The Impact of Trade-Through Prohibition on Liquidity Commonality

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Abstract

We examine changes in systemic liquidity risk brought about by Regulation National Market System (Reg NMS), particularly in its provisions against trade-throughs and the subsequent fragmentation of order flow. A dynamic factor model approach allows us to decompose liquidity co-variances into an "exchange-specific" component that is confined to an individual trading venue, and a "market-wide" component that spans across multiple trading venues. The results confirm an overall increase in liquidity co-movements within dollar volumes following the implementation of Reg NMS, supporting the idea of a contagion effect of trade-through protection on liquidity demand shocks. Meanwhile, bid-ask spreads see an overall decrease in liquidity co-movements, driven by a decrease in exchange-specific commonality. Hence, there is evidence for a smoothing effect on shocks to liquidity providers across trading venues under trade-through protection.

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1 Introduction

Regulation National Market System (Reg NMS) represented one of the most sweeping reforms to U.S. equity trading in recent decades. Implemented by the Security and Exchanges Commission (SEC) in 2007, the regulation aimed to encourage competition between trading venues, while simultaneously creating a "unified system" of electronic quotes to ensure traders receive the best possible executions. Reg NMS has seen equity markets become faster, more automated, and more competitive as new equity trading venues arise. Given the dramatic shifts in the equity market structure, there has been increasing concern among regulators about the "hidden consequences" of the regulation, such as excessive market complexity, and the proliferation of off-exchange "dark pools".[1]

This paper empirically examines a hidden consequence of Reg NMS: namely, that it has transformed the way in which the liquidity levels of individual assets co-move, also referred to as *liquidity commonality.* Since the seminal paper from Chordia et al. (2000), the study of liquidity commonality has shown that equity market liquidity is a priced state variable, with further studies confirming that equity market liquidity risk should and does imply a return premium.[2] Therefore, understanding the nature of what drives liquidity commonality in equity markets has important implications for asset pricing, risk management, and portfolio construction.

By unifying quotes into a centralized limit order book, Reg NMS has potentially increased the degree to which liquidity shocks are propagated throughout the equity market. In particular, Rule 611 of Reg NMS and its provision against trade-throughs – which mandate that orders be re-routed to whichever equity trading venue is offering the best price – increase the potential for market liquidity contagion between trading venues, as their order flows and prices become integrally linked. Related to this idea is the question of what exactly the "market" is, particularly in the post-Reg NMS era. Previous analyses of liquidity commonality have typically focused on liquidity co-movements within tradition exchanges such as the New York Stock Exchange (NYSE). Given the market dominance of the NYSE throughout most of its history, equating the NYSE with the equity market as a whole has perhaps been justified. However, by bolstering the competitiveness of smaller and more alternative trading venues, Reg NMS has expanded the definition of the U.S. equity market beyond the borders of traditional exchanges. According to an SEC Concept Report, in 2005, nearly 80% of trading in NYSE-listed stocks was conducted on

[1]See, e.g., SEC Memorandum on Rule 611 of Regulation NMS, 30 April 2015, available at https://www.sec.gov/spotlight/emsac/memo-rule-611-regulation-nms.pdf; and the House Subcommittee on Capital Markets and Government Sponsored Enterprises Hearing on "Equity Market Structure: A Review of SEC Regulation NMS", 28 February 2014, available at http://financialservices.house.gov/uploadedfiles/113-67.pdf.

[2]See, e.g., Pastor and Stambaugh (2003); Acharya and Pedersen (2005); Anderson et al. (2013).

the NYSE; by 2009, this had fallen to just 25%.[3] The analysis of liquidity co-movements within a single exchange is no longer sufficient to capture the increased diversity and complexity of the post-Reg NMS equity market. Therefore, this paper explores whether Reg NMS and trade-through protection have affected liquidity co-movements not just *within* individual trading venues, but *across* individual trading venues as well.

This question is particularly relevant in light of recent regulatory developments in equity markets. In April 2017, the SEC held a meeting to discuss the pitfalls of increasing market complexity under Reg NMS's Rule 611, and the Equity Market Structure Advisory Committee (EMSAC) has proposed a pilot program for its repeal.[4] Meanwhile, under the newly-implemented Market in Financial Instruments Directive (MiFID) II, European markets will continue to operate without any formal order protection requirements, resulting in high trade-through levels that may be harmful to investors.[5] Therefore, the impact of trade-through protection on various aspects of market quality remains an important question for regulators. Since its implementation, several studies, including O'Hara and Ye (2011) and Haslag and Ringgenberg (2016) have shown that Reg NMS led to a general improvement in liquidity *levels* by fostering competition between trading venues.[6] Hendershott and Jones (2005) and Foucault and Menkveld (2008) explore the implications of trade-through protections for market quality, and show either improvements in liquidity levels or no effects. The idea that regulation in general plays a role in liquidity co-movements due to regulatory uncertainty is explored in Chung and Chuwonganant (2014). To our knowledge, however, the question of how the mechanisms behind trade-through protection can contribute to systemic liquidity risk remain largely unexplored.

To understand this issue, we use a generalized dynamic factor model (GDFM) approach, in which liquidity commonality is measured as the amount of variance explained by the common factor(s) in a panel of liquidity measures. Explained variance thus represents the extent to which variance in the data is driven by a common shock(s). Using a block structure framework developed by Hallin and Liška (2011), the factor model is able to pool together into a single analysis subgroups of liquidity measures that may or may not share the same common shocks. This is an ideal feature, as it allows us to decompose liquidity co-movements into mutually orthogonal components that capture whether common shocks to liquidity are specific to an individual trading venue, or whether they span across multiple trading venues as something more akin to a "market liquidity" shock.

[3] See SEC Release No. 34-61358, available at https://www.sec.gov/rules/concept/2010/34-61358.pdf.

[4] See "Memorandum: Framework for Rule 611 & 610 Discussion", 3 April 2017, available at https://www.sec.gov/spotlight/emsac/emaac-regulation-nms-subcommittee-discussion-framework-040317.pdf.

[5] Foucault and Menkveld (2008) show that the trade-through level in Dutch markets exceeded 73%.

[6] Chung and Chuwonganant (2012) show a detrimental effect of Reg NMS on market quality.

Using this methodology, we first use consolidated high frequency trade and quote data from Thomson Reuters Tick History (TRTH) to examine whether there was an overall increase in liquidity commonality in the months following the implementation of Reg NMS. We examine these dynamics within two common measures of liquidity: dollar volumes, and time-weighted relative bid ask spreads. To address potential endogeneity concerns, we take advantage of the fact that the implementation of Reg NMS took place in stages: first for a pilot group of 250 NASDAQ, NYSE, and AMEX stocks, and then for all remaining stocks one month later. Comparing changes in the pilot group to changes in a matched control group allows us to improve identification, as both groups face common market conditions, but only the pilot group is subject to trade-through protection during the Pilot Phase.

In a second step, unconsolidated quote and trade data is used to compare changes in liquidity commonality within and between the NYSE and a group of regional stock exchanges. As Reg NMS trade-through provisions increase the connections between primary and regional exchanges, we expect an increase in the extent to which this network of exchanges experiences common liquidity shocks. We refer to this as *market-wide commonality*. At the same time, the extent to which liquidity shocks are isolated within individual exchanges – or *exchange-specific commonality* – should decrease. The net effect on total market commonality depends on the relative strength of the two effects. On the one hand, we might see a true "contagion" effect, as shocks gain momentum as they propagate throughout the market. On the other hand, Reg NMS may "smooth out" liquidity shocks by spreading their impacts across multiple venues.

A third analysis takes advantage of the unique status of the Financial Regulation Authority (FINRA) Alternative Display Facility (ADF) within the National Market System. The FINRA ADF is a display-only facility that requires its participants to report their trades and public quotes. By many accounts, the majority of participants reporting trade data to the ADF are so-called "dark pools", or alternative trading systems that do not provide pre-trade transparency. As dark pools by definition don't provide any quotes, we expect common shocks within the ADF to be less integrated with the rest of the equity market following the implementation of Reg NMS.

The results confirm an overall increase in liquidity commonality within dollar volumes following the implementation of Reg NMS. This increase in overall commonality is accompanied by an increase in market-wide commonality between the NYSE and regional exchanges. As dollar volumes are an ex post measure of liquidity consumption, this supports the idea of a "contagion" effect of trade-through protection on liquidity demand shocks. Meanwhile, within relative bid-ask spreads, a measure of the cost of immediacy, we see an overall decrease in liquidity commonality, together with a decrease in exchange-specific commonality on individual exchanges. Hence, there is evidence that shocks to the supply of liquidity are instead "smoothed out" across trading venues under trade-through protection. These results emphasize that Reg NMS fundamentally changed the nature of liquidity risk, by requiring investors to consider liquidity shocks across a wider and more diverse equity market.

The remainder of this paper is organized as follows. Section 2 describes the regulatory background of Reg NMS and its trade-through provisions, and develops our hypothesis on how trade-through protection could serve to transform liquidity commonality. Section 3 presents the data and measures of liquidity used in the analysis, while Section 4 discusses the methodology of the generalized dynamic factor model (GDFM) block analysis. Empirical results are presented in Section 5. Finally, Section 6 concludes.

2 Reg NMS as a Driver of Liquidity Commonality

The foundations for Reg NMS can be traced back to the 1970s, when concerns over the adverse liquidity effects of increasingly fragmented trading led the SEC and the U.S. Congress to commence the establishment of a National Market System, a single computerized market that would integrate all equity trades. With this purpose in mind, Reg NMS was adopted on 6 April 2005, and contained four main provisions: Rule 610 (Access Rule), providing for equal access to all market participants; Rule 611 (Order Protection Rule), preventing trade-throughs of protected quotes; Rule 612 (Sub-Penny Rule), prohibiting most quotations under \$0.01; and, lastly, Market Data Rules, aiming at improving reporting. The implementation of Reg NMS took place in stages throughout 2007. 9 July 2007 saw the implementation of Reg NMS for all trades for a pilot group of 250 NASDAQ, NYSE, and AMEX stocks, with the remaining stocks added on 20 August 2007.

Perhaps the most significant – and controversial – provision within Reg NMS has been Rule 611. This rule aims to guarantee market participants the best quoted prices across all markets by preventing trade-throughs of protected quotes, defined as quotes at the top level of the book. Table 1 presents a simple example of a joint order book for two trading venues, Platforms A and B, on the buy side of the book. Prior to the implementation of Reg NMS, a market sell order for 1,000 shares to Platform A would see 100 shares executed at \$1.30 with the remaining 900 executing at a price of \$1.10 – the better price of \$1.20 available on Platform B would be "traded through". However, with trade-through protection, the same 1,000-share sell order submitted to Platform A would result in 500 shares re-routed to Platform B for execution at the "protected" quote of \$1.20; if the order were submitted to Platform B, 100 shares would be re-routed to Platform A for execution at the protected quote of \$1.30.

(Insert Table 1 here.)

2.1 Market-wide vs. Exchange-Specific Commonality

In promoting a centralized limit order book, trade-through protection under Reg NMS has increased integration in equity trading (see, e.g., Spatt, 2016). In this spirit, O'Hara and Ye (2011) refer to the post-Reg NMS trading environment as a "single virtual market with multiple points of entry" (p. 459). This is likely to impact the way in which liquidity dynamics interact between various trading venues, affecting liquidity co-movements within the equity market as a whole.

We decompose overall liquidity into two components in order to capture market-wide and exchange-specific components. A single observed liquidity measure for stock $i = 1, ..., n$ on day $t = 1, ..., T$, LIQ_t^i, can be written as a factor equation:

$$\begin{aligned} LIQ_t^i &= MKT_t^i + EXCH_t^i + \xi_t^i \\ MKT_t^i &= b_i' F_t^M \\ EXCH_t^i &= c_i' F_t^E, \end{aligned} \tag{1}$$

in which b_i and c_i capture the extent to which the stock's liquidity loads onto market-wide factor(s) F_t^M, and exchange-specific factor(s) F_t^E, and ξ_t^i captures any idiosyncratic movements in liquidity. Defining stacked variables $\mathbf{LIQ}_t = [(LIQ_t^1, ..., LIQ_t^n)]$, if the components are uncorrelated, the variance of (1) can be written as:

$$\text{Var}[\mathbf{LIQ}_t] = \text{Var}[\mathbf{MKT}_t] + \text{Var}[\mathbf{EXCH}_t] + \text{Var}[\boldsymbol{\xi}_t], \tag{2}$$

implying a decomposition of the variance-covariance matrix of a panel of liquidity measures into the variance that can be explained by a market-wide component, variance that can be explained by an exchange-specific component, and an idiosyncratic component. The total commonality is equal to the total variance that can be explained by the non-idiosyncratic components – i.e., the sum of the effects of its market-wide and exchange-specific factors, $\text{Var}[\mathbf{MKT}_t] + \text{Var}[\mathbf{EXCH}_t]$.

How can we think about these market-wide and exchange-specific factors F_t^M and F_t^E in the context of real-world markets? Prior to Reg NMS, the liquidity dynamics within the primary and regional exchanges were likely driven by factors particular to individual exchanges (fee structures, latency, colocation, exchange-specific regulations, etc.). With quotes unified into a centralized limit order book, however, it becomes less important whether an order is initially submitted to the primary exchange or to a regional exchange. Therefore, the liquidity of a single stock within the primary and regional exchange should become more correlated.

This idea can be extended to consider not just the liquidity of a single stock, but the co-movements between liquidity levels of multiple stocks as well. Studies of demand-generated commonality mainly focus on the correlated trading activities of institutional investors, particularly in their use of index or program trading (see, e.g., Kamara et al., 2008; Corwin and Lipson, 2011; Koch et al., 2016; Karolyi et al., 2012). As large institutions will typically hold diversified baskets of stocks, their trading activity will induce co-movements in liquidity measures when they are faced with similar liquidity shocks. For example, consider an institutional trader who prefers to trade on a regional exchange, and faces a liquidity shock. She must sell a portion of her equity portfolio, and therefore submits market sell orders for a basket of stocks to the regional exchange. Prior to Reg NMS, a simultaneous drop in liquidity supply for a broad subset of stocks would cause commonality within the regional exchange to increase. However, this commonality would not extend to the primary exchange. After Reg NMS, on the other hand, at least some of her orders are likely to re-route to the primary exchange, effectively extending the drop in liquidity supply to the primary exchange.

Similar analogies can also be made for the supply side of liquidity. Supply-side arguments for liquidity commonality broadly explore the relationship between market liquidity and the costs of liquidity provision. As liquidity providers face similar costs, capital shocks, and information, this is likely to drive covariation in their liquidity provision. For traditional market makers, such correlations were typically limited to situations in which market makers are employed by the same specialist firm (Coughenour and Saad, 2004), or times of extreme market downturns when capital constraints become binding across the board (Brunnermeier and Pedersen, 2009; Hameed et al., 2010; Rösch and Kaserer, 2013). However, Reg NMS has led to the rise of "endogenous liquidity providers" (ELPs), who act as liquidity providers for profit on their own accounts. Regulatory agencies have expressed concern that, as ELPs are not under specific mandates to reliably supply liquidity, they are more likely to withdraw liquidity in unison when market conditions reduce the profitability of market making.[7] As such liquidity providers are more likely than traditional exchange-employed market makers to provide liquidity across multiple trading venues (see, e.g., Lescourret and Moinas, 2017), their inability or unwillingness to provide liquidity is more likely to affect multiple trading platforms simultaneously.

