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Abstract

This paper examines market liquidity in the post-crisis era in light of concerns that regulatory changes might have reduced dealers' ability and willingness to make markets. We begin with a discussion of the broader trading environment, including an overview of regulations and their potential effects on dealer balance sheets and market making, but also considering additional drivers of market liquidity. We document a stagnation of dealer balance sheets after the financial crisis of 2007-09, which occurred concurrently with dealer balance sheet deleveraging. However, using high-frequency trade and quote data for U.S. Treasury securities and corporate bonds, we find only limited evidence of a deterioration in market liquidity.

Key words: liquidity, market making, Treasury securities, corporate bonds, regulation

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1 Introduction

In the years since the financial crisis of 2007-09, market participants have expressed concerns about worsening liquidity in certain markets.[1] Market liquidity, broadly defined, refers to the cost of exchanging assets for cash. Liquidity considerations feature prominently in real and financial investment decisions because liquidity is priced, with investors demanding higher returns for less liquid assets (Amihud and Mendelson 1986). Moreover, asset illiquidity deters trade and hence investment, impeding the efficient allocation of risk and capital in the economy.

Frequently cited causes for the ostensibly worsening liquidity are the Dodd-Frank Act and the Basel III regulatory framework. In an effort to address the solvency and liquidity problems that arose during the crisis, this regulatory framework includes provisions that tighten bank capital requirements, introduce leverage ratios, and establish liquidity requirements. But while these regulations are intended to make the global financial system more resilient to shocks, market participants argue that they also increase the cost of market making by raising the cost of capital and restricting dealer risk taking. The differing perspectives of regulators and market participants suggest a tradeoff, with a banking sector that can draw on enhanced capital and liquidity buffers to maintain its market-making functions in times of stress, but that potentially provides less liquidity during normal times.

This paper examines the evidence surrounding market liquidity in the post-crisis era. We begin with a discussion of the broader trading environment in an effort to outline potential drivers of market liquidity since the crisis. This includes a discussion of regulations and their potential effects on dealer balance sheets and market making, but also plausible additional determinants of market liquidity. The drivers that we discuss include:

1. The post-crisis regulatory framework, reflecting the Dodd-Frank Act and the Basel III capital and liquidity requirements;

2. Voluntary changes in dealer risk-management practices and balance sheet composition following the housing market boom and bust;

3. Changes in market structure with the growth of electronic trading;

4. The changing landscape of institutional investors, including the evolving liquidity demands of large asset managers;

5. Changes in expected returns associated with the economic environment.

We argue that since these factors were all at play in the years immediately following the crisis, identification of the causal effects of any single factor must control for the others. Identification is

[1] See, for example, "Wall Street Bemoans Bond Market Liquidity Squeeze," Wall Street Journal, June 2, 2015; "People Are Worried About Bond Market Liquidity," Bloomberg View, June 3, 2015; "Bond Market Liquidity Dominates Conversation," Financial Times, June 12, 2015; "Who Will Fare Best In Bond-Market Liquidity Crunch?" Wall Street Journal, July 1, 2015; "Cracks Exposed in U.S. Bond Market as Liquidity Woes Warp Prices," Bloomberg News, January 24, 2016; "Liquidity Crunch Elevates Bond Traders," Financial Times, March 20, 2016; "U.S. Treasury Sees Bond Liquidity, But Not as We Know It," Bloomberg News, July 7, 2016.

further complicated by the fact that most (if not all) of these drivers are highly interrelated and endogenous.

We document the striking fact that dealer balance sheets stagnated after the crisis. In the years running up to the crisis, dealer assets grew at an exponential pace, peaking at around $5 trillion in early 2008. In late 2008, assets contracted sharply, to $3.5 trillion, a level that was first breached in 2005. After that, through mid-2016, dealer assets were stagnant around this $3.5 trillion level. The balance sheet stagnation coincided with dealer deleveraging. Curbing dealer leverage is of course an intended consequence of tighter capital regulation. However, the stagnation and deleveraging of dealer balance sheets raises the question of whether regulations might have had unintended consequences on market liquidity and whether liquidity in dealer-intermediated markets can still be provided efficiently. To get at this question, we analyze market liquidity empirically.

