange to measure queue size. According to the queue jumping hypothesis, we expect DARK-

[31] Additional robustness tests shown in the Internet Appendix divide the sample into constrained and unconstrained stocks based on the average time-weighted quoted spread. We find that the results of our analysis of higher priced stocks, presented in Tables 6 and 7, are driven by the subset of stocks that are tightly constrained by the minimum pricing increment, which is consistent with our earlier findings based on stocks crossing the $1.00 threshold.

ECN market share to increase with depth. This relation is expected to be strongest for stocks with spreads severely constrained by the minimum pricing increments.

For our 116 stocks, we calculate the average value of *Constrain* over the sample period. Stocks that exhibit a *Constrain* value in the top (bottom) quartile of stocks when ranked from highest to lowest are treated as constrained (unconstrained). Consistent with the queue jumping hypothesis, we see in Table 7, Panel B1, that dark trading venues (DARK-ECN, PING and OTHER) are more attractive and EXCH venues are less attractive on days with longer order queues for constrained stocks. Thus, when spreads are tight and there is a large buildup of depth, traders take advantage of DARK-ECN venues to avoid the long queues on the exchange. In contrast, for unconstrained stocks where spreads are wider and queues are relatively smaller, we see in Table 7, Panel B2, that there is no positive relation between depth and DARK-ECN market share.[32]

Taken together, our results provide further support for the conclusion that dark pools offer have a competitive advantage over traditional exchanges when trading is spread constrained. Specifically, we observe a movement of order flow towards dark trading venues when trading on the exchange becomes more constrained by the minimum pricing increment.

[32] Stock splits can also have a large impact on stock liquidity. For stocks priced above a dollar, reverse stock splits typically decrease the strength of a stock's spread constraint, while forward splits increase the strength of the spread constraint. In results reported in the Internet Appendix, we find a large drop in dark venue market share following large reverse stock splits that reduce the effectiveness of a stock's minimum spread constraint and a rise in dark venue market share following large splits, which raises the binding nature of the minimum spread.

7. Conclusion

U.S. stock exchanges have experienced a dramatic loss of market share in recent years, while 'dark' trading venues have experienced a remarkable gain in market share, accounting for over a third of total shares traded in early 2013. We investigate whether this rapid growth in dark pool trading is in part driven by Securities and Exchange Commission imposed trading rule differences across trading venues that yield significant competitive advantages. We show that differential market regulation has given dark pools an important economic advantage, leading to more dark pool trading at the expense of traditional exchanges. One clear result is increased market fragmentation of the U.S. stock markets.

Dark trading venues compete for order flow in a variety of ways. We use regression discontinuity analysis to isolate the effects of spread constraints on competition for order flow between exchanges and dark pools. The change in minimum pricing increment from $0.01 to $0.0001 when stock prices fall below $1.00 provides a clean natural experiment to test whether spread constraints provide some trading venues with an important competitive advantage. When spreads on traditional exchanges are constrained by minimum pricing increments, traders have incentives to migrate towards dark trading venues to bypass long queues of displayed limit orders on exchanges, and, thus, reduce their risk of delayed execution, while experiencing lower risk of non-execution in the dark pool.

Consistent with the prediction that dark pools successfully attract order flow when the NBBO is constrained, we find that when stocks trade just above $1.00, DARK-ECN market share rises to approximately double that observed when the same stock is trading just below $1.00. Further, the rise in DARK-ECN market share corresponds to a fall in traditional exchanges' market share. Importantly, these conclusions continue to hold when we examine a stratified sample of higher priced stocks that trade at the minimum penny spread, or trade at spreads of two or three pennies when predicted spreads are less.

As more order flow migrates to dark pools because of the minimum tick size regulations, the probability of execution in dark pools rises, which encourages more traders to submit their orders to these trading venues. This positive feedback loop in liquidity, initially triggered by minimum pricing requirements, is another important factor driving order flow off the exchanges and encouraging the rapid growth of dark venues.

Our study shows that there is strong demand for tighter tick sizes in many highly liquid stocks. Our analysis indicates that price discovery is taking place in off-exchange venues when bid-ask spreads on traditional exchanges are tick-size constrained by government regulation. Over time, the ability to queue jump on some dark venues can discourage traders from providing liquidity to traditional stock exchanges, resulting in wider spreads and less depth. Future work should consider the impact of imposing differential trading venue regulation on market fragmentation, exchange market quality, and how reduced transparency affects capital markets.

These concerns are reflected in the rapidly changing regulatory landscape for dark trading, with regulators in Australia and Canada recently requiring a minimum level of price improvement for dark trades in an effort to level the playing field between dark pools and traditional exchanges.[33] However, queue jumping and subpenny pricing are only two of the ways

[33] In 2012, the Investment Industry Regulatory Organization of Canada imposed a new regulation requiring dark orders to provide one full tick of price improvement relative to the prevailing NBBO, or a half tick if trading is already constrained to one tick. Foley and Putnins (2013) find a sharp reduction in dark trading when Canadian regulators introduced minimum price improvement requirements for dark pools on 15 October 2012. From 26 May 2013, the Australian Securities and Investments Commission requires that trades which are exempt from the pre-

trading venues compete for order flow. Other features, such as pre-trade opacity and exemptions from fair access requirements, also influence competitive positions of trading venues. For regulation to evolve, we need a deeper understanding of how these trading rule differences affect intermarket competition, both individually and in combination, their impact on the competitive positions of alternative trading venues and their ultimate effects on the quality of capital markets.

trade transparency requirement be carried out with meaningful price improvement of at least one price step or be at the midpoint of the NBBO.

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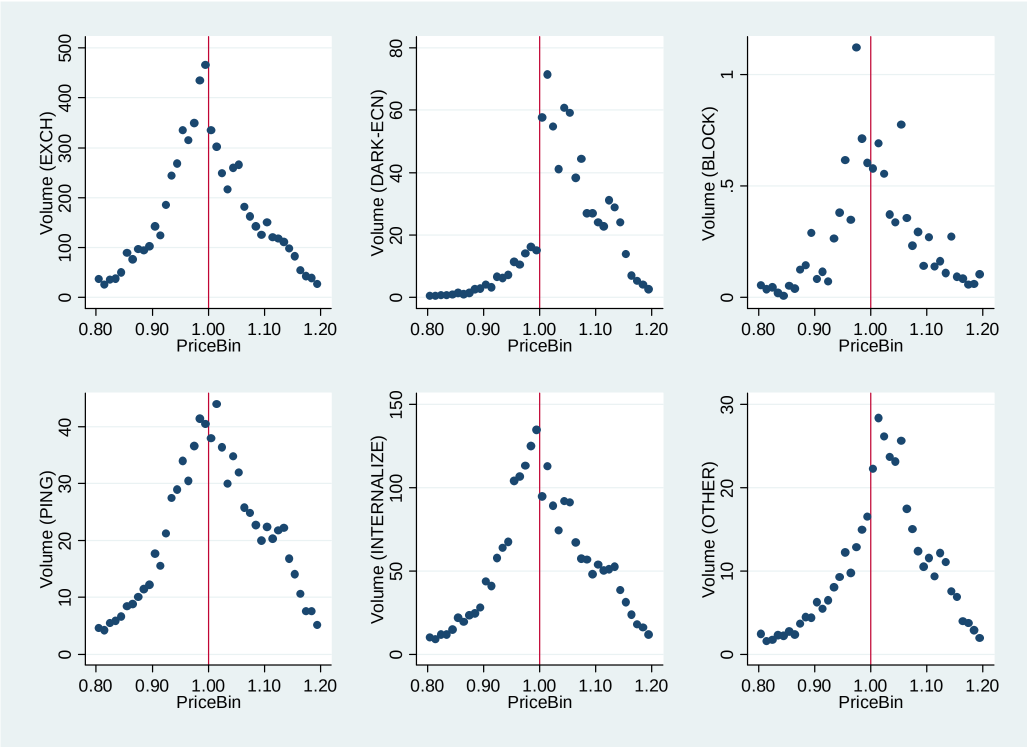

Fig. 1. Regression discontinuity plots: *Volume* against *PriceBin*.
This figure plots *Volume* against *PriceBin* for each trading venue type. For each penny price bin from \$0.80 to \$1.20, we find the total number of shares traded (*Volume* in millions). The vertical line in each plot indicates the \$1.00 price level.

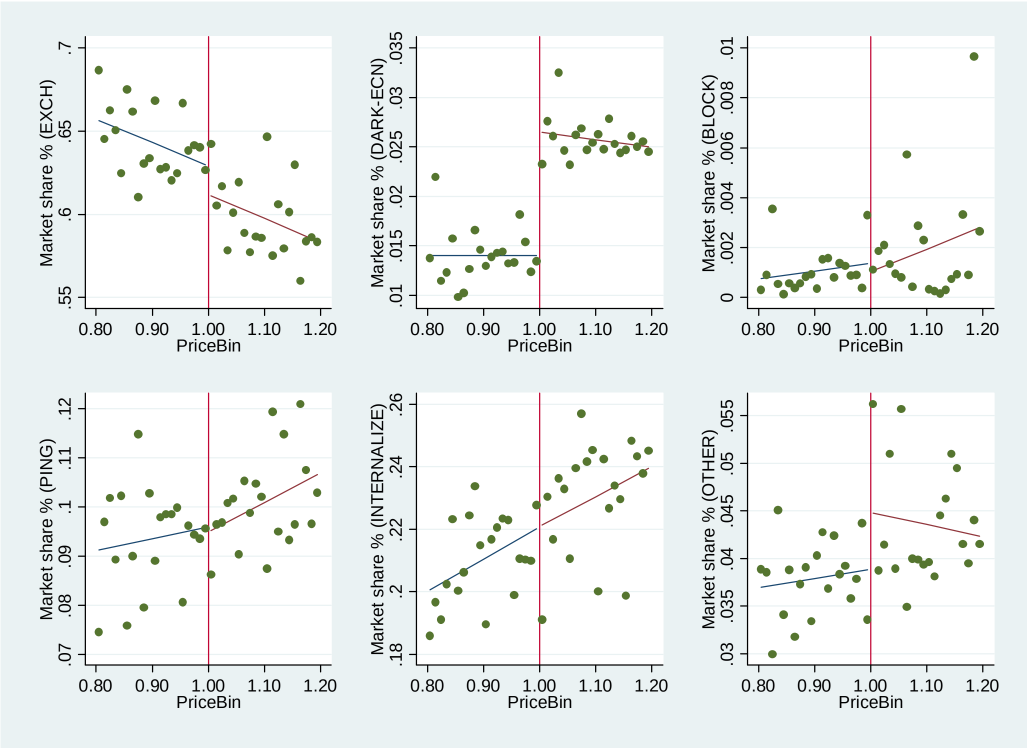

Fig. 2. Regression discontinuity plots: *Mktshare* against *PriceBin*.
This figure plots *Mktshare* against *PriceBin* for each trading venue type. For each penny price bin from \$0.80 to \$1.20, we find the *Mktshare* for each stock, where *Mktshare* is calculated as the number of shares traded for the trading venue type divided by the total number of shares traded in the price bin. These plots show the mean *Mktshare* for each *PriceBin* across all stocks. The vertical line in each plot indicates the \$1.00 price level.

