Shall We Haggle in Pennies at the Speed of Light or in Nickels in the Dark? How Minimum Price Variation Regulates High Frequency Trading and Dark Liquidity

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Abstract:

We demonstrate empirically how recent proposals to modify the penny-based system of stock trading may have simultaneous and opposite effects on the incidence of high frequency trading (HFT) and the trading of undisplayed (or "dark") liquidity. We do so by exploiting the fact that the existing ban on sub-penny quotations (Rule 612 of Regulation NMS) only applies to equity orders (bids or asks) priced at or above $1.00 per share, thus creating a sharp distinction in tick size regulation between those orders that are just above $1.00 and those just below it. Using a regression discontinuity design, we find that permitting sub-penny orders for stocks priced below $1.00 per share is associated with a sharp *increase* in the incidence of HFT and a sharp *decrease* in the trading of undisplayed liquidity (i.e., dark pools and broker internalization). Changes in market quality are mixed, with both quoted spreads and depths declining significantly for stocks priced just below the $1.00 cut-off. Our findings are robust to changes in stock exchange fee structures at the $1.00 cut-off, although maker/taker fee structures are shown to impair market quality both above and below this price point in certain contexts.

These results are strongly suggestive that recent proposals by major U.S. stock exchanges to permit sub-penny orders for stocks priced above $1.00 per share may result in greater HFT without necessarily changing the costs of trade execution. Conversely, Congress' mandate in Section 106(b) of the JOBS Act for the SEC to investigate increasing tick sizes for emerging growth companies can be expected to erode further the amount of trading that occurs on conventional stock exchanges while potentially reducing the incidence of HFT. Lastly, our findings indicate that any reform to either increase or decrease tick sizes should be accompanied by limitations on exchanges' maker/taker fees to minimize the incentive these fees can create for market manipulation.

1. Introduction

Over the past several years, a confluence of legal and technological factors has made U.S. market structure one of the most controversial domains of modern capital markets. Starting with the deregulation of the brokerage industry in 1975, a host of U.S. regulatory initiatives have sought to reduce and make uniform the costs of trading equity securities across an ever-growing number of trading venues. Yet while such efforts largely succeeded in reducing the cost of executing individual trades, they have also been accompanied by changes in U.S. market structure that, for many, seem considerably less benign. Perhaps most notably, these include the emergence of automated high-frequency trading (HFT) and an increase in trading in venues such as so-called "dark pools" that do not publicly display price quotations (what we refer to as trading hidden liquidity (THL)). Concerns with both developments have prompted regulators within the U.S. and internationally to propose curtailing each: HFT due to its potential role in facilitating market manipulation and in destabilizing markets; THL due to its potential role in undermining transparent price discovery and in diminishing the public liquidity available on conventional stocks exchanges.

In this paper, we exploit a regulatory discontinuity in the quoting of U.S. equity securities to demonstrate the central role that U.S. regulations concerning minimum tick size, or minimum price variation (MPV), have played in modulating the prevalence of both HFT and THL. Indeed, we demonstrate that such is the relation between MPV regulations and HFT and THL that certain regulatory proposals aimed at curtailing one practice may in fact increase the incidence of the other absent additional regulatory reform. In particular, recent regulatory proposals to curb HFT through policy interventions focused on pricing—such as through a "financial transactions tax" or increases in tick size increments—are likely to encourage THL. Understanding this relation is also of critical importance in assessing Congress' mandate in Section 106(b) of the Jumpstart Our Business Startups Act (the "JOBS Act") which mandates that the SEC investigate increasing the MPV for quoting the securities of emerging growth companies. To the extent the SEC acts to increase the MPV for certain companies, our findings suggest such an action may erode further the amount of trading that occurs on conventional stock exchanges while potentially reducing the incidence of HFT for these companies.

While often conflated within the popular press, HFT and THL reflect two distinct types of trading strategies which produce distinct consequences on price discovery and market liquidity. In terms of strategy, traders focusing on HFT typically seek to profit from discrete, short-lived pricing inefficiencies by rapidly bidding on and selling securities, customarily through pre-programed algorithms. The emergence of so-called "maker/taker" fee structures at stock exchanges—whereby limit order providers are paid a "maker" rebate and traders using market orders are assessed a "taker" fee—create an additional profit opportunity for such traders provided they can position their limit orders at the top of exchanges' order books. For firms engaged in HFT, minimizing the latency of processing information and entering orders is therefore of paramount importance to profitability. In contrast, a trader focusing on THL—typically a broker-dealer—will generally seek to profit by providing liquidity to investors without the necessity of publishing public bids or paying exchange access fees, thus minimizing the price impact and cost of the transaction. Access to investors looking for liquidity—rather than speed of trading per se—is accordingly a primary goal of those engaged in THL.

Notwithstanding these distinct strategies, each form of trading is intimately tied to regulations concerning the quotation of bids and offers. Indeed, as documented by Brogaard (2010), a primary catalyst for the emergence of high frequency trading was the decimalization of U.S. capital markets in 2000, which resulted in the price of stocks being quoted in pennies rather than fractions of a dollar. Smaller tick sizes led to both a surge in market message traffic as well as a dramatic reduction in quoted spreads for many stocks. Both developments favored algorithmic trading strategies capable of processing quickly the increased message traffic, while reducing the costs of rapidly trading in and out of positions.

Yet while more granular pricing promised to increase competition and lower trading costs, the years following decimalization also revealed that there were limits to the benefits offered by finer pricing increments. In particular, post-decimalization trading brought with it the possibility for both penny and *sub*-penny orders, raising concerns that traders might use sub-penny quotations to "step ahead" of penny-priced limit orders by an economically insignificant amount, thereby diminishing the incentive to provide liquidity. Such behavior might also facilitate "flickering" quotations among exchanges while limiting the depth that might be available at any particular price point. In response to these concerns, Rule 612 of Regulation National Market System ("Reg. NMS") therefore banned market participants from accepting, ranking, or displaying orders or quotation interest in a pricing increment finer than a penny.

In so doing, however, this price-based restriction on quotations facilitated the most dominant form of THL: broker internalization. Specifically, because Rule 612 only bans sub-penny *quoting* but not sub-penny *trading*, it permits broker-dealers to avoid routing retail order flow (in particular, market orders) to publicly displayed limit books by filling such orders internally without publicly displaying brokers' trading interest. The reason stems from the fact that while Reg. NMS and a broker-dealer's duty of best execution prohibit a broker from filling a customer's order at a price that is worse than the National Best Bid or Offer (NBBO) available through exchanges' publicly-displayed limited order books, a broker can satisfy Reg. NMS and its duty of best execution by filling such an order at a price that is better than the NBBO (Macey and O'Hara, 1997). Through allowing a broker to execute a sub-penny trade, Rule 612 thus allows a broker to execute internally a customer's market order in compliance with its legal obligations given that the price can always be superior to the prevailing penny-priced NBBO. Indeed, in promulgating Rule 612 the SEC specifically acknowledged the benefits to retail customers of allowing broker-dealers to execute trades in sub-penny increments insofar that it facilitated price improvement over the NBBO for market orders—one of the standard metrics for evaluating whether a broker has discharged its best execution obligation.

Despite these links between MPV regulations and HTF as well as between MPV regulations and THL, remarkably little research has emerged examining how U.S. pricing regulations might jointly affect the incidence of both. Although a burgeoning academic literature now exists that analyzes HTF and THL and their effects on market quality, prevailing studies have largely treated each as distinct, unrelated phenomenon. Indeed, recent studies on THL have largely ignored entirely the role of broker-dealer internalization as a source of THL, focusing instead on formal "dark pools"—broker-dealers that operate as regulated Alternative Trading Systems—in providing undisplayed liquidity to institutional investors (see, e.g., Weaver, 2010; Buti, Rindi, and Werner, 2010; O'Hara & Ye, 2011). Yet as emphasized by the Securities Exchange Commission in its 2010 Concept Release on Equity Market Structure, the rise in undisplayed liquidity has been driven primarily by broker-dealer internalization which accounted for almost 70% of trades executed in undisplayed venues in 2009 compared to just 30% being executed in

dark pools. To the extent regulators and market participants express concerns about the consequence of undisplayed liquidity on the price discovery process and the incentives of market participants to provide public liquidity, it is therefore broker-dealer internalization that is often the focus of their inquiry (Securities and Exchange Commission, 2010; Dick, 2010).

As we demonstrate below, documenting how MPV regulations jointly affect both HTF and THL provides a novel means to examine what is often a trade-off between HTF and THL and its effects on market quality. While Rule 612 of Reg. NMS mandates that all orders be priced in an increment of $0.01, an important exception exists for those orders priced at below $1.00 in which case quotations can be priced in increments of $0.0001. This exception, which was designed to allow more granular bidding of low-priced stocks, permits the use of a regression discontinuity (RD) design insofar that orders resting on either side of the $1.00 cut-off can effectively be viewed as having been assigned randomly to one of two treatments: Above the $1.00 cut-off, orders are subject to both (i) higher trading costs imposed by the minimum penny quote size (thus theoretically deterring HTF) and (ii) greater opportunities for sub-penny price improvement (thus theoretically encouraging BD internalization); below the cut-off, orders are subject to both (i) lower trading costs by virtue of the ability to quote in sub-penny increments (thus theoretically encouraging HTF) and (ii) a diminished risk of sub-penny price improvement (thus theoretically discouraging BD internalization). Figures 1(a) and 1(b) show visually the sharp effect Rule 612 has on subpenny orders by plotting the average incidence of subpenny quotations (bids and offers) during 2011 as a function of order price truncated to two decimal places. Figure 2 shows a similarly sharp increase in the average incidence of subpenny trades during 2011 immediately below the $1.00 cut-off. (Point estimates and standard errors for each figure are contained in the legends.)

[INSERT FIGURES 1A AND 1B HERE]

Our analysis yields a number of results. We provide compelling new evidence on the relation between MPV regulations and their simultaneous effects on both HFT and THL. Over the course of 2011, we find that stocks trading immediately below the $1.00 cut-off evidenced a discontinuous eight percentage point drop in the incidence of off-exchange trading relative to those trading at $1.00, a result consistent with a decrease in THL caused by a decrease in the MPV from $0.01 to $0.0001. At the same time, we find that quotations just below the $1.00 cut-off were associated with a discontinuous increase in HFT, as measured by the frequency with which exchanges update their Best Bid and Offer (BBO) published on the consolidated tape. Significantly, analysis of these effects in light of changes in maker-taker fee structures at the $1.00 cut-off suggest both results are likely to be conservative estimates of the true effect of changes in MPV on the incidence of THL and HFT. Overall, our results provide striking evidence of the extent to which MPV regulations can play in modulating the prevalence of HFT and THL.

Turning to the effect of changes in MPV on market quality, we find that both quoted spreads and quoted depths decrease below the $1.00 cut-off. In the case of spreads, our RD analysis reveals a drop in quoted spreads just below $1.00 of approximately 1.3 cents, or about one-half the average spread at the $1.00 cut-off. This savings in quoted spreads, however, was considerably offset by a significant drop in quoted depths. For instance, analysis of quoted bid depth at the national best bid reveals a discontinuous 79% drop in average bid depth and a 63% drop in average ask depth just below $1.00. Combined with the large increase in message traffic below $1, these results provide reason to doubt whether further decreases in MPV would result in meaningfully greater liquidity. At the same time, they suggest recent

proposals to increase the MPV for certain companies are unlikely to a have uniformly negative effect on trading costs, but will likely increase both quoted spreads and depths. These effects would be in addition to the more general change in the incidence of HFT and THL occasioned by an increase (or decrease) in the MPV.

An immediate application of our results is to the ongoing policy debate concerning the use of MPV regulations to address a variety of perceived problems with existing U.S. market structure. For instance, in response to research suggesting that decimalization has harmed the liquidity for small and middle capitalization company securities (Weild, Kim, and Newport, 2012), the 2012 JOBS Act specifically authorizes the Securities and Exchange Commission to increase the minimum pricing increment to as high as $0.10 for small- and medium-sized publicly-traded companies. Concerns that HFT might contribute to market instability have similarly led to proposals to limit HFT by increasing the cost of trading to HFT firms through increasing the minimum pricing increment. At the same time, the major U.S. stock exchanges and the SEC in its 2010 Concept Release on Market Structure have suggested permitting sub-penny quoting as a means to reduce broker-dealer internalization.[1] Emphasizing the amount of trading that takes place through undisplayed liquidity, the SEC and the exchanges have suggested that moving to sub-penny quoting will permit better price discovery through returning trades to conventional, public trading venues. In light of these conflicting policy proposals, our research highlights the challenge of using MPV reform as a mechanism for advancing any one of them.