Our main empirical exercise consists of assessing the evolution of market liquidity in U.S. Treasury and U.S. corporate bond markets. Market participants' concerns about liquidity center on fixed income markets and these are the most important fixed income markets that are dealer intermediated. Given the multi-faceted nature of market liquidity, we compute a variety of liquidity measures, including bid-ask spreads, depth, price impact, and trade size. The measures are based on tick-level order book and transactions data from the interdealer Treasury market, and corporate bond transactions data from FINRA's TRACE database.

Overall, we do not find strong quantitative evidence of a widespread deterioration in bond market liquidity in the years after the crisis. As of mid-2016, average bid-ask spreads for benchmark notes in the interdealer Treasury market were narrow and stable. Moreover, Treasury market depth and price impact, though suggesting reduced liquidity, were within historical variation and far from crisis levels. For corporate bonds, average bid-ask spreads and price impact declined after the crisis, albeit to levels higher than those before the crisis for institutional trades (i.e., trades of $100,000 and above). Moreover, corporate bond trading volume and issuance were at record highs.

Our empirical findings on market liquidity are broadly consistent with those of others. Analyzing TRACE corporate bond transactions data from 2003 to 2015, Mizrach (2015) concludes that "most measures suggest a healthy market" with rising transaction volumes, narrowing bid-ask spreads, and falling price impact of trades. Looking at price impact, round-trip costs, and other measures, Trebbi and Xiao (2015) report "a lack of any form of systematic evidence of deterioration in liquidity levels or breaks in liquidity risk for corporate bonds." Bessembinder, Jacobsen, Maxwell, and Venkataraman (2016) further find lower transaction costs during the 2012-14 Dodd-Frank phase-in period than in the 2003-07 pre-crisis period. Anderson and Stulz (2017) also report lower average transaction costs and price impact post-crisis vs. pre-crisis for all corporate bond transactions, albeit somewhat worse liquidity for large (over $100,000) trades, in line with our findings.

In contrast to these studies on broad liquidity trends, a number of studies have documented worsening liquidity along some dimension. Bao, O'Hara, and Zhou (2016) find that price impact increased among recently downgraded corporate bonds when comparing the pre- and post-Volcker rule periods. Similarly, Dick-Nielsen and Rossi (2016) use bond index exclusions as a natural experiment during which index tracking investors demand immediacy from dealers and find that the price of immediacy significantly increased post-crisis vs. pre-crisis. Choi and Huh (2016) show that dealers are providing liquidity for a decreasing share of trades over time, and that transaction costs have increased for this subset of trades. Furthermore, while Bessembinder, Jacobsen, Maxwell, and Venkataraman (2016) estimate lower transaction costs after the crisis, they document a structural break that suggests a decline in dealers' capital commitment relative to the pre-crisis period. Adrian, Boyarchenko, and Shachar (2016) find that corporate bond liquidity provision declined significantly in recent years for dealers that are relatively more constrained by regulations.

We also present three case studies on the resilience of market liquidity to shocks in the post-crisis era. The first analyzes dealer balance sheet behavior during the 2013 "taper tantrum" when Treasury yields rose over 100 basis points within a 10-week period. The second looks at the October 2014 "flash rally" in the U.S. Treasury market, when yields rose and fell rapidly within a 12-minute event window. The third reviews the extent to which the liquidation of Third Avenue's high-yield bond fund in December 2015 affected market liquidity. In all three cases, the degree of deterioration in market liquidity was within historical norms, suggesting that liquidity remained resilient.