Table 1

Summary statistics

Table 1 reports statistics for the 173 stocks in our sample. For the period 1 January 2010 to 31 May 2011, we select stocks that move from having a closing price below $1.00 to above $1.00 and vice versa. We analyze trade data for the 11-day event window from day -5 to +5 (without replacement), where day 0 is the first day the closing price of the stock is above or below $1.00. Panel A and Panels B-D report statistics for stock and venue characteristics, respectively. Panel C (Panel D) reports venue characteristics for trading days where the average daily trade price is equal to or above $1.00 (below $1.00). *MCap* is the stock's market capitalization on day 0 in millions. If a stock crosses the $1.00 threshold more than once, we average *MCap* across all events for the stock. *Price* is the average trade price in dollars. *Qspread* is the time-weighted average difference between the NBBO prices in dollars. *Volume* is the average daily volume in 10,000s. *Ntrades* is the average daily number of transactions. *TradeSize* is the average daily trade size. *Mktshare* is the number of trades for the indicated venue type divided by the total number of trades across all venue types.

Panel A: Stock characteristics						
	Obs	Mean	Std. Dev.	Q1	Median	Q3
Mcap (mil.)	171	93.60	343.4	13.29	26.01	57.38
Price	173	1.195	1.292	0.988	1.016	1.065
Qspread	173	0.030	0.036	0.009	0.016	0.035
Volume (10,000s)	173	210.3	870.6	4.679	19.39	72.81
Ntrades	173	1,981	5,240	83.38	351.4	1,362
TradeSize	173	623.6	446.6	457.4	571.9	640.2

	Volume		Ntrades		TradeSize		Mktshare	
	Mean	Med	Mean	Med	Mean	Med	Mean	Med
Panel B: Venue characteristics (All stocks)								
EXCH	118.9	11.41	1,433	254.9	502.9	465.1	62.08	60.38
DARK-ECN	8.490	0.346	124.2	9.103	341.7	322.5	1.948	1.730
BLOCK	0.300	0.002	2.560	0.071	2,266	467.7	0.143	0.009
PING	17.72	1.534	156.4	23.40	736.5	717.1	9.459	9.472
INTERNALIZE	55.32	3.323	191.5	33.71	1,323	1,145	22.34	22.36
OTHER	9.561	0.725	73.18	10.63	1,117	715.0	4.032	3.918
Panel C: Venue characteristics (Price ≥ $1.00)								
EXCH	122.3	12.85	1,589	325.8	503.5	447.3	60.35	59.20
DARK-ECN	14.40	0.468	210.2	14.02	333.9	305.3	2.506	1.905
BLOCK	0.362	0.000	3.084	0.000	3,103	403.6	0.159	0.000
PING	20.71	2.152	201.6	31.33	717.0	719.0	9.762	9.586
INTERNALIZE	52.68	3.748	265.1	42.93	1,196	1,097	23.00	23.36
OTHER	11.08	1.102	98.20	12.38	1,562	672.3	4.230	4.026

Table 1—Continued

Panel D: Venue characteristics (Price < $1.00)								
EXCH	123.6	8.931	1,374	183.0	515.9	475.4	64.19	62.20
DARK-ECN	3.378	0.182	48.78	5.11	360.9	342.6	1.375	1.221
BLOCK	0.247	0.000	2.159	0.000	1,766	429.2	0.137	0.000
PING	16.38	1.289	125.47	19.85	777.4	707.6	9.105	9.267
INTERNALIZE	61.75	2.602	129.13	22.17	1,490	1,235	21.34	21.95
OTHER	8.453	0.556	52.23	8.71	1,081	650.1	3.851	3.597

Table 2
Regression discontinuity tests – Market share

Table 2 reports regression discontinuity tests for market share. For the period 1 January 2010 to 31 May 2011, we select stocks that move from having a closing price below \$1.00 to above \$1.00 and vice versa. We analyze trade data for the 11-day event window from day -5 to +5, where day 0 is the first day the closing price of the stock is either above or below \$1.00. Trades are grouped into penny price bins and classified into six types: exchange, EXCH; DARK-ECN; block crossing networks, BLOCK; ping destinations, PING; retail market makers, INTERNALIZE, and those not previously classified, OTHER. The results are based on the following linear regression around the \$1.00 threshold:

$$Mktshare_{i,k} = \beta_0 + \delta_0 DollarPrice_{i,k} + \beta_1 \left(PriceBin_{i,k} - \$1.00\right) + \beta_2 DollarPrice_{i,k} \cdot (PriceBin_{i,k} - \$1.00) + \epsilon_{i,k}$$

where $Mktshare_{i,k}$ is the number of shares traded for the indicated trading venue type divided by the total number of shares traded, for stock i and price bin k. k represents the lower bound of the price bin. For example, trades priced at \$1.00 to \$1.0099 are contained in $PriceBin_{i,1.00}$. $DollarPrice_{i,k}$ is an indicator variable equal to 1 if k is equal to or greater than \$1.00. Panels A and B report results for trading between \$0.80 and \$1.20, and \$0.90 and \$1.10, respectively. All regressions control for stock fixed effects. We report heteroskedasticity-robust standard errors clustered by stock in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
			Panel A: \$0.80 ≤ PriceBin ≤ \$1.20			
DollarPrice	-2.244***	1.389***	-0.010	0.102	0.396	0.367
	(0.77)	(0.24)	(0.05)	(0.40)	(0.61)	(0.28)
PriceBin - \$1.00	-12.697*	-0.092	0.294	2.897	9.445*	0.153
	(7.25)	(1.34)	(0.48)	(3.63)	(5.68)	(2.23)
DollarPrice × (PriceBin - \$1.00)	2.785	-1.091	-0.186	1.263	-2.520	-0.251
	(10.04)	(1.83)	(0.58)	(4.53)	(7.88)	(2.97)
Constant	62.303***	0.533***	0.106**	11.691***	20.055***	5.312***
	(0.69)	(0.15)	(0.04)	(0.33)	(0.54)	(0.24)
Observations	4,861	4,861	4,861	4,861	4,861	4,861
Adjusted R-squared	0.232	0.259	0.014	0.125	0.217	0.087

Table 2—Continued

	Panel B: \$0.90 ≤ PriceBin ≤ \$1.10					
DollarPrice	-2.412**	1.167***	-0.007	0.040	0.488	0.724**
	(0.93)	(0.26)	(0.07)	(0.45)	(0.72)	(0.31)
PriceBin - \$1.00	-14.500	1.728	1.071	2.891	11.805	-2.995
	(9.95)	(1.97)	(0.65)	(5.93)	(9.09)	(4.00)
DollarPrice × (PriceBin - \$1.00)	8.899	-0.872	-1.773*	0.601	-4.138	-2.717
	(14.13)	(3.32)	(1.06)	(7.91)	(12.00)	(5.75)
Constant	60.090***	0.967***	0.214***	12.645***	19.975***	6.110***
	(0.63)	(0.15)	(0.04)	(0.36)	(0.54)	(0.23)
Observations	3,037	3,037	3,037	3,037	3,037	3,037
Adjusted R-squared	0.295	0.272	0.023	0.154	0.275	0.125

Table 3

Regression discontinuity tests with additional controls – Market share

Table 3 reports regression discontinuity tests for market share, after controlling for *Ntrades* and *Tradesize*. For the period 1 January 2010 to 31 May 2011, we select stocks that move from having a closing price below \$1.00 to above \$1.00 and vice versa. We analyze trade data for the 11-day event window from day -5 to +5, where day 0 is the first day the closing price of the stock is above or below \$1.00. Trades are grouped into penny price bins and classified into six types: exchange, EXCH; DARK-ECN; block crossing networks, BLOCK; ping destinations, PING; retail market makers, INTERNALIZE, and those not previously classified, OTHER. We estimate the following linear regression:

$$Mktshare_{ik} = \beta_0 + \delta_0 DollarPrice_{i,k} + \beta_1\left(PriceBin_{i,k} - \$1.00\right) + \beta_2 DollarPrice_{i,k} \cdot (PriceBin_{i,k} - \$1.00) + \beta_3 \text{Ln}(Ntrades_{ik}) + \beta_4 \text{Ln}(TradeSize_{ik}) + \epsilon_{ik}$$

where $Mktshare_{i,k}$ is the number of shares traded for the indicated trading venue type divided by the total number of shares traded, for stock i and price bin k. k represents the lower bound of the price bin. For example, trades priced at \$1.00 to \$1.0099 are contained in $PriceBin_{i,1.00}$. $DollarPrice_{i,k}$ is an indicator variable equal to 1 if k is equal to or greater than \$1.00. $Ntrades_{ik}$ and $TradeSize_{ik}$ are the total number of trades and average transaction size across all trading venues, respectively. Panels A and B report results for trading between \$0.80 and \$1.20, and \$0.90 and \$1.10, respectively. All regressions control for stock fixed effects. We report heteroskedasticity-robust standard errors clustered by stock in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
			Panel A: \$0.80 ≤ PriceBin ≤ \$1.20			
DollarPrice	-1.971**	1.492***	-0.017	0.108	0.057	0.331
	(0.78)	(0.24)	(0.05)	(0.39)	(0.62)	(0.28)
PriceBin - \$1.00	-21.035***	-1.726	0.002	7.769**	15.479***	-0.488
	(7.47)	(1.35)	(0.45)	(3.58)	(5.71)	(2.37)
DollarPrice × (PriceBin - \$1.00)	17.419	1.543	0.405	-8.067	-12.444	1.144
	(10.93)	(1.84)	(0.57)	(5.01)	(8.21)	(3.21)
Log(Ntrades)	1.215***	0.211***	0.052***	-0.801***	-0.802***	0.125
	(0.37)	(0.07)	(0.02)	(0.19)	(0.26)	(0.10)
Log(TradeSize)	-2.466***	-0.870***	0.042	0.151	2.887***	0.256
	(0.93)	(0.21)	(0.04)	(0.53)	(0.71)	(0.31)
Constant	69.494***	4.550***	-0.507	16.186***	7.417	2.859
	(6.92)	(1.51)	(0.32)	(3.84)	(5.20)	(2.15)
Observations	4,861	4,861	4,861	4,861	4,861	4,861
Adjusted R-squared	0.241	0.272	0.016	0.132	0.228	0.087

Table 3—Continued

Panel B: $0.90 ≤ PriceBin ≤ $1.10						
DollarPrice	-2.331**	1.217***	-0.016	0.123	0.373	0.633**
	(0.95)	(0.27)	(0.06)	(0.44)	(0.75)	(0.32)
PriceBin - $1.00	-24.001**	0.591	0.813	8.785	18.642**	-4.830
	(9.79)	(1.90)	(0.64)	(6.04)	(8.68)	(3.97)
DollarPrice × (PriceBin - $1.00)	27.044*	1.051	-1.212	-11.480	-16.849	1.447
	(14.67)	(3.23)	(1.02)	(8.34)	(11.94)	(5.87)
Log(Ntrades)	1.966***	0.236**	0.053**	-1.218***	-1.416***	0.379***
	(0.48)	(0.11)	(0.02)	(0.22)	(0.38)	(0.11)
Log(TradeSize)	-1.514	-0.496	0.045	-0.097	1.526**	0.536
	(1.01)	(0.31)	(0.04)	(0.67)	(0.76)	(0.45)
Constant	56.470***	2.512	-0.427	21.406***	19.836***	0.202
	(7.52)	(2.33)	(0.30)	(4.54)	(5.96)	(3.20)
Observations	3,037	3,037	3,037	3,037	3,037	3,037
Adjusted R-squared	0.307	0.279	0.024	0.167	0.286	0.128