We caution, however, that as with prior empirical work, our analysis has limitations. Most notably, our research design is necessarily limited to trading behavior in the context of equity securities that are quoted on either side of our $1.00 price threshold. These securities no doubt differ in important respects from securities that trade at higher price points. Critically, to the extent these differences are not discontinuous at $1.00, such differences do little to undermine our central findings. However, focusing on this domain of the market nevertheless constrains our ability to ascertain the magnitude of the effect of MPV regulations on the trading of securities priced far from the $1.00 cut-off. And as discussed below, even within this domain of the market, the structure of prevailing maker-taker fee arrangements at stock exchanges likely induces a downward bias in our estimates of the effect of MPV regulations on THL and HFT at $1.00. As such, our findings are best viewed as providing a rare empirical look at the general relation between tick size and two critical phenomenon of market structure.

This paper is organized as follows. The next section sets out theoretical arguments and empirical evidence surrounding the relation between MPV regulations and various measures for market quality, including the overall incidence of HFT and THL. Section 3 presents our empirical predictions and identification strategy. Section 4 describes our data, the proxies we use for measuring the incidence of HFT and THL, and our method for selecting our sample of securities. Section 5 presents results on the effect of sub-penny quoting on the incidence of HFT and THL, as well as on traditional metrics of market quality. Section 6 concludes by discussing the implications of these results on contending proposals to decrease as well as increase the MPV.

[1] See Letter to the Securities Exchange Commission from BATS, the NYSE, and Nasdaq, April 30, 2010.

2. Tick Size Regulation, Market Quality, and the Incidence of HFT and THL

Rules establishing an MPV for quoting and trading equity securities have long been a primary area of regulatory focus for modern securities markets. By fixing the number of price points over a dollar at which traders can express buying and selling interest in a security, MPV regulations can critically shape trading dynamics. For instance, constraining the number of price points within a dollar over which traders can place orders forces orders to cluster along those points, potentially increasing the depth of liquidity at any given point. Limiting price points at which traders can place orders might also facilitate trading by reducing the time required for buyers and sellers to negotiate a transaction (Angel, 1997; Harris, 1991). At the same time, forcing traders to bid at fewer fixed points prevents traders from competing for orders within them, potentially increasing the cost of trading by keeping spreads wider than would occur were traders free to place orders at more granular prices. For these reasons, regulatory efforts over the past twenty years to make U.S. markets more efficient and liquid have often focused on modifying the MPV.

2.1 Regulatory History of U.S. Tick Size Regulation

For most of the history of U.S. capital markets, stock exchanges themselves tended to regulate the MPV at which securities could be quoted and traded, with most adopting fractional increments of a dollar to limit the number of price points over which orders could be placed. Rules for the New York Stock Exchange, for instance, required an MPV of one-eighth of a dollar from the time the NYSE switched from quoting prices as a percentage of par value to quoting in dollars (Angel, 1997). A similar rule prevailed on the over-the-counter market which would eventually become Nasdaq.

Concerns during the 1990s that fractional pricing was unduly hindering quote competition eventually led the SEC to investigate the advisability of moving to a finer-grained MPV. In light of the public discussion that followed the SEC's investigation, U.S. exchanges and Nasdaq began to voluntarily reduce the MPV for certain securities from 1/8th of a dollar to 1/16th. With pressure from the SEC and Congress, the exchanges and Nasdaq further agreed in the late 1990s to implement decimal pricing for all securities but expressed the need for a coordinated, phased-in plan to implement the changes. In January 2000, the SEC established a coordinated plan for full decimalization and ordered the exchanges and Nasdaq to develop an implementation plan for decimal pricing. In compliance with this order, the exchanges and Nasdaq commenced a series of phase-ins throughout 2000 and 2001, with full decimalization being completed in April 2001.

Because the original decimalization order did not specify a precise decimal increment, trading venues initially differed in how they permitted market participants to submit decimalized orders. For instance, while the major exchanges and Nasdaq limited orders to penny increments, several electronic communication networks (ECNs) permitted quotations in sub-penny increments, with many of these quotations resulting in trades at the $0.001 and $0.009 price points. The experience eventually raised concerns among both the exchanges and the SEC that sub-penny quoting was being used primarily by traders to "step ahead" of penny-priced limit orders rather than for legitimate price discovery. The SEC was also concerned that sub-penny quoting could also cause "flickering" quotations while limiting the depth that might be available at any particular price point.

In response to these concerns, the SEC proposed Rule 612 (the "Sub-Penny Rule") in 2004 as part of Reg. NMS to establish an MPV of one penny. In general, the rule sought to avoid the problems associated with sub-penny quotations by prohibiting market participants from accepting, ranking, or displaying orders or quotation interest in a pricing increment finer than a penny for most National Market System stocks. Since its inception, the single exception to this rule has been for orders priced at less than $1.00 per share, in which case the minimum pricing increment is $0.0001. While Rule 612 formally allows a trading venue to increase the MPV from these levels (subject to SEC review), no trading venue has exercised this flexibility since the adoption of Reg. NMS in 2005. As a result, all National Market System securities are presently subject to an MPV of one penny, except for those orders priced at less than $1.00 per share.[2]

2.2 Tick Size and Market Quality: Empirical Evidence

In light of the potential effect of MPV regulations on trading dynamics, a number of studies have examined how changes in the MPV over time have affected market quality. Most of these studies have examined the issue by turning to well-established measures concerning the liquidity of securities markets—that is, the ability of an investor to trade a given size of a security position quickly and at a low cost. Several studies, for instance, have examined the consequence of decimalization on both quoted and effective spreads. Overall, these studies found that, on average, quoted and effective spreads each declined following decimalization, consistent with the notion that a smaller MPV should result in greater price competition among market makers (e.g., Chakravarty, Harris, and Wood, 2001; Bacidore, Battalio, and Jennings, 2003; Bessembinder, 2003), with the effect being especially pronounced among large- and mid-capitalization companies (Bessembinder, 2003). However, consistent with the theory that a larger MPV can create greater depth at any given price point, depth at quoted prices also declined with decimalization (e.g., Bessembinder, 2003); Chakravarty, Harris, and Wood, 2001).

In light of this combination of lower average spreads and diminished quoted depth, researchers have turned to alternative measures of liquidity to evaluate how decimalization affected overall market quality. Bacidore, Battalio, and Jennings (2003), for instance, found that while depth at the NBBO declined following decimalization, the cumulative depth within 15 cents of the quote midpoint was unchanged, suggesting that decimalization might have had only a minor effect on the depth available within a specified range of the quote midpoint. Consistent with this theory, they also found a decrease in effective spreads for large trades, a result somewhat at odds with an earlier study by Chakravarty, Harris, and Wood (2001) finding that decimalization did not change effective spreads for large trades. Using institutional order data, Chakravarty, Panchapagesan, and Wood (2005) as well as Werner (2003) similarly found that institutional transaction costs declined, on average, following decimalization. These declines in effective spreads, however, appeared to depend on the speed with which an order was executed. Specifically, by comparing orders worked for more than a day with orders executed within a day, Chakravarty, Panchapagesan, and Wood (2005) found that orders executed within a day saw increases in transaction costs. Werner (2003) similarly finds that the reduction in depth following decimalization has led institutional investors to divide trades into smaller orders, resulting in longer trade

[2] Beginning in 2012, several stock exchanges successfully petitioned the SEC to exempt from the Sub-Penny Rule the exchanges' Retail Price Improvement Programs to be run on a pilot basis. In general, these programs seek to enable stock exchanges to compete with broker-dealer internalizers for retail order flow by allowing program participants (liquidity suppliers) to submit non-displayed orders that are better than the NBBO by a subpenny amount.

executions. Collectively, these findings suggest that whether a smaller MPV results in lower trading costs for larger trades is dependent on the speed with which the trade needs to be completed.

Although initial studies of decimalization focused primarily on traditional liquidity measures, a separate line of research has increasingly examined how MPV regulation can both effect—and be effected by—other aspects of market structure. Several studies of MPV regulation on spreads, for instance, have revealed that the greatest declines in spreads associated with decreasing the MPV occurred for stocks trading in a continuous auction market (such as the NYSE) where competing liquidity providers can use decimal pricing to outbid rivals (Goldstein and Kavajecz, 2000). These effects are in stark contrast to what occurred in a true dealer market (such as Nasdaq prior to 1997) where spreads remained virtually unchanged following a decrease in the MPV from $1/8^{th}$ to $1/16^{th}$ of a dollar, highlighting the importance of allowing liquidity providers to interact before MPV regulations can have any meaningful effect on spreads (Christie, Harris, Kandel, 2008). Recent concerns that decimalization has adversely affected the incentive of small and middle-sized companies to go public in U.S. equity markets (Weild, Kim and Newport, 2012) are similarly rooted in an understanding that the consequence of MPV regulation can be powerfully moderated by other attributes of market structure. In particular, proponents of this theory argue that by diminishing the profitability of market making activities, reductions in the MPV have forced market participants to discontinue a tradition in which profits from market-making for more liquid issuers were used to subsidize market support and research for smaller, less liquid issuers. It is this argument that has induced Congress and the SEC to consider increasing the MPV for small- and medium-sized issuers.

2.3 Tick Size and the Incidence of HFT and THL

Although not currently part of the public policy debate concerning changes to the MPV, there are strong reasons to believe that MPV regulations also affect market quality through their ability to modulate the incidence of both HFT and THL. Research on each phenomenon has increasingly suggested that they have potentially powerful effects on overall market quality.

2.3.1 Market Quality and Trading Hidden Liquidity

With respect to THL, the SEC and academic researchers have long been concerned about the consequence of routing customer orders to broker-dealers where they are executed internally without being sent to public exchanges. Indeed, practices such as internalization and routing orders to dark pools are part of a broader, well-established category of order routing called “preferencing” in which a broker executes a customer order without sending it to an exchange. In general, because a broker typically has discretion over where to route a customer’s order for execution, a broker might prefer to route the order to any number of non-exchange venues including: executing an order internally against another customer’s contra-side order, executing the order internally against the broker’s own capital and covering in the market to capture the spread, or routing the order to another market-maker in exchange for a payment. To be sure, a broker’s duty of best execution constrains this discretion, but the conventional approach to this standard permits such practices so long as the trade executes at price equal to or better than the then-prevailing national best bid or offer (NBBO). Indeed, it is this desire to comply with best execution obligations that creates such a strong inducement for broker-dealers to provide subpenny price

improvement over the NBBO for their internalized orders.[3] As a result, a broker receiving a marketable order will often have an incentive either to internalize the order with a subpenny trade to capture the spread or, alternatively, to route the order to a market-maker or dark-pool through a payment-for-order flow arrangement in which the customer receives a final price that is at or better than the NBBO. In recent years, the incentive to avoid exchanges has been further enhanced by the growth of so-called "maker/taker" access fees (disclosed below) in which marketable orders that are routed to exchanges are charged a fee for taking liquidity from the exchange which arguably discourages brokers from routing orders there.

As order-flow arrangements grew during the 1990s, a number of papers sought to examine how the practice of preferencing might affect market quality (see Macey & O'Hara, 1997, for a review). One area of concern was the extent to which preferencing advantaged dealer markets rather than continuous auction markets where orders directly interact with one another (Ferrell, 2001). In contrast to a dealer market where a broker collects the bid-ask spread on marketable orders, a continuous auction market generates no spread when orders interact, thus impairing the ability of an auction market to purchase order flow from brokers deciding where to route customer orders. As such, according to Ferrell (2001) the practice of preferencing both deprives customers the opportunity for price improvement over the NBBO while potentially impairing the price discovery process for the market as a whole. In particular, the latter effect might occur if dealers quote larger spreads in anticipation that actual trades will be negotiated at better prices (Harris, 1995) or if limit order providers cease submitting orders to exchanges given the decreased chance of being filled (Dick, 2010). Price discovery and market quality might also be impaired by the quality of the orders that make it to the public limit books. According to this "cream skimming" hypothesis, dealers have an incentive to internalize uninformed orders (such as those submitted by retail traders), causing non-preferenced orders to pose a higher risk of being submitted by informed traders (Harris, 1995; Easley, Keifer, and O'Hara, 1996; Bessembinder and Kaufman, 1997). To the extent this occurs, preferencing should result in wider spreads and reduced depth in the public, "lit" market to compensate for the increased percentage of informed traders in the public order flow (Chakravarty and Sarkar, 2002).