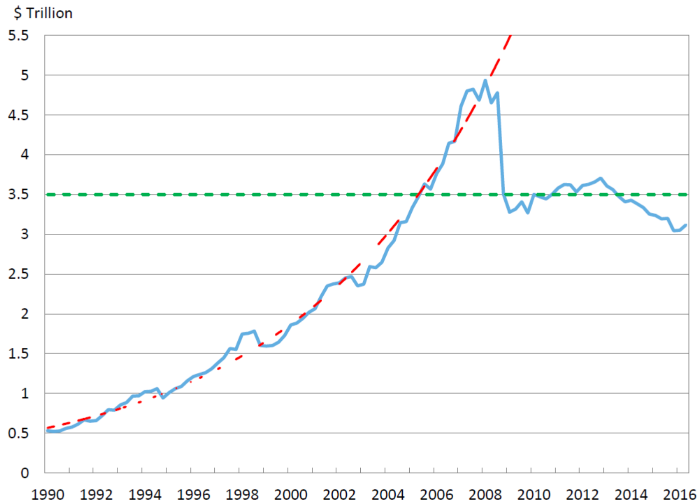
While we do not uncover clear indications of a widespread worsening of bond market liquidity, our analysis faces several limitations. Most importantly, our review of corporate bond liquidity relies on trades that have occurred, and does not account for any trades that have not taken place due to changes in the regulatory environment or other factors. Future work should thus consider both a wider range of data and methodological improvements to better exploit existing data. Moreover, dealer balance sheets have undergone dramatic changes, reflecting macroeconomic trends and the evolution of the market-making business model, and some funding cost metrics, such as interest rate swap spreads and the credit default swap (CDS)-bond basis, imply increased balance sheet costs. Further researching the determinants of these funding cost metrics is a promising avenue of future research, particularly given the close relationship between funding liquidity and market liquidity (Brunnermeier and Pedersen (2009)). Additional topics for future research include endogeneities in the data generating process and the concept of liquidity risk.

The paper proceeds as follows. Section 2 discusses the evolving trading environment for broker dealers as well as the broader trading environment. Section 3 presents our main empirical findings on market liquidity and their relation to the recent literature. Section 4 discusses directions for future research, and Section 5 concludes.

2 The Post-Crisis Trading Environment

Securities brokers and dealers ("dealers") trade securities on behalf of their customers and for their own account, and use their balance sheets primarily for trading operations, particularly market making. The dealer business model has changed rapidly in recent years, which we illustrate through dealer balance sheet size. A priori, we would expect the size of dealer balance sheets to expand exponentially over time, similar to gross domestic product or population.

Figure 1: **Dealer Assets**



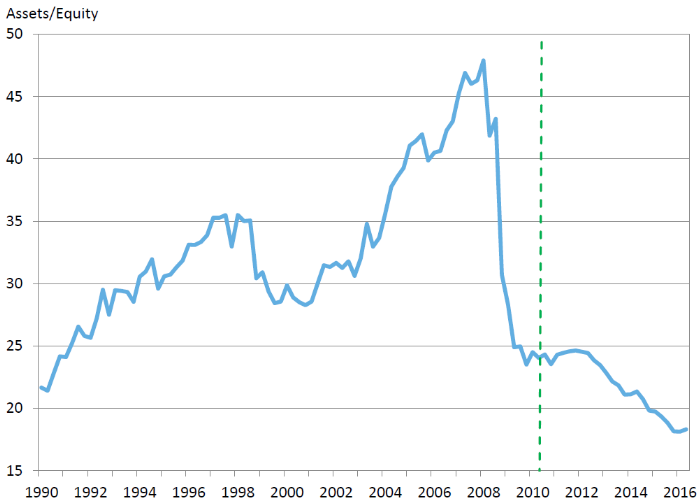
The figure plots the total financial assets of security brokers and dealers at the subsidiary level. The red-dotted curve shows the exponential growth trend computed over the 1990-2008 period. The green-dotted line is set at \$3.5 trillion. The data are from the Financial Accounts of the United States published by the Board of Governors of the Federal Reserve System.