Table 4
First-differenced estimation – Market share

Table 4 reports the results from first-differenced regressions for changes in market share. For the period 1 January 2010 to 31 May 2011, we select stocks that move from having a closing price below \$1.00 to above \$1.00 and vice versa. We analyze trade data for the 11-day event window from day -5 to +5, where day 0 is the first day the closing price of the stock is above or below \$1.00. Trades are grouped into penny price bins and classified into six types: exchange, EXCH; DARK-ECN; block crossing networks, BLOCK; ping destinations, PING; retail market makers, INTERNALIZE, and those not previously classified as OTHER. The results are based on the following first-differenced regression:

$$\Delta Mktshare_i = \delta_0 + \beta_1 \Delta \text{Ln}(Ntrades_i) + \beta_2 \Delta \text{Ln}\,(Tradesize_i) + \beta_3 \Delta Volatility_i + \epsilon_i$$

where $Mktshare_i$ is the daily number of shares traded in the trading venue type divided by the total number of shares traded for event i, $Ntrades_i$ is the daily number of trades, $Tradesize_i$ is the average daily trade size, and $Volatility_i$ is the difference between the log of the intraday high price and the log of the intraday low price. All variables are first measured on a daily basis then averaged across the 5 trading days in the pre-event window and the 5 trading days in the post-event window (including the cross day). For each variable, we subtract the mean value for the trading days below \$1.00 from the mean of the trading days above \$1.00. Panels A–C present results for *All events*, *Single events* and *Constrained single events*, respectively. *Single events* contains only events where the stock is consecutively above (below) \$1.00 from day -5 to -1 and then below (above) \$1.00 from day 0 to +4. *Constrained single events* is a subset of *Single events* and contains events where the time-weighted quoted spread is below \$0.011 on days when the time-weighted average bid-ask midpoint (*Midpoint*) is above \$1.00 and below \$0.01 on days when *Midpoint* is below \$1.00. We report heteroskedasticity-robust standard errors clustered by stock in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
			Panel A: All events			
δ_0	-1.781***	0.433***	0.027	0.032	0.411	0.217*
	(0.30)	(0.08)	(0.03)	(0.18)	(0.36)	(0.12)
ΔNtrades	3.345***	0.075	0.032	-0.331	-2.556***	-0.132
	(0.59)	(0.08)	(0.03)	(0.20)	(0.52)	(0.16)
ΔTradeSize	-0.716	-0.444	-0.017	0.007	-0.039	0.156
	(1.69)	(0.29)	(0.04)	(0.43)	(1.00)	(0.78)
ΔVolatility	-7.412**	-0.978	-0.605	-4.394*	1.033	1.721
	(3.34)	(0.77)	(0.51)	(2.35)	(3.50)	(1.76)
Observations	1,060	1,060	1,060	1,060	1,060	1,060
Adjusted R-squared	0.051	0.009	0.001	0.010	0.034	-0.001

Table 4—Continued

			Panel B: Single events			
δ_0	-4.896***	1.104***	0.110	0.890**	2.735***	1.090***
	(0.68)	(0.24)	(0.10)	(0.38)	(0.79)	(0.30)
ΔNtrades	3.485***	0.029	0.037	-0.617	-2.879***	-0.453*
	(0.71)	(0.16)	(0.06)	(0.37)	(0.72)	(0.27)
ΔTradeSize	-1.643	-1.131	-0.058	0.895	-0.383	1.690**
	(2.19)	(0.81)	(0.12)	(0.95)	(1.80)	(0.69)
ΔVolatility	-8.274***	-0.406	-0.568	-2.444*	5.270	2.702
	(2.91)	(1.08)	(0.69)	(1.45)	(4.62)	(1.77)
Observations	279	279	279	279	279	279
Adjusted R-squared	0.094	0.021	-0.008	0.018	0.048	0.025
			Panel C: Constrained single events			
δ_0	-5.417***	2.146***	0.021	1.104*	0.910	1.310***
	(0.90)	(0.60)	(0.21)	(0.55)	(1.61)	(0.35)
ΔNtrades	4.188***	0.793*	0.035	-1.144	-3.722**	-0.098
	(1.39)	(0.40)	(0.10)	(0.70)	(1.62)	(0.29)
ΔTradeSize	-5.875**	-3.506	0.161	0.607	12.420**	-1.518
	(2.74)	(2.52)	(0.46)	(0.96)	(5.03)	(0.97)
ΔVolatility	-12.252**	-4.152	-0.292	4.733	2.753	4.001***
	(6.04)	(2.80)	(0.67)	(2.89)	(8.38)	(1.25)
Observations	82	82	82	82	82	82
Adjusted R-squared	0.172	0.123	-0.037	0.003	0.140	0.021

Table 5

Summary statistics – Higher priced stocks

Table 5 reports statistics for a stratified sample of 116 stocks trading in the first 3 months of 2011. Panel A and B report statistics for stock and venue characteristics, respectively. *Mcap* is the stock's market capitalization on 3 January 2011 in billions and *Volatility* is the standard deviation of daily returns over the sample period. All remaining variables are measured daily. *Price* is the average trade price in dollars. *Qspread* is the time-weighted average difference between the NBBO prices in dollars. *Volume* is the average number of shares traded in millions. *Ntrades* is the average number of transactions in thousands. *Tradesize* is the average daily trade size in number of shares. *Mktshare* is the number of shares traded on a specific trading venue as a percentage of the total number of shares traded across all trading venues. Trades are classified into six trading venue types: exchange, EXCH; DARK-ECN; block crossing networks, BLOCK; ping destinations, PING; retail market makers, INTERNALIZE, and those not previously classified as OTHER. Panel C reports statistics for *Constrain*, which is calculated as the difference between the natural log of the observed spread and the natural log of the predicted spread.

	Mean	Std.Dev	Q1	Median	Q3
Panel A: Stock characteristics					
Mcap (bil.)	20.72	44.95	0.644	2.256	20.77
Price	46.44	70.04	16.26	30.79	54.35
Qspread	0.038	0.071	0.011	0.020	0.035
Volume (mil.)	4.526	10.76	0.221	0.449	3.518
Ntrades (000s)	17.46	28.60	1.347	3.298	22.07
Tradesize	170.6	62.77	137.5	152.4	171.6

Panel B: Venue characteristics

	Volume (10,000s)		Ntrades (100s)		TradeSize		Mktshare	
	Mean	Med	Mean	Med	Mean	Med	Mean	Med
EXCH	313.2	33.92	135.7	28.33	153.4	134.0	74.29	74.47
DARK-ECN	41.53	3.592	16.35	2.25	168.3	154.5	7.845	7.760
BLOCK	5.140	1.593	0.90	0.34	618.2	516.6	2.317	1.885
PING	21.76	1.827	7.20	1.12	222.3	211.5	4.538	4.420
INTERNALIZE	40.32	2.457	7.32	0.80	334.0	299.5	5.777	4.863
OTHER	30.62	3.018	7.18	0.90	365.6	301.4	5.545	5.167

Panel C: Constrain

	Mean	Std.Dev	Q1	Median	Q3
Constrain	0.371	0.457	0.077	0.316	0.576

Table 6

Relation between *Mktshare* and *Constrain* in the cross-section

Table 6 reports the cross-sectional regression of *Mktshare* against *Constrain* for the stocks described in Table 5. The dependent variable is *Mktshare*, the number of shares traded for the indicated trading venue type divided by the total number of shares traded, expressed as a percentage. *Constrain* is a daily measure of the severity of the spread constraint. We estimate *Constrain* using a Tobit regression model in Panel A and OLS in Panel B (see text for the estimation equation). For each stock, *Mktshare* and *Constrain* are averaged over all the days in our sample period. We report heteroskedasticity-robust standard errors in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
Panel A: Constrain estimated via Tobit regressions						
Constrain	-6.177***	1.992***	-1.539***	0.433*	3.536***	1.532***
	(0.88)	(0.34)	(0.23)	(0.23)	(0.71)	(0.47)
Constant	76.331***	7.185***	2.827***	4.395***	4.608***	5.038***
	(0.55)	(0.19)	(0.21)	(0.16)	(0.27)	(0.24)
Observations	116	116	116	116	116	116
Adj. R-squared	0.217	0.156	0.119	0.007	0.193	0.078
Panel B: Constrain estimated via OLS regressions						
Constrain	-6.728***	2.142***	-1.667***	0.448*	3.952***	1.653***
	(1.00)	(0.39)	(0.26)	(0.25)	(0.80)	(0.54)
Constant	76.397***	7.173***	2.840***	4.398***	4.538***	5.026***
	(0.56)	(0.19)	(0.21)	(0.16)	(0.28)	(0.25)
Observations	116	116	116	116	116	116
Adj. R-squared	0.205	0.143	0.111	0.004	0.192	0.072

Table 7

Relation between *Mktshare*, *Constrain* and *Depth* in the time-series

Table 7 reports the regression of *Mktshare* against *Constrain* for the stocks described in Table 5. The dependent variable is *Mktshare*, the number of shares traded for the indicated trading venue type divided by the total number of shares traded, expressed as a percentage. *Constrain* is a daily measure of the severity of the spread constraint (see text for the construction of *Constrain*). In Panel B, we regress *Mktshare* against *Log(Depth)*, where *Depth* is the daily time-weighted depth across all exchange venues at the prevailing best bid and ask prices. Panel B1 (Panel B2) contains a subset of constrained (unconstrained) stocks based on the stock's average value of *Constrain*. A stock is considered constrained (unconstrained) if *Constrain* is in the top (bottom) quartile of *Constrain* across all stocks in the sample. All regressions control for stock and day fixed effects. Standard errors clustered by stock and day are in parentheses (Thompson, 2011). ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
			Panel A: Baseline regression			
Constrain	-4.167***	3.595***	1.372**	-0.932***	-2.574***	2.614***
	(1.46)	(0.80)	(0.65)	(0.32)	(0.47)	(0.75)
Constant	70.723***	2.995***	-1.398*	6.962***	19.041***	1.903**
	(1.89)	(1.07)	(0.81)	(0.44)	(0.59)	(0.91)
Observations	7,192	7,175	6,583	7,171	7,174	7,131
Adj. R-squared	0.285	0.163	0.106	0.286	0.586	0.116

Table 7—Continued

Panel B: *Mktshare* and *Log(depth)*						
Panel B1: Constrained stocks						
Log(depth)	-2.515***	0.719*	-0.138	0.687***	0.114	1.315***
	(0.72)	(0.38)	(0.19)	(0.22)	(0.28)	(0.35)
Log(mcap)	5.944*	-2.034	-1.781**	-0.047	1.283	-3.957**
	(3.10)	(1.46)	(0.77)	(0.91)	(1.19)	(1.82)
Log(price)	11.967**	-3.601	-2.546*	1.146	-1.943	-4.330
	(5.30)	(2.48)	(1.49)	(1.41)	(2.02)	(2.89)
Volatility	-13.866	-11.310	4.565	-4.480	16.134**	1.675
	(29.66)	(15.26)	(4.27)	(4.97)	(6.66)	(12.70)
Constant	-80.986	57.219	50.808**	-3.745	-10.162	96.985*
	(86.47)	(40.48)	(22.80)	(24.38)	(33.11)	(50.04)
Observations	1,798	1,786	1,725	1,789	1,788	1,783
Adj. R-squared	0.458	0.327	0.079	0.379	0.726	0.199
Panel B2: Unconstrained stocks						
Log(depth)	0.981	-1.037**	-0.775	-0.524***	-0.020	1.200
	(0.86)	(0.52)	(0.59)	(0.06)	(0.12)	(0.78)
Log(mcap)	-2.357	0.913	3.035	-1.285**	-0.932	1.231
	(6.47)	(2.39)	(2.89)	(0.55)	(0.92)	(2.39)
Log(price)	6.067	-1.987	-7.259	2.157*	1.664	-2.261
	(14.32)	(5.32)	(6.39)	(1.22)	(2.05)	(5.25)
Volatility	-9.698	-4.424	-0.229	-1.443	14.581***	-3.942
	(26.34)	(10.86)	(10.32)	(3.79)	(4.30)	(14.03)
Constant	99.583	1.476	-35.598	30.779***	21.880	-24.560
	(98.44)	(35.86)	(43.47)	(8.34)	(13.87)	(37.44)
Observations	2,480	2,480	2,277	2,476	2,478	2,474
Adj. R-squared	0.202	0.094	0.087	0.295	0.229	0.112

INTERNET APPENDIX

for

"**Trading rules, competition for order flow and market fragmentation**"

April 23 2014

This Internet Appendix, which comprises three sections, reports on and tabulates myriad robustness tests for the results reported in the main body of the paper.