As a result of Reg NMS, we expect a decrease in the extent to which exchange-specific

[7]In a speech before the Economic Club of New York on 7 September 2010, SEC Chairman Mary L. Shapiro stated, "The issue is whether the firms that effectively act as market makers during normal times should have any obligations to support the market in reasonable ways in tough times." Anand and Venkataraman (2016) show that liquidity commonality is higher in stocks with a higher rate of endogenous liquidity provision, even in large and liquid stocks.

factors drive liquidity commonality within an individual exchange, and an increase in the extent to which *market-wide factors* drive liquidity commonality both within and across exchanges. However, the net impact of these two countervailing effects on total commonality is difficult to determine ex ante. If shocks that were previously exchange-specific are simply one-to-one converted into market-wide shocks, the net effect on total commonality should be zero. On the one hand, the conversion of exchange-specific into market-wide shocks might create a "contagion effect" that increases the total number of market-wide shocks, as shocks that previously were isolated to individual exchanges are now transmitted to the wider market. On the other hand, trade-through protection may decrease total commonality by mitigating the impact of liquidity shocks. Note from the example in Table 1 that, under Reg NMS, the reduction in depth and increase in spreads following the market order is smaller on Platform A than it should be otherwise, due to the fact that some of the orders impact was re-routed to Platform B. This "smoothing out" of liquidity shocks may reduce the variance (and even the co-variance) of liquidity shocks. In other words, though we see an increase in the number of factors, the impact of each individual factor may be reduced. This may serve to reduce total commonality, as exchange-specific commonality decreases more than market-wide commonality increases. To explore this question, Section 5.2 examines the variance explained by market-wide and exchange-specific factors and their impact on total commonality within both primary and regional exchange liquidity around the implementation of Reg NMS.

2.2 The FINRA ADF

The unique nature of the Financial Regulation Authority (FINRA) Alternative Display Facility (ADF) allows for an additional strategy with which to identify the impact of Reg NMS on market-wide and exchange-specific liquidity commonalities.

The FINRA ADF is a display-only facility that allows participants to report off-exchange trades and quotations. While the FINRA ADF itself is not subject to Reg NMS, participants in the ADF are required to adhere to trade-through provisions, mandating ADF trades occur at or within than the prevailing national best bid and offer (NBBO). Trading volumes reported through the FINRA ADF include transactions from off-exchange market makers, internalized orders from broker-dealers, and dark pools.[8] Dark pool trading volume constitutes a substantial portion of FINRA ADF-reported trading volumes (see, e.g., Hasbrouck, 2017). Therefore, trading volume within the FINRA ADF is used as an additional control group to identify the impact of Reg NMS on market-

[8]In 2007, participants were required to report trades and their associated timestamp to the ADF within 90 seconds of a transaction. See FINRA Manual Rule 07-23, NASD Trade Reporting Requirements Related to Regulation NMS. The reporting time has since been reduced to 10 seconds.

wide and exchange-specific liquidity commonalities.

This identification is based on the fact that, while dark pools are required under Reg NMS to prevent trades at a price worse than a NMS-protected quote, dark pools rely on quotes from lit markets. Therefore, it is less likely that dark trades must be re-routed to other exchanges to transact against other protected quotes, as prices in the dark pool are directly tied to the NBBO. Likewise, it is unlikely that orders on traditional exchanges (at least directly) re-route to dark pools. Emphasizing the disconnect between the trade-through provisions of Reg NMS and dark pools, the SEC states that "Rule [611] does not require that orders be routed to dark venues in any context. Consequently, there is no direct link between Rule 611 and the increased volume of trading on dark venues."[9] All-in-all, this should limit the extent to which Reg NMS directly impacts market-wide commonality within FINRA ADF-reported trading volumes. Consequently, Reg NMS should not necessarily impact the extent to which primary exchange and ADF trading volumes share common shocks. Furthermore, the impact of Reg NMS on the commonality between primary and ADF trading volume should be less than its impact on the commonality between trading volumes on the primary and regional exchanges, which both regularly supply protected quotes.[10] This analysis will be explored in Section 5.3.

3 Measures of Liquidity and Data

3.1 Measures of Price and Volume Dimensions of Liquidity

This study considers two common measures of liquidity: dollar volumes and relative bid-ask spreads. Time-weighted relative bid-ask spreads are calculated for one-hour intervals in each trading day. For firm $i = 1, ..., n$ at time τ, the relative bid-ask spread is equal to $spr^i_\tau := (ask^i_\tau - bid^i_\tau)/((ask^i_\tau + bid^i_\tau)/2)$. Our calculation of time-weighted relative bid-ask spreads follows from McInish and Wood (1992). Suppose that over the interval $t := (\tau, \tau')$ there are J updates of spreads spr^i_j, $j = 1, ..., J$ occurring at times τ_j, $j = 1, ..., J$, where $\tau_0 = \tau$ and $\tau_{J+1} = \tau'$. spr^i_0 is set equal to the spread that is outstanding at time τ. The time-weighted relative bid-ask spread SPR^i_t for firm i over each hour-interval t is thus defined as:

[9]SEC Memorandum on Rule 611 of Regulation NMS, 30 April 2015, available at https://www.sec.gov/spotlight/emsac/memo-rule-611-regulation-nms.pdf.

[10]Note that Reg NMS's impact on bid-ask spreads within the FINRA ADF are less clear. Quotes disseminated from the FINRA ADF originate from participants that exclude dark pools, such as off-exchange market makers and broker-dealers. Hasbrouck (2010) reports that FINRA ADF quotations are often stale and are typically excluded from calculations of the NBBO.

$$SPR_t^i := \sum_{j=0}^{J} \frac{spr_j^i(\tau_{j+1} - \tau_j)}{(\tau' - \tau)}.$$

Likewise, suppose that there are K trades over the interval $t := (\tau, \tau')$. Dollar volumes for firm $i = 1, ..., n$ for each hour-interval t are defined as:

$$VOL_t^i = \sum_{k=1}^{K} price_k^i \times volume_k^i,$$

where $price_k^i$ and $volume_k^i$ indicate the price and volume of each trade $k = 1, ..., K$.

3.2 Data

Our sample is composed of the 250 NYSE, Nasdaq, and AMEX pilot stocks that faced early implementation of Reg NMS on 9 July 2007.[11] To create the control group, each pilot stock is matched to a stock that was not part of the pilot program, based on its proximity to the pilot stocks in terms of market capitalization and price as in Davies and Kim (2009) and O'Hara and Ye (2011). Specifically, for each pilot stock i, a matching non-pilot stock j is chosen such that the following matching error is minimized:

$$D_{ij} = \left| \frac{MCAP_i}{MCAP_j} - 1 \right| + \left| \frac{PRC_i}{PRC_j} - 1 \right|.$$

To isolate the effects of exchange-specific factors, matched stocks are additionally required to have the same primary exchange as the pilot stock. To calculate the variables used for matching, daily market capitalization, prices, and primary exchange information are extracted from the Center for Research in Security Prices (CRSP) daily stock files for the entire CRSP universe. Stocks that merged or were de-listed during the sample period are excluded, leaving us with 93 NYSE stocks, 48 AMEX stocks,[12] and 99 Nasdaq pilot stocks ($n^{pilot} = 240$), along with an equally-sized matched control group ($n^{control} = 240$)

For each stock, both consolidated and unconsolidated tick-level trade and quote information are obtained from Thomson Reuters Tick History (TRTH). For a single stock, the TRTH consolidated file includes all trades and the best available quotes across primary and regional exchanges. Meanwhile, the unconsolidated file contains trades and the

[11]In order to avoid selection bias, the assumption is that the pilot group of stocks were chosen irrespective of their liquidity levels. According to the SEC, the pilot group was to be "chosen by the primary listing market [...] to be reasonably representative of the range of each Network's securities" (SEC Release No. 34-53829). Thus, these securities should represent a well-diversified group, i.e., not simply composed of the most liquid securities.

[12]One AMEX match is removed (the SPDR S&P 500 ETF, or SPDR). SPDR is unparalleled in financial markets in terms of its market capitalization and liquidity, and thus represented an extreme outlier compared to the rest of the sample.

best available quotes for each particular exchange. Unconsolidated files are obtained for primary exchanges including the NYSE and Nasdaq, as well as for regional exchanges including the Boston Stock Exchange, National Stock Exchange, Chicago Stock Exchange, OMX PSX, Chicago Board Options Exchange, and International Stock Exchange.[13] Unconsolidated files for trades on the Financial Regulation Authority (FINRA) Alternative Display Facility (ADF) are also obtained.

The time period considered in this analysis includes the Reg NMS Pilot Phase ("Pilot Phase") from 9 July to 16 August 2007 (30 trading days), as well as the 30 trading days prior ("Pre Phase", 23 May to 6 July 2007).[14] We also include 30 trading days after the Pilot Phase ("Post Phase", 20 August to 2 October 2007), during which all sample stocks were subject to Reg NMS. The first and last 15 minutes of the trading day are discarded. Hourly liquidity measures are then calculated as described in Section 3.1. Non-positive spreads are considered as data errors and treated as missing. To ensure a sufficient number of observations, stocks with more than 75% missing observations or zero-volume intervals are discarded. Any remaining missing dollar volumes are treated as zero, while missing bid-ask spreads are linearly interpolated.[15]

Table 2 reports summary statistics for the sample of consolidated dollar volumes (Panel A) and bid-ask spreads (Panel B) during the three analyzed phases, as well as for the full time period. Results are reported separately for the pilot and control groups, as well as for the full sample. Also reported are the differences in liquidity measures both between the various phases and between the pilot and control groups, along with their statistical significance according to standard t-tests.

(Insert Table 2 here.)

These summary statistics show, first, the the pilot group has significantly higher trading volumes and lower bid-ask spreads than the control group. However, these differences are relatively small in magnitude (about 17% higher trading volumes and 15% lower spreads) and relatively stable throughout time. Secondly, t-tests show that dollar volume increases during the Pilot Phase for both groups, but significantly more so for the pilot group. Likewise, bid-ask spreads increase for both groups during the Pilot Phase, but significantly less so for the pilot group. This supports the results from O'Hara and Ye (2011)

[13]To obtain this list of regional exchanges, we start with the trading venues for which TRTH trading volume data is available during our sample. We then exclude the following: primary exchanges besides the NYSE and Nasdaq (AMEX and NYSE Arca), third market broker-dealers, and grey markets. These primary and regional exchanges were defined as self-regulatory organizations (SRO) at the time of Reg NMS's implementation, and were therefore subject to the trade-through provisions of Reg NMS.

[14]3 July is excluded, due to it begin a half-day in U.S. markets.

[15]Linear interpolation assumes that the missing observations between two observed spreads evolve linearly over the missing time-points. To further reduce the presence of outliers, relative bid-ask spreads greater than 5% are removed, along with dollar volumes associated with non-boardlot or off-market trade qualifiers.

and Haslag and Ringgenberg (2016), that Reg NMS led to increased liquidity within the pilot group during the Pilot Phase. Interestingly, however, this trend is shown to revert in the Post Phase, as dollar volumes revert back to their Pre Phase levels. Meanwhile, bid-ask spreads continue to increase in the Post Phase for both groups of stocks.

Table 2 presents results from an augmented Dickey-Fuller test (ADF) for each time series within the sample; reported is the proportion of stocks for which the null hypothesis of a unit root fails to be rejected. The results show that non-stationarity fails to be rejected for between 33-67% of the time series within each phase. Our methodology requires second-order stationarity, so we consider the first differences of liquidity measures, $\Delta SPR_t^i = SPR_t^i - SPR_{t-1}^i$ and $\Delta VOL_t^i = VOL_t^i - VOL_{t-1}^i$.[16]

Figures 1a and 1b plot, respectively, the cross-sectional averages of dollar volumes and relative bid-ask spreads over the full time period, with vertical lines corresponding to the cutoffs between the Pre, Pilot, and Post Phase introductions. The plots highlight the lower spreads and higher trading volumes for the pilot group. Furthermore, the increase in dollar volumes in the Pilot Phase (and subsequent reversal in the Post Phase) for both groups can be clearly seen from the plots, along with the increase in bid-ask spreads for both groups over the course of the sample period.

(Insert Figure 1 here.)

Table 3 reports summary statistics for the aggregated sample of pilot and control stocks, separated into the primary and regional exchanges, as well as the FINRA ADF. Statistics are reported separately for stocks with either NYSE or Nasdaq as their primary listing exchange. As expected, trading volumes are higher, and relative-bid ask spreads are lower on the primary exchanges than on the regional exchanges. Further, volumes are higher and spreads are lower for the NYSE than for Nasdaq, reflecting the dominance of NYSE at the time of Reg NMS's implementation. In nearly all cases dollar volumes increase during the Pilot Phase, and subsequently drop in the Post Phase; bid-ask spreads also increase from the Pre to Post Phases for nearly all exchanges. Table 3 also reports the number of firms per exchange with sufficient observations to meet our filtration requirements, showing that NYSE-listed firms are traded more actively on the regional exchanges than Nasdaq-listed stocks.

(Insert Table 3 here.)

Figures 2a-2d plot the average dollar volume and bid-ask spreads for NYSE- and Nasdaq-listed stocks, separately for each exchange. The liquidity dominance of the pri-

[16] The first observation of each trading day is subsequently discarded, leaving a time dimension of t = 150 hourly liquidity observations per phase. Unreported results show that the unit root null is rejected for 100% of the series after taking first differences.

mary exchanges vis-à-vis the regional exchanges is evident from their higher trading volumes and lower spreads. The plots also highlight the lower rate of non-missing trading variables for NYSE-listed stocks on the regional exchanges. This is likely because Nasdaq stocks were not part of the Intermarket Trading System (ITS) Plan, which facilitated trading between primary and regional exchanges prior to Reg NMS. Hence, subsequent analyses will focus on the results for NYSE-listed stocks.

(Insert Figure 2 here.)

4 Methodology

4.1 The Generalized Dynamic Factor Model (GDFM)

Our analysis decomposes the variances in liquidity into market-wide and exchange-specific components, as in equation (2). To do so, we make use of the generalized dynamic factor model (GDFM), developed in Forni et al. (2000, 2004, 2005, 2009), Forni and Lippi (2001), and Hallin and Liška (2007). Denoting by q the number of dynamic factors, the GDFM decomposes the panel X_t^i $(i = 1, ..., n; t = 1, ..., T)$ into two components: a common component χ_t^i, and an idiosyncratic component ξ_t^i, in which the common component can be written as the combination of q common shocks, as:

$$\begin{aligned} X_t^i &= \chi_t^i + \xi_t^i \\ \chi_t^i &= \mathbf{B}_i'(L)\mathbf{u}_t, \end{aligned} \tag{3}$$

where $\mathbf{u}_t = (u_{1t}, ..., u_{qt})'$ is a q-dimensional orthonormal white noise process, and $\mathbf{B}_i(L) = (B_{i1}(L), ..., B_{iq}(L))'$ is a vector of (two-sided) square-summable filters. In this way, the GDFM avoids the assumption of *static* factor loadings, such that the factors and data vector can be *dynamically* related at leads and lags. This is an ideal feature, as it is able to take into account potential non-synchronicities between the response of primary and regional exchanges to liquidity shocks.