Empirically, efforts to identify whether preferencing results in these effects have produced mixed results. While Hasbrouck (1995) as well as Bessembinder and Kaufmann (1995) find evidence consistent with cream-skimming, preferencing has not been found to produce uniformly wider spreads. Battalio, Green and Jennings (1998), for instance, examined Merrill Lynch's October 1995 decision to reduce its routing of orders to Merrill-affiliated specialists on the Boston and Pacific stock exchanges and found that relative to a matched sample of stocks, spreads on the NYSE fell in the stocks affected by Merrill's

[3] As discussed in Ferrell (2001), the pressure to provide price improvement over the NBBO arose in large part due to the Third Circuit's decision in Newton v. Merrill, Lynch, Pierce, Fenner& Smith, Inc., 135 F.3d 266 (3d Cir. 1998), where the Third Circuit found that a broker-dealer that automatically executed customer trades at the NBBO may not be in compliance with its best execution obligations. Additionally, the manner in which Reg. NMS discussed the desirability of brokers' providing price improvement for their customers has also created a perception within the industry that best execution may require a broker to seek out opportunities for customer price improvement. In a comment letter to the SEC outlining how internalizers can often be subject to significant market risk when trading with their customers, TD Ameritrade (2010) articulated this perception: "One could certainly suggest that the [market-maker] simply avoid the price improvement opportunity and that the market maker or broker should have simply sent the order to fill at the NBBO. In such case, however, the broker would run the risk of being accused of violating its best execution obligation, as Regulation NMS elevated price improvement above all else." Finally, the incentive for offering price improvement over the NBBO is also encouraged by Rule 605 of Reg. NMS, which requires that broker-dealers publicly disclose their rate of price improvement over the NBBO as a core measure of execution quality.

decision. In contrast, Battalio (1997) finds that effective bid-ask spreads did not increase and quoted spreads fell when a major third market broker-dealer (Madoff Securities) began selectively purchasing order flow. Battalio, Green and Jennings (1997) obtained results along similar lines, and empirically demonstrated that the opportunities the Boston and Cincinnati stock exchanges offered to internalize their orders during the 1990s did not have a significant effect on quoted or effective spreads. More recent studies, however, suggest that preferencing may have more pernicious effects on market quality in the current trading environment. Using trades reported to FINRA's trade reporting facility (TRF) as a proxy for internalized order flow, Weaver (2011) finds a significant negative relation between off-exchange reporting and effective spreads. Internationally, a similar result appears in Larrymore and Murphy (2009) who find that quoted spreads declined significantly following the 1998 decision by the Toronto Stock Exchange to restrict internalization.

2.3.2 Market Quality and High Frequency Trading

The growth of automated trading technologies in recent years has inspired a large number of academic studies concerning its effect on market quality. Of particular note has been the emergence of proprietary trading firms who utilize low latency, automated trading protocols to capture short-term profits from the bid-ask spread as well as incentive rebates offered by various trading venues (Zhang, 2010). Such trading—which we refer to as HFT in keeping with both the academic literature (see Gomber, Arndt, Lutat, and Uhle, 2011) and SEC usage (Securities and Exchange Commission, 2010)—is estimated to account for over seventy percent of trading volume in U.S. equity markets, up from zero in 1995 (Zhang, 2010). It differs from other forms of common algorithmic trading used by institutional investors primarily in the speed with which HFT firms seek to enter and close out positions. Whereas an institutional investor might choose to exit a position held for several months by using a Volume-Weighted Average Price (VWAP) algorithm that executes a trade over the course of one or more days, a firm dedicated to HFT will typically utilize a trading algorithm to enter and then close a position within the course of minutes, seconds, or even milliseconds. Gomber, Arndt, Lutat, and Uhle (2011) provide an overview of the different trading strategies often used by HFT firms.

Initial research on HFT largely focused on how the presence of HFT affected liquidity measures such as quoted and effective spreads as well as quoted depth. Consistent with the view that HFT firms often engage in passive market making and arbitrage strategies, these studies generally found HFT to have a positive effect on liquidity while contributing to efficient price discovery. Using Nasdaq order book data, for instance, Hasbrouck and Saar (2012) identify proxies for low-latency trading and find that increases in HFT improve traditional market quality measures such as short-term volatility, spreads, and displayed depth in the limit order book. Similarly, using NYSE message traffic as a proxy for algorithmic trading, Hendershott, Jones and Menkveld (2011) similarly find that higher rates of algorithmic trading are associated with narrower spreads as well as a reduced amount of price discovery associated with trades, but quoted depth decreased suggesting a non-uniform effect on overall market quality. Brogaard (2010) also finds in a sample of 120 Nasdaq stocks that HFT firms add substantially to the price discovery process by providing the best bid and offer quotes for a significant portion of the trading day. Similar results have also been found at non-U.S. exchanges (see, e.g., Hendershott and Riordan, 2011; Jovanovic and Menkveld, 2010; Groth, 2011).

Recently, a number of high profile trading irregularities involving trading algorithms, such as the near-collapse of Knight Trading in August 2012 and the tumultuous IPOs of Facebook and BATs Exchange, have caused regulators and academics to examine the effect of HFT on the broader question of market stability (Lauer, 2012). Kirilenko, Kyle, Samadi, and Tuzun (2011), for instance, examine the behavior of high frequency traders in Emini S&P 500 futures contracts during the events surrounding the Flash Crash, concluding that while high frequency traders may not have caused the flash crash, their response to the high selling pressure exacerbated volatility. Zhang (2010) similarly examines the relationship between HFT and longer-term measures of stock volatility and price discovery. Consistent with the theoretical model of Froot, Scharfstein, and Stein (1992) in which a market with short-horizon traders performs less efficiently than one with long-term traders, Zhang finds that HFT hinders the incorporation of fundamental news into stock prices and is also positively correlated with daily stock price volatility. To explain this latter result, Zhang suggests (among other possibilities) HFT firms may be using low-latency technologies (such as co-location services and fast data feeds offered by exchanges) to detect and front-run large institutional orders. Using a formal model, Cartera and Penalva (2011) build on this view of HFT firms and conclude that the presence of HFT firms who seek to extract rents from other traders can increase stock price volatility through increasing the price impact of trades and causing greater fluctuation of prices.

In addition to concerns with front-running institutional investors, Ye, Yao and Gai (2012) investigate how HFT might also create a system-wide externality born by all traders. In particular, they examine periodic bursts of message traffic typically associated with HFT and find that such bursts of activity often arise simultaneously across companies sharing the same data feed for the consolidated tape. They interpret this evidence as consistent with a "quote stuffing" hypothesis in which HFT firms seek to overwhelm a stock exchange with cancelled quotations in order to slow down rival traders. Moreover, because stock exchanges must continuously upgrade their trading systems to accommodate the increased message flow from HFT firms, HFT firms must continuously increase their message flow to produce the desired effect of quote stuffing. The end result, they claim, is a vicious cycle of infrastructure investment by HFT firms and stock exchanges, much of which is born by traders as a whole who must pay for the costs of operating national exchanges. Egginton, Van Ness and Van Ness (2012) similarly find intense, episodic spikes in quote activity, which they note is often linked to HFT. Regardless of whether such activity represents market manipulation, they find that episodes of quote stuffing produce wider spreads for the targeted stock as well as increased short term volatility and higher trading costs.

3. Empirical Predictions and Identification Strategy

3.1 MPV as a Regulator of THL and HFT

These considerations regarding the effect of THL and HFT on market quality become all the more important in the context of current proposals to modify the MPV given the potential for any such modification to change significantly the incidence of each phenomenon. In the case of HFT, a further decrease to the MPV (as has been proposed by the major U.S. stock exchanges) is likely to increase the incidence of this form of trading for the same two reasons that decimalization is often cited as a contributing factor to its rise after 2000. First, to the extent that the MPV artificially widens the spread that liquidity providers would demand for a security, decreasing the MPV below one penny should result in reduced spreads, which should reduce the cost of executing high-frequency trading transactions.

Second, reducing the MPV should result in additional message traffic due to smaller pricing increments. In particular, as suggested by Harris (1999) in the context of decimalization, order and cancellation messages should increase with smaller pricing increments as traders seek to profit from arbitrage trading strategies. For instance, a trader who seeks to peg a limit order to an underlying index in a sub-penny quoting environment will likely submit more cancellation and change messages for a given continuous change in the index than in a penny quoting environment. The resulting increase in message traffic should benefit firms having the capability of processing quickly large volumes of message traffic while creating new low-latency trading opportunities as other traders (e.g., institutional investors) struggle with increased information processing demands. Conversely, increasing the MPV should lessen the incidence of HFT for the same two reasons.

In contrast, increases in the MPV (as contemplated by Section 106(b) of the JOBS Act) should be expected to have similarly strong effects on the incidence of THL. As noted previously, a primary reason for brokers to avoid routing orders to an exchange arises from the opportunity for them to capture the bid-ask spread on marketable orders (either directly through broker internalization or indirectly through payment for order flow). Accordingly, as argued in the context of decimalization by Chordia and Subrahmanyam (1995), Kandel and Marx (1999) and Harris (1999), an MPV that artificially widens the bid-ask spread should therefore encourage preferencing. Consistent with this theory, Chung, Chuwonganant, and McCormick (2004) found that preferencing rates on Nasdaq generally declined following decimalization. For similar reasons, any further decrease in MPV should be expected to decrease the rate of preferencing while modifying the MPV to above one penny should result in an increase in it.

In addition to influencing market quality through these two "structural" features of trading, research on the effects of decimalization during 2000 suggests that modification of decimal-based pricing should also continue to affect more conventional measures of liquidity such as trading spreads and depth. Specifically, just as reducing the MPV from sixteenths to pennies generally resulted in lower spreads and depth in 2000, further reductions in the MPV should at the margin be expected to have similar effects in today's market. In contrast to the era of decimalization, however, the growing influence of both HFT and THL since 2000 makes it an open question whether any of the proposed modifications to the MPV will continue to have these direct effects on liquidity. For instance, studies such as Cartera and Penalva (2011) concerning the positive association of HFT and volatility, when combined with the hypothesize that lower tick size increases the incidence of HFT, raises the possibility that the negative effect of HFT on trading spreads might overwhelm whatever spread reductions might otherwise have been achieved through a lower MPV.

3.2 **Empirical Approach: A Regression Discontinuity Design**

In contrast to prior studies of decimalization, the absence of any changes to U.S. MPV regulations in the recent past naturally poses a significant obstacle for identifying how further changes to the MPV might affect market structure in the current trading environment. We therefore turn to a regression discontinuity design to overcome this challenge. As noted by Hahn, Todd and van der Klaauw (2001), the "regression discontinuity data design is a quasi-experimental data design with the defining characteristic that the probability of receiving treatment changes discontinuously as a function of one or more underlying variables" (p. 1). As applied to MPV regulations, the current regulatory regime fits

nicely into this data design on account of the sharp regulatory distinction involving the MPV created by Rule 612 of Regulation NMS. As noted previously, the rule (which generally establishes an MPV of one penny) functions by prohibiting quotations in sub-penny increments for all orders at or above $1.00 while permitting a pricing increment of $0.0001 for orders that are less than $1.00. The MPV regulation that applies to any given trading order will therefore vary discontinuously based on the following function:

$$Subpenny_o = \begin{cases} 1, & p_o < 1 \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

where *Subpenny* is an MPV rule that permits subpenny quoting of an order (i.e., a bid or ask), *o* indexes orders, and *p* is the price of the order.

Using this discontinuous treatment of MPV regime, we develop the following baseline model to evaluate the effect of changing the MPV on various measures of market quality:

$$Market\ Quality_i = \alpha_0 + \beta_0 Subpenny_i + \varepsilon_i \quad (2)$$

where *i* indexes order prices truncated to two-digits (e.g., $0.98, $.0.99, $1.00, $1.01, etc.), $Market\ Quality_i$ represents the outcome variable of interest averaged for a given two-digit order price (e.g., the average incidence of HFT at orders priced at $0.98, $0.99, $1.00, etc.), and ε_i is a random error term. Because inclusion in the treatment group is based on the predetermined cut-off point of $1.00, the variable *Subpenny* generates a discontinuity in the treatment around this point which allows us to estimate the effect of modifying the MPV regime on market quality. Moreover, our estimate of β will not be affected by any omitted variables contained in ε_i—even if they are correlated with the price of an order—as long as their effect is continuous around the threshold of $1.00. Intuitively, orders just below the cut-off point should be similar to those orders just above the cut-off point, implying that the distribution of the unobserved ε_i should be similar for observations with *Subpenny=0* and for observations with *Subpenny=1*. This reasoning suggests that *Subpenny* status is locally randomly assigned—that is, it suggests that *Subpenny* should be of no utility in predicting ε_i.

Although this approach overcomes a critical data limitation, it nevertheless comes with a disadvantage common to all RD designs, which is the difficulty of generalizing the results to domains far from the cut-off. For instance, qualitative differences may exist in the trading of equities securities far above $1.00 per share that might moderate the effect of MPV regulations on market quality, requiring caution in applying the local treatment effect to these higher-priced securities. We consider these limitations in more detail in Section 4.3.

4. Data, Measures, and Sample Selection

Because we are interested in examining how MPV regulations affect both the incidence of HFT and THL within the overall equity markets, all analyses were conducted using the Consolidated Tape Data for 2011 obtained from the NYSE Euronext's monthly Trade and Quote (TAQ) database. The TAQ database provides intraday trade and quote data time-stamped to the second for publicly-traded equities across all U.S. equity markets based on reporting obligations imposed on exchanges and FINRA members by Reg. NMS. We describe below how these obligations relate to our primary measures for HFT and THL as well as how we used the TAQ data to generate our list of sample securities.