Section 1 corresponds to our analysis of the dollar stock sample, i.e., stocks that fall below or rise above the $1 price threshold. Fig. A1 presents plots of EXCH activity for alternative price thresholds at $2, $5, and $50 and Table A1 reports the corresponding regression discontinuity (RD) results. Table A2 presents RD results for subsamples of constrained and unconstrained stocks. Tables A3 to A5 report RD results for alternative market share measures. Table A6 reports our multinomial logistic results and Table A7 shows RD results for different event types. Table A8 summarizes maker-taker pricing schemes across the major exchanges.

Section 2 provides additional information and results for our stratified sample of 116 stocks. Table A9 provides the ticker symbol and their respective market capitalizations. Tables A10 and A11 presents results based on subsamples of constrained and unconstrained stocks.

Section 3 provides details on our stock split analysis, which examines changes to dark venue market share pre- and post- forward and reverse splits. Table A12 reports the results from this analysis.

1. Dollar stocks

Fig. A1 shows plots of EXCH activity for $2.00, $5.00, and $50.00 price cutoffs. Given that there is no change to the minimum pricing increment at prices other than a dollar, we do not expect to observe significant decreases in EXCH market share, or increases in DARK-ECN market share, when the price rises above other thresholds. Because we can only classify trades into exchange and non-exchange based on TAQ data, we only present the results for EXCH *Mktshare*. For robustness, we also repeat tests around the $1.00 threshold using TAQ data. The left column, which is analogous to Fig. 1 of the main text, shows the number of trades within each price bin, averaged across all stocks. The right column, corresponding to Fig. 2, shows the average market share for each price bin. The plots for $1.00 closely track those reported in the main analysis. We observe a sharp drop in both EXCH *Volume* and *Market share* when the stock price crosses $1.00. We do not observe a similar drop in EXCH trading metrics at the alternative price cutoffs discussed above, further supporting our hypothesis.

We also find some evidence of price clustering at integers, which is consistent with prior findings in the literature (see Harris, 1991; Chiao and Wang, 2009; Cellier and Bourghelle, 2007; and Bhattacharya, Holden, and Jacobsen, 2012). In plots of $2.00, $5.00 and $50.00 cutoff points, we observe a positive jump in *Volume* for EXCH when the stock crosses above the price threshold, which is not seen in the $1.00 plot. Moreover, we observe price clustering at 5 cent intervals for plots of *Volume* around the $5.00 and $50.00 thresholds and in plots of *Mktshare* for the $2.00 and $5.00 thresholds.

Table A1 reports the results for the RD analysis of market shares of competing trading venues around the alternative price thresholds. We run regressions analogous to those reported in Table 2 of the main text. We find that EXCH market share increases once the price crosses the $2 and $5 price thresholds, which is opposite to our findings for the $1 price threshold. These results correspond to Fig. A1, which shows that a clear decrease in EXCH market share only occurs for the $1 plot. The increase in the number of EXCH trades at $2 and $5, as shown in Fig. A1, are likely to reflect order clustering at whole price integers documented in the previous literature (Chiao and Wang, 2009; Cellier and Bourghelle, 2007). There is no significant change for the $50 price threshold. These tests confirm that our results only hold around the dollar threshold, where there is a change in the minimum pricing increment.

Table A2, Panels A and B, report the regression discontinuity results for the constrained and unconstrained subsamples, respectively. We expect to see the strongest results for stocks that are tightly constrained by the minimum pricing increment. A constrained stock has a *Qspread* below 1.1 pennies on days with an average trade price above a dollar and experiences a reduction in the spread when the average trade price falls below a dollar. Unconstrained stocks have a *Qspread* above 1.1 pennies, regardless of price. Comparing between Panels A and B, we see that our results are driven by our constrained stocks. Specifically, Panel A shows a decrease in EXCH *Mktshare* and an increase in DARK-ECN *Mktshare* when the stock price crosses above the dollar threshold. The results are statistically insignificant for the unconstrained stocks in Panel B.

Table A3 reports our results using volume-weighted measures of market share. Consistent with our main results in Table 2, the results show a decrease (increase) in EXCH (DARK-ECN) *Mktshare* when the stock price crosses above the $1.00 threshold. Note that the volume-weighted results show much larger changes in EXCH and DARK-ECN *Mktshare*. Specifically, EXCH *Mktshare* decreases by about 13% and DARK-ECN *Mktshare* increases by approximately 11% when stocks cross above $1.00.

Tables A4 and A5 present results using *Mktshare* in terms of the number of trades as our dependent variable. Analogous to our main text, Table A4 reports the basic RD results and Table A5 incorporates additional control variables for the level of trading activity. Again, our results remain qualitatively similar to our main findings presented in Tables 2 and 3.

Table A6 reports the results for the multinomial logit models. The dependent variable, $Venue$, takes a value from 0 to 5, depending on the venue type in which the trade is executed, where 0 to 5 represents EXCH, DARK-ECN, BLOCK, PING, INTERNALIZE and OTHER, respectively. The independent variable is $DollarPrice$, an indicator that takes a value of 1 if the trade price is at or above \$1.00 and is 0 otherwise. We control for $Tradesize$ and $Price$, re-centered such that a \$1.00 trade price corresponds to '0'. Standard errors are robust to heteroskedasticity and clustered by individual stocks. In Table A6, Panel A, we restrict the sample to trades between \$0.80 and \$1.20 to maintain the same local interpretation as the regression discontinuity results (see Keys, Mukherjee, Seru and Vig, 2010). The coefficients represent the log odds ratio of a trade executing in the indicated venue versus execution on the exchange. Consistent with our earlier findings, we find that the log of the odds ratio of execution in a DARK-ECN relative to an exchange increases by 2.08 when the price moves above the \$1.00 threshold. Holding all continuous variables at their means, we find that the probability of a trade occurring in DARK-ECNs increases by 12.2% after the stock price jumps above \$1.00. These results are again consistent with a migration of order flow away from EXCH to take advantage of queue jumping on DARK-ECNs when exchange trading is constrained by minimum pricing increments.

In Table A6, Panels B and C, we separate the sample into constrained and unconstrained trades to further investigate why order flow migrates from traditional exchanges to dark trading venues. Because dark venues offer greater advantages when trading is constrained, we expect stronger results for the constrained subsample. For trades at prices equal to or above $1.00, a trade is categorized as constrained (unconstrained) if the prevailing bid-ask spread is equal to (greater than) a penny. Trades below $1.00 are included in both subsamples. Comparing Panels B and C of Table A6, we find that the results reported in Panel A are driven by constrained trades. For DARK-ECN, *DollarPrice* is positive and significant in Panel B for constrained trades and negative and insignificant in Panel C for unconstrained trades, which implies that DARK-ECN trading venues are only attractive to investors when the NBBO is constrained by minimum pricing increments. For most other trading venue types,[34] we find that *DollarPrice* is positive and significant in both Panels B and C, indicating that other off-exchange venues are competing through different means. These findings provide further support for the prediction that order flow migrates to DARK-ECNs to take advantage of narrower tick sizes and higher time priorities at times when exchange trading is constrained by minimum pricing increments.

Table A7 presents results for three event types: Permanent risers (Panel A), permanent decliners (Panel B) and fluctuating stocks (Panel C). Permanent risers (decliners) remain consistently below (above) one dollar for five consecutive days and then stay above (below) one dollar for the next five]days. Other stocks trading both above and below $1.00, but following a different time pattern, are classified as fluctuating stocks. We find that across all the panels, *DollarPrice* is positive and significant for DARK-ECN and negative and significant for EXCH, which is consistent with the results from our main tests. Table A8 summarizes the maker-taker fee structures for the major exchanges: NYSE, NYSE Arca and Nasdaq.

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[34] The exception is BLOCK. However, the negligible change in trading probabilities indicates that the results are not economically significant.