The aim of factor models is typically to determine the amount of variance in the data that can be explained by the variance in the common component. Forni et al. (2000) show that the common and idiosyncratic components (χ_t^i and ξ_t^i) can be uniquely identified, and their variances can be consistently estimated. Defining the stacked variables $\mathbf{X}_t = (X_t^1, ..., X_t^n)$, $\boldsymbol{\chi}_t = (\chi_t^1, ..., \chi_t^n)$ and $\boldsymbol{\xi}_t = (\xi_t^1, ..., \xi_t^n)$, under assumptions of mutually orthogonal components, the variance of (3) can be written as:

$$\mathrm{Var}[\mathbf{X}_t] = \mathrm{Var}[\boldsymbol{\chi}_t] + \mathrm{Var}[\boldsymbol{\xi}_t], \tag{4}$$

in which $\text{Var}[\mathbf{X}_t] = \mathbb{E}[\mathbf{X}_t\mathbf{X}_t']$ is the $n \times n$ variance-covariance matrix of the centered data. Equation (4) is also known as the *factor equation.* The amount of variance explained by the common component is thus a measure of commonality in the data, as it represents the extent to which variance in the data is explained by a common shock.[17]

Given an estimated number of dynamic factors $\hat{q}$, the amount of variance that they explain is calculated using a spectral decomposition analogous to equation (4). A precise description of the procedure for estimating the explained variance is given in Appendix A.1.

4.2 GDFM in a Block Structure

Hallin and Liška (2011) show that, when panel data is organized according to "blocks" (i.e., large subpanels), one can use the GDFM to develop a more detailed picture of how various subsets of the data are related. For example, consider the joint panel $\mathbf{Z}_t = (\mathbf{X}_t', \mathbf{Y}_t')$, which is composed of the union of the two blocks, e.g., corresponding to liquidity measures in a primary exchange and in a regional exchange. The aim is to find the variance explained by common factors within the *intersection* of these two blocks, thus giving the significance of the factors shared by both sets of liquidity measures, and within the disjunctive union of the these two blocks, as this represents the significance of the factors unique to each individual block.

This block estimation procedure, described in more detail Appendix A.2, further decomposes the variance in (4) into:

$$\begin{aligned}\text{Var}[\mathbf{X}_t] &= \text{Var}[\boldsymbol{\phi}_{X,Y;t}] + \text{Var}[\boldsymbol{\psi}_{X(Y);t}] + \text{Var}[\boldsymbol{\xi}_{X;t}] \\ \text{Var}[\mathbf{X}_t] &= \text{Var}[\boldsymbol{\phi}_{Y,X;t}] + \text{Var}[\boldsymbol{\psi}_{Y(X);t}] + \text{Var}[\boldsymbol{\xi}_{Y;t}],\end{aligned} \tag{5}$$

in which, for example, the "strongly common" component $\boldsymbol{\phi}_{X,Y;t}$ represents the component of the panel $\mathbf{X}_t$ that is common to both subpanels (i.e., the entire panel $\mathbf{Z}_t$), and the

[17]Note that the model presented in equations (3) and (4) does not require two assumptions common to most traditional factor models. First, the GDFM avoids the assumption that the idiosyncratic component is independently and identically distributed (i.e., that $\text{Var}[\boldsymbol{\xi}_t]$ in equation (4) is a diagonal matrix), which is the traditional way in which the common and idiosyncratic components are identified. Instead, the GDFM has an approximate structure, which does allow for a finite amount of correlation in the idiosyncratic component by redefining $\text{Var}[\boldsymbol{\xi}_t]$ as a series of $n \times n$ matrices with uniformly bounded eigenvalues. The intuition is that, while the eigenvalues of the common component will grow to infinity as $n \to \infty$ (i.e., they will grow at least proportionally to the sample size), the eigenvalues of the idiosyncratic component will remain bounded as long as the correlation in the idiosyncratic component is "reasonably" small (see. e.g., Chamberlain and Rothschild, 1983). Furthermore, in order to achieve a consistent estimation, most factor model approaches necessitate a time series length T that is "much larger" than sample size n. This requirement is relaxed within the GDFM framework.

"weakly common" component $\boldsymbol{\psi}_{X(Y);t}$ represents the component that is common to $\mathbf{X}_t$, but idiosyncratic to $\mathbf{Y}_t$. Putting this in the context of our analysis, consider a panel of liquidity measures, e.g., dollar volumes, $\Delta\mathbf{VOL}_t = (\Delta\mathbf{VOL}'_{PRIM;t}, \Delta\mathbf{VOL}'_{REG;t})$, in which $\Delta\mathbf{VOL}_{PRIM;t}$ represents a panel of dollar volumes on a primary exchange, and $\Delta\mathbf{VOL}_{REG;t}$, is the corresponding panel of dollar volumes on a regional exchange for the same group of stocks. Thus, the GDFM in a block structure gives us the variance decomposition from equation (2), allowing us to decompose the variance-covariance matrix of liquidity measures into the variance that can be explained by a market-wide component (i.e., the component shared by both exchanges), the variance that can be explained by an exchange-specific component (i.e., the components unique to each individual exchange), and an idiosyncratic component.

5 Empirical Results

5.1 Changes in Liquidity Commonality Within Dollar Volumes and Relative Bid-Ask Spreads

We first examine whether there is an overall change in the liquidity dynamics of dollar volumes and relative bid-ask spreads around the implementation of Reg NMS. In order to disentangle the potential effects of Reg NMS from other concurrent market-wide events,[18] we take advantage of the staggered introduction of Reg NMS: first for a pilot group of stocks, and then for all stocks one month later. Comparing changes in the pilot group to changes in the control group during the Pilot Phase allows us to alleviate endogeneity problems, as both groups face common market conditions, but (in theory) only the pilot group is subject to Reg NMS during the Pilot Phase.

Our analysis allows us to examine whether there is an increase not only within, but also across, liquidity measures following the implementation of Reg NMS. Using the GDFM block structure, total explained variance is decomposed into the variance that can be explained by a factor that is common to both measures of liquidity ("measure common" variance), and by factors that are unique to each individual liquidity measure ("volume-specific" and "spread-specific" variance). If we think of relative bid-ask spreads, a measure of the cost of immediacy, as a measure of the ex ante supply of liquidity, while dollar volumes, as a measure of liquidity consumption, represents a measure of the ex post demand for liquidity, then decomposing explained variance into these components allows us to examine whether Reg NMS has altered the interaction between the supply- and demand-side

[18]See Chung and Chuwonganant (2012) for a discussion of events concurrent to the implementation of Reg NMS.

arguments for liquidity commonality. We might expect these liquidity supply and demand dynamics to co-move more strongly under trade-through protection, as order volume is now mandatorily routed to the exchange with the lowest trading costs. Therefore, we restate the variance decomposition from (5) as:

$$\begin{aligned}\mathrm{Var}[\Delta \mathbf{VOL}_t] &= \mathrm{Var}[\boldsymbol{\phi}_{VOL,SPR;t}] + \mathrm{Var}[\boldsymbol{\psi}_{VOL(SPR);t}] + \mathrm{Var}[\boldsymbol{\xi}_{VOL;t}] \\ \mathrm{Var}[\Delta \mathbf{SPR}_t] &= \mathrm{Var}[\boldsymbol{\phi}_{SPR,VOL;t}] + \mathrm{Var}[\boldsymbol{\psi}_{SPR(VOL);t}] + \mathrm{Var}[\boldsymbol{\xi}_{SPR;t}],\end{aligned}$$

in which the variances in the panel of, for example, dollar volumes ($\mathbf{VOL}_t$) are decomposed into $\mathrm{Var}[\boldsymbol{\phi}_{VOL,SPR;t}]$, which captures the variance in dollar volumes that can be explained by a “measure-common” factor that is common to both dollar volumes and bid-ask spreads, and $\mathrm{Var}[\boldsymbol{\psi}_{VOL(SPR);t}]$, which captures explained variance from a “volume-specific” factor unique to dollar volumes, and an idiosyncratic component. The variances in the panel of relative bid-ask spreads, $\mathbf{SPR}_t$, are similarly decomposed. Figure 3 illustrates how these liquidity dynamics within the pilot and control groups evolve across the Pre, Pilot, and Post Phases. Full results are presented in Table 4, including the difference-in-differences between the pilot and control groups and their statistical significance according to a bootstrapping procedure described in Appendix A.3.

(Insert Figure 3 here.)
(Insert Table 4 here.)

Results for dollar volumes are presented in Figure 3a and in Panel A of Table 4. Moving from the Pre to Pilot Phase, total commonality (i.e., measure-common + volume-specific variance) significantly increases for both groups, but there is no statistically significant difference between the groups in terms of the magnitude of the increase. Furthermore, it is not clear whether this increase is driven by a change in measure-common or volume-specific variance, as the changes within both components are not statistically significant. Instead, we see significant changes once we move from the Pilot to the Post Phase. Measure-common variance increases and volume-common variance decreases for both groups. However, total commonality increases significantly only for the pilot group, a relative increase of 6.2%. The overall results from the Pre to Post Phase also confirm a statistically significantly higher increase in total commonality within the pilot group than within the control group. These results indicate that Reg NMS increased the total commonality within dollar volumes, driven mainly by a factor shared by both measures, though with some delay as the market adjusted to the new regulation. This is consistent with, e.g., McInish et al. (2014), who show that high-frequency trading strategies enabled by trade-through protection have led to greater market-wide impacts of liquidity demand shocks.

The results for relative bid-ask spreads, reported in Figure 3b and in Panel B of Table 4, show an overall increase in total commonality within both groups when moving from the Pre to Post Phase. However, focusing on the Pilot Phase, total commonality increases *less* in the pilot group than in the control group. Only the pilot group sees a statistically significant increase in measure-common variance, but the difference between the pilot and control groups is insignificant. Meanwhile, the control group experiences a significant increase in spread-specific variance (a relative increase of 18%) that is not experienced by the pilot group. This implies that the provisions of Reg NMS lowered the impact of a supply-specific shock.

As described in Section 2.1, supply-specific shocks to liquidity commonality could be generated by the funding constraints of liquidity providers (see, e.g., Brunnermeier and Pedersen, 2009). One explanation for this result is that, in the face of funding constraints, liquidity providers with access to multiple markets may be able to more easily adjust their inventory, leading to a lower withdrawal from the liquidity supply. This is especially the case when dollar volume becomes more correlated across markets, as market makers can more easily unwind large inventory positions (see, e.g., Lescourret and Moinas, 2017). As discussed in Section 2.1, this supports the idea of a "smoothing" effect of trade-through protection in limiting the impact of shocks to the spread.

While spread-specific variance decreases in the pilot group relative to the control group, there is no corresponding relative increase in measure-common variance. This leads to the relative decrease in total commonality within the pilot group. The finding that measure-common variance does not increase within bid-ask spreads after Reg NMS is perhaps surprising, but is consistent with the theoretical model from Van Kervel (2015) in which, as the proportion of traders with multi-market access increases (i.e., the probability of a trade-through decreases), the ability of market makers to adjust quotes following trades diminishes. This is because informed trades are likely to sweep attractively-priced quotes across all available markets before market makers can react, leading to a lower sensitivity of spreads to market-wide demand shocks.

Therefore, Reg NMS has indeed impacted the dynamics within individual measures of liquidity, either by increasing the extent to which these measures of liquidity share the same shocks (in the case of dollar volumes), or by limiting the impact of shocks that are unique to the individual measure (in the case of relative bid-ask spreads). The result is an overall increase in co-movements within dollar volumes, while co-movements in spreads see an overall decrease. It should be stressed that dollar volumes and relative bid-ask spreads still retain their own individual dynamics, as shown by the fair amount of, respectively, volume-specific and spread-specific variance. Their cross-market properties are thus are likely differently affected by trade-through protection. The next sections will explore whether changes in total commonality within these two measures are driven by changing dynamics, both within and across the various trading venues that formed the new National Market System.

5.2 Comparing Liquidity Commonality Across the Primary and Regional Exchanges

The next section sheds more light on the changes in dynamics within dollar volumes and relative bid-ask spreads, by exploring whether they are due to changes in the extent to which the various trading venues that became part of the new National Market System share common liquidity shocks. Therefore, this section presents results from the GDFM in a block structure, in which explained variance is decomposed into strongly common ("market-wide") and weakly common ("exchange-specific") variance. The block structure is composed of a panel of liquidity measures on the primary exchange, $\mathbf{LIQ}_{PRIM;t}$, and a panel of liquidity measures on the regional exchange, $\mathbf{LIQ}_{REG;t}$, for the same set of stocks. The panels of regional exchange liquidity measures are constructed by taking the sum across regional exchanges in the case of dollar volumes, and the equal-weighted average across regional exchanges in the case of relative bid-ask spreads. We then perform the following variance decomposition:

$$\begin{aligned} \mathrm{Var}[\mathbf{LIQ}_{PRIM;t}] &= \mathrm{Var}[\boldsymbol{\phi}_{PRIM,REG;t}] + \mathrm{Var}[\boldsymbol{\psi}_{PRIM(REG);t}] + \mathrm{Var}[\boldsymbol{\xi}_{PRIM;t}] \\ \mathrm{Var}[\mathbf{LIQ}_{REG;t}] &= \mathrm{Var}[\boldsymbol{\phi}_{REG,PRIM;t}] + \mathrm{Var}[\boldsymbol{\psi}_{REG(PRIM);t}] + \mathrm{Var}[\boldsymbol{\xi}_{REG;t}], \end{aligned} \tag{6}$$

in which $\mathbf{LIQ}_{;t}$ can take the form of either dollar volumes or relative bid-ask spreads, $\mathbf{LIQ}_{;t} \in \{\Delta\mathbf{VOL}_{;t}, \Delta\mathbf{SPR}_{;t}\}$. For example, the variance of dollar volumes on the NYSE $\Delta\mathbf{VOL}_{PRIM;t}$ is decomposed into $\mathrm{Var}[\boldsymbol{\phi}_{PRIM,REG;t}]$, capturing the variance in dollar volumes that can be explained by a factor that is strongly common to both the NYSE and the regional exchanges ("market-wide"), and $\mathrm{Var}[\boldsymbol{\psi}_{PRIM(REG);t}]$, which captures explained variance from a weakly common factor unique to the NYSE ("exchange-specific"), and an idiosyncratic component. The dollar volumes in the regional exchanges, $\Delta\mathbf{VOL}_{REG;t}$, are similarly decomposed.