Figure 1 shows dealer balance sheet size from 1990 to 2016. Dealer size grew exponentially from 1990 through 2008, with a peak close to \$5 trillion. Dealer assets then collapsed after Lehman Brothers' failure and remained stalled at around \$3.5 trillion, the level of 2005 (indicated by the green-dotted line in the figure). If the previous trend growth had continued (indicated by the red-dotted line), dealer balance sheet size would have been several times larger in 2016 than it was. The stagnation of dealer balance sheet size after the crisis raises the question of whether the \$5 trillion peak was excessive, whether the pre-crisis growth was sustainable, and whether the 2016 level was, in some sense, depressed. The stagnation also raises the concern that dealers' market-making capacity could be constrained, adversely affecting market liquidity (also see Adrian, Fleming, Stackman, and Vogt (2015c)).

One possible explanation for the stagnation of dealer balance sheet size is regulation. In fact, tighter capital regulation explicitly seeks to limit balance sheet leverage, and deleveraging can occur through either an increase in capital or a reduction in assets. However, the extent to which the stagnation of dealer balance sheet size has been caused by regulation is difficult to quantify because dealers continuously adjust the size and composition of their balance sheets during the normal course of business. Recent research (Adrian and Shin (2014)) suggests that dealers expand their balance sheets in booms and contract them in busts, primarily by adjusting leverage. Dealers' balance sheets and risk appetite are highly correlated, because (other things equal) higher leverage mechanically exposes dealers to more risk by amplifying potential losses. It is therefore not uncommon to see dealers rationally deleverage to reduce risk taking during downturns as potential losses are realized.

Figure 2 shows that the private incentives of dealers to deleverage and the social incentives of regulators to impose limits on leverage coincided in the wake of the housing market boom and bust. Leverage peaked at 48 in the first quarter of 2008, just prior to the near failure of Bear

Figure 2: **Procyclical Dealer Leverage**



The figure shows the leverage of security brokers and dealers at the subsidiary level. Leverage is defined as (total assets)/(book equity capital). The green-dotted line marks the passage of Dodd-Frank and the announcement of Basel III capital reforms in July 2010. The data are from the Financial Accounts of the United States published by the Board of Governors of the Federal Reserve System.

Stearns, but then dropped to 25 by June 2009, roughly a year before the passage of Dodd-Frank and the announcement of Basel III banking capital regulations in July 2010 (marked by the vertical green line). Most deleveraging thus occurred prior to the announcement of potentially constraining regulation. Dodd-Frank and Basel III regulations may help explain the deleveraging since 2010, but it is unclear to what extent regulations constrain growth in dealer leverage and risk taking today.

There are a number of possible explanations for the remarkable change in dealer balance sheets:

1. The post-crisis regulatory framework, reflecting the Dodd-Frank Act and the Basel III capital and liquidity requirements;

2. Voluntary changes in dealer risk-management practices and balance sheet composition following the housing market boom and bust;

3. Changes in market structure with the growth of electronic trading;

4. The changing landscape of institutional investors, including the evolving liquidity demands of large asset managers;

5. Changes in expected returns associated with the economic environment.

We discuss each of these factors in detail.

2.1 Post-Crisis Regulatory Framework

Regulations affecting the dealer sector tightened markedly after the financial crisis of 2007-09. While the five major independent U.S. dealers were outside of the safety net prior to the crisis and regulated under Basel II capital rules, all of them either failed (Lehman), were acquired by banking organizations (Bear Stearns and Merrill Lynch), or became bank holding companies themselves (Goldman Sachs and Morgan Stanley). All major U.S. dealers are now subject to the Federal Reserve's stress tests and enhanced capital and liquidity requirements, as well as more stringent Basel III rules.

Regulatory reforms after the crisis stems directly from shortcomings in the regulatory framework uncovered during the crisis. During the crisis, banks, dealers, financial market utilities, and other systemically important market participants experienced both solvency and liquidity problems. That motivated subsequent tightening of capital and liquidity requirements. In addition, some regulations directly restrict certain activities, such as the Volcker rule, which prohibits proprietary trading by banks. The regulations have affected institutions' business models markedly. We briefly review these regulatory changes, and provide further references.