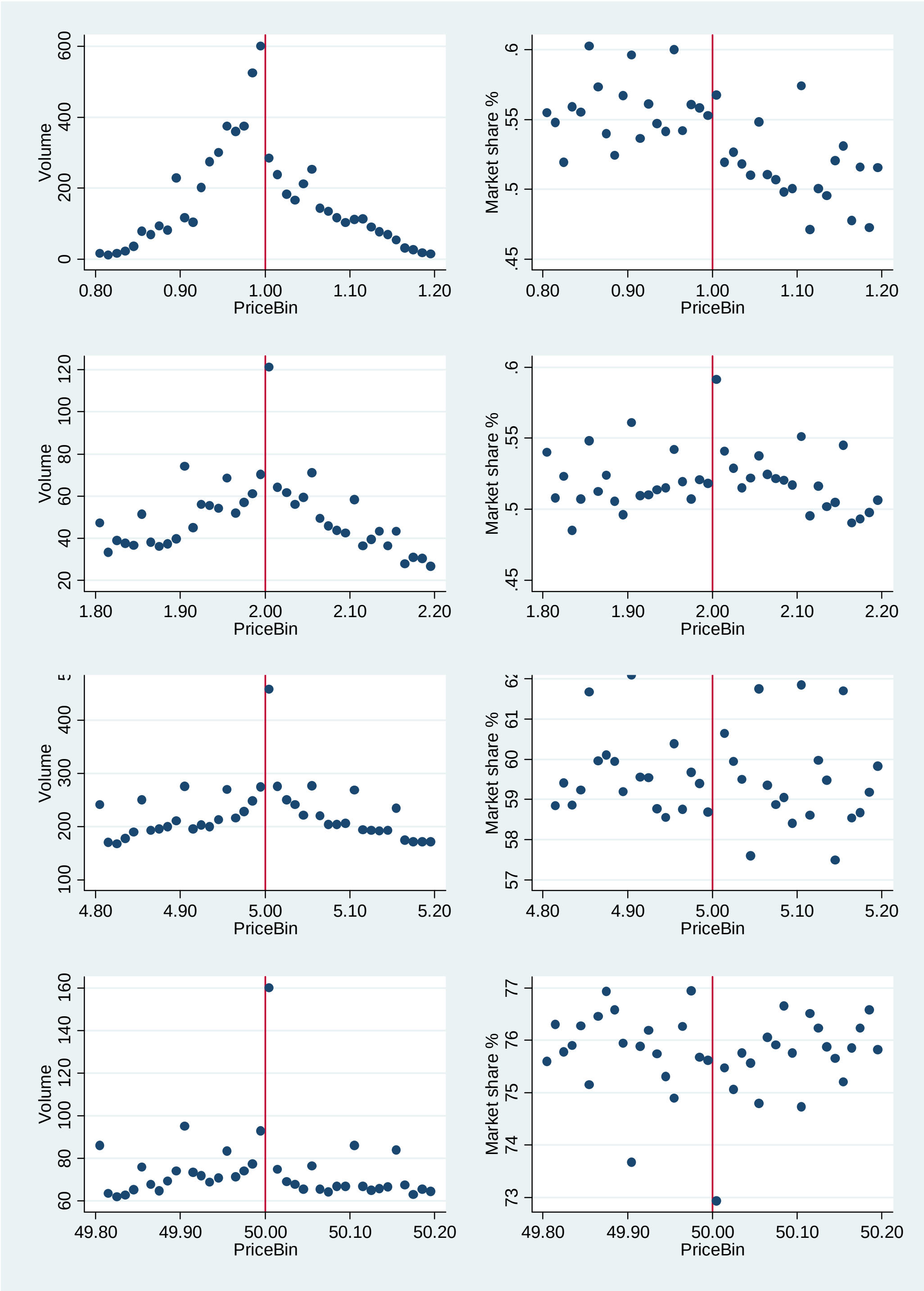

Fig. A1. EXCH trading around alternative price thresholds.
This figure plots EXCH *Volume* (column 1) and *Mktshare* (column 2). We identify stocks from CRSP that cross the \$1.00, \$2.00, \$5.00 and \$50.00 price thresholds. We extract trades ±\$0.20 from the price threshold and categorize these trades into penny price bins. *Volume* is the total number of shares traded on EXCH falling into each price bin (in millions). *Mktshare* is number of shares traded for EXCH divided by the total number of shares trades in the price bin per individual stock.

Table A1: Regression discontinuity tests – Alternative price thresholds

Table A1 reports regression discontinuity tests for alternative price thresholds of $2, $5 and $50. For the period 1 January 2010 to 31 Dec 2010, we select stocks that move from having a closing price below $2.00 ($5.00 or $50.00) to above $2.00 ($5.00 or $50.00) and vice versa. We analyze trade data for the 11-day event window from day -5 to +5, where day 0 is the first day the closing price of the stock is above or below $2.00 ($5.00 or $50.00). Trades are grouped into penny price bins and classified into two types: exchange and non-exchange. The results are based on the following linear regression around the $2.00 threshold:

$$Mktshare_{i,k} = \beta_0 + \delta_0 DollarPrice_{i,k} + \beta_1 (PriceBin_{i,k} - \$2.00) + \beta_2 DollarPrice_{i,k} \cdot (PriceBin_{i,k} - \$2.00) + \epsilon_{i,k}$$

where $Mktshare_{i,k}$ is the number of shares traded for exchange venues divided by the total number of shares traded, for stock *i* and price bin *k*. *k* represents the lower bound of the price bin. For example, trades priced at $2.00 to $2.0099 are contained in $PriceBin_{i,2.00}$. $DollarPrice_{i,k}$ is an indicator variable equal to 1 if k is equal to or greater than $2.00. Variables are similarly defined for the $5.00 and $50.00 price thresholds. All regressions control for stock fixed effects. We report heteroskedasticity-robust standard errors clustered by stock in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	$2	**$5**	**$50**
DollarPrice	3.214***	1.263**	-0.564
	(0.66)	(0.52)	(0.53)
PriceBin - $2.00/$5.00/$50.00	-13.118***	-8.996***	-1.946
	(4.68)	(3.26)	(3.23)
DollarPrice × (PriceBin - $2.00/$5.00/$50.00)	-3.769	3.586	8.663**
	(6.73)	(4.48)	(4.27)
Constant	75.930***	67.887***	80.826***
	(0.38)	(0.36)	(0.36)
Observations	15,365	27,763	15,637
Adjusted R-squared	0.258	0.252	0.259

Table A2: Regression discontinuity tests – Constrained and unconstrained stocks

Table A2 reports regression discontinuity tests for market share. For the period 1 January 2010 to 31 May 2011, we select stocks that move from having a closing price below $1.00 to above $1.00 and vice versa. We analyze trade data for the 11-day event window from day -5 to +5, where day 0 is the first day the closing price of the stock is either above or below $1.00. Trades are grouped into penny price bins and classified into six types: exchange, EXCH; DARK-ECN; block crossing networks, BLOCK; ping destinations, PING; retail market makers, INTERNALIZE, and those not previously classified, OTHER. Panel A (Panel B) reports the results for constrained (unconstrained) stocks. A constrained (unconstrained) stock has a *Qspread* below (above) 1.1 pennies on days when the average trade price is above a dollar and below (above) a penny on days when the average trade price is below a dollar. The results are based on the following linear regression around the $1.00 threshold:

$$Mktshare_{i,k} = \beta_0 + \delta_0 DollarPrice_{i,k} + \beta_1\left(PriceBin_{i,k} - \$1.00\right) + \beta_2 DollarPrice_{i,k} \cdot (PriceBin_{i,k} - \$1.00) + \epsilon_{i,k}$$

where $Mktshare_{i,k}$ is the number of trades for the indicated trading venue type divided by the total number of trades, for stock i and price bin k. k represents the lower bound of the price bin. For example, trades priced at $1.00 to $1.0099 are contained in $PriceBin_{i,1.00}$. $DollarPrice_{i,k}$ is an indicator variable equal to 1 if k is equal to or greater than $1.00. All regressions control for stock fixed effects. We report heteroskedasticity-robust standard errors clustered by stock in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
Panel A: Constrained stocks (n = 1,532)						
DollarPrice	-5.651***	2.675***	-0.166	0.383	2.215	0.545
	(1.18)	(0.47)	(0.12)	(0.62)	(1.33)	(0.39)
PriceBin - $1.00	11.423	-0.957	1.476**	-3.922	-14.493	6.472**
	(13.03)	(1.65)	(0.66)	(6.34)	(10.69)	(2.67)
DollarPrice × (PriceBin - $1.00)	-18.631	-0.813	-1.663*	13.108*	15.895	-7.896*
	(14.40)	(3.12)	(0.87)	(6.95)	(11.86)	(4.40)
Constant	59.481***	2.007***	0.223**	10.104***	23.166***	5.019***
	(0.99)	(0.27)	(0.09)	(0.49)	(1.08)	(0.30)
Adjusted R-squared	0.237	0.367	0.039	0.125	0.217	0.107

Table A2—Continued

Panel B: Unconstrained stocks (n = 2,486)						
DollarPrice	0.897	0.667	-0.085	0.033	-1.207	-0.306
	(1.98)	(0.44)	(0.11)	(1.01)	(1.76)	(0.63)
PriceBin - $1.00	-19.382	-1.357	-0.009	3.872	10.316	6.560
	(16.56)	(2.44)	(0.31)	(6.81)	(13.01)	(4.03)
DollarPrice × (PriceBin - $1.00)	-2.020	3.859	2.169	4.702	1.019	-9.729*
	(22.63)	(4.06)	(1.94)	(9.69)	(19.46)	(5.68)
Constant	64.833***	0.716***	-0.083	5.958***	23.863***	4.712***
	(1.43)	(0.24)	(0.06)	(0.69)	(1.16)	(0.40)
Adjusted R-squared	0.106	0.050	0.015	0.051	0.084	0.038

Table A3: Regression discontinuity tests – Market share (value-weighted)

Table A3 reports regression discontinuity tests for value-weighted market share. For the period 1 January 2010 to 31 May 2011, we select stocks that move from having a closing price below \$1.00 to above \$1.00 and vice versa. We analyze trade data for the 11-day event window from day -5 to +5, where day 0 is the first day the closing price of the stock is above or below \$1.00. Trades are grouped into penny price bins and classified into six types: exchange, EXCH; DARK-ECN; block crossing networks, BLOCK; ping destinations, PING; retail market makers, INTERNALIZE, and those not previously classified, OTHER. The results are based on the following linear regression around the \$1.00 threshold:

$$Mktshare_k = \beta_0 + \delta_0 DollarPrice_k + \beta_1(PriceBin_k - \$1.00) + \beta_2 DollarPrice_k \cdot (PriceBin_k - \$1.00) + \epsilon_k$$

where $Mktshare_k$ is the number of shares traded for the indicated trading venue type summed across all stocks divided the total number of shares traded, for price bin k. k represents the lower bound of the price bin. For example, trades priced at \$1.00 to \$1.0099 are contained in $PriceBin_{1.00}$. $DollarPrice_k$ is an indicator variable equal to 1 if k is equal to or greater than \$1.00. We report heteroskedasticity-robust standard errors in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
DollarPrice	-12.881***	10.662***	-0.015	0.749**	-1.826**	3.311***
	(1.40)	(0.78)	(0.03)	(0.33)	(0.80)	(0.35)
PriceBin - \$1.00	9.460	8.648***	0.301*	-16.185***	5.342	-7.566***
	(9.12)	(0.80)	(0.17)	(3.18)	(6.05)	(1.98)
DollarPrice × (PriceBin - \$1.00)	-20.312	-36.901***	-0.318	34.654***	21.306***	1.571
	(13.87)	(8.28)	(0.27)	(3.72)	(7.10)	(3.17)
Constant	68.705***	2.637***	0.117***	6.235***	20.301***	2.006***
	(0.80)	(0.11)	(0.02)	(0.23)	(0.69)	(0.16)
Observations	40	40	40	40	40	40
Adjusted R-squared	0.879	0.906	0.023	0.747	0.450	0.825

Table A4: Regression discontinuity tests – Market share (*ntrades*)

Table A4 reports regression discontinuity tests for market share. For the period 1 January 2010 to 31 May 2011, we select stocks that move from having a closing price below \$1.00 to above \$1.00 and vice versa. We analyze trade data for the 11-day event window from day -5 to +5, where day 0 is the first day the closing price of the stock is either above or below \$1.00. Trades are grouped into penny price bins and classified into six types: exchange, EXCH; DARK-ECN; block crossing networks, BLOCK; ping destinations, PING; retail market makers, INTERNALIZE, and those not previously classified, OTHER. The results are based on the following linear regression around the \$1.00 threshold:

$$Mktshare_{i,k} = \beta_0 + \delta_0 DollarPrice_{i,k} + \beta_1(PriceBin_{i,k} - \$1.00) + \beta_2 DollarPrice_{i,k} \cdot (PriceBin_{i,k} - \$1.00) + \epsilon_{i,k}$$

where $Mktshare_{i,k}$ is the number of trades for the indicated trading venue type divided by the total number of trades, for stock i and price bin k. k represents the lower bound of the price bin. For example, trades priced at \$1.00 to \$1.0099 are contained in $PriceBin_{i,1.00}$. $DollarPrice_{i,k}$ is an indicator variable equal to 1 if k is equal to or greater than \$1.00. Panels A and B report results for trading between \$0.80 and \$1.20, and \$0.90 and \$1.10, respectively. All regressions control for stock fixed effects. We report heteroskedasticity-robust standard errors clustered by stock in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
			Panel A: \$0.80 ≤ PriceBin ≤ \$1.20 (n = 6,125)			
DollarPrice	-3.687***	2.135***	-0.003	-0.172	1.359**	0.368
	(0.91)	(0.34)	(0.03)	(0.39)	(0.62)	(0.26)
PriceBin - \$1.00	-7.638	-0.173	-0.085	2.229	3.792	1.874
	(6.18)	(1.37)	(0.36)	(3.13)	(4.20)	(2.06)
DollarPrice × (PriceBin - \$1.00)	-3.701	-1.388	0.038	4.833	2.756	-2.538
	(8.97)	(2.65)	(0.40)	(4.40)	(6.53)	(2.52)
Constant	77.292***	0.803***	0.083***	8.778***	9.491***	3.552***
	(0.66)	(0.19)	(0.03)	(0.32)	(0.44)	(0.23)
Adjusted R-squared	0.166	0.231	0.068	0.092	0.157	0.066