The variance explained by market-wide factors captures the extent to which NYSE liquidity co-moves with the liquidity within the regional exchanges. Conversely, the variance explained by the exchange-specific factor captures the co-movements in the NYSE that are not shared by the regional exchanges. This analysis also takes advantage of the tiered nature of implementation, by comparing results between the pilot stocks and the matched group of control stocks.

5.2.1 Dollar Volumes

Results from the variance decomposition in (6) for dollar volumes are presented in Figure 5, with the full results in Table 5.

(Insert Figure 5 here.)
(Insert Table 5 here.)

Panel A1 of Table 5 presents the variance explained by the market-wide and exchange-specific factors within the NYSE for pilot stocks, while Panel A2 shows the same from the control group. Panel A3 shows results for the differences and difference-in-differences between the pilot and control groups, along with their statistical significance according to the bootstrapping procedure. Also shown is the difference between the variance explained by the market-wide and exchange-specific factors (MKT-EXCH), indicating the changes in the relative importance of each factor and its contribution to total commonality, as well as total commonality (MKT+EXCH). Results for the regional exchanges are shown in Panels B1, B2, and B3 of Table 5.

Mirroring the findings in Section 5.1, the results show very little change during the Pilot Phase within the NYSE. There is a statistically significant increase in total commonality when moving from the Pre to Pilot Phase (a relative increase of 6% and 11% for the pilot and control groups, respectively), but it is unclear whether this is driven by an increase in market-wide or exchange-specific commonality. While only the control group sees a significant increase in market-wide commonality, the difference-in-differences is not statistically significant between the pilot and control group.

Again, however, for both groups we see a significant increase in market-wide commonality and no change or even a decrease in exchange-specific commonality overall from the Pre to Post Phase. As the increase in market-wide commonality is greater than the decrease in exchange-specific commonality, this results in a relative increase in total commonality of 7% for both the pilot and control groups. The difference between market-wide and exchange-specific commonality increases substantially for both groups – from about 10 percentage points in the Pre Phase, to more than 20 percentage points in the Post Phase. Therefore, it seems that Reg NMS may have led to an increase in total commonality within dollar volumes on the NYSE, driven primarily by an increase in its exposure to market-wide common shocks.

Examining the results from the regional exchange, it is important to note that the dynamics within the primary and regional exchanges are not necessarily reciprocal; for example, the primary exchange could be much more sensitive to market-wide shocks stemming from within the regional exchanges than vice versa. In fact, this appears to have been in case prior to the implementation of Reg NMS: during the Pre Phase, market-wide commonality in the regional exchanges is only about one-third of its level in the NYSE. This is likely due to the fact that, prior to Reg NMS, liquidity on the regional exchanges was much more fragmented and insulated from the rest of the market. Due to the limited liquidity available in the regional exchanges, it is likely that all agents trading in a regional exchange were required to access the NYSE to at least some extent, thus "transferring" shocks on the regional exchanges to the primary exchange. Meanwhile, not all agents trading in the NYSE necessarily needed to access the regional exchanges, which may have insulated them to some extent from NYSE-generated shocks.

However, by bolstering the ability of regional exchanges to compete for order flow, Reg NMS has increased the extent to which regional exchanges are interconnected with the rest of the market. Market-wide commonality significantly increases across all time periods for both pilot and control groups; at respectively 62% and 79%, the increase is substantial.[19] Overall, between the Pre and Post phases, total commonality increases substantially for both the pilot and control group – a relative increase of 42% and 50%, respectively. In fact, following the implementation of Reg NMS, the liquidity dynamics within dollar volumes on the regional exchanges begin to look more similar to those of the NYSE. Again, as in the NYSE, this increase in total commonality is seen in both the pilot and control group. In fact, Panel B3 confirms that there are no significant differences between the changes in liquidity dynamics between the pilot and control groups over time.

To understand why this might be the case, it is important to note that trading centers and brokers were already required to fully comply with the technological requirements of Reg NMS prior to the Pilot Phase.[20] This included the adoption of smart order routers (SORs) by brokers wishing to submit a newly designated order type known as an inter-market sweep order (ISO). An ISO is an order that allows traders to more quickly execute orders by specifying execution in a designated market center, while simultaneously sweeping other markets for protected quotes. In order to properly execute an ISO, a trader would need access to an SRO, which can search across markets for the best possible price. Studies of ISO order usage, such as Chakravarty et al. (2012) and McInish et al. (2014), show that the speed advantage of ISOs became increasing valuable to traders following the implementation of Reg NMS.

The adoption of an SRO technology represents a large fixed cost for traders. However, Foucault and Menkveld (2008) show that, if enough traders adopt SORs such that sufficient liquidity on peripheral markets is ensured, their use generates profits through

[19]Exchange-specific commonality also increases, though by much less than the increase in market-wide commonality – this is evidenced by the significant increase in the difference MKT-EXCH.

[20]See Extension Release II, 72 FR at 4203 SEC, January 30 2007, available at https://www.gpo.gov/fdsys/pkg/FR-2007-01-30/pdf/FR-2007-01-30.pdf.

improvements in both prices and execution probabilities. This critical mass is most likely achieved, as their use increases in value following Reg NMS. Therefore, after facing the fixed cost, it is unlikely that traders would limit the use of their smart order routing technologies to pilot stocks, but seek out price improvements for all transactions. This is confirmed in the data. Figure 4 compares ISO usage for the pilot and control stocks during our sample period, and shows that ISO usage increased significantly after the introduction of the Reg NMS pilot program, and again around the implementation of Reg NMS for all stocks.[21] However, there is no visible difference between the rate of ISO usage between the pilot and control stocks, and t-tests confirm that the difference between the two groups is insignificant in each subperiod. The indiscriminate use of ISOs could thus cause some of the effects of Reg NMS to spill over into the control group, particularly within transaction volumes.[22]

Given the lack of separation between the impact of Reg NMS on dollar volumes within pilot and control stocks, our analysis in Section 5.3 examines a second control group to identify the impact of trade-through protection: a comparison of the dollar volume dynamics between the primary and regional exchanges that became part of the National Market System, with the dynamics between the primary exchange and the FINRA ADF, whose dollar volumes are less affected by the trade-through protection.

5.2.2 Relative Bid-Ask Spreads

Figure 6 and Table 6 present results from the same variance decomposition in (6) performed for relative bid-ask spreads. From Panel A3, the difference-in-differences between the pilot and control groups from the Pre to Pilot phases shows that market-wide commonality increases significantly more in the pilot group than in the control group, and likewise exchange-specific commonality exhibits a significantly stronger decrease during the Pilot Phase. In fact, exchange-specific commonality actually significantly *increases* in the control group during the Pilot Phase, while there is no such increase in the pilot group. Similar to the results from Section 5.1, this indicates that Reg NMS had the effect of insulating the pilot group against a liquidity shock. Overall, both the pilot and control groups experience a significant drop in exchange-specific commonality from the Pre to Post Phase. This decrease is not counteracted by an equally-sized increase in market-wide commonality. The net result is thus a drop in total commonality.

[21] ISO trades are identified using the TRTH qualifier "MSW[CTS_QUAL]". t-tests confirm that these increases are significant at A $< 1\%$ level.

[22] A prevention of trade-through requires both brokers to re-route market orders to ensure best prices, and trading venues to ensure quotes that are at least as good as the NBBO. While there is an inherent incentive for traders to re-route market orders to achieve best prices even prior to the Pilot Phase, it is less clear that there is such an inherent incentive for trading venues to monitor the state of their limit orders such that they ensure traders receive best prices.

(Insert Figure 6 here.)

(Insert Table 6 here.)

Results for the regional exchanges in Panel B are similar. The pilot group experiences a significant drop in exchange-wide commonality during the Pilot Phase, while there is no change in exchange-wide commonality within the control group. This leads to a 13% relative decrease in total commonality within the pilot group. Interestingly, these effects are partially reversed in the Post Period, when both groups experience significant increases in market-wide commonality – by 47% and 31% for the pilot and control group, respectively. This causes an increase in total commonality within the regional exchange from the Pre to Post Phase for both groups.

This is an interesting result, given that total commonality within the NYSE is shown to decrease overall, and again points out the non-reciprocal relationship between liquidity dynamics on the NYSE and the regional exchanges. While exchange-specific commonality decreases within the NYSE, this is not matched by an increase in the extent to which the NYSE is driven by market-wide shocks and thus total commonality decreases. On the contrary, the regional exchanges, in being drawn more closely to the market through trade-through provisions, experience an increase in the extent to which they are affected by market-wide shocks. This provides additional evidence for Reg NMS drawing regional exchanges out of the periphery and into the equity market network.

5.3 Comparing Liquidity Commonality Across the Primary Exchange and FINRA ADF

As previously discussed, the distinction between trading volume dynamics in the pilot and control group becomes less clear if traders used their newly adopted smart order routing technologies to re-route transactions for all stocks already during the Pilot Phase. Therefore, we perform an additional analysis that includes data from the FINRA ADF. As described in Section 5.3, orders in the FINRA ADF are less likely to be re-routed to or directly re-routed from the National Market System, and therefore should be less influenced by the introduction of trade-through protection. We should therefore see more of an impact on the extent to which the NYSE co-moves with the regional exchanges, and less on co-movements of the NYSE with the ADF. Given that this should be the case for both pilot and control stocks, and to take advantage of the full sample size, this analysis considers the full sample of pilot and control stocks as a single group of 186 stocks.[23]

[23]If this assumption is false and in fact the control group is not impact by Reg NMS during the Pilot Phase, this should only add more noise to the analysis and work against finding significance.

We compare the variance decomposition in (6), performed for the entire sample of stocks, with the following variance decomposition:

$$\mathrm{Var}[\Delta\mathbf{VOL}_{PRIM;t}] = \mathrm{Var}[\boldsymbol{\phi}_{PRIM,ADF;t}] + \mathrm{Var}[\boldsymbol{\psi}_{PRIM(ADF);t}] + \mathrm{Var}[\boldsymbol{\xi}_{PRIM;t}]$$
$$\mathrm{Var}[\Delta\mathbf{VOL}_{ADF;t}] = \mathrm{Var}[\boldsymbol{\phi}_{ADF,PRIM;t}] + \mathrm{Var}[\boldsymbol{\psi}_{ADF(PRIM);t}] + \mathrm{Var}[\boldsymbol{\xi}_{ADF;t}],$$

in which the variances in the panel of dollar volumes, $\Delta\mathbf{VOL}_{;t}$, are decomposed into the variance in dollar volumes that can be explained by a factor that is strongly common to both the primary and the FINRA ADF, and variance that can be explained by a factor unique to each trading venue. The variance decomposition is presented in Figure 7, while Table 7 presents the full tabulated results.

(Insert Figure 7 here.)
(Insert Table 7 here.)

The variance decompositions for the NYSE are presented in Panel A of Table 7. Panel A1 captures the extent to which the NYSE shares liquidity dynamics with the regional exchanges, while Panel A2 captures the extent to which the NYSE shares liquidity dynamics with the FINRA ADF. Panel A3 shows the differences and difference-in-differences between the NYSE-regional dynamics and the NYSE-ADF dynamics over time. The same results are shown in Panel B for the regional exchanges, capturing the extent to which the regional exchanges (Panel B1) and the ADF (Panel B2) share liquidity dynamics with the NYSE, and their differences (Panel B3).

As expected, the NYSE co-moves more closely with the regional exchanges than with the ADF, at least during the Pilot Phase. Market-wide commonality between the NYSE and regional exchanges increases by 16%, while there is no statistically significant change in market-wide commonality between the NYSE and the ADF. Meanwhile, exchange-specific commonality between the NYSE and ADF increases by 40%. Overall from the Pre to Post Phase, total commonality between the NYSE and the regional exchanges increases more than between the NYSE and ADF. In sum, the liquidity dynamics within the NYSE are indeed shown to become more closely tied with the regional exchanges than with the ADF. This is as expected, as it is unlikely a NYSE execution would be generated by a re-routed order from the ADF, limiting the extent to which ADF-specific shocks are propagated to the NYSE.

Interestingly, the results from Panel B show a stronger impact on market-wide commonality within the ADF than within the regional exchanges. Market-wide commonality increases during all periods for both sets of trading venues, but it increases significantly more within the ADF. All-in-all, market commonality within the ADF nearly doubles from the Pre to Post Phase, increasing by 84%, while increase in the regional exchange by only 21%. This shows that the liquidity dynamics within the ADF actually become more connected to the NYSE than do those of the regional exchanges. This result could be for several reasons. First, prices within the ADF are set by the NBBO, thus limiting the competitive advantage of traditional exchanges over ADF participants in terms of price. Furthermore, dark pools in particular are often more attractive than regional exchanges in terms of fee structures, anonymity, and faster processing speeds (see, e.g., Shorter and Miller, 2014). Therefore, it could be the case that more order flow migrates from the NYSE to the ADF than to the regional exchanges.[24] This order flow migration is not a direct result of the mechanics of trade-through protection, but a result of trader preferences for faster and more innovative markets in the absence of price competition. Thus, while the SEC's statement that there "is no direct link between Rule 611 and the increased volume of trading on dark venues" is technically correct, it misses the indirect consequences of Reg NMS for dark pool volumes in terms of changes in trader preferences.

6 Conclusion

This study contributes to the literature on the drivers of liquidity commonality by examining the role that Regulation National Market System (Reg NMS), particularly in its provisions for trade-through protection, played in contributing to changes in systemic liquidity risk. This paper makes use of the generalized dynamic factor model (GDFM), a recent innovation in factor model methods, in order to examine these questions. By considering liquidity measures corresponding to different subspaces of the equity market as subpanels or *blocks* within a larger liquidity panel, the factor model analysis is able to examine changes in liquidity commonality both within and across multiple trading venues.

The results confirm an overall increase in market liquidity commonality within dollar volumes following the implementation of trade-through protection rules under Reg NMS. This increase is accompanied by an increase in market-wide liquidity commonality between primary and regional exchanges, supporting the idea of a "contagion" effect of trade-through protection on liquidity demand shocks. Meanwhile, bid-ask spreads see an overall decrease in liquidity commonality, driven by a decrease in exchange-specific commonality. Hence, there is evidence that shocks to liquidity providers are instead "smoothed out" across trading venues under trade-through protection.

This study has important implications for securities market regulators, particularly in European markets which have yet to adopt formal trade-through protection rules. The

[24] A 2015 report from the SEC confirms that, in many cases, alternative trading systems (ATS) transact more volume than smaller traditional exchanges. See SEC Release No. 34-73639, available at `https://www.sec.gov/rules/final/2014/34-73639.pdf`.

Market in Financial Instruments Directive (MiFID), aimed towards harmonizing financial regulation of investment services across the member states of the European Economic Area (EEA), has a similar goal to that of Reg NMS. However, MiFID contains no formal provisions on trade-through protection, and instead has what Pagnotta and Philippon (In Press) refer to as a "principals-based model". This model, rather than specifying that clients should get the best available price, gives a much more general definition of best execution.[25] Furthermore, the directive specifies no direct enforcement of best execution, but relies on clients to monitor this themselves. Our analysis highlights a relatively under-explored channel through which formal trade-through protection rules may increase liquidity risk. This represents an additional consideration to be taken into account when assessing the impact of introducing such regulations for equity trading.