4.1 Trade Reporting Obligations and Measures for THL

Our primary measure for THL activity arises from the obligations of exchanges and FINRA members to report publicly trade executions under Reg. NMS. Rule 601 of Reg. NMS obligates each securities exchange and national securities association (i.e., FINRA) to adopt a transaction reporting plan for all transactions by their members in listed equity securities and further requires that the plan provide for a mechanism for consolidating and publicly disseminating such reports with all other Rule 601 transaction reports.[4] To discharge these obligations, U.S. exchanges and FINRA are parties to the Consolidated Tape Association (CTA) Plan, which requires the exchanges and FINRA to collect and report to the Securities Industry Automation Corporation (SIAC) for dissemination on the Consolidated Tape last sale data in all "Eligible Securities," which generally covers securities listed on the NYSE, the Amex, and regional exchanges. FINRA and exchanges trading Nasdaq-listed securities are also parties to a separate UTP Plan which imposes similar obligations on the parties with respect Nasdaq-listed securities. Each plan requires that each reported trade include, among other things, the date, time, price, size, and market on which the transaction occurred or to which it was reported. The TAQ database contains transaction data from the Consolidated Tape within its monthly Consolidated Trade file.

From this data, we use the reported market for each trade to measure the incidence of THL. Although the consolidated tape does not directly record the identity of non-exchange participants reporting a trade, the SEC has required since March 2007 that all off-exchange transactions be reported to a formal FINRA-managed Trade Reporting Facility (TRF) established at certain stock exchanges which report directly to the consolidated tape. As described by O'Hara and Ye (2011), this requirement effectively means that off-exchange trades made through a broker-dealer internalization or in dark pool (both of which were historically reported to an exchange and then consolidated with the exchanges' own trades when reported to the consolidated tape) are now effectively segregated and reported as having been executed at a FINRA TRF. While FINRA-reported trades include more than just broker-dealer internalizations and dark pool executions (e.g., transactions through Alternative Trading Systems), we follow Weaver (2011) and use the incidence of these trades reported by FINRA TRFs to proxy for THL.

4.2 Quote Reporting Obligations and Measures for HFT

Our measure for HFT activity relies on separate obligations imposed on exchanges and FINRA members under Reg. NMS to publish information concerning all bids and offers for Reg. NMS securities made on an exchange or by a FINRA member. Specifically, Rule 602(a) of Reg. NMS requires FINRA and each stock exchange to collect and make available to vendors the best bid and the best offer (including aggregate quotation sizes) for Reg. NMS securities that are currently available on each trading venue on a continuous basis.[5] As with their obligation to report trade executions, Rule 603 then obligates each exchange and FINRA to adopt a consolidated quotation plan, by which the exchanges and FINRA have agreed to provide this information to SAIC for publication in the Consolidated Quotation System (CQS). Because of these obligations, the CQS thus provides for any moment of the trading day a snapshot of the total, consolidated trading interest at the best bid and offer ("Consolidated BBO") available at each exchange and through a FINRA member. The TAQ database's Consolidated Quote file

[4] Prior to the implementation of Reg. NMS, a similar obligation was imposed on exchanges and members of FINRA (which was then the NASD) through Exchange Act Rule 11Aa3-1.

[5] Rule 602(b) further requires that each FINRA member promptly communicate to each exchange or FINRA (as applicable) its best bids, best offers, and quotation sizes for any Reg. NMS security.

contains the historical Consolidated BBO across exchanges for all Reg. NMS securities on a second-by-second basis.

While the TAQ data does not identify individual bids and offers made on a particular exchange, the legal obligations of a broker-dealer posting a bid or offer nevertheless make the TAQ quotation data useful for evaluating the level of trading interest across exchanges. Under Rule 602(b), each broker dealer is obligated to honor its bids and offers that comprise a venue's Consolidated BBO, thereby creating strong incentives for a broker-dealer to revise and update as promptly as possible its posted orders as the broker's buying or selling interest changes.[6] For any given stock the result is a steady stream of changing BBOs across exchanges throughout the trading day. Table 1, for example, shows the TAQ data for the company StemCells, Inc. on June 1, 2011 for the ten second interval following 10:56:41. As reflected in the table, activity at each reporting exchange can easily be inferred from changes in either order price or size (reported in round lots). The first two rows, for instance, reveal that on Exchange "P" (the NYSE Arca) a broker that had previously had an offer posted at $0.6551 at 10:56:40 had by 10:56:41 reduced its offer amount by 4 round lots (or 400 shares). Not surprisingly, updates occurring within a single second (such as those occurring in STEM at 10:56:44) are reported as having the same time entry; however, TAQ preserves the order in which the SAIC received the BBO update (Hasbrouck, 2010). As such, the TAQ data provides time series information on how frequently orders comprising the BBO are being changed across exchanges.[7] Because order updating is likely to signal the presence of algorithmic trading by HFT traders (Hendershott, Jones, and Menkveld, 2011), we use the rate of order updates per second to proxy for the presence of HFT.

[INSERT TABLE 1 HERE]

4.3 Sample Construction and Descriptive Statistics

To generate our sample of securities, we first merged the TAQ dataset for 2011 with all equity securities listed in CRSP as having been traded during that year. This initial screening process was necessary to eliminate from TAQ a number of order entries involving so-called "test" securities that allow market participants to test exchanges' integrated trading systems. Among the resulting 7,083 securities, we then identified all securities that had at least one order (bid/ask) below $2.00 during 2011. Because the discontinuity in orders at $1.00 is the source of identifying information, this latter restriction allowed us to estimate equation (2) on the subsample of firms trades and orders that are close to the point of discontinuity. Our final sample consisted of 974 securities issued by 962 firms that satisfied this condition. Where available, we obtained financial and accounting data for each firm from S&P's CapitalIQ database.

Table 2 provides descriptive statistics for the sample of firms compared to non-sample firms and to the entire CRSP dataset for 2011. As shown in Panel A, the 962 firms in the sample represented a broad cross-section of industries, with a slightly heavier concentration of manufacturing firms and a lower concentration of financial firms than are represented in the overall CRSP dataset. Inspection of the non-

[6] Rule 602(b)(3) specifically encourages such updating by broker-dealers by discharging a broker-dealer from its obligation to honor a previously posted bid or offer so long as "prior to the presentation of an order for the purchase or sale of a subject security, a responsible broker or dealer has communicated to its exchange or association … a revised quotation size."
[7] [Add note regarding under-reporting of all trading interest due Rule 604 and the definition of "bids" and "offers" in Rule 600.]

sample firms, however, revealed that this difference was driven primarily by the large number of exchange-traded funds (ETFs) among the non-sample firms which rarely traded below $2.00 per share. Sample firms also reflected a combination of both U.S. and foreign-incorporated entities. Among non-financial firms (which more consistently reported country of incorporation), approximately 20% of sample firms were incorporated in non-U.S. jurisdictions—slightly higher than the 18.6% reported by non-sample firms.

[INSERT TABLE 2 HERE]

The fact that the sample was limited to those securities having orders below $2.00 per share naturally raises the possibility that sample and non-sample firms differ according to financial performance and the overall liquidity of their securities. Most notably, because all major U.S. exchanges impose a $1.00 minimum bid price requirement for continued listing, a firm that trades for an extended period of time below $1.00 is at a heightened risk of having its securities delisted. On Nasdaq and the NYSE, for instance, a firm that trades for thirty consecutive days with a closing bid below $1.00 risks triggering a review of its continued listing eligibility. Although such firms are entitled to a lengthy compliance period of 180 days to increase their stock price (e.g., through a reverse stock split), such listing rules nevertheless create a heightened risk of delisting for our sample firms. As shown in Panel A, approximately 10% of sample firms had their securities involuntarily delisted in 2011 for reasons other than a merger or securities exchange compared to just 1% of non-sample firms.

Panel B of Table 2 further examines how sample and non-sample firms compared according to several accounting and performance metrics. Not surprisingly, firms in the sample were considerably smaller than non-sample firms in terms of both market capitalization and total assets. Sample firms also had notably lower mean and median return on equity, return on assets, and annual sales growth, suggesting overall weaker financial performance than non-sample firms. Although sample firms had slightly lower median leverage, they nevertheless had considerably greater stock price volatility. Trading volumes were also notably lower for sample firms compared to non-sample firms. In particular, mean and median price volatility for sample firms was almost twice that of non-sample firms while daily trading volumes for sample firms were approximately one-half those for non-sample firms. The similarity across sample and non-sample firms with respect to both mean and median Tobin's Q and Market-to-Book ratio, however, suggests investors nevertheless found sample firms attractive investments.

To evaluate whether these differences between sample and non-sample firms might comprise our research design, we looked into whether a hedge fund would be as interested in holding securities of sample firms as it would be in holding those of non-sample firms. Figure 0 indicates that returns are largely similar. Intuitively, this makes sense because the relative risk of holding sample firms is slight, and if there were meaningful disparities in returns, investors should gravitate towards sample or non-sample firms accordingly. In unreported results, we also investigated the Markowitz (1952, 1959) efficient frontier separately for sample and non-sample firms and found them to be qualitatively similar.

5. Results

We analyzed the effects of Rule 612 on the trading of securities in our sample in three separate steps. First, we evaluated the extent to which trading and order activity around the $1.00 cut-off was associated with different levels of THL and HFT. Next, we evaluated how trading and order activity around the

$1.00 cut-off was associated with different metrics for market quality. Finally, we evaluated the extent to which these results might be influenced by maker-taker fee structures at stock exchanges which often changed discontinuously for trades executed below $1.00 per share.

5.1 Subpenny Pricing and the Incidence of THL and HFT

To examine how subpenny pricing might affect the incidence of THL and HFT we relied on the findings presented in Figures 1(a) and 1(b) concerning the incidence of subpenny trading and quoting around the $1.00 cut-off established by Rule 612. After all, if being permitted to quote to four decimal places for sub-dollar orders had no effect on the incidence of subpenny quotes or trades, there would be no need to assess how subpenny trading affects THL or HFT for stocks priced less than $1.00 per share, for there would be no subpenny treatment at the cut-off. However, Figures 1(a) and 1(b) (discussed previously) provide compelling evidence that Rule 612 does indeed cause a pronounced increase in sub-penny orders for orders priced below $1.00 per share. In particular, the solid lines in Figures 1(a) and 1(b) plot fitted values from a regression of the dependent variable—the incidence of subpenny orders at each order price truncated to two decimal places—on a fourth order polynomial in two-decimal order price. The analysis reveals a significant increase of 0.208 percentage points in the fraction of bids submitted as subpenny orders below the $1.00 cut-off and a 0.219 percentage point increase in the fraction of offers submitted as subpenny orders below this cut-off.

As discussed previously, we examine the impact of subpenny quoting on the incidence of THL by using the reported market center for each executed trade within the TAQ dataset. Among the sample of 974 securities, over 86 million trades were executed during the course of 2011 reported across fifteen market centers. Table 3 provides a breakdown of these trades by market center. Consistent with Weaver (2011), approximately 29% of all trades were reported through a FINRA TRF facility, highlighting the prominence of off-exchange trading within the sample. Our RD analysis, however, indicates a significant shift in trading venue for stocks priced below $1.00 per share. In particular, Figure 3(a) presents our RD estimates of the effect of subpenny quoting on TRF-reported trades. As the figure indicates, trades executed at prices immediately below $1.00 per share revealed a sharp decrease in TRF-reported executions. Specifically, the fourth-order polynomial estimate of the discontinuous change in TRF-trading at $1.00 per share indicates a decrease of 8.0 percentage points (SE=.008) in the percent of trades reported in a TRF facility. Because all other market centers reflect stock exchanges, this translates to a corresponding jump of 8.0 percentage points in the incidence of exchange-based executions.

[INSERT FIGURE 3(a) HERE]

To more fully explore this change in reported market center, Figure 3(b) presents total trading volume at each price point between $0 and $2.00 per share in 2011, truncating all prices to two-decimal places. Visual inspection of the figure indicates an overall drop in trading volume just below the $1.00 cut-off. Combined with Figure 3(a), the change in reported trading venue at $1.00 per share is therefore a story about a general decline in trading volume across all exchanges below $1.00 per share, with the greatest decline occurring in the proportion of trades reported at TRF facilities. While this result remains consistent with a drop in THL below $1.00 per share, we explore below the causes for this general decline in trading at the $1.00 price point in Section 5.3.

[INSERT FIGURE 3(b) HERE]

With respect to the HFT, we first examined the effect of subpenny quoting on the incidence of HFT by analyzing the average rate of BBO updates per second across the $1.00 per share pricing threshold. Our RD estimates appear in Figure 4. In contrast to the findings presented in Figure 3(a), Figure 4 indicates that subpenny quoting under $1.00 per share appears to have the opposite effect on the incidence of HFT compared to THL. Specifically, the point estimate indicates that the average rate of BBO updates increases by 0.241 orders per second for offers priced below $1.00 per share (SE=0.047).