Basel 2.5 Market Risk Amendment: In 2010, the Basel Committee on Banking Supervision put forth the market risk amendment (see BCBS 2010), recognizing that the existing capital framework for market risk did not capture some key risks. The value-at-risk (VaR) based trading book framework was supplemented with an incremental risk capital charge, which accounted for default and migration risk for credit products. The incremental risk capital charge aims to reduce the incentive for regulatory arbitrage between the banking and trading books. In addition, the framework introduced a stressed VaR requirement. The incremental risk capital charge and the stressed VaR requirement significantly affect balance sheet costs, particularly for corporate bonds and bespoke credit derivatives (CGFS 2014).

Basel III Capital Requirements: The 2010 Basel III capital framework aims to strengthen the resilience of the banking sector through enhanced capital requirements (see BCBS 2011). The reforms raise both the quality and quantity of the regulatory capital base and enhance the risk coverage of the capital framework. The committee also introduced a number of macroprudential elements into the capital framework to help contain systemic risk arising from procyclicality and the interconnectedness of financial institutions.

In order to improve the quality of capital, Basel III requires the predominant form of tier 1 capital to be in the form of common shares and retained earnings. Common tier 1 equity has to be at least 4.5% of risk-weighted assets at all times. The committee also introduced a capital conservation buffer of 2.5% that can be drawn down in periods of stress. Furthermore, the committee introduced a countercyclical capital buffer that can be set by regulators in a range of 0-2.5%, depending on the state of the credit cycle.

Basel III introduced measures to strengthen the capital requirements for counterparty credit exposures arising from banks' derivatives, repurchase agreement (repo) and securities financing activities. Banks must determine their capital requirement for counterparty credit risk using stress assumptions in order to address concerns about capital charges becoming too low during periods of compressed market volatility and thereby help address the procyclicality of leverage. Banks are subject to a capital charge for potential mark-to-market losses, referred to as a credit valuation adjustment, associated with a deterioration in counterparty creditworthiness.

The Basel Committee also introduced a leverage ratio requirement to constrain leverage in the banking sector. The leverage ratio provides an additional safeguard against model risk and measurement error by supplementing the risk-based capital measure with a simple, transparent, independent measure of risk. The leverage ratio requirement is 3%, with an additional 2% supplement for the largest U.S. institutions. The requirement increases balance sheet costs relatively more for low-margin businesses such as market making in repo and highly rated sovereign bonds (see CGFS 2014).

The committee additionally introduced a macroprudential surcharge to reduce the probability of failure of global systemically important banks (GSIBs), by increasing their going-concern loss absorbency, and to reduce the cost of failure of GSIBs, by improving global recovery and resolution frameworks (see BCBS 2013b). The systemic importance of GSIBs is assessed using an indicator-based measurement approach. The selected indicators are chosen to reflect the different aspects of what generates negative externalities and what makes a bank critical for the stability of the financial system, and include size, cross-jurisdictional activity, interconnectedness, substitutability/financial institution infrastructure, and complexity.

Liquidity Regulation: To bolster the liquidity positions of banks, the Basel Committee developed the liquidity coverage ratio (LCR) and the net stable funding ratio (NSFR, see BCBS 2013a, 2014). The objective of the LCR is to promote the short-term resilience of banks' liquidity risk profile by ensuring that banks have an adequate stock of liquid assets to meet liquidity needs for a 30-day stress scenario. The objective of the NSFR is to reduce banks' funding risk over a longer time horizon by requiring banks to maintain sufficiently stable sources of funding. The NSFR is defined as the amount of available stable funding relative to the amount of required stable funding and must equal or exceed 100% on an ongoing basis.

Total Loss Absorbing Capacity (TLAC): In 2013, G20 leaders asked regulators to assess and develop proposals to ensure the adequacy of global systemically important financial institutions' loss-absorbing capacity when they fail. The aim is to reduce both the probability and impact of failure of GSIBs by requiring sufficient loss-absorbing and recapitalization capacity in resolution to implement an orderly resolution that minimizes effects on financial stability, ensures the continuity of critical functions, and avoids exposing public funds to loss. A TLAC requirement thus imposes a minimum level of bail-in-able debt, which can be transformed into equity during the resolution of a GSIB. See FSB (2015) for an overview.