[25]See Article 21 of the Directive 2004/39/EC of the European Parliament and of the Council of 21 April 2004 on Markets in Financial Instruments: "Member States shall require that investment firms take all reasonable steps to obtain, when executing orders, the best possible result for their clients taking into account price, costs, speed, likelihood of execution and settlement, size, nature or any other consideration relevant to the execution of the order." Available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02004L0039-20110104&from=EN.

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A Appendix

A.1 Estimation of Explained Variance in the GDFM

Given a number of dynamic factors, a key objective of factor model estimation is to determine the variance in the data panel that these factors are able to explain. In static models, explained variances are calculated using the eigenvalues of the contemporaneous covariance matrix, given its decomposition into the factor equation as in (4). However, a dynamic approach requires the estimation of spectral eigenvalues. Given the GDFM as in equation (3) and its corresponding factor equation, the spectral density of $\mathbf{X}_t = (X_t^i, ..., X_t^n), t = 1, ..., T$, can be decomposed as:

$$\mathbf{\Sigma}^X(\theta) = \mathbf{P}(\theta)\mathbf{D}(\theta)\tilde{\mathbf{P}}(\theta) + \mathbf{\Sigma}^\xi(\theta),$$

where, given some $\theta \in [-\pi, \pi]$, $\mathbf{D}(\theta)$ is a $q \times q$ matrix with the q largest dynamic eigenvalues on the diagonal, and $\mathbf{P}(\theta)$ are the corresponding eigenvalues (with tilde denoting its conjugate transpose). In this analysis, the spectral density matrix is calculated using the Fourier transform of contemporaneous and lagged covariances truncated at $M_T = \frac{1}{2}\sqrt{T}$, at frequency $h = M_T$. Dynamic eigenvalues $\mathbf{D}(\theta)$ are then calculated as the average of the $(2M_T + 1)$ spectral eigenvalues estimated from the spectral density. Variance explained by each dynamic factor can thus be calculated using the proportional size of the $\hat{q}$ largest dynamic eigenvalues.

A.2 GDFM in a Block Structure

Given a joint panel $\mathbf{Z}_t = (\mathbf{X}_t', \mathbf{Y}_t')$, composed of the union of the two blocks, the method proposed by Hallin and Liška (2011) allows for a decomposition of variance into joint and block-specific components. First, the number of common factors within the *intersection* of these two blocks, $q_{X\cap Y}$, can be estimated by:

$$\hat{q}_{X\cap Y} = \hat{q}_X + \hat{q}_Y - \hat{q}_Z, \tag{7}$$

where $\hat{q}_X$ and $\hat{q}_Y$ are the number of factors estimated in the subpanels $\mathbf{X}_t = [(X_t^1, ..., X_t^n)]$ and $\mathbf{Y}_t = [(Y_t^1, ..., Y_t^n)]$, and $\hat{q}_Z = \hat{q}_{X\cup Y}$ is the number of factors estimated in the joint panel $\mathbf{Z}_t$. In subsequent analyses, for ease of interpretation we impose a factor structure in which the number of dynamic factors are held fixed as $q_X = q_Y = 2$ and $q_Z = 3$, such that there is one factor shared by the two blocks, and each block further contains one factor unique to each block.

Next, to estimate the variance explained by these factors, we can decompose the variables in $\mathbf{Z}_t$ and its subpanels into:

$$\begin{aligned} Z_t^i &= \chi_{Z;t}^i + \xi_{Z;t}^i \\ X_t^i &= \chi_{X;t}^i + \xi_{X;t}^i && (8) \\ Y_t^i &= \chi_{Y;t}^i + \xi_{Y;t}^i. && (9) \end{aligned}$$

This approach decomposes the space spanning the common factor $\hat{q}_Z$ estimated from the joint panel into a number of subspaces spanned by the one-block factors (*weakly common factors*) and the factors that are common to both blocks (*strongly common factors*). Projecting the blocks $\mathbf{X}_t$ and $\mathbf{Y}_t$ onto (decreasing sequences of) these subspaces yields the further decomposition of equations (8)-(9) into four mutually orthogonal components:

$$X_t^i = \phi_{X,Y;t}^i + \psi_{X(Y);t}^i + \nu_{(X)Y;t}^i + \xi_{(X)(Y);t}^i \tag{10}$$

$$Y_t^i = \phi_{Y,X;t}^i + \psi_{Y(X);t}^i + \nu_{(Y)X;t}^i + \xi_{(Y)(X);t}^i, \tag{11}$$

where $\phi_{;t}^i$, $\psi_{;t}^i$, $\nu_{;t}^i$, and $\xi_{;t}^i$ represent respectively the strongly common, weakly common, weakly idiosyncratic, and strongly idiosyncratic components of the respective panel. For example, the strongly common component $\phi_{X,Y;t}^i$ represents the component of the panel

$\mathbf{X}_t$ that is common to both subpanels (i.e., the entire panel $\mathbf{Z}_t$); the weakly common component $\psi^i_{X(Y);t}$ represents the component that is common to $\mathbf{X}_t$, but idiosyncratic to $\mathbf{Y}_t$. Likewise, the weakly idiosyncratic component $\nu_{(X)Y;t}$ represents the component of the spreads that is common to $\mathbf{Y}_t$, but idiosyncratic to $\mathbf{X}_t$. Lastly, the strongly idiosyncratic component $\xi^i_{(X)(Y);t}$ represents the component of spreads that is idiosyncratic to both subpanels. Tying these equations to the two-way decompositions in (8)-(9), total commonality is equal to the sum of the weakly and strongly common components, i.e., $\chi^i_{X;t} = \phi^i_{X,Y;t} + \psi^i_{X(Y);t}$, and likewise total idiosyncratic variance can be written as $\xi^i_{X;t} = \nu^i_{(X)Y;t} + \xi^i_{(X)(Y);t}$. Analagous to the factor equation in (4), we can therefore write the variances of the subpanels as in (5). The data is standardized to have mean zero and variance one, such that the sum of components is equal to one. For more details, see Hallin and Liška (2011).

A.3 Bootstrapping Procedure

In order to calculate standard errors and determine the significance of the empirical results from Section 5, we use the subsampling method of bootstrapping, as developed in Politis and Romano (1994), without replacement. The bootstrapping procedure consists of the following steps:

1. A bootstrap subsample size of $m = \text{floor}(zn)$, where n is the full sample size and $0 < z < 1$, is drawn without replacement from subpanels $\mathbf{X}_t = (X^1_t, ..., X^n_t)'$ and $\mathbf{Y}_t = (Y^1_t, ..., Y^n_t)'$. For this analysis, we choose $z = 0.75$. The subpanels form the joint panel $\mathbf{Z}_{mt} = ((X^1_t, ..., X^m_t)', (Y^1_t, ..., Y^m_t)')$. Subsample sizes and subpanels vary according to the analysis. For example, for Section 5.2.1, we draw $m = 63$ stocks from the full sample of $n^{pilot} = 85$ NYSE-listed pilot stocks and construct the joint panel:

$$\mathbf{VOL}_{mt} = ((\Delta VOL^1_{PRIM;t}, ..., \Delta VOL^m_{PRIM;t})', (\Delta VOL^1_{REG;t}, ..., \Delta VOL^m_{REG;t})');$$

the same joint panel is constructed for the control stocks that match the pilot stocks from the subsample draw.

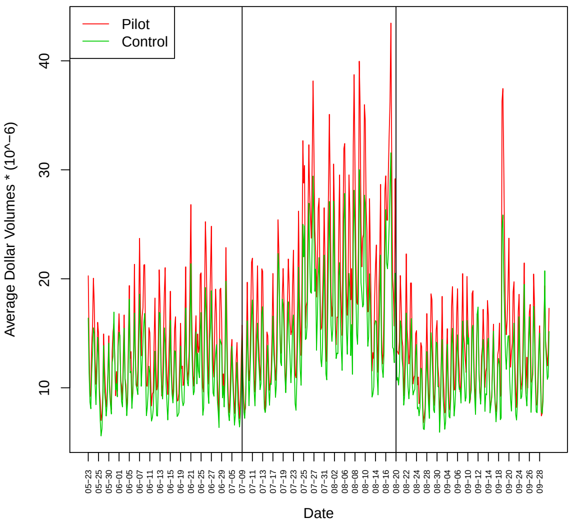
2. The relevant GDFM block analysis is performed using the subsample draw. For example, for Section 5.2.1, we decompose the variances of $\mathbf{VOL}_{PRIM;t}$ and $\mathbf{VOL}_{REG;t}$ into their market-wide and exchange-specific components, separately for the pilot and control subsamples, during time windows before, during, and after the Pilot Phase of Reg NMS.

3. Steps 1 and 2 are repeated a total of S times. Literature on the optimal choice of S remains conflicted; for example, Efron and Tibshirani (1994) suggest that $S = 200$ is enough for most purposes. This analysis uses a relatively large number of repetitions, $S = 1,000$, in order to ensure the asymptotic validity of the bootstrap.

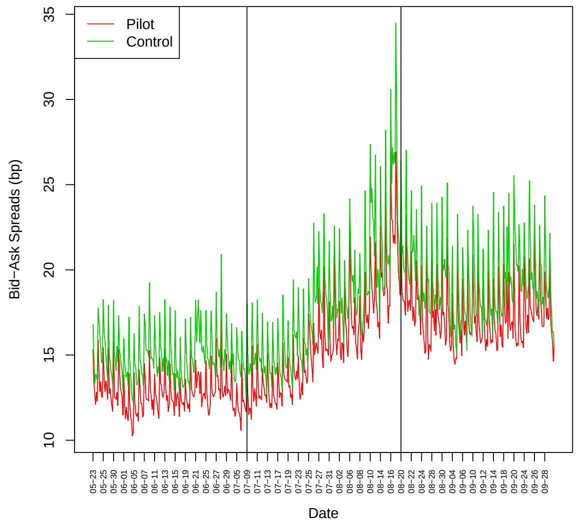
4. The resulting series of S explained variances, for example the $S \times 1$ vector of variances explained by the market-wide component for dollar volumes, (Var[$\hat{\boldsymbol{\phi}}^{1}_{PRIM,REG;t}$],..., Var[$\hat{\boldsymbol{\phi}}^{S}_{PRIM,REG;t}$]), are used to calculate standard errors and p-values. Standard errors are calculated as the standard deviation of the estimates. The p-value is calculated as a one-sided test for a significant increase or decrease. Denote by $\mathcal{S}$ the $S \times 1$ vector of parameter estimates from the subsample draws. If the full sample estimate of the difference is positive, then the p-value is calculated as $p = \#[\mathcal{S} > 0]/S$. If the full sample estimated difference is negative, then $p = \#[\mathcal{S} < 0]/S$. This shows the probability of getting an estimate that is greater than (respectively less than) zero.

Note that bootstrap estimation is typically meant for i.i.d. data; as a model of dependence structures, a factor model approach typically violates this assumption. However, Liu and Singh (1995) show that, while non-i.i.d. data tends to bias bootstrapping results, it does so conservatively.

Figure 1: Average Liquidity Measures



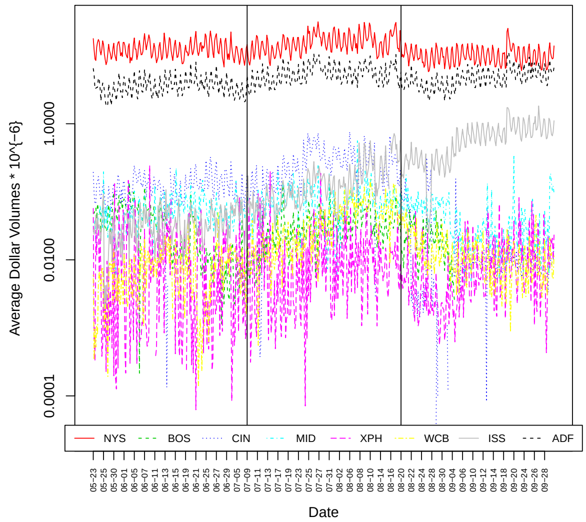
(a) Average Dollar Volumes



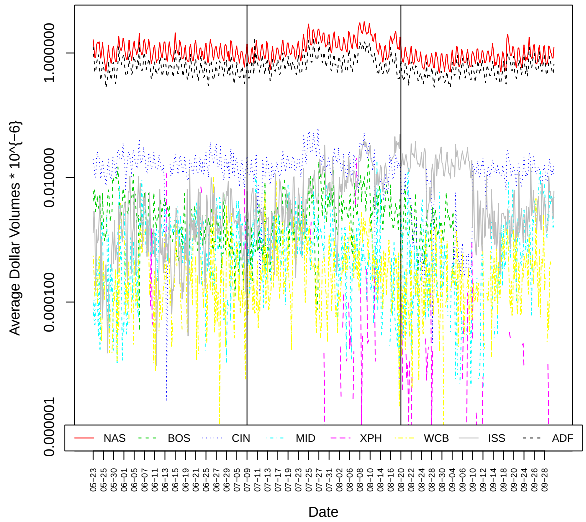
(b) Average Relative Bid-Ask Spreads

These figures shows equal-weighted average dollar volumes VOL_t^i (Figure 1a) and relative bid-ask spreads SPR_t^i (Figure 1b) during the time period 23 May to 2 October 2007, for the Reg NMS pilot (red line) and control (green line) groups. Dollar volume levels are scaled by a factor of 10^{-6} and relative bid-ask are reported in basis points (bp). The solid black vertical lines correspond to the breakpoints between Pre, Pilot, and Post Phases.