[INSERT FIGURE 4 HERE]

We also examined the incidence of HFT by looking for evidence of "strategic runs" within the TAQ order data. As described by Hasbrouck and Saar (2010), proprietary algorithms utilized by HFT firms (as distinct from agency algorithms used by institutional investors to minimize trading costs) typically operate in a millisecond environment in which they periodically send a battery of order and cancellation messages within a single second either to trigger or respond to market events. While the TAQ data does not permit tracking individual orders for the reasons discussed previously, evidence of such strategic runs nevertheless appear in the TAQ data to the extent they affect an exchange's BBO which must be continually updated to reflect new orders. Accordingly, we measure for each second of the trading day the rate of BBO updates for each security in the sample (a "security-second"). As might be expected, the vast majority of security-seconds experienced no update of an exchange's BBO. In particular, over 90% of the security-seconds in the sample showed no BBO updates, with higher-priced orders generally being more likely to have at least one BBO update per second. As shown in Figure 5(a), RD analysis of security-seconds having one or more BBO updates by two-decimal order price reveals that this trend was generally continuous at the $1.00 cut-off. In contrast, analysis of those security-seconds where a BBO was updated with significant frequency reveals a sharp increase in the incidence of such strategic runs below the cut-off. Figure 5(b), for instance, provides our RD estimates for the incidence of security-seconds where a BBO was updated at least fifty times per second. Consistent with Figure 5(a), the rate of these strategic runs generally declines from $2.00 to $1.00 where it reveals a discontinuous upward jump from .03% of all security-seconds to .1% of all security seconds.

[INSERT FIGURES 5(a) AND 5(b) HERE]

5.2 Subpenny Pricing and Market Quality

The sharp change in the incidence of HFT and THL at the $1.00 cut-off naturally raises the question of what our RD design might say about the effects of HFT and THL on market quality, particularly in light of the mixed empirical evidence on the effects of HFT and THL. Unfortunately, the fact that Rule 612 produces simultaneous and opposite effects on HFT and THL compromises the ability of our design to identify the independent effects on market quality of either phenomenon. Our design nevertheless speaks directly to pending proposals to change the tick size to either more or less than one penny given the role of MPV in modulating the prevalence of HFT relative to THL. That is, in light of our findings concerning the incidence of HFT and THL when going from a sub-penny environment to a penny environment, examining market quality around the $1.00 cut-off provides us with some basis to understand how market quality might be expected to change under proposals to increase the MPV above one penny, as contemplated by Section 106(b) of the JOBs Act. Conversely, proposals by stock exchanges to permit sub-penny pricing for all equity securities should be also be expected to increase the

incidence of HFT while reducing THL, thus similarly underscoring the relevance of examining changes in market quality as we move from the penny environment to the subpenny environment at the $1.00 cut-off.

Using the TAQ order level data, we focused on two primary measures of market quality: quoted spreads and quoted depth. With respect to spreads, our measure *quoted spread relative to quote midpoint* is the time-weighted average quoted spread (calculated as the difference between the national best offer and the national best bid reflected in the TAQ order data) as a fraction of the quote midpoint. With respect to quoted depth, application of Rule 612 required a bifurcated analysis of order-depth and bid-depth. In particular, because the rule applies differently depending whether an individual order (which could be either a bid *or* an ask) is below the $1.00 cut-off, the possibility exists for the national best bid to be below the $1.00 cut-off while the national best ask is at or above it. Accordingly, our measure *quoted bid depth* is the time-weighted average number of shares at the national best bid while our measure *quoted ask depth* is the time-weighted average number of shares at the national best ask.

[INSERT FIGURE 6 HERE]

Overall, our results indicate that moving from the penny-increment environment to the subpenny environment yields a reduction in quoted spreads but also a fairly sizable reduction in quoted depth. Figure 6, for instance, presents our RD estimates for quoted spreads. As reflected in the figure, the point estimate for the $1.00 cut-off was 0.011 with a standard error of 0.003. In terms of trading costs, to the extent they were executed at the NBBO, trades paying the spread just above the $1.00 cut-off were therefore, on average, about one penny more expensive to execute per share (1% of each share's value) than similar trades just below the cut-off. Our RD analysis for quoted depth at just below the $1.00 cut-off, however, indicates a significant drop in the available liquidity at the NBBO, suggesting traders may not necessarily realize these savings in quoted spreads in the subpenny environment. In Figures 7(a) and 7(b), *quoted bid depth* and *quoted ask depth* each decrease significantly below the $1.00 cut-off. In the case of quoted bids, for instance, our RD analysis suggests that below the $1.00 cut-off, offers to buy securities that are priced at the national best bid drop by approximately 127 round lots. Considering that *quoted bid depth* just above $1.00 was approximately 160 round lots, this point estimate suggests a drop of almost 80% of the available bid liquidity at the national best offer. Quoted ask depth similarly displayed a sharp drop in offers to sell securities that are priced at the national best ask with Figure 7(b) suggesting a change in quoted ask depth of approximately 74 round lots (SE=17.31).

[INSERT FIGURES 7(a) AND 7(b) HERE]

5.3 Subpenny Pricing and Maker/Taker Pricing Models

A potential limitation of examining the effect of MPV regulations at the $1.00 cut-off concerns the role of so-called "maker/taker pricing" models used by many stock exchanges. In general, exchanges adopting this pricing model charge an access fee (a "take fee") to any market order that removes liquidity from the trading exchange while paying a liquidity rebate (a "make fee") to the customer that posted the standing order filled by the incoming market order. The aim of such models is to draw liquidity providers (i.e, limit orders) to the exchange while allowing the exchange to profit by keeping the liquidity rebate slightly less than the access fee. For present purposes, the complicating feature of these pricing models arises from the fact that Rule 610(c) of Reg. NMS limits access fees for accessing the NBBO differently for quotations above and below $1.00. Specifically, for quotations priced above $1.00, access fees can be

no more than $0.003 per share, while for quotations below $1.00, they can be no more than 0.30% of a trade's total value.

As outlined by Angel, Harris, and Spatt (2011), maker/taker pricing has the potential to affect order routing decisions, raising the possibility that different maker/taker price regimes at the $1.00 cut-off might explain the reason for the lower incidence of TRF-based trading below the $1.00 cut-off. For instance, to the extent exchanges set access fees for trades priced above $1.00 per share higher than for trades priced below $1.00 per share, a broker receiving a market order for a stock priced at more than $1.00 per share may have stronger incentives to route the order to an internalizer rather than to an exchange. The reason arises from the fact that both Reg. NMS and best execution practices generally require brokers to route orders to venues based on the best available quote without regard to access fees. As such, if the NBBO resides on an exchange with high access fees, a broker might therefore prefer to send an order to an internalizer who has agreed to execute the trade at or better than the NBBO. This is particularly true in light of the common practice of retail brokerage firms to charge a low fixed commission per trade, resulting in the brokerage firm absorbing any access fees incurred when routing orders to exchanges. Likewise, because internalizers generally absorb any access fees incurred by their routing away of orders, an internalizer receiving a market order from a broker might similarly prefer to avoid routing the order to an exchange charging a high access fee. Rather, as explained to us by a trader at one prominent internalizer, such an internalizer might choose to trade the order on a principal basis even if the internalizer might otherwise prefer to route the order away in the absence of such fees (e.g., because of inventory holding costs, adverse selection costs, etc.). For these same reasons, a decrease in access fees for stocks priced below $1.00 per share might lead both brokers and internalizers to send more orders to exchanges, a result consistent with Figure 3(a) above.

To examine the extent to which maker/taker fees can explain the results in Figure 3(a), access fees and rebates were collected for the calendar year 2011 based on exchanges' regulatory filings with the SEC. Panel A of Table 4 provides the fees and rebates for trades priced above and below $1.00 per share across all exchanges with the exception of the Chicago Board Options Exchange (CBOE).[8] For ease of presentation, rows are sorted according to the lowest to highest access fees for stocks priced less than $1.00 per share (column 1). Additionally, because some exchanges based their pricing on a per-share basis while others priced on a per trade-value basis, Panel A presents the fees and rebates as a percentage of a $10,000 trade of a stock valued at either $1.00 or $0.99. As reflected in the table, the exchanges showed considerable variation in both access fees and rebates. In terms of access fees, fees for transactions priced at $0.99 per share ranged from a low of zero to a high of 0.30% of trade value, while transactions priced at $1.00 per share had fees ranging from a positive rebate of 0.02% of trade value to a fee of 0.30% of trade value. The fact that at least one exchange was charging a positive rebate of 0.02% (rather than a fee) for taking liquidity underscores the tremendous variation in pricing structures that existed across exchanges in 2011.[9] As is suggested from the first two columns, there is little evidence that access fees were uniformly lower in the subdollar market, with some exchanges seeing a decrease in

[8] The CBOE was excluded on the basis that it significantly changed its pricing model several times during 2011. In contrast, all other exchanges had generally stable pricing structures for the year.

[9] This rebate at the BATS Y Exchange reflected an "inverted" pricing structure in which takers of liquidity were offered a rebate while providers of liquidity were charged a slightly higher fee. The aim of these structures is to allow an exchange to compete more effectively with internalizers who obtain retail order flow from brokers by paying for it.

access fees (e.g., EdgeA), others seeing an increase (e.g., the National Stock Exchange), and many staying the same (e.g., NYSE, Nasdaq).

[INSERT TABLE 4 HERE]

In Panel B of Table 4, we exploit this variation in maker/taker fee structures to examine more precisely how maker/taker fees might influence order routing decisions at the $1.00 cut-off. The first two columns show the results from a series regressions of each exchange's trading volume in 2011 in stocks priced between $0 and $2.00 on a fourth order polynomial in two-decimal stock price. To facilitate comparison across exchanges, the third column of Panel B provides the average trading volume on each exchange for stocks priced between $1.00 and $2.00, with the fourth column showing the point estimate in column 1 as a fraction of this average trading volume. A positive percentage in this column can therefore be interpreted as an approximation of the discontinuous percentage increase in trading volume on an exchange for stocks priced just above $1.00 per share relative to the overall average trading volume on the exchange for such stocks. If the decline in FINRA trading shown in Figure 3(a) was due to lower access fees in the subdollar trading environment, those exchanges having the lowest subdollar access fees should therefore be associated with a negative percentage in the fourth column.

Somewhat surprisingly, the table reveals almost exactly the opposite of this hypothesized result. Rather than seeing an increase in trading volumes, exchanges charging the lowest access fees for trades under $1.00 per share actually saw the most dramatic drop in their trading volume below the $1.00 cut-off. Rather, it was only on those exchanges charging some of the highest subdollar access fees that the table showed either an increase in subdollar trading volume or an otherwise insignificant change at the $1.00 cut-off. Indeed, the exchange revealing the most significant increase in subdollar trading volume was the National Stock Exchange (the NSX) which had a *higher* access fee under the $1.00 price point than above it. The explanation for these results can most likely be found in the higher rebates these exchanges were offering for subdollar trades compared to exchanges charging lower access fees on such trades. For instance, while the NSX charged one of the highest subdollar access fees at 0.28%, it also offered the highest subdollar rebate of 0.025% of trading value, which likely explains its 151% increase in trading volume in stocks priced just below $1.00 per share. Presumably, these relatively high rebates drew a disproportionate amount of liquidity to the exchange, increasing the likelihood that the exchange would hold the NBBO and, consequently, that orders would be routed to it. To the extent this was the case in 2011, it is worth noting that (unlike access fees) rebates across all exchanges uniformly declined for subdollar trades, indicating that the results in Figure 3(a) were also not being driven by overall higher subdollar rebates on stock exchanges.

While the foregoing suggests that neither low access fees nor high rebates were responsible for the decline in internalization rates below the $1.00 cut-off, the fact that trades were being routed to exchanges paying the highest subdollar rebates nevertheless raises the question whether maker/taker pricing might bias downward our point estimate for changes in THL at the $1.00 cut-off. In particular, to the extent Table 4 indicates that subdollar liquidity is drawn to those exchanges charging the highest access fee permitted by Rule 610(c), subdollar trading may systematically be more expensive than non-subdollar trading. The reason stems from the basic structure of Rule 610(c) in which access fees for subdollar trades are capped at 0.3% of *trade value* while fees for non-subdollar trades are capped at $0.003 *per share.* As a result, if trades are routed to exchanges charging the maximum permitted fee, any trade

executed at a per share price greater than exactly $1.00 will be charged an access fee that is lower (as a percentage of trade value) than the subdollar fee of 0.3%. Consequently, internalizers receiving subdollar orders would find themselves in precisely the position suggested previously when the NBBO arises on exchanges with the highest rebates: Rather than pay the high access fees for routing orders to the most liquid exchanges, might an internalizer simply choose to increase the rate at which it internalizes marginal orders? If so, the rate of subdollar internalization in Figure 3(a) would actually be *overstated* compared to an environment with no maker/taker pricing models.