Table A4—Continued

Panel B: $0.90 ≤ PriceBin ≤ $1.10 (n = 3,380)						
DollarPrice	-2.848***	2.335***	0.008	-0.419	0.422	0.502
	(1.06)	(0.35)	(0.03)	(0.56)	(0.67)	(0.36)
PriceBin - $1.00	-13.520	0.329	0.023	-0.398	11.656	1.910
	(12.33)	(2.74)	(0.31)	(7.85)	(9.37)	(5.73)
DollarPrice × (PriceBin - $1.00)	-14.223	-9.882**	-0.382	17.784	14.177	-7.474
	(19.78)	(4.84)	(0.57)	(11.60)	(13.21)	(7.49)
Constant	75.869***	1.436***	0.165***	8.865***	9.351***	4.314***
	(0.76)	(0.19)	(0.02)	(0.44)	(0.52)	(0.33)
Adjusted R-squared	0.200	0.273	0.117	0.110	0.210	0.070

Table A5: Regression discontinuity tests with additional controls – Market share (*ntrades*)

Table A5 reports regression discontinuity tests for market share, after controlling for *Ntrades* and *Tradesize*. For the period 1 January 2010 to 31 May 2011, we select stocks that move from having a closing price below \$1.00 to above \$1.00 and vice versa. We analyze trade data for the 11-day event window from day -5 to +5, where day 0 is the first day the closing price of the stock is above or below \$1.00. Trades are grouped into penny price bins and classified into six types: exchange, EXCH; DARK-ECN; block crossing networks, BLOCK; ping destinations, PING; retail market makers, INTERNALIZE, and those not previously classified, OTHER. We estimate the following linear regression:

$$Mktshare_{ik} = \beta_0 + \delta_0 DollarPrice_{i,k} + \beta_1(PriceBin_{i,k} - \$1.00) + \beta_2 DollarPrice_{i,k} \cdot (PriceBin_{i,k} - \$1.00) + \beta_3 \text{Log}(Ntrades_{ik}) + \beta_4 \text{Log}(TradeSize_{ik}) + \epsilon_{ik}$$

where $Mktshare_{i,k}$ is the number of trades for the indicated trading venue type divided by the total number of trades, for stock i and price bin k. k represents the lower bound of the price bin. For example, trades priced at \$1.00 to \$1.0099 are contained in $PriceBin_{i,1.00}$. $DollarPrice_{i,k}$ is an indicator variable equal to 1 if k is equal to or greater than \$1.00. $Ntrades_{ik}$ and $TradeSize_{ik}$ are the total number of trades and average transaction size across all trading venues, respectively. Panels A and B report results for trading between \$0.80 and \$1.20, and \$0.90 and \$1.10, respectively. All regressions control for stock fixed effects. We report heteroskedasticity-robust standard errors clustered by stock in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
Panel A: \$0.80 ≤ PriceBin ≤ \$1.20 (n = 6,125)						
DollarPrice	-3.270***	2.119***	-0.005	-0.226	1.118*	0.265
	(0.87)	(0.34)	(0.03)	(0.38)	(0.57)	(0.28)
PriceBin - \$1.00	-18.776***	-2.268*	-0.184	6.579**	14.320***	0.329
	(6.53)	(1.37)	(0.35)	(3.21)	(4.51)	(2.13)
DollarPrice × (PriceBin - \$1.00)	13.239	2.550	0.230	-2.644	-14.473**	1.098
	(9.64)	(2.53)	(0.39)	(4.46)	(7.20)	(2.55)
Log(Ntrades)	1.531***	0.307***	0.015**	-0.620***	-1.478***	0.245***
	(0.34)	(0.07)	(0.01)	(0.19)	(0.27)	(0.06)
Log(TradeSize)	-5.009***	-0.122	0.002	1.015**	3.405***	0.710**
	(0.66)	(0.15)	(0.01)	(0.42)	(0.45)	(0.28)
Constant	98.532***	-0.526	-0.029	6.591**	-1.952	-2.617*
	(5.03)	(1.06)	(0.06)	(3.05)	(3.38)	(1.58)
Adjusted R-squared	0.197	0.236	0.069	0.100	0.189	0.074

Table A5—Continued

Panel B: \$0.90 ≤ PriceBin ≤ \$1.10 (n = 3,380)						
DollarPrice	-2.597**	2.228***	0.004	-0.351	0.442	0.274
	(1.00)	(0.35)	(0.03)	(0.54)	(0.64)	(0.41)
PriceBin - \$1.00	-22.369*	-1.866	-0.028	3.762	19.496**	1.006
	(12.49)	(2.67)	(0.31)	(7.78)	(9.52)	(5.76)
DollarPrice × (PriceBin - \$1.00)	-0.478	-3.698	-0.198	8.276	-1.980	-1.921
	(21.00)	(4.40)	(0.58)	(11.34)	(13.56)	(6.98)
Log(Ntrades)	1.617***	0.487***	0.013*	-0.854***	-1.555***	0.293**
	(0.46)	(0.10)	(0.01)	(0.26)	(0.39)	(0.12)
Log(TradeSize)	-4.136***	-0.175	0.008	1.010*	2.443***	0.849*
	(0.96)	(0.22)	(0.01)	(0.60)	(0.57)	(0.48)
Constant	91.007***	-0.726	0.031	8.245*	4.424	-2.982
	(7.47)	(1.66)	(0.12)	(4.58)	(4.57)	(2.76)
Adjusted R-squared	0.223	0.283	0.117	0.120	0.233	0.078

Table A6: Multinomial logit regression – Choice of trading venue type (conditional on execution)

Table A6 reports results from a multinomial logit regression for the choice of trading venue. For the period 1 January 2010 to 31 May 2011, we select stocks that move from having a closing price below \$1.00 to above \$1.00 and vice versa. We analyze trade data for the 11-day event window from day -5 to +5, where day 0 is the first day the closing price of the stock is above or below \$1.00. Trades are classified into six types: exchange, EXCH; DARK-ECN; block crossing networks, BLOCK; ping destinations, PING; retail market makers, INTERNALIZE, and those not previously classified as OTHER. The results are based on the following multinomial logit regression for trades priced between \$0.80 and \$1.20:

$$\Pr(Venue_j) = \beta_0 + \delta_0 DollarPrice_j + \beta_1(Price_j - \$1.00) + \beta_2 \operatorname{Log}(Tradesize_j)$$

The dependent variable takes the value of 0 to 5 depending on the venue of trade execution (EXCH, DARK-ECN, BLOCK, PING, INTERNALIZE and OTHER, respectively). $DollarPrice_j$ is an indicator variable that takes the value of 1 if the trade price is equal to or greater than \$1.00. $Price_j$ and $Tradesize_j$ represent the trade price and trade size, respectively. The results presented refer to the log odds of a trade occurring in the venue indicated relative to a trade taking place on EXCH. The change in probabilities for when the stock price moves above \$1.00 is calculated by holding continuous variables at their means. Panels B and C present estimates for the constrained and unconstrained trade subsamples, respectively. For trades equal to or above \$1.00, a trade is constrained (unconstrained) if the prevailing bid-ask spread is equal to (greater than) a penny. Trades below \$1.00 are included in both subsamples. We report standard errors clustered by stock in parentheses. ***, ** and * indicate significance levels of 0.1%, 1% and 5%, respectively.

	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
Panel A: All trades (n = 10,782,695)					
DollarPrice	2.075***	0.523**	0.272**	1.052***	1.453***
	(0.073)	(0.224)	(0.138)	(0.163)	(0.211)
Price - \$1.00	-0.859	0.764	0.504	0.227	-1.756***
	(0.586)	(2.067)	(0.437)	(0.525)	(0.529)
Log(TradeSize)	-0.037	-0.152***	0.166***	0.337***	-0.048
	(0.045)	(0.053)	(0.035)	(0.084)	(0.055)
Constant	-3.196***	-5.459***	-3.445***	-4.387***	-3.199***
	(0.227)	(0.322)	(0.173)	(0.592)	(0.347)
Change in probabilities	0.122	0.000	-0.005	0.073	0.050
Pseudo R-squared	0.1063				

Table A6—Continued

Panel B: Constrained trades (n = 10,597,506)					
DollarPrice	2.093***	0.540**	0.274**	1.066***	1.472***
	(0.069)	(0.226)	(0.138)	(0.160)	(0.206)
Price - $1.00	-0.734	0.831	0.458	0.231	-1.705***
	(0.608)	(2.104)	(0.453)	(0.567)	(0.532)
Log(TradeSize)	-0.04	-0.156***	0.163***	0.333***	-0.052
	(0.044)	(0.053)	(0.035)	(0.084)	(0.054)
Constant	-3.17***	-5.433***	-3.427***	-4.359***	-3.171***
	(0.224)	(0.322)	(0.174)	(0.595)	(0.346)
Change in probabilities	0.124	0.000	-0.006	0.074	-0.193
Pseudo R-squared	0.1094				
Panel C: Unconstrained trades (n = 5,123,881)					
DollarPrice	-0.305	-0.434	0.636***	0.849***	0.050
	(0.301)	(0.638)	(0.177)	(0.074)	(0.154)
Price - $1.00	3.972***	1.068	-1.555***	-0.22	1.504
	(1.366)	(3.386)	(0.538)	(0.395)	(0.931)
Log(TradeSize)	0.018	-0.037	0.166***	0.644***	0.085
	(0.015)	(0.098)	(0.045)	(0.046)	(0.088)
Constant	-3.222***	-6.086***	-3.559***	-6.507***	-3.755***
	(0.204)	(0.532)	(0.210)	(0.283)	(0.553)
Change in probabilities	-0.010	-0.001	0.046	0.058	-0.187
Pseudo R-squared	0.0829				