Figure 2: Average Liquidity Measures by Exchange

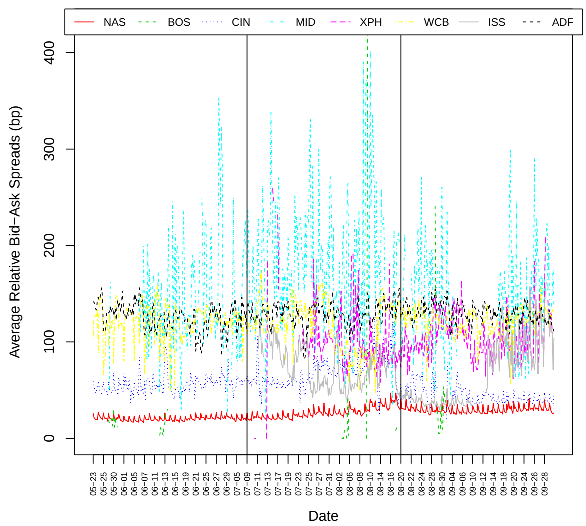


(a) Average Dollar Volumes:
NYSE Stocks



(b) Average Dollar Volumes:
Nasdaq Stocks

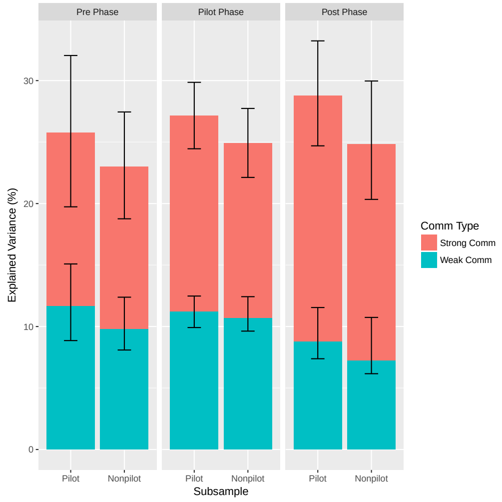
(c) Average Relative Bid-Ask Spreads:
NYSE Stocks



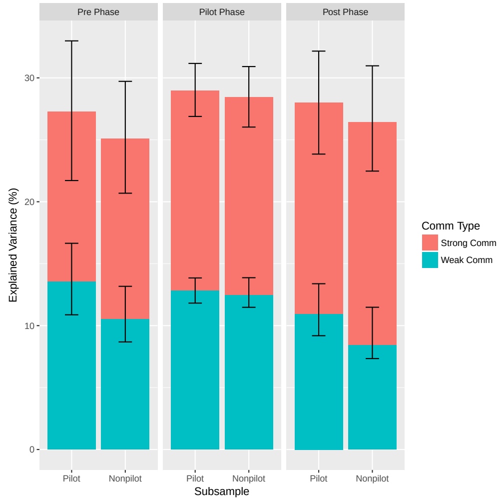
(d) Average Relative Bid-Ask Spreads:
Nasdaq Stocks

These figures shows the average dollar volumes VOL_t^i (Figures 2a and 2b) and relative bid-ask spreads SPR_t^i (Figures 2c and 2d) during the time period 23 May to 2 October 2007, separately for NYSE- and Nasdaq-listed stocks. Plotted separately are the equal-weighted average liquidity measures for each primary and regional exchange. Dollar volume levels are scaled by a factor of 10^{-6} and relative bid-ask are reported in basis points (bp). The solid black vertical lines correspond to the breakpoints between Pre, Pilot, and Post Phases.

Figure 3: Explained Variances: Dollar Volumes vs. Relative Bid-Ask Spreads



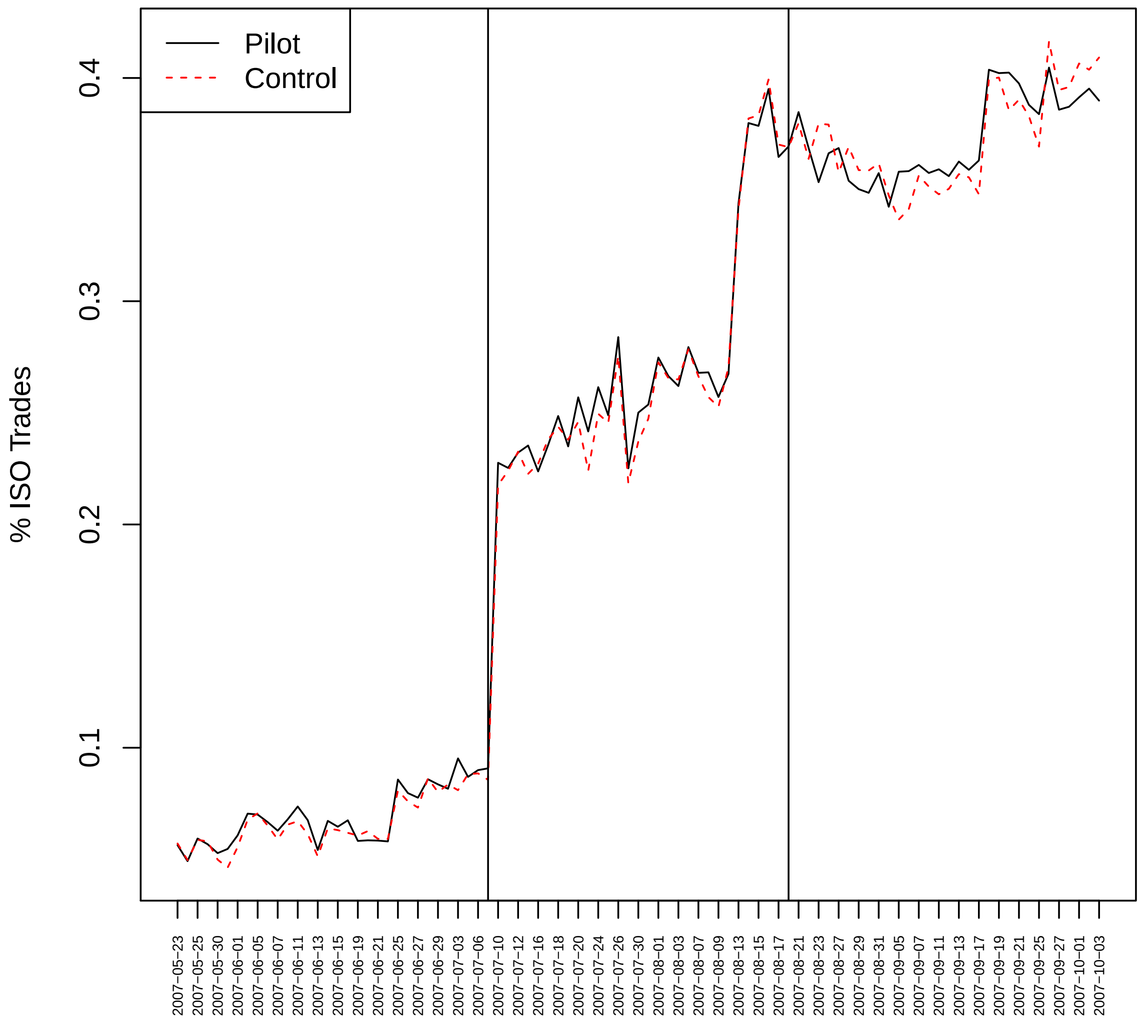
(a) Dollar Volumes



(b) Relative Bid-Ask Spreads

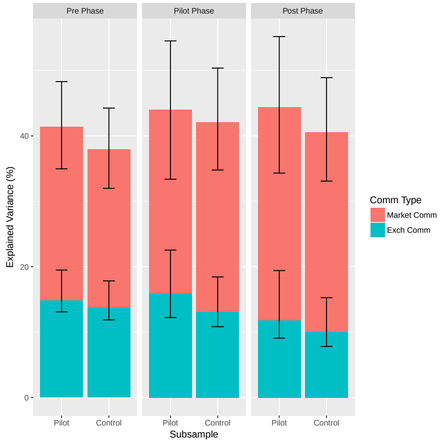
These figures plot results from a generalized dynamic factor model in a block structure that decomposes the variance within dollar volumes (Figure 3a) and relative bid-ask spreads (Figure 3b). The results are presented separately for the Reg NMS pilot stocks (Pilot), and for a matched control group (Control), as well as separately for the Pre, Pilot, and Post Phases. Presented are the variances explained by a factor common to both measures of liquidity (Strong Comm, in red), and factors unique to each individual measure of liquidity (Weak Comm, in blue). Black bars correspond to bootstrapped 95% confidence intervals calculated as described in Section A.3.

Figure 4: ISO Order Usage for Pilot and Control Stocks

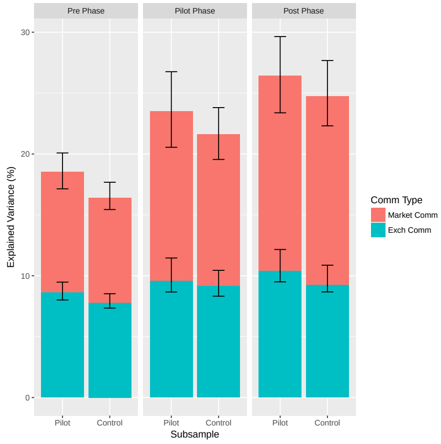


This figure plots the average daily percentage of trades that are designated as intermarket sweep orders (ISOs) during the time period 23 May to 3 October 2007. ISOs are idenfitied in the TRTH dataset with the qualifier "MSW[CTS_QUAL]". The number of ISO orders are summed across exchanges for the pilot stocks (black solid line) and control stocks (red dotted line), and are expressed as a percentage of the total daily number of orders.

Figure 5: Explained Variance, Primary vs. Regional Exchanges: Dollar Volumes



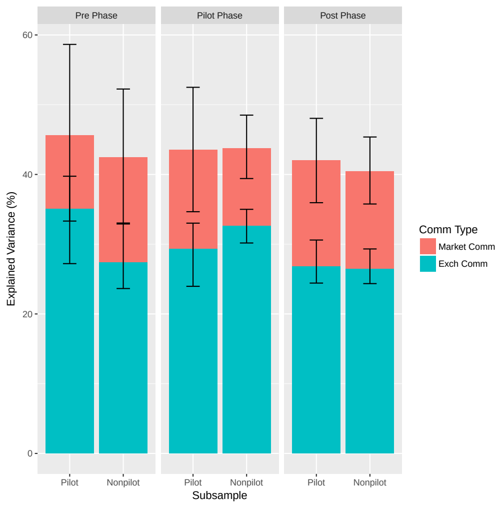
(a) Primary Exchange



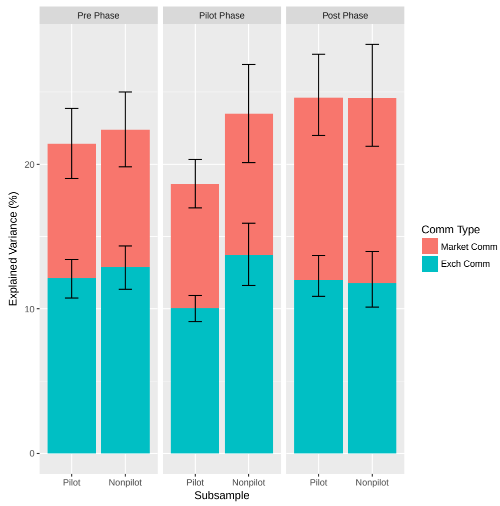
(b) Regional Exchange

These figures plot results from a generalized dynamic factor model in a block structure that decomposes the variance within dollar volumes on the NYSE (Primary Exchange, Figure 5a) and on a subset of regional exchanges (Figure 5b). The results are presented separately for a subsample of 84 NYSE-listed pilot stocks that were part of the Reg NMS Pilot Phase (Pilot), and for a matched control group (Control), as well as separately for the Pre, Pilot, and Post Phases. Presented are the variances explained by a market-wide factor common to both groups of exchanges (Market Comm, in red), and exchange-specific factors unique to each individual exchange (Exch Comm, in blue). Black bars correspond to bootstrapped 95% confidence intervals calculated as described in Section A.3.

Figure 6: Explained Variance, Primary vs. Regional Exchanges: Bid-Ask Spreads



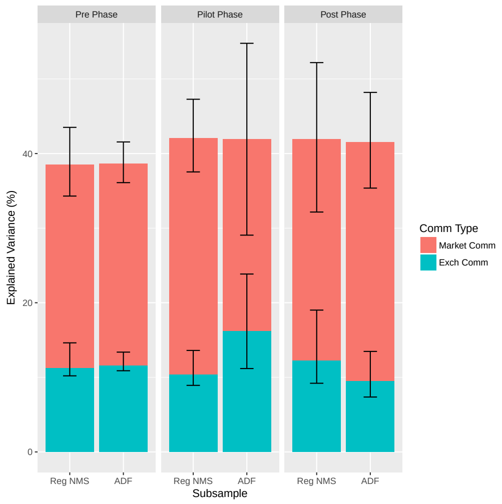
(a) Primary Exchange



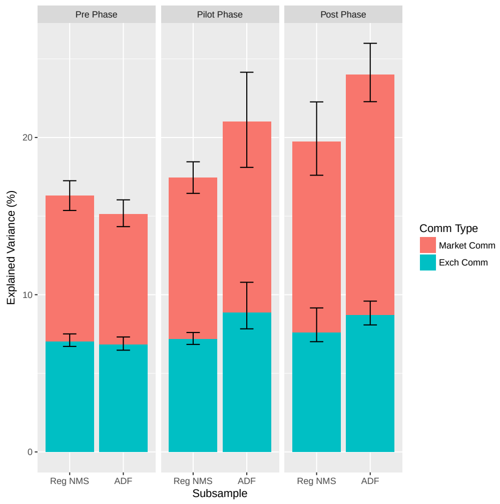
(b) Regional Exchange

These figures plot results from a generalized dynamic factor model in a block structure that decomposes the variance within relative bid-ask spreads on the NYSE (Primary Exchange, Figure 6a) and on a subset of regional exchanges (Figure 6b). The results are presented separately for a subsample of 76 NYSE-listed stocks that were part of the Reg NMS Pilot Phase (Pilot), and for a matched control group (Control), as well as separately for the Pre, Pilot, and Post Phases. Presented are the variances explained by a market-wide factor common to both groups of exchanges (Market Comm, in red), and exchange-specific factors unique to each individual exchange (Exch Comm, in blue). Black bars correspond to bootstrapped 95% confidence intervals calculated as in Section A.3.

Figure 7: Explained Variance, ADF vs. Regional Exchanges



(a) Primary Exchange



(b) Non-Primary Trading Venue

These figures plot results from a generalized dynamic factor model in a block structure that decomposes the variance within dollar volumes on the NYSE and a non-primary trading venue, which can either be the regional exchanges that were a part of Reg NMS (Reg NMS), or the FINRA ADF (ADF). Results are presented separately for the NYSE (Primary Exchange, Figure 7a), and for the non-primary trading venue (Figure 7b). The analysis is performed for the full sample of 168 NYSE-listed stocks, and results are presented separately for the Pre, Pilot, and Post Phases. Presented are the variances explained by a market-wide factor common to both groups of trading venues (Market Comm, in red), and exchange-specific factors unique to each individual trading venue (Exch Comm, in blue). Black bars correspond to bootstrapped 95% confidence intervals calculated as in Section A.3.