To examine whether high subdollar maker/taker fees might inflate the incidence of subdollar internalization, we turned to a brief pricing war among exchanges in 2010 involving the payment of unusually high liquidity rebates for subdollar trades. In contrast to the generally low rebates prevailing for subdollar trades in 2011, the first few months of 2010 witnessed a dramatic increase in liquidity rebates following Direct Edge's January 2010 decision to adopt maker/taker pricing for all subdollar trades. Whereas the venue had previously charged a 0.2% transaction fee for accessing its liquidity, its move to maker/taker pricing resulted in a 0.3% access fee and a 0.15% liquidity rebate for all trades priced under $1.00 per share. By the end of February, Nasdaq, the NSX, the Boston Stock Exchange (which would eventually become Nasdaq OMX BX), the CBOE, and the Chicago Stock Exchange had all adopted similar maker/taker pricing structures for subdollar trades. The Boston Stock Exchange (BSX) and the CBOE were especially aggressive in their pricing, with each offering subdollar liquidity rebates of 0.25% of trade value. As a result, maker fees and access fees on these exchanges increased dramatically for trades executed under $1.00 per share. At Boston, for instance, maker fees increased from 0.01% for trades at $1.00 per share and higher to 0.25% for trades below $1.00 per share with a corresponding increase in taker fees from 0.03% to 0.3%. While most of the exchanges subsequently reduced their maker/taker fees by the Summer of 2010, the CBOE would not reduce its pricing structure until October of that year.

In addition to causing a sudden increase in maker/taker pricing for subdollar trades, this temporary pricing war is also useful for examining the effect of such fees on the incidence of internalization due to reports that the pricing structures were increasing the frequency with which the NBBO resided on those exchanges offering the highest rebates. As summarized by Angel, Harris, and Spatt (2011), the reason stemmed from allegedly manipulative behavior among traders seeking out the rich subdollar liquidity rebates. For instance, a single trader might seek to profit from an exchange's high rebate by first posting on the exchange an aggressively priced buy (or sell) order in a subdollar stock for which the bid-ask spread was wider than the MPV of $0.0001, thereby improving the NBBO in that stock. Next, the trader would immediately submit a marketable sell (or buy) order at the same price to a broker charging a flat, per-trade commission, who would be obligated to route the order to the exchange with the NBBO or sell it to an internalizer promising to execute the order at or better than the NBBO. If the order were sufficiently large, the trader would thus earn a net profit from the liquidity rebate less the brokerage commission, while the broker or internalizer (if the broker had sold its order flow) would absorb the higher access fee. From an internalizer's perspective, it is this prospect of having to route an unusually large number of market orders to exchanges charging large access fees that might lead to a decision to internalize more subdollar trades than might otherwise occur with more moderate maker/taker pricing structures.

As was done for our analysis of 2011, we analyzed the consequence of this pricing war on the incidence of internalization by turning to the 2010 TAQ data. Figure 8(a) compares overall trading volume in 2010 for stocks priced under $2.00 per share while Figure 8(b) shows the rate of subpenny trade executions by two-digit price in 2010. Both figures provide strong support for the claim that large maker rebates in 2010 were inflating overall volume around the $1.00 cut-off. In contrast to 2011 (Figure 3(b)) where trading volume sharply declined for trades under $1.00 per share, Figure 8(a) shows a sudden increase in trading around the dollar price point in 2010, reaching a maximum of 1.7 billion shares traded at $0.99 per share. Likewise, the rate at which trades were executed in 2010 in subpenny prices exhibits a distinct U-shaped trend under $1.00 per share which would be expected if traders were competing fiercely to position their orders at the NBBO for stocks priced just under $1. Notably, the shape is in stark contrast with the data for 2011 (Figure 2) which shows a smooth, increasing rate of subpenny trades priced from $1.00 to $0. In combination with the uniformly low rebates offered by exchanges in 2011, these data provide strong evidence of the extent to which maker/taker pricing can potentially induce rebate-driven trading volume. They also explain the sudden decrease in trading volume in 2011 at the $1.00 cut-off noted previously. More troubling, they provide reason to believe that a considerable amount of trading volume in stocks priced around $1.00 per share during 2010 was in fact attributable to the type of rebate-seeking arbitrage suggested by Angel, Harris and Spatt (2011).

[INSERT FIGURES 8(a) AND 8(b) HERE]

To examine how this surge in volume in stocks priced around $1.00 per share impacted routing decisions, Figure 9 looks at trading volume in 2010 across the TRF facilities as well as at the BSX and the CBOE, the two exchanges offering the greatest subdollar maker rebates in 2010. For comparison, it also provides total 2010 trading volume for the NYSE Amex, an exchange that did not participate in the subdollar pricing war. Notwithstanding the relatively high access fees charged by the BSX and the CBOE, Figure 9 shows a sharp increase in the total volume of trading as stock prices decline from $1.00 per share, with the exchanges' combined trading volume increasing from well under 2% of trading volume for stocks priced above $1.00 per share to almost 40% for those stocks priced around $0.99 per share. In contrast, trading remained relatively flat across all price points at the NYSE Amex, with some evidence of a slight decline for trades priced just below $1.00 per share. With respect to trades reported to a TRF facility, volume also increased significantly and discontinuously at just under the $1.00 cut-off, causing the incidence of FINRA trades to decline more moderately around the $1.00 cut-off in 2010 than was observed for 2011. In general, this large jump in FINRA trading at around $1.00 cut-off is consistent with internalizers choosing to internalize orders at a greater rate to avoid routing them to exchanges such as BSX and CBOE which had significant liquidity but also charged the highest access fees. This interpretation is made all the more likely by several press reports in late 2010 in which market makers such as Knight Trading voiced concerns that the exchanges' subdollar pricing war was costing Knight "tens of thousands of dollars" per day (Retuers, 2010).

[INSERT FIGURE 9 HERE]

In short, while the 2010 pricing war makes the year unique in many respects, the foregoing analysis nevertheless provides good reason to believe that subdollar access fees likely inflate the natural rate of internalization for subdollar trades. As such, even in 2011, the differential regulation of access fees set forth in Rule 610(c) for trades above and below $1.00 per share might therefore provide a slightly greater

incentive for internalizing trades priced below $1.00 per share than above it. For this reason, the primary implication of maker/taker pricing for our research design is that it potentially causes us to understate (rather than overstate) the extent to which increasing the MPV will result in an increase in THL.

6. Conclusion: Assessing Current Proposals to Increase or Decrease the MPV

The foregoing results suggest a number of conclusions to be drawn with respect to current proposals to change the minimum price variation for publicly-traded equity securities. While our findings do not uniformly support either decreasing the MPV (as proposed by the NYSE, Nasdaq, and BATS Exchange) or increasing it (as contemplated by Section 106(b) of the JOBS Act), the critical link we show between MPV regulations and the incidence of HFT and THL helps reveal the costs and benefits either such approach might produce.

First, with respect to proposals to decrease further the MPV, our findings are strongly suggestive that further decreases in the MPV for stocks priced above $1.00 per share will almost certainly result in a lower incidence of THL but a greater incidence of HFT. For some, this fact alone may be of concern due to the growing body of literature questioning the benefits of HFT. That is, to the extent HFT firms focus on trading tactics such as "quote stuffing" or rebate trading, the cost these strategies impose on the market in terms of infrastructure burdens and the heightened risk of manipulative behavior might easily overwhelm whatever additional liquidity HFT firms provide the marketplace.

Our study, however, cautions against such a generalized approach to HFT. It is notable, for instance, that our RD design detected a strong discontinuous increase in HFT just below the $1.00 cut-off despite the fact that neither a quote-stuffing strategy nor a rebate strategy should result in a *discontinuous* change for orders priced at less than $1.00 per share. Indeed, a rebate-driven HTF firm should, if anything, demonstrate a discontinuous *decrease* in trading below this price point in light of the significant decline in the overall size of liquidity rebates in the subdollar trading environment. Instead, our findings of greater HFT in stocks priced less than $1.00 per share may be driven by those HFT strategies where more granular pricing can be used to manage basis risk or to calibrate more accurately the idiosyncratic price risk associated with a nonzero stock position. To the extent subpenny pricing facilitates this form of "new market-making" (Menkveld, 2012), decreases in the MPV might yield more beneficial effects on overall market quality.

Yet even with this more positive depiction of subdollar HFT trading, it remains notable that our analysis of subdollar market quality metrics produced such mixed results. Consistent with the notion that HFT market-making can add to price discovery, quoted spreads declined just under the $1.00 cut-off, but so too did quoted depth. In this regard, the findings mirror those of Hendershott, Jones and Menkveld (2011) who similarly found a sharp reduction in both spreads and depth associated with algorithmic trading.

Moreover, assessing the overall effect of subpenny pricing on market quality is made all the more difficult by the potential interaction of increased HFT and maker/taker fees. For instance, with regard to the decline in quoted spreads, Angel, Harris, and Spatt (2011) suggest that in competitive markets, investors will effectively price into spreads the cost of access fees. Therefore, the fact that most subdollar trading occurred in 2011 on venues charging the maximum subdollar fee of 0.3% may mean that real spreads declined much less across the $1.00 cut-off. Conversely, the low rebate environment of 2011

may have deterred some HFT firms from trading in subdollar stocks, which could lower trading costs for investors notwithstanding lower quoted depths. For instance, low rebate fees might have made posting orders at (or slightly better than) the NBBO less competitive for institutional investors liquidating positions, thereby allowing them to avoid paying the spread at all when seeking liquidity. This would be in contrast to the extreme competition for being at the NBBO during the 2010 subdollar pricing war, which illustrated how large rebates in a subpenny environment can make it much more difficult for investors to have orders filled at the NBBO (forcing investors to pay the spread). The 2010 subdollar pricing war also highlighted how high rebates in a subpenny environment can create perverse incentives for transacting in wash sales. Overall, these results caution against a further decrease in the MPV without imposing limits on maker/taker pricing structures to ensure that spreads are transparent across MPV regimes while minimizing the risk of market manipulation.

A similar set of considerations applies to the analysis of current proposals to increase the MPV. As with our analysis of proposed decreases in the MPV, our results suggest that any such change can be expected to affect both the overall nature of the trading environment as well as conventional metrics of market quality. First, with respect to the overall trading environment, the significant increase in THL for trades priced just above $1.00 per share predicts that an increase in the MPV should be associated with a large increase in THL for the reasons hypothesized in Section 3. Given the number of stocks that trade at a penny spread, increasing further the MPV will result in a penny-for-penny increase in quoted spreads, increasing both the profitability of internalizing a trade and the opportunities for offering price improvement over the NBBO.

While not typically discussed in terms of dark liquidity, this structural change in trading from a higher MPV would actually be consistent with a core objective of Section 106(b) of the JOBS Act (and its proponents such as Weild, Kim, and Newport (2012)) insofar that it would increase the profitability of market-making in affected stocks. However, our finding that these market-making profits are generally captured by internalizers and dark pools causes us to question how these enhanced profits will translate into additional analyst coverage and sales support for emerging growth companies. For instance, most dark pools and the two largest internalizers by volume—Citadel Investments and Knight Trading—do not offer sell-side analysis or advisory services. Moreover, the new retail price improvement (RPI) programs at major U.S. stock exchanges—which seek to allow exchanges to compete with internalizers through establishing *de facto* dark pools to capture trading spreads—only further undermine the theorized benefits for IPO firms of larger tick sizes given that the beneficiaries of such programs (i.e., stock exchanges and RPI participants) are also not known to provide market support for emerging growth companies. To the extent the SEC chooses to increase tick sizes pursuant to Section 106(b) of the JOBS Act, coupling such a change with increased disclosure concerning which broker-dealers are reporting trades to a FINRA TRF could help ascertain whether the appropriate market participants are benefiting from the wider spreads.

Finally, with regard to market quality metrics, our analysis of changes to both quoted spreads and depth at the $1.00 cut-off suggests both are likely to increase in the event of an increase in the MPV. As with our discussion of market quality at just below the $1.00 cut-off, however, the real effect of these changes on market quality are likely to be affected significantly by maker/taker fee structures at stock exchanges. For instance, while stocks that currently trade at penny-spreads would clearly experience an increase in quoted spreads, the effect on stocks that currently trade at wider spreads may be less than is suggested by our point estimate for spread changes at the $1.00 cut-off. Again, the reason arises from the

overall higher access fees in the subdollar environment in 2011, which Angel, Harris, and Spatt (2011) postulate should cause quoted spreads to narrow for stocks priced just under $1.00 per share. Likewise, while restricting traders to set prices at fewer price points along a dollar should increase quoted depth, the potential for large rebates (as a percent of trade value) combined with larger quoted spreads could induce significant competition among liquidity providers to be at the NBBO, as was seen during the 2010 subdollar pricing war. In such a situation, institutional investors could find it more difficult to use limit orders to exit positions, forcing them to pay the (now much larger) spread. As with proposals to decrease the MPV, requiring that any increases in MPV are accompanied by limitations on both access fees and liquidity rebates could help ensure that spreads are transparent across MPV regimes while minimizing the disruptive effects of a larger MPV on liquidity-seekers.