Stress Tests: In the U.S., the Federal Reserve conducts annual stress tests for the largest bank holding companies (BHCs) and designated systemically important financial institutions (SIFIs). The Dodd-Frank Act requires such tests to ascertain whether BHCs and SIFIs have sufficient capital to absorb losses resulting from adverse economic conditions. The tests are based on a hypothetical, severely adverse scenario designed by the Fed, incorporate detailed information about the risk characteristics and business activities of each BHC, and are estimated using a consistent approach across BHCs. The projected losses under the scenario thereby provide a unique perspective on the robustness of the capital positions of these firms and provide comparable results across firms.

The Federal Reserve's annual Comprehensive Capital Analysis and Review (CCAR) is an intensive assessment of the capital adequacy and capital planning processes of large U.S. BHCs based on the stress tests. Through CCAR, the Fed seeks to ensure that large BHCs have strong processes for assessing their capital needs supported by effective firm-wide practices to identify, measure, and manage their material risks; strong internal controls; and effective oversight by boards of directors and senior management. CCAR helps promote greater resiliency at the firms by requiring each BHC to support its capital management decisions with forward-looking comprehensive analysis that takes into account the BHC's unique risk profile and activities as well as the effect of highly stressful operating environments on financial performance.

Volcker Rule: Section 619 of the Dodd-Frank Act, referred to as the Volcker rule, prohibits insured depository institutions and any company affiliated with an insured depository institution from engaging in proprietary trading and from acquiring or retaining ownership interests in, sponsoring, or having certain relationships with, a hedge fund or private equity fund. The rule, aiming to rein in excessive risk taking in the over-the-counter (OTC) markets, essentially prohibits proprietary trading by banks except for market-making activities. While the rule directly affects market-makers' capacity to provide liquidity, Duffie (2012) argues that overall market liquidity might not be hampered if lost market-making capacity is filled by non-bank firms such as hedge funds or insurance companies. U.S. Treasuries, agency mortgage-backed securities (MBS), and agency debt securities are exempt from the Volcker rule.

Impact of the Regulatory Reforms for Dealers: CGFS (2014) considers the effects of these regulations for dealer business models and market making more generally. Regulatory changes after the crisis likely affect dealer balance sheets and profitability, and market participants assert they raise market-making costs. Risk weights and credit risk charges make trading of corporate bonds and credit derivatives more expensive. In particular, the incremental risk capital charge and the stressed VaR increase holding costs of corporate bonds. Furthermore, less liquid corporate bonds are ineligible for the LCR, which is thought to reduce the willingness of banks to warehouse these assets. Moreover, the leverage ratio increases the balance sheet cost of repos, including those backed by corporate bonds and structured credit, increasing dealers' financing costs.

CGFS (2016) provides results of an informal survey of market participants on the effects of regulatory reforms. Respondents provided estimates of the relative importance of different cost drivers, including regulatory capital requirements as well as trading and operational costs, using two highly stylized portfolios: one of sovereign bonds and one of corporate bonds. The survey results suggest that the effects of post-crisis regulatory changes are differentiated. For sovereign bonds, the Basel III leverage ratio and higher risk-weighted capital requirements are thought to have the largest effect on regulatory capital charges and, hence, dealer profits. For corporate bonds, by comparison, revisions to the Basel II market risk framework (Basel 2.5) are thought to have the largest effect on regulatory charges. The survey responses imply that the gross revenue required to yield a return on capital of 8% under a fully phased-in Basel III framework would have resulted in returns above 20% under Basel II.

The academic evidence on the effects of regulatory reforms is mixed, at least partially reflecting the challenges in estimating effects of regulations considered, approved, and implemented over extended periods amid numerous other developments. As noted earlier, Mizrach (2015), Bessembinder, Jacobsen, Maxwell, and Venkataraman (2016), and Anderson and Stulz (2017) find that corporate bond liquidity overall is better in the post-crisis period than the pre-crisis period, although Anderson and Stulz (2017) find higher transaction costs and price impact for large (over $100,000) trades, a finding that we will also present below. Trebbi and Xiao (2015) test for break points in various liquidity measures and find that none of their estimated structural breaks occur around the approval of Dodd-Frank, the occurrence of major bank proprietary trading desk closures, or the Volcker rule finalization, and conclude that post-crisis regulatory changes have not produced a structural deterioration in bond market liquidity.