Table A7: Regression discontinuity tests by event type

Table A7 reports regression discontinuity tests for market share. For the period 1 January 2010 to 31 May 2011, we select stocks that move from having a closing price below \$1.00 to above \$1.00 and vice versa. We analyze trade data for the 11-day event window from day -5 to +5, where day 0 is the first day the closing price of the stock is either above or below \$1.00. Trades are grouped into penny price bins and classified into six types: exchange, EXCH; DARK-ECN; block crossing networks, BLOCK; ping destinations, PING; retail market makers, INTERNALIZE, and those not previously classified, as OTHER. The results are based on the following linear regression around the \$1.00 threshold:

$$Mktshare_{i,k} = \beta_0 + \delta_0 DollarPrice_{i,k} + \beta_1 (PriceBin_{i,k} - \$1.00) + \beta_2 DollarPrice_{i,k} \cdot (PriceBin_{i,k} - \$1.00) + \epsilon_{i,k}$$

where $Mktshare_{i,k}$ is the number of shares traded for the indicated trading venue type divided by the total number of shares traded, for stock i and price bin k. k represents the lower bound of the price bin. For example, trades priced at \$1.00 to \$1.0099 are contained in $PriceBin_{i,1.00}$. $DollarPrice_{i,k}$ is an indicator variable equal to 1 if k is equal to or greater than \$1.00. Panels A (Panel B) reports results for stocks that are below (above) \$1.00 on days -5 to -1 and above (below) \$1.00 on days 0 to +5. Panel C reports results for stocks that fluctuate above and below \$1.00. All regressions control for stock fixed effects. We report heteroskedasticity-robust standard errors clustered by stock in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
Panel A: Permanent Risers (n = 1,565)						
DollarPrice	-3.845**	1.660***	-0.043	-0.155	1.730	0.654
	(1.59)	(0.39)	(0.19)	(0.80)	(1.29)	(0.61)
PriceBin - \$1.00	25.100	1.492	3.138	-8.211	-26.001**	4.482
	(15.55)	(2.60)	(2.53)	(8.96)	(12.21)	(7.34)
DollarPrice × (PriceBin - \$1.00)	-64.002**	3.742	-2.034	17.674	57.050***	-12.430
	(24.51)	(4.52)	(4.42)	(13.88)	(19.75)	(11.32)
Constant	75.579***	0.210	0.267	12.989***	8.224***	2.732***
	(1.32)	(0.22)	(0.22)	(0.76)	(1.04)	(0.62)
Adjusted R-squared	0.244	0.226	-0.002	0.114	0.235	0.100

Table A7—Continued

Panel B: Permanent Decliners (n = 1,626)						
DollarPrice	-5.208**	0.992*	-0.332	2.179*	2.344	0.026
	(2.04)	(0.51)	(0.30)	(1.22)	(1.74)	(0.78)
PriceBin - $1.00	26.752	0.179	3.146	-26.658*	-8.092	4.673
	(28.18)	(5.86)	(5.72)	(13.67)	(25.23)	(12.83)
DollarPrice × (PriceBin - $1.00)	-34.596	-4.056	-5.317	39.767**	9.961	-5.759
	(36.94)	(8.16)	(7.40)	(18.17)	(32.02)	(14.66)
Constant	63.956***	1.573***	0.351	10.344***	18.142***	5.634***
	(1.71)	(0.39)	(0.36)	(0.87)	(1.46)	(0.69)
Adjusted R-squared	0.152	0.151	0.069	0.109	0.144	0.073
Panel C: Fluctuating Stocks (n = 3,253)						
DollarPrice	-2.314*	1.017***	-0.024	0.553	0.081	0.688
	(1.35)	(0.32)	(0.05)	(0.72)	(1.07)	(0.48)
PriceBin - $1.00	-8.108	0.878	0.261	-6.905	12.919	0.955
	(17.26)	(3.17)	(0.66)	(8.65)	(13.55)	(7.76)
DollarPrice × (PriceBin - $1.00)	6.815	-3.405	-0.159	15.633	-8.168	-10.716
	(24.04)	(5.06)	(1.24)	(11.50)	(18.56)	(9.41)
Constant	58.484***	0.845***	0.249***	12.853***	20.632***	6.938***
	(1.09)	(0.22)	(0.04)	(0.54)	(0.84)	(0.42)
Adjusted R-squared	0.190	0.148	0.037	0.082	0.170	0.051

Table A8: Maker-taker fees

For the NYSE, NYSE Arca and Nasdaq, we show the rebates for adding liquidity and the fee for removing liquidity.

	Price $1 or above		Price below $1	
	Make rebate	Take fee	Make rebate	Take fee
NYSE	$0.0015/share	$0.0025/share	$0.0004/share	0.3% of dollar value
NYSE Arca	$0.0023/share	$0.0030/share	0	0.1% of dollar value
Nasdaq	$0.0020/share	$0.0030/share	0	0.3% of dollar value

2. Higher-priced stocks

Table A9 lists the 116 stock symbols and their respective market capitalizations for our stratified sample of stocks. Tables A10 and A11 present additional results for the stratified stocks based on subsamples of constrained and unconstrained stocks. A constrained (unconstrained) stock has an average time-weighted quoted spread (*Qspread*) in the bottom (top) quartile relative to all other stocks in the sample period. The *Qspread* cut-off for the bottom and top quartiles are 1.15 pennies and 3.49 pennies, respectively. Table A10 replicates our tests from Table 6, Panel A, in the main text. For constrained stocks in Panel A, *Constrain* is positive and significant for DARK-ECN and negative and significant for EXCH. The coefficients for EXCH and DARK-ECN for the unconstrained stocks in Table A10, Panel B, are statistically insignificant.

Similarly, Table A11, Panels A and B, replicate the regressions from Table 7, Panels A and B, respectively. We consistently find stronger results for our sample of constrained stocks. For the time-series analysis in Panel A, while DARK-ECN *Mktshare* increases with *Constrain* for both subsamples, we do not find a significant decrease in ECXH *Mktshare* for the unconstrained sample (Table 11, Panel A2). These results show that DARK-ECN venues can offer benefits to traders when the bid-ask spread is wider than one penny. In these situations, traders are still able to queue jump in a DARK-ECN, or, alternatively, reduce their execution costs by transacting within the bid-ask spread at sub-penny increments. For the other trading venues, we observe some inconsistencies between the cross-sectional results in Table A10 and the time-series results in Table A11, Panel A. These findings indicate that there are likely to be other important factors driving the intraday variation in venue market shares, rather than the size of the spread constraint.

Table A11, Panel B, tests the relationship between *Mktshare* and *Log(depth)*. For the constrained stocks in Table A11, Panel B1, we find that *Log(depth)* is positively related to DARK-ECN *Mktshare* and negatively related to EXCH *Mktshare*. Thus, when limit order queues are longer, traders have stronger incentives to migrate their order flow away from EXCH venues towards DARK-ECN venues. The relationship is not observed for the unconstrained stock sample in Table A11, Panel B2.

Table A9: Sample stocks

In our tests for higher priced stocks, we use the 116 stocks analyzed by Brogaard, Hendershott, and Riordan (2013) for which we have data. The ticker symbol for these securities and their respective market capitalizations (*Mcap* in billions USD) on 3 January 2011 are presented here.

Ticker	Mcap	Ticker	Mcap	Ticker	Mcap	Ticker	Mcap
AA	16.14	CELG	28.25	FL	3.062	MDCO	0.768
AAPL	302.3	CETV	1.205	FMER	2.210	MELI	3.094
ABD	0.485	CKH	2.199	FPO	0.658	MFB	0.574
ADBE	15.92	CMCSA	46.30	FRED	0.553	MIG	0.553
AGN	21.36	CNQR	2.768	FULT	2.083	MMM	62.04
AINV	2.200	COO	2.606	GAS	2.294	MOD	0.801
AMAT	18.79	COST	31.33	GE	195.4	MOS	33.98
AMED	1.013	CPSI	0.512	GENZ	18.59	MRTN	0.480
AMGN	52.48	CPWR	2.571	GILD	29.70	MXWL	0.509
AMZN	82.68	CR	2.452	GLW	29.99	NC	0.743
ANGO	0.390	CRI	1.681	GOOG	150.1	NSR	1.945
APOG	0.394	CRVL	0.584	GPS	13.65	NUS	1.894
ARCC	3.451	CSCO	113.6	HON	42.29	NXTM	1.238
AXP	52.24	CSE	2.318	HPQ	93.62	PBH	0.593
AYI	2.556	CSL	2.469	IMGN	0.654	PFE	141.6
AZZ	0.510	CTRN	0.367	INTC	116.3	PG	183.8
BAS	0.693	CTSH	22.87	IPAR	0.585	PNC	32.32
BHI	24.71	DCOM	0.525	ISIL	1.824	PNY	2.039
BIIB	16.01	DELL	26.62	ISRG	10.57	PPD	0.610
BRCM	20.19	DIS	71.62	JKHY	2.534	PTP	1.776
BRE	2.822	DK	0.402	KMB	25.54	RIGL	0.402
BXS	1.378	DOW	40.60	KNOL	0.592	ROC	3.070
BZ	0.687	EBAY	37.39	KR	14.00	ROCK	0.423
CB	18.37	EBF	0.452	LANC	1.616	ROG	0.633
CBEY	0.478	ERIE	3.383	LECO	2.820	RVI	0.802
CBT	2.558	ESRX	29.63	LPNT	1.968	SF	2.217
CBZ	0.313	EWBC	2.920	LSTR	2.028	SFG	2.136
CCO	0.600	FCN	1.700	MAKO	0.591	SJW	0.489
CDR	0.433	FFIC	0.451	MANT	0.963	SWN	13.20

Table A10: Relationship between *Mktshare* and *Constrain* in the cross-section – Constrained and unconstrained stocks

Table A10 reports the cross-sectional regression of *Mktshare* against *Constrain* for the stocks described in Table 5. The dependent variable is *Mktshare*, the number of shares traded for the indicated trading venue type divided by the total number of shares traded, expressed as a percentage. *Constrain* is a daily measure of the severity of the spread constraint. We estimate *Constrain* using a Tobit regression model (see text for the estimation equation). For each stock, *Mktshare* and *Constrain* are averaged over all the days in our sample period. Panel A (Panel B) reports the results for constrained (unconstrained) stocks, defined as those stocks with *Qspread* in the bottom (top) quartile for the 116 stocks. We report heteroskedasticity-robust standard errors in parentheses. ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
Panel A: Constrained stocks (n = 29)						
Constrain	-4.703***	0.894**	-0.397***	-0.700	3.245***	1.655***
	(1.27)	(0.43)	(0.11)	(0.50)	(1.16)	(0.60)
Constant	74.868***	8.919***	1.502***	5.520***	4.086***	5.114***
	(1.16)	(0.45)	(0.12)	(0.60)	(1.06)	(0.44)
Adj. R-squared	0.329	0.070	0.226	0.022	0.172	0.173
Panel B: Unconstrained stocks (n = 29)						
Constrain	-4.977	-2.129	-5.528***	3.077**	12.200***	-2.038**
	(4.95)	(1.56)	(1.56)	(1.24)	(2.98)	(0.98)
Constant	77.943***	6.825***	4.331***	3.443***	3.283***	4.930***
	(1.32)	(0.44)	(0.66)	(0.31)	(0.54)	(0.34)
Adj. R-squared	-0.002	0.015	0.190	0.131	0.361	0.058

Table A11: Relationship between *Mktshare* and *Constrain* in the time series – Constrained and unconstrained stocks