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Table 1: Quotations for StemCell, Inc. Reflected in the NYSE TAQ Data

symbol	date	time	bid	ofr	bidsiz	ofrsiz	mode	ex
STEM	1-Jun-11	10:56:41	0.6541	0.6551	5	25	12	P
STEM	1-Jun-11	10:56:42	0.6541	0.6551	5	21	12	P
STEM	1-Jun-11	10:56:42	0.655	0.6551	196	26	12	T
STEM	1-Jun-11	10:56:44	0.655	0.6551	196	24	12	T
STEM	1-Jun-11	10:56:45	0.655	0.6551	196	14	12	T
STEM	1-Jun-11	10:56:45	0.65	0.6551	21	15	12	K
STEM	1-Jun-11	10:56:45	0.65	0.6551	2	15	12	Z
STEM	1-Jun-11	10:56:45	0.655	0.6551	158	14	12	T
STEM	1-Jun-11	10:56:45	0.6541	0.6551	5	11	12	P
STEM	1-Jun-11	10:56:50	0.6541	0.659	5	2	12	C
STEM	1-Jun-11	10:56:50	0.655	0.6551	158	1	12	T
STEM	1-Jun-11	10:56:50	0.65	0.6593	21	1	12	K
STEM	1-Jun-11	10:56:50	0.65	0.66	2	3	12	Z
STEM	1-Jun-11	10:56:50	0.655	0.6551	102	1	12	T
STEM	1-Jun-11	10:56:50	0.65	0.67	2	3	12	Z
STEM	1-Jun-11	10:56:50	0.655	0.67	2	3	12	Z
STEM	1-Jun-11	10:56:50	0.6541	0.66	5	11	12	P
STEM	1-Jun-11	10:56:50	0.6541	0.66	5	8	12	P

Table 2 - Sample Description and Sample Selection Comparison

Panel A provides a description of the composition of our sample firms compared to other firms within the CRSP dataset for 2011 according to standard industrial classifications, foreign-incorporation, and propensity to be delisted involuntarily. Sample firms are any firm within CRSP whose securities traded below $2.00 per share at some point during 2011. Non-Sample firms consist of all other CRSP firms trading during 2011. Panel B presents summary financial statistics—averages, [medians], and (standard errors)—for the sample, non-sample, and all CRSP firms. All data in Table 2 was taken from CapitalIQ.

Panel A

	Sample Firms		Non-Sample Firms		All CRSP Firms	
Variable	N	%	N	%	N	%
Industrial Classification:						
Agriculture, Forestry, And Fishing	4	0.4%	15	0.2%	19	0.3%
Mining	75	7.8%	278	4.6%	353	5.0%
Construction	10	1.0%	39	0.6%	49	0.7%
Manufacturing	435	45.4%	1,498	24.8%	1,933	27.6%
Transportation, Communications, Electric, Gas, And Sanitary Services	63	6.6%	429	7.1%	492	7.0%
Wholesale Trade	20	2.1%	107	1.8%	127	1.8%
Retail Trade	33	3.4%	223	3.7%	256	3.7%
Finance, Insurance, And Real Estate	162	16.9%	2,802	46.3%	2,964	42.3%
Services	156	16.3%	639	10.6%	795	11.3%
Public Administration	1	0.1%	16	0.3%	17	0.2%
	959	100%	6,046	100%	7,005	100%
Total Non-Financial	797		3,244		4,041	
Foreign. Incorporation	159	20.0%	605	18.6%	764	18.9%
Involuntary Delistings:	99	10.3%	63	1.0%	162	2.3%

Panel B

	Sample Firms		Non-Sample Firms		All CRSP Firms	
Variable	Mean [Median]	(SE)	Mean [Median]	(SE)	Mean [Median]	(SE)
Market Cap ($ millions)	916.91	(390.75)	108,688.60	(42,467.84)	93,162.28	(36,352.25)
	[65.36]		[481.40]		[349.82]	
Total Assets	3,300.12	(1185.83)	448,210.10	(119,637.70)	375,846.10	(100,200.20)
	[89.51]		[818.32]		[609.63]	
ROE	-0.63	(0.13)	0.14	(0.05)	0.01	(0.05)
	[-0.15]		[0.09]		[0.08]	
ROA	-0.09	(0.01)	0.03	(0.00)	0.01	(0.00)
	[-0.03]		[0.03]		[0.03]	
Sales Growth	2.08	(0.88)	6.22	(5.75)	5.60	(4.89)
	[0.08]		[0.10]		[0.10]	
Leverage	0.31	(0.04)	0.26	(0.01)	0.27	(0.01)
	[0.17]		[0.19]		[0.19]	
Public Float	0.68	(0.01)	0.79	(0.00)	0.77	(0.00)
	[0.73]		[0.87]		[0.84]	
Volatility	0.68	(0.01)	0.34	(0.00)	0.39	(0.00)
	[0.62]		[0.32]		[0.35]	
Daily Trading Volume	0.64	(0.13)	1.67	(0.13)	1.52	(0.11)
	[0.08]		[0.15]		[0.14]	
Tobins q	2.13	(0.13)	2.68	(0.58)	2.59	(0.48)
	[1.22]		[1.22]		[1.22]	
Market-to-Book	1.59	(0.77)	3.09	(2.03)	2.84	(1.70)
	[1.20]		[1.48]		[1.44]	

[To come: comparative trading metrics]

Table 3 –Trades Involving the Securities of Sample Firms Executed in 2011 by Reported Market Center

Exchange	Number of trades	% of Total 2011 Trades
American Stock Exchange	1,794,016	2.08%
Boston Stock Exchange	3,416,200	3.96%
National (Cincinnati) Stock Exchange	2,265,754	2.62%
FINRA Trade Reporting Facility	25,300,000	29.30%
Direct Edge A Stock Exchange	5,146,107	5.96%
Direct Edge X Stock Exchange	7,633,681	8.84%
Chicago Stock Exchange	118,645	0.14%
New York Stock Exchange	2,053,069	2.38%
NYSE Arca SM	10,800,000	12.51%
NASDAQ Stock Exchange	10,600,000	12.27%
NASDAQ OMX Stock Exchange	4,072,291	4.72%
CBOE Stock Exchange	56,768	0.07%
NASDAQ OMX PSX Stock Exchange	610,878	0.71%
BATS Y-Exchange	3,241,613	3.75%
BATS Exchange	9,247,740	10.71%
Total	86,356,762	100.00%

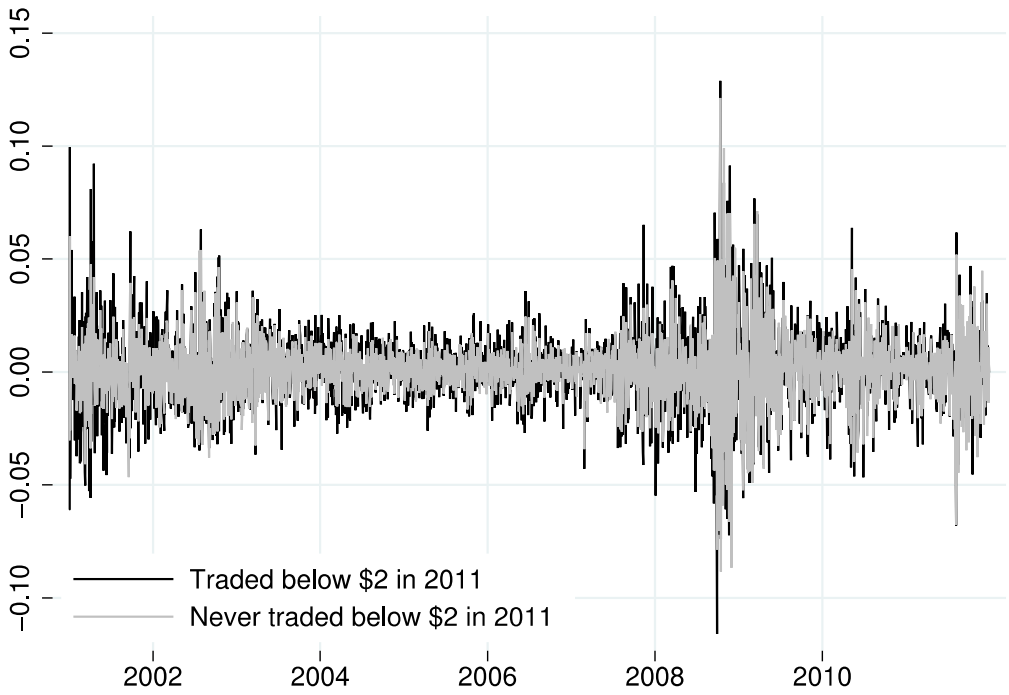
Table 4: Access Fees and Rebates Offered By Exchanges in 2011.

Panel A reports access fees and liquidity rebates for all U.S. exchanges (with the exception of the CBOE) for 2011, according to whether a trade involved a stock priced above or below $1.00 per share. Because certain exchanges charged fees and paid rebates on a per share basis while others used a percentage of trade value, fees and rebates are presented as a percentage of a $10,000 trade of a stock valued at either $1.00 or $0.99. In Panel B, the first two columns present the regression results of a series of sequential regressions of each exchange's trading volume in 2011 in stocks priced between $0 and $2.00 on a fourth order polynomial in two-decimal stock price. Columns 3 of Panel B shows each exchanges average trading volume during 2011 in stocks priced between $1 and $2 per share while Column 4 shows the point estimate obtained in Column 1 as a percentage of this average trading volume. ***, **, and * indicate statistics are significant at the 1%, 5%, and 10% levels, respectively.

	Panel A				Panel B			
	Access Fee Charged to Liquidity Taker (% of $10,000 trade value)		Rebate Paid to Liquidity Provider (% of $10,000 trade value)					
Exchange:	Price=$0.99	Price=$1.00	Price=$0.99	Price=$1.00	Loc. Poly. Coef.	Robust Std. Err.	Average Volume Traded Between $1 and $2	Point Estimate / Average Volume Traded Between $1 and $2
EDGA Exchange	0.00%	-0.06%	0.000%	0.05%	**6,600,000*** **	2,100,000	20,300,000	33%
NYSE Arca	-0.10%	-0.30%	0.000%	0.30%	**9,600,000*** **	2,700,000	40,900,000	23%
Nasdaq OMX BX	-0.10%	0.14%	0.000%	-0.18%	**5,800,000*** **	2,500,000	14,000,000	41%
BATS BZX	-0.10%	-0.29%	0.000%	0.29%	**14,000,000*** **	1,200,000	34,200,000	41%
BATS BYX	-0.10%	0.02%	0.000%	-0.02%	**4,600,000*** **	1,400,000	10,800,000	43%
Nasdaq OMX PH	-0.20%	-0.25%	0.000%	0.24%	520,000	410,000	3,154,835	16%
NYSE	-0.23%	-0.23%	0.000%	0.15%	6,000,000	6,700,000	14,700,000	41%
NYSE Amex	-0.25%	-0.28%	0.000%	0.16%	440,000	1,300,000	7,262,181	6%
Nasdaq	-0.30%	-0.30%	0.009%	0.29%	**8,900,000*** **	5,000,000	67,100,000	13%
EDGX Exchange	-0.30%	-0.30%	0.003%	0.23%	6,000,000	4,400,000	32,200,000	19%
Chicago Stock Exchange	-0.30%	-0.30%	0.009%	0.25%	-3,597	360,000	748,054	-0.5%
National Stock Exchange	-0.30%	-0.28%	0.025%	0.26%	**-5,200,000*** **	880,000	3,447,609	-151%

FIGURES

Figure 0—Returns for Sample and Non-sample Firms from 2001-2011



Note: Lines represent value−weighted average returns.