Table 1: Example of a Limit Order Book

Bid Price	**Platform A Quantity**	**Platform B Quantity**
\$1.30	100	
\$1.20		500
\$1.10	1,000	
\$1.00	5,000	500

Table 2: Summary Statistics of Liquidity Measures by Group

(A) Summary Statistics for Dollar Volumes

	(A1) Pilot Group					(A2) Control Group					(A3) Pilot v. Control Group	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Mean	Mean.Diff	Median	Std.Dev	DF	Mean	Mean.Diff	Median	Std.Dev	DF	Diff	Diff.in.Diff
Pre	13.35		2.72	7.56	0.41	11.26		1.7	6.23	0.33	2.09***	
Pilot	20.11	6.76***	3.46	11.36	0.55	16.16	4.9***	2.27	8.91	0.49	3.95***	1.86***
Post	13.55	−6.56***	2.18	7.6	0.42	11.41	−4.75***	1.53	6.12	0.29	2.14***	−1.81***
Full	15.67		2.74	10.12	0	12.94		1.8	8.01	0	2.73***	

	(A4) Full Sample				
	(1)	(2)	(3)	(4)	(5)
	Mean	Mean.Diff	Median	Std.Dev	DF
Pre	12.3		2.18	6.89	0.37
Pilot	18.13	5.83***	2.81	10.13	0.52
Post	12.48	−5.66***	1.81	6.86	0.36
Full	14.31		2.23	9.07	0

(B) Summary Statistics for Relative Bid-Ask Spreads

	(B1) Pilot Group					(B2) Control Group					(B3) Pilot v. Control Group	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Mean	Mean.Diff	Median	Std.Dev	DF	Mean	Mean.Diff	Median	Std.Dev	DF	Diff	Diff.in.Diff
Pre	12.77		6.15	3.04	0.67	15		7.29	4.5	0.57	−2.23***	
Pilot	15.84	3.07***	7.7	4.97	0.63	18.2	3.2***	9.53	6.68	0.64	−2.36***	−0.13***
Post	17.34	1.5***	8.23	4.83	0.51	19.49	1.29***	9.74	6.35	0.55	−2.15***	0.21*
Full	15.32		7.27	5.21	0.27	17.56		8.79	6.6	0.23	−2.25***	

	(B4) Full Sample				
	(1)	(2)	(3)	(4)	(5)
	Mean	Mean.Diff	Median	Std.Dev	DF
Pre	13.88		6.66	3.77	0.62
Pilot	17.02	3.14***	8.51	5.82	0.64
Post	18.42	1.4***	8.84	5.59	0.53
Full	16.44		7.92	5.9	0.25

This table reports summary statistics for consolidated dollar volumes (Panel A) and time-weighted relative bid-ask spreads (Panel B), measured at an hourly frequency over the time period 23 May to 2 October 2017. Statistics are reported separately for each subperiod (Pre, Pilot, and Post Phases), as well as for the full time period. Reported are the mean (Mean), time difference in the mean between subperiods (Mean.Diff), median (Median), standard deviation (Std.Dev), and proportion of stocks for which the null hypothesis of a unit root is not rejected according to the augmented Dickey-Fuller test (DF). The Pilot Group is composed of the 240 Reg NMS pilot stocks (Columns 1-5), and the Control Group is composed of a matched group of control stocks (Columns 6-10). Column 11 reports the cross-sectional differences between the Pilot and Control Groups within each time period. Finally, Column 12 reports the difference-in-differences across both the time series and cross-sectional dimensions. *, **, *** refer to the significance levels of 10%, 5%, and 1%, respectively, according to standard t-tests. Dollar volumes are scaled by 10^{-6} and relative bid-ask spreads are reported in basis points (bp).

Table 3: Summary Statistics of Liquidity Measures by Exchange

	(A) Dollar Volumes by Exchange								(B) Relative Bid-Ask Spreads by Exchange							
	(A1) NYSE-Listed Stocks				(A2) Nasdaq-List Stocks				(B1) NYSE-Listed Stocks				(B2) Nasdaq-List Stocks			
	NYSE				Nasdaq				NYSE				Nasdaq			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs
Pre	12.75		6.28	185	1.08		0.88	198	6.97		1.44	185	20.83		6.08	198
Pilot	16.23	3.48^{***}	8.17	185	1.44	0.35^{***}	1.18	198	9.96	2.99^{***}	3.41	185	26.78	5.95^{***}	9.82	198
Post	10.44	-5.79^{***}	5.14	185	0.89	-0.55^{***}	0.72	198	10.24	0.28^{**}	2.59	185	29.8	3.02^{***}	10.01	198
Full	13.14		7.36	185	1.13		1.09	198	9.05		3.19	185	25.81		10.11	198
	Boston Stock Exchange								Boston Stock Exchange							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs
Pre	0.05		0.13	111	0.01		0.05	8				0				0
Pilot	0.05	0.00	0.13	111	0.03	0.01^{***}	0.08	8				0				0
Post	0.01	-0.04^{***}	0.05	111	0	-0.03^{***}	0.02	8				0				0
Full	0.04		0.12	111	0.02		0.06	8				0				0
	National Stock Exchange								National Stock Exchange							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs
Pre	0.14		0.13	166	0.02		0.02	181	13.22		9.15	173	57.33		35.75	192
Pilot	0.29	0.16^{***}	0.31	166	0.02	0^{***}	0.03	181	23.29	10.07^{***}	23.47	173	73.81	16.49^{***}	48.38	192
Post	0.02	-0.27^{***}	0.07	166	0.01	-0.01^{***}	0.02	181	31.37	8.08^{***}	23.43	173	45.86	-27.95^{***}	27.45	192
Full	0.15		0.24	166	0.02		0.03	181	22.63		24.98	173	59		47.15	192
	Chicago Stock Exchange								Chicago Stock Exchange							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs
Pre	0.12		0.27	70	0.07		0.12	2	147.02		89.78	84	125.03		51.54	2
Pilot	0.18	0.06^{***}	0.49	70	0.04	-0.03^{***}	0.08	2	137.45	-17.86^{***}	112.66	89	172.21	47.18^{***}	63.83	2
Post	0.1	-0.08^{***}	0.28	70	0.03	-0.01^{*}	0.07	2	129.74	-8.74^{***}	75.24	86	164.08	-8.13^{*}	47.03	2
Full	0.14		0.41	70	0.04		0.09	2	140.49		103.97	89	153.77		59.31	2
	OMX PSX								OMX PSX							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs
Pre	0.05		0.27	8				0	16.3		4.76	8				0
Pilot	0.12	0.07^{***}	0.46	8				0	18.4	3.17^{***}	6.28	10	99.69	3.3^{**}	21.4	1
Post	0.09	-0.03	0.21	8				0	23	4.6^{***}	15.13	10	104.89	5.2^{**}	24.33	1
Full	0.09		0.37	8				0	18.88		11.48	10	100.32		19	1
	Chicago Board Options Exchange								Chicago Board Options Exchange							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs
Pre	0.04		0.08	33				0	67.25		47.63	115	126.67		57.37	65
Pilot	0.21	0.17^{***}	0.24	33				0	74.5	10.53^{***}	61.95	127	122.22	-4.25^{***}	92	65
Post	0.06	-0.15^{***}	0.09	33				0	86.78	-2.66^{***}	53.63	104	131.76	-0.57	67.44	60
Full	0.1		0.19	33				0	66.21		56.63	132	119.82		82.19	67
	International Stock Exchange								International Stock Exchange							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs
Pre	0.04		0.14	165	0		0.03	63	14.12		3.82	32	71.61		10.01	1
Pilot	0.18	0.14^{***}	0.31	165	0.02	0.02^{***}	0.06	64	35.33	0.24	21.6	139	62.43	-6.56^{***}	34.23	41
Post	0.71	0.53^{***}	0.62	165	0.02	0^{***}	0.05	64	19.43	-15.39^{***}	16.42	169	42.27	-20.15^{***}	23.55	41
Full	0.31		0.52	165	0.02		0.06	64	29.61		23.06	169	57.9		38.3	41
	FINRA ADF								FINRA ADF							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs	Mean	Mean.Diff	Std.Dev	Num.Obs
Pre	3.71		3.54	185	0.6		0.81	198	91.05		56.76	185	126.04		90.9	196
Pilot	5.63	1.91^{***}	4.87	185	0.77	0.17^{***}	1.02	198	114.21	23.16^{***}	65.78	185	128.52	2.48^{***}	91.08	196
Post	4.86	-0.77^{***}	3.85	185	0.55	-0.22^{***}	0.68	198	106.12	-8.09^{***}	52.1	185	129.7	1.18	90.1	196
Full	4.73		4.49	185	0.64		0.97	198	103.79		64.95	185	128.08		93.36	196

This table reports summary statistics for unconsolidated dollar volumes (Panel A) and time-weighted relative bid-ask spreads (Panel B), measured at an hourly frequency over the time period 23 May to 2 October 2017 for the pilot and control sample stocks that list either NYSE or Nasdaq as their primary exchange. Statistics are reported separately for NYSE- and Nasdaq-listed stocks, as well as separately by exchange and subperiod (Pre, Pilot, and Post Phases). Reported are the mean (Mean), time difference in the mean between subperiods (Mean.Diff), standard deviation (Std.Dev), and number of stocks that are found to have sufficient time series observations to be included in the sample (Num.Obs, deemed as less $\leq 75\%$ missing or zero values). *, **, *** refer to significance levels of 10%, 5%, and 1%, respectively, according to standard t-tests. Dollar volumes are scaled by 10^{-6} and relative bid-ask spreads are reported in basis points (bp).

Table 4: Explained Variances: Dollar Volumes vs. Bid-Ask Spreads

	(A) Dollar Volumes						(B) Relative Bid-Ask Spreads					
	(A1) Pilot Group						(B1) Pilot Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
STRONG	14.09	15.91	20	1.82	4.09**	5.91***	13.7	16.13	17.06	2.43*	0.92	3.35**
	(1.61)	(1.11)	(0.72)	(1.74)	(1.32)	(1.94)	(1.45)	(1.05)	(0.6)	(1.6)	(1.18)	(1.79)
WEAK	11.69	11.22	8.8	−0.47	−2.42*	−2.89*	13.57	12.84	10.94	−0.73	−1.9*	−2.63*
	(1.63)	(1.12)	(0.7)	(1.76)	(1.34)	(1.91)	(1.55)	(1.08)	(0.53)	(1.63)	(1.18)	(1.8)
STRONG-WEAK	2.4	4.69***	11.2***	2.29	6.51**	8.8**	0.13	3.29***	6.12**	3.16*	2.82	5.98*
	(3.2)	(1.3)	(2.14)	(1.74)	(2.6)	(3.81)	(2.96)	(1.03)	(2.06)	(1.6)	(2.31)	(3.55)
TOTAL	25.77	27.13	28.8	1.35***	1.67***	3.03***	27.27	28.98	28	1.7***	−0.98**	0.72*
	(0.54)	(0.63)	(0.57)	(0.48)	(0.51)	(0.51)	(0.47)	(0.53)	(0.47)	(0.53)	(0.52)	(0.53)
	(A2) Control Group						(B2) Control Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
STRONG	13.21	14.21	17.61	1	3.39**	4.4**	14.55	15.95	17.97	1.39	2.02*	3.42**
	(1.1)	(1.3)	(0.69)	(1.33)	(1.43)	(1.68)	(1.18)	(1.15)	(0.63)	(1.34)	(1.27)	(1.61)
WEAK	9.81	10.69	7.26	0.88	−3.43**	−2.55*	10.55	12.5	8.45	1.95*	−4.05***	−2.1
	(1.09)	(1.26)	(0.71)	(1.26)	(1.36)	(1.62)	(1.17)	(1.13)	(0.62)	(1.32)	(1.25)	(1.58)
STRONG-WEAK	3.4*	3.53**	10.35***	0.12	6.82**	6.95**	4*	3.45**	9.52***	−0.56	6.07**	5.52*
	(2.13)	(1.28)	(2.49)	(1.33)	(2.76)	(3.27)	(2.29)	(1.17)	(2.21)	(1.34)	(2.47)	(3.16)
TOTAL	23.01	24.9	24.86	1.89***	−0.04	1.85***	25.1	28.45	26.42	3.34***	−2.02***	1.32***
	(0.51)	(0.59)	(0.56)	(0.43)	(0.45)	(0.41)	(0.51)	(0.54)	(0.45)	(0.5)	(0.47)	(0.48)
	(A3) Pilot - Control Group						(B3) Pilot - Control Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
STRONG	0.88	1.69**	2.39**	0.82	0.7	1.52	−0.85	0.19	−0.91	1.04	−1.1	−0.06
	(1.89)	(0.93)	(1.66)	(2.1)	(1.93)	(2.56)	(1.84)	(0.85)	(1.54)	(2.09)	(1.76)	(2.43)
WEAK	1.88	0.53	1.54	−1.35	1.01	−0.34	3.02*	0.34	2.49*	−2.68*	2.15	−0.53
	(1.9)	(0.9)	(1.71)	(2.11)	(1.92)	(2.52)	(1.88)	(0.79)	(1.52)	(2.05)	(1.71)	(2.42)
STRONG-WEAK	−1	1.16	0.85	2.16	−0.31	1.85	−3.87	−0.15	−3.4	3.72	−3.25	0.47
	(3.75)	(1.74)	(3.32)	(4.16)	(3.79)	(5.03)	(3.67)	(1.51)	(2.99)	(4.07)	(3.4)	(4.8)
TOTAL	2.76***	2.23***	3.94***	−0.53	1.71***	1.18**	2.17***	0.53	1.57**	−1.64**	1.04*	−0.59
	(0.52)	(0.58)	(0.59)	(0.63)	(0.7)	(0.64)	(0.57)	(0.64)	(0.63)	(0.73)	(0.71)	(0.65)

This table shows results from a generalized dynamic factor model in a block structure that decomposes the variance within dollar volumes (Panel A) and relative bid-ask spreads (Panel B). Results are presented separately for the $n = 240$ Reg NMS pilot stocks (Panels A1 and B1), and for a matched control group (Panels A2 and Panels B2), as well as by subperiod (Pre, Pilot, and Post Phases). Presented are the variances explained by a factor common to both measures of liquidity (STRONG), factors unique to each individual measure of liquidity (WEAK), the difference between the two components (STRONG-WEAK), and a measure of total commonality (TOTAL=STRONG+WEAK). Panels A3 and B3 reported the differences between the two sample groups. Presented are the median explained variances and bootstrapped standard errors (in parentheses) from the bootstrapping procedure described in Section A.3. *, **, *** refer to significance levels of 10%, 5%, and 1%, respectively, according to a bootstrapped p-value. Explained variances are reported in percentage points.