Table A11 reports the regression of *Mktshare* against *Constrain* for the stocks described in Table 5. The dependent variable is *Mktshare*, the number of shares traded for the indicated trading venue type divided by the total number of shares traded, expressed as a percentage. In Panel A, we regress *Mktshare* against *Constrain,* which is a daily measure of the severity of the spread constraint (see text for the construction of *Constrain*). Panel A1 (Panel A2) contains a subset of constrained (unconstrained) stocks, defined as those stocks with an average *Qspread* in the bottom (top) quartile of the 116 stocks. In Panel B, we regress *Mktshare* against *Log(Depth)*, where *Depth* is the daily time-weighted depth across all exchange venues at the prevailing best bid and ask prices. Panel B1 (Panel B2) contains the subset of constrained (unconstrained) stocks. All regressions control for stock and day fixed effects. Standard errors clustered by stock and day are in parentheses (Thompson, 2011). ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	EXCH	DARK-ECN	BLOCK	PING	INTERNALIZE	OTHER
			Panel A: *Mktshare* and *Constrain*			
			Panel A1: Constrained stocks			
Constrain	-5.310***	3.121***	0.498	0.283	-2.527***	3.958***
	(1.36)	(0.76)	(0.41)	(0.53)	(0.96)	(0.82)
Constant	70.661***	2.582**	-0.599	6.039***	19.883***	1.440*
	(1.94)	(1.07)	(0.63)	(0.56)	(1.46)	(0.81)
Observations	1,798	1,798	1,791	1,798	1,798	1,798
Adj. R-squared	0.481	0.244	0.056	0.534	0.820	0.282
			Panel A2: Unconstrained stocks			
Constrain	-5.155	3.904**	2.543**	-0.982*	-2.649***	2.718
	(3.60)	(1.79)	(1.29)	(0.51)	(0.82)	(2.07)
Constant	75.557***	6.199***	3.472***	5.330***	5.840***	3.514***
	(0.31)	(0.17)	(0.31)	(0.21)	(0.14)	(0.67)
Observations	1,798	1,782	1,437	1,778	1,783	1,741
Adj. R-squared	0.200	0.094	0.099	0.219	0.544	0.030

Table A11—continued

Panel B: *Mktshare* and *Log(depth)*						
Panel B1: Constrained stocks						
Log(depth)	-2.717***	1.561***	-0.294	0.351	-0.061	1.153***
	(0.83)	(0.41)	(0.19)	(0.24)	(0.30)	(0.44)
Log(mcap)	-2.090*	-1.178*	0.540	-0.034	3.010***	-0.240
	(1.24)	(0.68)	(0.35)	(0.29)	(0.46)	(0.59)
Log(price)	9.401**	-1.829	-2.868**	-0.873	-0.801	-3.061
	(4.57)	(2.76)	(1.37)	(1.15)	(2.10)	(2.16)
Volatility	-13.761	-6.449	5.278	-11.364**	11.895*	13.973
	(12.90)	(7.80)	(5.14)	(5.22)	(6.51)	(9.91)
Constant	117.080***	22.319***	-1.531	6.007**	-51.556***	7.722*
	(9.99)	(5.99)	(3.05)	(2.47)	(4.43)	(4.15)
Observations	1,798	1,798	1,791	1,798	1,798	1,798
Adj. R-squared	0.490	0.248	0.058	0.538	0.815	0.276
Panel B2: Unconstrained stocks						
Log(depth)	0.469	0.308	-1.851*	-0.341	0.511	-0.058
	(1.63)	(0.82)	(1.02)	(0.29)	(0.51)	(0.96)
Log(mcap)	-2.202	0.927	1.683	-0.844	-0.202	0.538
	(3.81)	(2.06)	(2.58)	(0.75)	(1.43)	(2.08)
Log(price)	3.821	-4.029	-4.178	2.963*	3.439	-2.174
	(7.88)	(4.16)	(5.32)	(1.53)	(2.91)	(4.28)
Volatility	41.184	-44.289***	-0.777	3.297	16.723**	-27.530*
	(35.19)	(15.44)	(11.92)	(5.53)	(7.85)	(16.43)
Constant	99.788*	1.841	-7.214	14.545	-0.790	2.239
	(57.50)	(29.64)	(37.21)	(10.60)	(20.52)	(31.84)
Observations	1,798	1,782	1,437	1,778	1,783	1,741
Adj. R-squared	0.196	0.093	0.099	0.219	0.540	0.028

3. Stock splits

Stock splits and reverse stock splits provide an ideal setting to examine intermarket competition as they are often accompanied by large increases and decreases in the stock price and liquidity. In this section, we investigate the effects of three types of stock splits, which are expected to affect market competition in different ways.

First, we investigate reverse stock splits of penny stocks, where the stock price changes from below $1.00 to above $1.00. For these stocks, there is an increase in tick size at $1.00, meaning that the stock is less spread constrained pre reverse split and more spread constrained post reverse split. Hence, for this sample of reverse splits, we expect dark venue market share to increase following the split, which is analogous to the main results for the dollar stock analysis.[35]

Second, we examine the effects of reverse splits on dark venue market share, where the pre-reverse split stock price is above a dollar and thus, there is no change in the allowed minimum pricing increment. Based on our hypothesis, we expect the dark market share of the stock to decline following the reverse split as the minimum pricing increment becomes less binding. To capture one dimension of the spread constraint's strength, we measure changes in the percentage spread, *Spread%* which scales quoted dollar spread by the stock price.[36] For example, a pre-reverse split stock priced at $5 with a penny spread has a higher *Spread%,* and, thus, is likely to be more constrained than the post-reverse split stock priced at $50 that is also trading at the minimum penny spread. When the stock becomes less spread constrained as *Spread%* declines, dark trading venues offer fewer advantages to traders and we expect less order flow to be directed toward dark trading venues. Borkovec, Domowitz, and Tyurin (2011) report a shift in

[35] We note that some of this increase in dark venue market share may be due to a reduction in the risk of delisting since under exchange listing rules, stocks with a bid price below $1.00 may be subject to delisting.

[36] This measure has the limitation of not identifying when a stock is trading at the minimum dollar spread.

trading activity from dark markets to exchanges after Citigroup's 1 for 10 reverse split, providing evidence consistent with our hypothesis.

We expect the strongest results for stocks that show the largest reductions in the strength of the spread constraint. We define this subsample of reverse stock splits as stocks that are 1) trading at the minimum pricing increment pre-split and 2) experience a sharp reduction in quoted depth (i.e. the percentage change in depth is below the median). Thus, trading in these stocks is less constrained post-split and dark trading become less attractive.

Third, we examine the effects of forward splits on dark market share, which offer opposite predictions to reverse splits. For forward splits, a large reduction in stock price can increase the binding nature of the minimum pricing increment as the percentage spread rises. As the strength of the spread constraint increases, dark trading venues become more attractive as traders can take advantage of potentially faster executions within the quoted spread.

Again, we expect the results to be strongest for the subsample of stock splits that experience the largest strengthening of the spread constraint. Since we do not observe any stocks that trade at the minimum penny spread post-split, *Spread%* is used as an alternative to the dollar spread as a measure of the spread constraint. We identify the subsample of forward stock splits with the greatest strengthening of the spread constraint as stocks that 1) experience an increase in *Spread%* and 2) have the largest percentage increase in quoted depth (above the median).

We obtain stock split data over the 1 January 2009 to 31 December 2012 period and trading characteristics for an 11 day trading window (5 days before, the split ex date and 5 days after) from CRSP. To ensure that reverse (forward) splits result in a substantial price change, we require the split factor, measured by the ratio of old shares to new shares, to be at least 2 to 3. Because this analysis is conducted using TAQ, rather than TRF data, our dependent variable is

Dark%, which represents the percentage of share volume transacted on all dark venues. We expect *Dark%* of penny stocks to increase post-reverse split, and for nonpenny stocks to decrease post-reverse split and increase post-forward splits.

Table A12, Column 2, shows the results for the reverse stock splits of penny stocks. To ensure that trader types are comparable in the pre- and post-split, we require a post-split price below $5.00 to remain within the SEC's definition of a penny stock.[37] *Dark%* increases by an economically and statistically significant 2.9% when the stock reverse splits from a price below $1.00 to a price above $1.00. This result is consistent with the findings of the regression discontinuity experiments, which together support our hypothesis that traders take advantage of dark trading venues when trading in a stock becomes more constrained.

Table A12, Columns 3 and 4, present results for reverse splits of nonpenny stocks. Column 3 analyzes reverse splits that produce the largest decreases in the strength of the spread constraint. As defined above, reverse stock splits that decrease the binding nature of the minimum pricing increment include stocks that are 1) trading at the minimum pricing increment pre-split and 2) experience a sharp reduction in the quoted depth (i.e., the percentage decrease in depth is above the median). Reverse splits that do not decrease the strength of the spread constraint (i.e., stocks not trading at the minimum pricing increment pre-split and having a percentage decrease in quoted depth below the median) are analyzed in Column 4. In support of our hypothesis, we observe a 6.3% decrease in *Dark%* for reverse splits that reduce the strength of the spread constraint. For reverse splits that do not reduce the strength of the spread constraint, we do not observe a change in *Dark%*.

Table A12, Columns 5 and 6 present results from our analysis of forward splits. Column 5 analyzes stocks that experience the largest increases in the strength of the spread constraint

[37] To reduce the effects of outliers, we require at least 20 trades per trading day.

post-split. These observations include stocks that 1) experience an increase in *Spread%* and 2) have a large percentage increase in quoted depth (above the median). Forward splits that have a decrease in *Spread%* and lower changes in percentage quoted depths (below the median) are analyzed in Column 6. These stocks do not show a stronger spread constraint, and, thus, we do not expect to see an increase in *Dark%.* Consistent with our predictions, Table A12, Column 5 shows that post-split *Dark%* increases by almost 3% for the subsample of stocks for which the minimum pricing increment becomes more binding. This increase in *Dark%* is in contrast to the second subsample in Column 6, where we observe no significant change in post-split *Dark%.*

Table A12: Stock splits and off-exchange market share

Table A12 presents results for stock splits completed between 1 January 2009 and 31 December 2012, where the absolute split factor is at least 0.5. We examine three types of splits: reverse splits of penny stocks, other reverse splits and forward splits. We analyze trade and quote data for the 11-day event window from day -5 to +5, where day 0 is the day of the split. The dependent variable is *Dark%*, which is the ratio of off-exchange share volume to total volume, expressed as a percentage. For the penny stock reverse split sample, we require a pre-split price that is less than \$1.00 and a post-split price of less than \$5.00. For other reverse splits and forward splits, we subsample based on the change in stock liquidity. Decrease (increase) in depth refers to stock splits where the percentage change in depth is below (above) the median, relative to the full sample of reverse or forward splits. A reverse split is pre-split constrained if the mean pre-split spread is \$0.01 and pre-split unconstrained otherwise. Forward splits are divided into stocks that experience a post-split decrease or increase in the percentage quoted spread. All regressions control for stock and day fixed effects. Standard errors clustered by stock and day are in parentheses (Thompson, 2011). ***, ** and * indicate significance levels of 1%, 5% and 10%, respectively.

	Reverse splits (penny stocks)	Reverse splits (non-penny stocks)		Forward splits	
	Pre-split < \$1.00, post-split < \$5.00	Decrease depth, pre-split constrained	Increase depth, pre-split unconstrained	Increase depth, decrease Spread%	Decrease depth, increase Spread%
PostSplit	2.846***	-6.288**	2.040	2.966**	-0.233
	(1.06)	(2.69)	(2.40)	(1.49)	(2.10)
Log(tradesize)	-2.632***	6.490**	11.006***	10.590**	12.352
	(0.86)	(2.56)	(3.99)	(4.28)	(12.60)
Log(ntrades)	-4.902***	-1.923*	0.564	-2.319	1.983
	(0.52)	(1.07)	(1.43)	(1.81)	(1.92)
Volatility	-0.532	10.709**	-4.456	-68.542*	-51.818
	(4.20)	(4.50)	(10.34)	(40.00)	(48.65)
Constant	95.774***	13.710	-14.173	21.509	-33.598
	(7.25)	(17.11)	(22.94)	(19.03)	(62.28)
Observations	1,464	407	488	231	256
Adjusted R-squared	0.403	0.532	0.415	0.753	0.454

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