In contrast, Bao, O'Hara, and Zhou (2016) find that price impact increased among recently downgraded corporate bonds when comparing the pre- and post-Volcker rule periods. Similarly, Dick-Nielsen and Rossi (2016) find that the price of immediacy (which they measure around bond index inclusions) significantly increased post-crisis vs. pre-crisis. Moreover, Choi and Huh (2016) show that dealers are providing liquidity for a decreasing share of trades over time, and that transaction costs have increased for this subset of trades. Bessembinder, Jacobsen, Maxwell, and Venkataraman (2016) also find that dealers propensity to intermediate on an agency basis increases at times of market stress and dealers appear less willing to commit capital on a principal basis in the post-crisis period. While their study does not rule out other explanations, they note that the timing of these changes is consistent with dealer behavior having been affected by the implementation of Dodd-Frank.

Adrian, Boyarchenko, and Shachar (2016) study the relationship between bond-level liquidity and financial institutions' balance sheet constraints. They first document that there is a relationship between institutional constraints and bond liquidity. Bonds traded by more levered and systemic institutions (those with higher leverage, a higher ratio of securities bought under repurchase agreements to assets, and higher financial vulnerability), and bonds traded by institutions more akin to investment banks (BHCs with smaller ratio of risk-weighted assets to assets, smaller allocation to loans, and higher trading revenues) are less liquid. These results hold across bonds with different credit ratings, issued by companies in different industries, with different issuance sizes, and with different prior levels of liquidity.

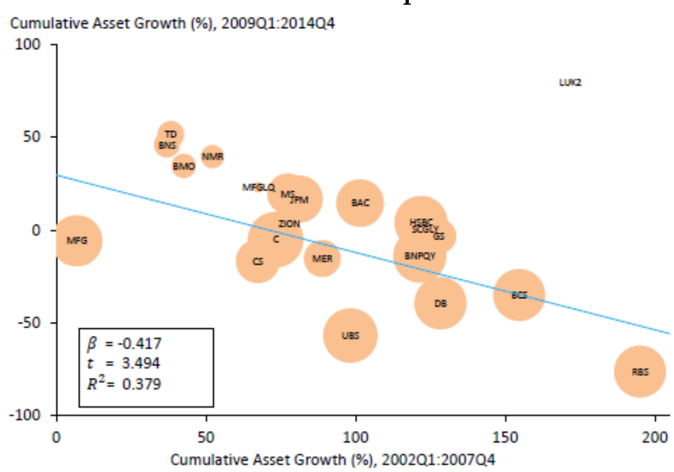
The relationship between bond liquidity and institution-level constraints does, however, change significantly over time. Adrian, Boyarchenko, and Shachar (2016) find that, prior to the crisis, bonds traded by institutions with higher leverage, higher return on assets, lower risk-weighted assets, lower reliance on repo funding, and lower vulnerability were more liquid. During the rule implementation period (starting in January 2014), these relationships reversed: bonds traded by institutions with lower leverage, higher risk-weighted assets, more reliance on repo funding and lower return on assets were more liquid. That is, the relationship between bond liquidity and dealer constraints that we see in the full sample is primarily driven by that same relationship in the post-crisis period. These findings are consistent with more stringent leverage regulation and greater regulation of dealer banks reducing institutions' ability to provide liquidity to the market overall.

2.2 Consequences of the Housing Market Boom and Bust

Dealer balance sheet management is reflective of dealer risk appetite. Adrian and Shin (2010, 2014) thus document that dealer risk taking is closely tied to dealer risk-management constraints, particularly balance sheet VaR. In booms, when volatility tends to be compressed, dealers have loose VaR constraints, allowing them to expand their balance sheets by increasing leverage. When an adverse shock hits, such as a sudden decline in housing prices, the VaR constraints can act as an amplification mechanism: declining asset prices are associated with increased measured risk, forcing dealers to sell, thus inducing further price declines. The tightness of dealer VaR constraints thus determines dealer risk appetite.