Table 5: Explained Variances, Primary vs. Regional Exchanges: Dollar Volumes

	(A) Primary Exchange						(B) Regional Exchange					
	(A1) Pilot Group						(B1) Pilot Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
MKT	26.52	28.05	32.53	1.54	4.48	6.01^{*}	9.88	13.91	16.02	4.03^{***}	2.11^{**}	6.14^{***}
	(1.76)	(2.79)	(2.82)	(3.25)	(3.84)	(3.29)	(0.38)	(0.88)	(0.88)	(0.93)	(1.04)	(0.87)
EXCH	14.88	15.92	11.8	1.04	−4.12	−3.07	8.66	9.61	10.4	0.96^{*}	0.78	1.74^{***}
	(1.66)	(2.62)	(2.76)	(3.23)	(3.82)	(3.2)	(0.39)	(0.69)	(0.75)	(0.86)	(1)	(0.81)
MKT-EXCH	11.64^{**}	12.13^{**}	20.73^{***}	0.49	8.59	9.09^{*}	1.22^{**}	4.3^{***}	5.62^{***}	3.07^{***}	1.33	4.4^{**}
	(3.32)	(5.52)	(5.35)	(3.25)	(7.62)	(6.45)	(0.58)	(1.47)	(1.38)	(0.93)	(1.87)	(1.47)
TOTAL	41.39	43.97	44.33	2.58^{***}	0.36	2.94^{***}	18.54	23.53	26.42	4.99^{***}	2.89^{***}	7.88^{***}
	(0.81)	(0.89)	(0.77)	(0.67)	(0.71)	(0.73)	(0.49)	(0.77)	(0.69)	(0.76)	(0.82)	(0.81)
	(A2) Control Group						(B2) Control Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
MKT	24.17	29	30.5	4.83^{**}	1.5	6.33^{**}	8.63	12.42	15.49	3.79^{***}	3.07^{***}	6.87^{***}
	(1.56)	(2.14)	(2.11)	(2.48)	(2.8)	(2.43)	(0.28)	(0.79)	(0.53)	(0.54)	(0.85)	(0.83)
EXCH	13.77	13.1	10.03	−0.67	-3.07^{*}	-3.74^{*}	7.78	9.21	9.27	1.43^{***}	0.06	1.49^{***}
	(1.46)	(1.84)	(1.97)	(2.45)	(2.75)	(2.34)	(0.31)	(0.53)	(0.53)	(0.6)	(0.76)	(0.63)
MKT-EXCH	10.4^{**}	15.9^{***}	20.47^{***}	5.5^{**}	4.57	10.07^{**}	0.85^{**}	3.21^{***}	6.22^{***}	2.36^{***}	3.01^{**}	5.37^{***}
	(2.91)	(3.98)	(3.9)	(2.48)	(5.5)	(4.72)	(0.42)	(0.88)	(1.19)	(0.54)	(1.4)	(1.27)
TOTAL	37.94	42.09	40.53	4.15^{***}	-1.57^{**}	2.59^{***}	16.4	21.62	24.76	5.22^{***}	3.14^{***}	8.36^{***}
	(0.82)	(0.87)	(0.93)	(0.74)	(0.68)	(0.68)	(0.41)	(0.62)	(0.58)	(0.66)	(0.8)	(0.74)
	(A3) Pilot - Control Group						(B3) Pilot - Control Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
MKT	2.35	−0.94	2.03	−3.29	2.98	−0.32	1.26^{***}	1.49^{*}	0.53	0.24	−0.96	−0.73
	(2.27)	(3.54)	(3.42)	(4.23)	(4.73)	(4.09)	(0.46)	(0.97)	(1.18)	(1.03)	(1.38)	(1.18)
EXCH	1.11	2.82	1.77	1.72	−1.05	0.67	0.88^{*}	0.41	1.13^{*}	−0.47	0.72	0.25
	(2.29)	(3.41)	(3.16)	(4.19)	(4.73)	(3.96)	(0.51)	(0.96)	(0.88)	(1.08)	(1.32)	(1.05)
MKT-EXCH	1.24	−3.77	0.26	−5.01	4.03	−0.98	0.37	1.08	−0.6	0.71	−1.68	−0.97
	(4.48)	(6.86)	(6.51)	(8.35)	(9.39)	(7.98)	(0.71)	(1.7)	(1.85)	(1.87)	(2.4)	(1.95)
TOTAL	3.45^{***}	1.88^{*}	3.81^{***}	-1.57^{**}	1.93^{**}	0.35	2.14^{***}	1.9^{**}	1.66^{**}	−0.24	−0.25	−0.48
	(0.85)	(1.08)	(1.02)	(1.02)	(1.08)	(0.98)	(0.67)	(0.92)	(0.95)	(1)	(1.23)	(1.1)

This table shows results from a generalized dynamic factor model in a block structure that decomposes the variance within dollar volumes on the primary exchange (Panel A) and regional exchanges (Panel B). The results are presented separately for a subsample of $n = 93$ NYSE-listed pilot stocks (Panels A1 and B1), and for a matched control group (Panels A2 and Panels B2), as well as by subperiod (Pre, Pilot, and Post Phases). Presented are the variances explained by a "market-wide" factor common to both trading venues (MKT), "exchange-specific" factors unique to each individual trading venue (EXCH), the difference between the two components (MKT-EXCH), and a measure of total commonality (TOTAL=MKT+EXCH). Panels A3 and B3 reported the differences between the two sample groups. Presented are the median explained variances and bootstrapped standard errors (in parentheses) from the bootstrapping procedure described in Section A.3. *, **, *** refer to significance levels of 10%, 5%, and 1%, respectively, according to a bootstrapped p-value. Explained variances are presented in percentage points.

Table 6: Explained Variances, Primary vs. Regional Exchanges: Relative Bid-Ask Spreads

	(A) Primary Exchange						(B) Regional Exchange					
	(A1) Pilot Group						(B1) Pilot Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
MKT	10.52	14.19	15.18	3.66	1	4.66	9.29	8.57	12.57	−0.73	4***	3.28***
	(3.7)	(1.48)	(2.29)	(4.23)	(2.43)	(3.99)	(0.58)	(0.71)	(0.39)	(0.63)	(0.81)	(0.76)
EXCH	35.08	29.33	26.87	−5.75	−2.45	−8.2**	12.12	10.03	12.02	−2.09***	1.99***	−0.1
	(3.55)	(1.58)	(2.27)	(4.1)	(2.4)	(3.82)	(0.68)	(0.72)	(0.46)	(0.82)	(0.83)	(0.94)
MKT-EXCH	−24.55***	−15.14***	−11.69***	9.41	3.45	12.86*	−2.83***	−1.46**	0.55	1.37	2.01*	3.38**
	(7.2)	(4.49)	(2.92)	(4.23)	(4.77)	(7.77)	(0.73)	(0.59)	(1.13)	(0.63)	(1.33)	(1.25)
TOTAL	45.6	43.51	42.06	−2.09***	−1.46**	−3.55***	21.41	18.6	24.59	−2.82***	6***	3.18***
	(0.96)	(0.93)	(0.81)	(0.85)	(0.76)	(0.78)	(1.03)	(0.86)	(0.63)	(1.09)	(0.97)	(1.15)
	(A2) Control Group						(B2) Control Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
MKT	15.03	11.1	13.99	−3.93	2.89**	−1.04	9.49	9.77	12.79	0.27	3.02***	3.3***
	(2.64)	(1.21)	(1.09)	(2.69)	(1.38)	(2.71)	(0.55)	(0.81)	(0.62)	(0.84)	(0.98)	(0.78)
EXCH	27.45	32.67	26.49	5.22**	−6.18***	−0.96	12.9	13.74	11.76	0.83	−1.97*	−1.14
	(2.44)	(1.3)	(1.23)	(2.55)	(1.53)	(2.51)	(0.77)	(0.99)	(1.12)	(1.33)	(1.49)	(1.18)
MKT-EXCH	−12.42***	−21.56***	−12.49***	−9.15	9.07***	−0.08	−3.41***	−3.97***	1.02	−0.56	4.99***	4.43***
	(4.99)	(2.12)	(2.31)	(2.69)	(2.75)	(5.14)	(0.97)	(1.28)	(1.32)	(0.84)	(1.96)	(1.47)
TOTAL	42.48	43.77	40.48	1.29*	−3.29***	−2***	22.39	23.5	24.55	1.11	1.05	2.16*
	(1)	(0.97)	(0.98)	(0.89)	(0.94)	(0.89)	(0.92)	(1.23)	(1.28)	(1.46)	(1.58)	(1.36)
	(A3) Pilot - Control Group						(B3) Pilot - Control Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
MKT	−4.51	3.08*	1.19	7.59*	−1.89	5.7	−0.2	−1.2**	−0.22	−1	0.98	−0.02
	(4.24)	(2.4)	(1.84)	(4.85)	(2.67)	(4.61)	(0.76)	(0.67)	(0.96)	(0.98)	(1.2)	(1.07)
EXCH	7.63*	−3.34*	0.39	−10.97**	3.73*	−7.24*	−0.78	−3.71***	0.26	−2.93**	3.97***	1.04
	(4.06)	(2.52)	(1.97)	(4.75)	(2.88)	(4.41)	(1.11)	(1.2)	(1.16)	(1.59)	(1.65)	(1.53)
MKT-EXCH	−12.14	6.42*	0.8	18.56**	−5.62	12.94	0.58	2.51**	−0.48	1.93	−2.98*	−1.06
	(8.21)	(4.8)	(3.6)	(9.51)	(5.44)	(8.94)	(1.24)	(1.35)	(1.67)	(1.89)	(2.25)	(1.9)
TOTAL	3.13***	−0.26	1.58	−3.38***	1.83*	−1.55*	−0.98	−4.91***	0.04	−3.93**	4.95***	1.02
	(1.19)	(1.14)	(1.25)	(1.24)	(1.12)	(1.22)	(1.45)	(1.41)	(1.33)	(1.85)	(1.81)	(1.84)

This table shows results from a generalized dynamic factor model in a block structure that decomposes the variance within relative bid-ask spreads on the primary exchange (Panel A) and regional exchanges (Panel B). The results are presented separately for a subsample of $n = 93$ NYSE-listed pilot stocks (Panels A1 and B1), and for a matched control group (Panels A2 and Panels B2), as well as by subperiod (Pre, Pilot, and Post Phases). Presented are the variances explained by a "market-wide" factor common to both trading venues (MKT), "exchange-specific" factors unique to each individual trading venue (EXCH), the difference between the two components (MKT-EXCH), and a measure of total commonality (TOTAL=MKT+EXCH). Panels A3 and B3 reported the differences between the two sample groups. Presented are the median explained variances and bootstrapped standard errors (in parentheses) from the bootstrapping procedure described in Section A.3. *, **, *** refer to significance levels of 10%, 5%, and 1%, respectively, according to a bootstrapped p-value. Explained variances are presented in percentage points.

Table 7: Explained Variances: ADF vs. Regional Exchanges

	(A) Primary Exchange						(B) Non-Primary Trading Venue					
	(A1) Reg NMS Group						(B1) Reg NMS Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
MKT	27.25	31.7	29.67	4.45**	−2.03	2.42	9.27	10.27	12.13	1***	1.86**	2.87***
	(1.28)	(2.58)	(1.31)	(1.73)	(2.78)	(2.75)	(0.29)	(0.62)	(0.33)	(0.34)	(0.64)	(0.62)
EXCH	11.29	10.4	12.3	−0.89	1.89	1	7.02	7.18	7.6	0.16	0.41	0.57*
	(1.19)	(2.5)	(1.21)	(1.7)	(2.77)	(2.74)	(0.21)	(0.57)	(0.21)	(0.29)	(0.61)	(0.61)
MKT-EXCH	15.96***	21.29***	17.38***	5.34**	−3.92	1.42	2.24***	3.08***	4.53***	0.84***	1.45	2.29*
	(2.39)	(2.44)	(5.03)	(1.73)	(5.52)	(5.47)	(0.4)	(0.42)	(1.09)	(0.34)	(1.14)	(1.14)
TOTAL	38.54	42.1	41.97	3.56***	−0.13	3.43***	16.29	17.45	19.73	1.16***	2.28***	3.44***
	(0.61)	(0.67)	(0.63)	(0.51)	(0.54)	(0.52)	(0.3)	(0.46)	(0.36)	(0.36)	(0.5)	(0.47)
	(A2) ADF Group						(B2) ADF Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
MKT	27.05	25.72	31.98	−1.33	6.26**	4.93**	8.29	12.12	15.29	3.83***	3.17***	7***
	(0.91)	(1.73)	(3.46)	(3.52)	(3.83)	(1.85)	(0.22)	(0.57)	(0.83)	(0.85)	(0.94)	(0.58)
EXCH	11.58	16.21	9.56	4.63*	−6.66**	−2.03	6.84	8.88	8.7	2.04***	−0.18	1.85***
	(0.78)	(1.53)	(3.4)	(3.5)	(3.8)	(1.77)	(0.21)	(0.4)	(0.81)	(0.85)	(0.91)	(0.45)
MKT-EXCH	15.46***	9.51	22.42***	−5.95	12.91**	6.96**	1.45***	3.24**	6.59***	1.79***	3.35***	5.14***
	(1.58)	(6.83)	(3.2)	(3.52)	(7.61)	(3.59)	(0.32)	(1.58)	(0.84)	(0.85)	(1.76)	(0.88)
TOTAL	38.63	41.93	41.53	3.3***	−0.4	2.9***	15.14	21	23.99	5.87***	2.99***	8.85***
	(0.61)	(0.67)	(0.63)	(0.5)	(0.54)	(0.52)	(0.28)	(0.51)	(0.44)	(0.47)	(0.56)	(0.55)
	(A3) Reg NMS - ADF Group						(B3) Reg NMS - ADF Group					
	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre	Pre	Pilot	Post	Pilot-Pre	Post-Pilot	Post-Pre
MKT	0.21	5.98**	−2.3	5.77**	−8.28**	−2.51	0.97***	−1.85**	−3.16***	−2.83***	−1.31*	−4.13***
	(1.42)	(3.58)	(2.77)	(3.84)	(4.69)	(3.11)	(0.3)	(0.86)	(0.69)	(0.91)	(1.12)	(0.74)
EXCH	−0.29	−5.81**	2.74	−5.52**	8.55**	3.03	0.18	−1.7***	−1.1*	−1.88***	0.6	−1.28*
	(1.4)	(3.58)	(2.77)	(3.84)	(4.68)	(3.09)	(0.29)	(0.84)	(0.66)	(0.88)	(1.09)	(0.73)
MKT-EXCH	0.5	11.79**	−5.05	11.29**	−16.83**	−5.54	0.79**	−0.16	−2.06**	−0.95	−1.9	−2.85**
	(2.81)	(7.16)	(5.54)	(7.69)	(9.37)	(6.19)	(0.46)	(1.61)	(1.27)	(1.68)	(2.11)	(1.35)
TOTAL	−0.09	0.17**	0.44***	0.26*	0.27	0.52**	1.15***	−3.55***	−4.26***	−4.7***	−0.71	−5.41***
	(0.11)	(0.09)	(0.11)	(0.14)	(0.14)	(0.16)	(0.36)	(0.53)	(0.43)	(0.62)	(0.68)	(0.58)

This table shows results from a generalized dynamic factor model in a block structure that decomposes the variance between dollar volumes on the NYSE and a non-primary trading venue, which can either be the regional exchanges (Reg NMS Group), or the FINRA ADF (ADF Group). The analysis is performed for a group of $n = 186$ NYSE-listed pilot stocks, and results are presented separately for the NYSE (Panel A), and for the non-primary trading venues (Panel B), as well as by subperiod (Pre, Pilot, and Post Phases). Presented are the variances explained by a "market-wide" factor common to both trading venues (MKT), "exchange-specific" factors unique to each individual trading venue (EXCH), the difference between the two components (MKT-EXCH), and the measure of total commonality (TOTAL=MKT+EXCH). Panels A3 and B3 reported the differences between the two sample groups. Presented are the median explained variances and bootstrapped standard errors (in parentheses) from the bootstrapping procedure described in Section A.3. *, **, *** refer to significance levels of 10%, 5%, and 1%, respectively, according to a bootstrapped p-value. Explained variances are presented in percentage points.