Figure 1(a): Incidence of Sub-Penny Bids in 2011

National Best Bids Priced Less Than $2.00/share

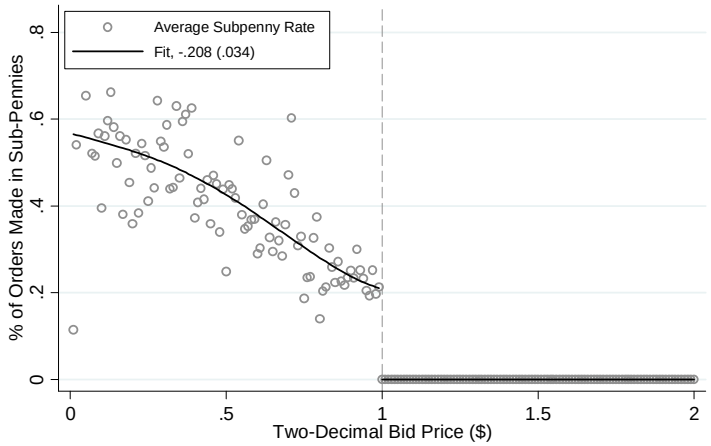


Figure 1(b): Incidence of Sub-Penny Offers in 2011

National Best Offers Priced Less Than $2.00/share

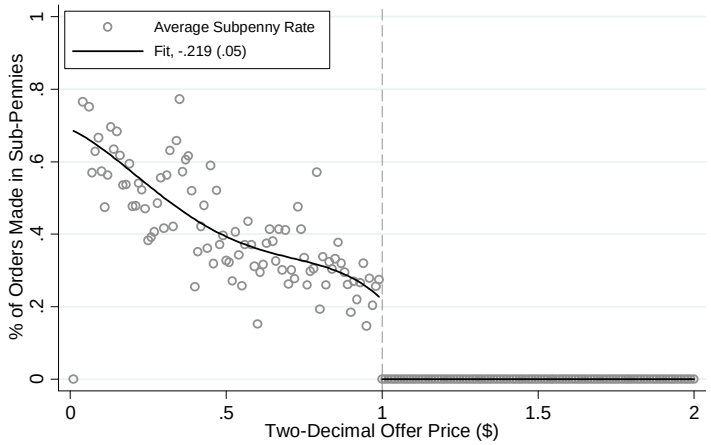


Figure 2: Incidence of Sub-Penny Priced Trades in 2011
As a Function of Two-Decimal Trade Price

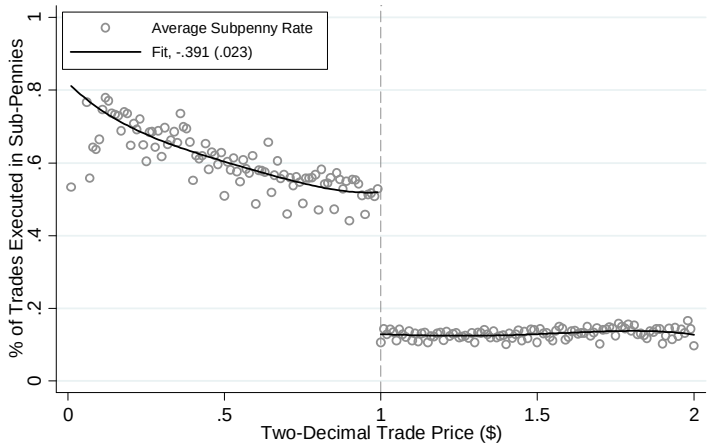


Figure 3(a): Incidence of FINRA-Reported Trades in 2011
As a Function of Two-Decimal Trade Price

Figure 3(b): 2011 Trading Volume
As a Function of Two-Decimal Trade Price

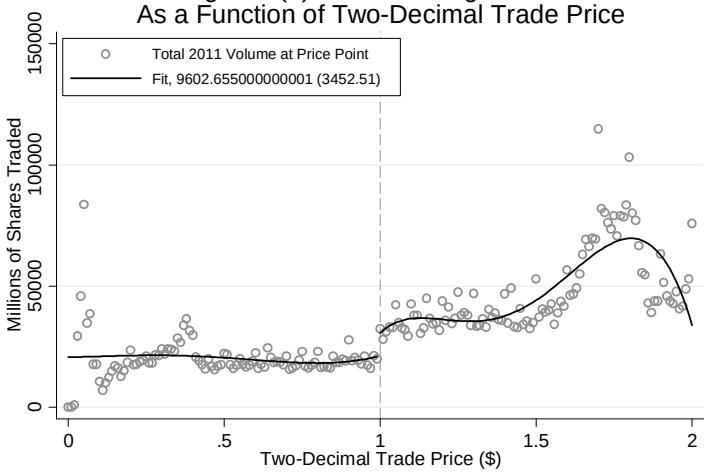


Figure 4: BBO Updates Per Second
As a Function of Two-Decimal Ask Price

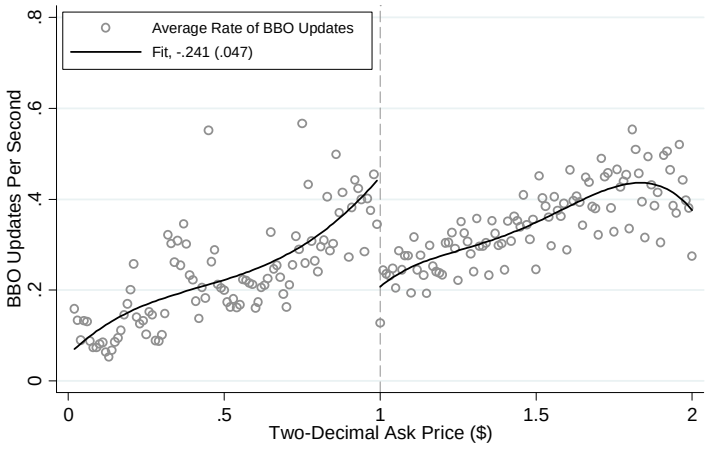


Figure 5(a): Incidence of Security-Seconds Having At Least One BBO Update

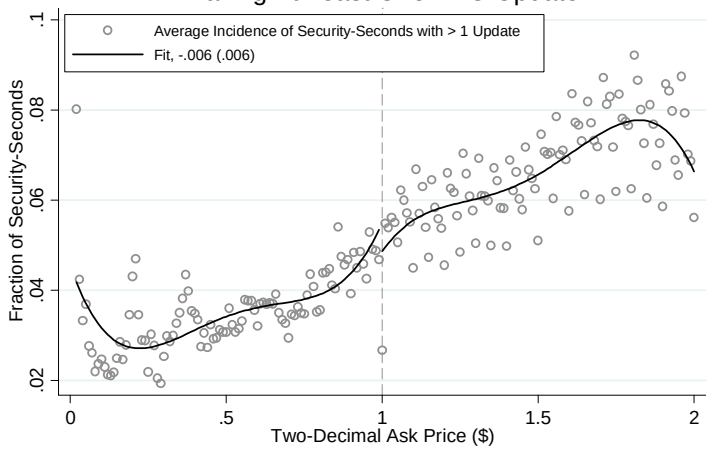


Figure 5(b): Incidence of Security-Seconds Having At Least Fifty BBO Updates

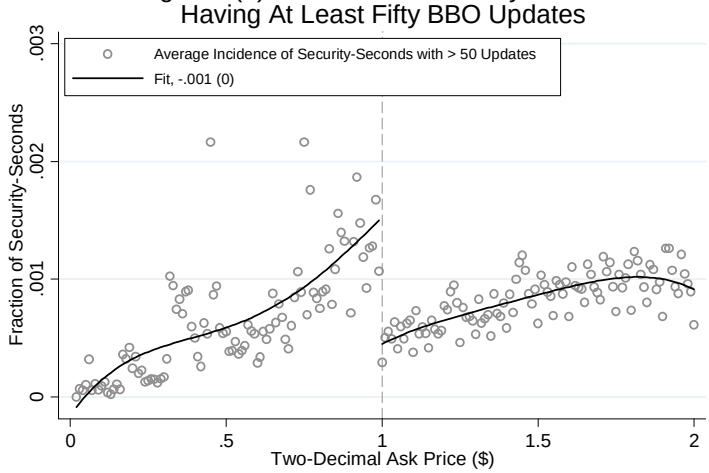


Figure 6: Quoted Spreads At the $1.00 Cut-off

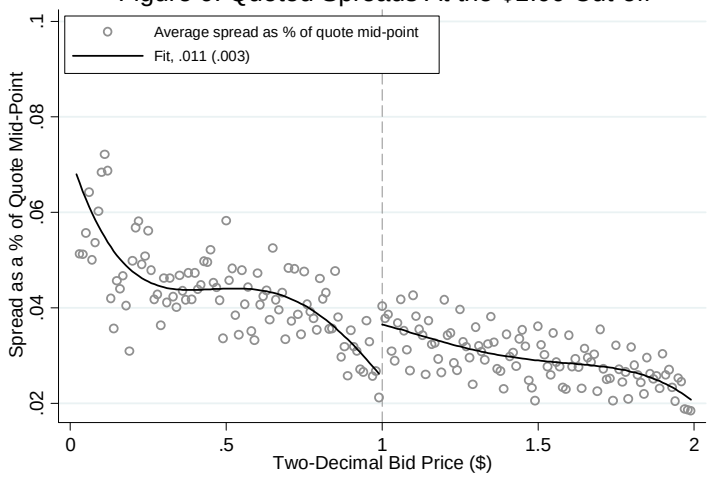


Figure 7(a): Quoted Bid Depth At the $1.00 Cut-off

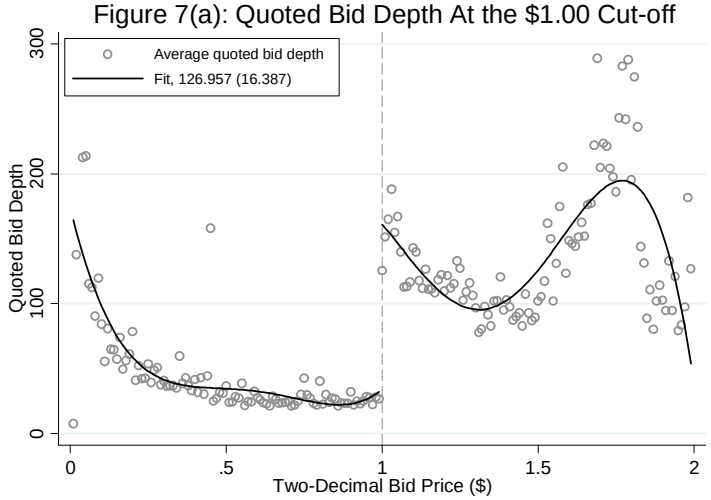


Figure 7(b): Quoted Ask Depth At the $1.00 Cut-off

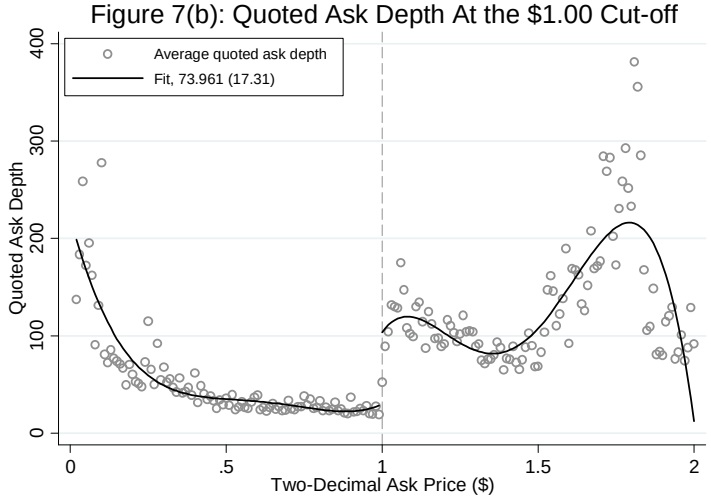
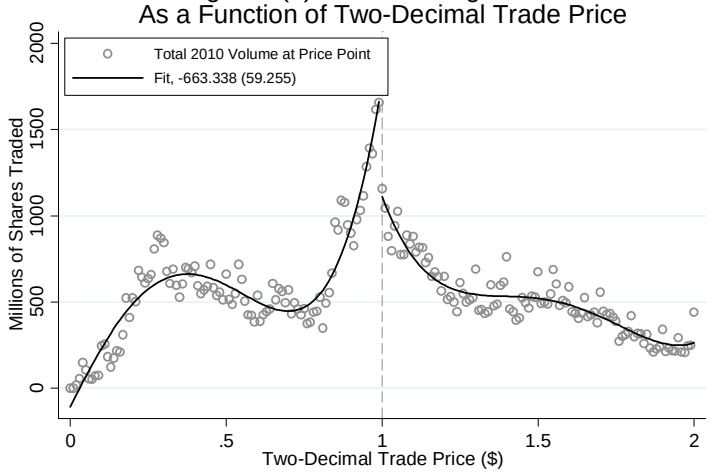


Figure 8(a): 2010 Trading Volume
As a Function of Two-Decimal Trade Price



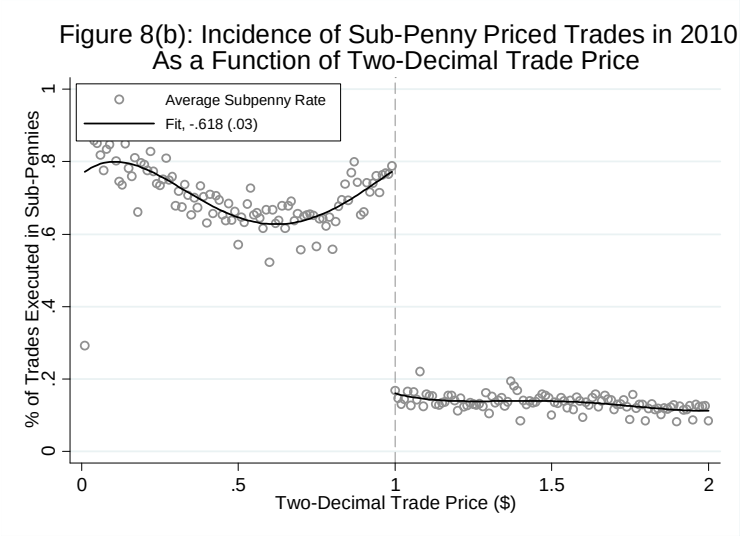


FIGURE 9: 2010 Trading of Sub-$2 stocks by Certain Market Centers