To investigate the effect of risk appetite on dealer balance sheet contraction, we examine whether the cross section of dealer risk-taking behavior during the housing boom shaped dealer growth in the subsequent housing bust. In Figure 3, we show that dealers that expanded their balance sheets more in the run-up to the financial crisis (2002-2007) tended to contract their balance sheets more after the crisis (2009-2014). This finding is a cross-sectional version of the procyclicality of dealer balance sheets documented by Adrian and Shin (2010, 2014).

Figure 3: **Dealer Balance Sheet Expansions and Contractions**



The figure compares asset growth pre-crisis to asset growth post-crisis for the primary dealers for which data are available. Dots are labeled with each dealer's stock market ticker and are scaled to reflect dealer size as measured by average total assets from 2002 to 2007. The asset-weighted least squares regression line is in blue. The data are from Compustat.

Adrian, Fleming, Stackman, and Vogt (2015c) further investigate the cross section of risk taking using the realized volatility of equity returns over the pre-crisis period as a measure of risk taking. They find that riskier dealers tended to have larger losses during the crisis.[2] Furthermore, greater

[2] A related academic study by Cheng, Hong, and Scheinkman (2015) shows that the propensity to take risk across

risk taking during the crisis—as measured by dealers' VaR—predicts greater contraction of assets post-crisis. These findings are consistent with the interpretation that dealers' propensity to take risk amplified the growth of dealer balance sheets going into the crisis, causing crisis losses and a subsequent sharp contraction of balance sheets after the crisis.

This evidence is thus suggestive of balance sheet contraction being related to dealer risk taking behavior in the run-up to the crisis. In particular, many European banking organizations aggressively entered the U.S. investment banking market in the late 1990s and early 2000s, fueling the increase in aggregate balance sheet size. Furthermore, many major dealers aggressively expanded their securitization activities and holdings of securitized assets. Both factors likely increased balance sheet growth before the crisis, and both factors are (cross-sectionally) associated with losses during the crisis and balance sheet reduction after the crisis.

2.3 Electronification

Another key development in recent years is the electronification of fixed-income markets. Electronification refers to the shift toward trading through computer systems, increased automated trading (which relies on algorithms for trading decisions and executions), and the reliance on speed to identify and act upon trading opportunities (that is, high-frequency trading). The growth of electronic trading has likely reduced dealers' profits from intermediating customer order flow, causing dealers to step back from making markets and reducing their need for large balance sheets. The Joint Staff Report on the U.S. Treasury Market on October 15, 2014 (Joint Staff Report (2015)) showed that trading in the interdealer cash and futures markets is now dominated by principal trading firms (PTFs), which typically execute high-frequency trading (HFT) strategies.

BIS (2016) provides an overview of electronic trading in fixed-income markets and argues that electronic and automated trading tends to have a positive impact on market quality. Indeed, academic studies show that automated trading is associated with a compression in bid-ask spreads, an increase in trading volume, and smaller trade sizes, on average (see the surveys by Jones (2013) and Menkveld (2016)).[3] Hasbrouck and Saar (2013) show that low latency reduces bid-ask spreads, the total price impact of trades, and short-term volatility, and Hendershott, Jones, and Menkveld (2011) find that algorithmic trading narrows bid-ask spreads and enhances price discovery. Menkveld (2013) studies the trading strategy of a large high-frequency trader whose entry coincided with a 50% drop in the bid-ask spread.

However, automated trading may also be associated with an increase in liquidity risk, as suggested in BIS (2016). Some have thus linked the flash events in the equity market on May 6, 2010, in the U.S. Treasury market on October 15, 2014, and in the foreign exchange market on March 18, 2015 to the presence of automated trading (see Securities and Exchange Commission (2010), Joint Staff Report (2015), and Schaumburg and Yang (2015)). Automated trading might therefore

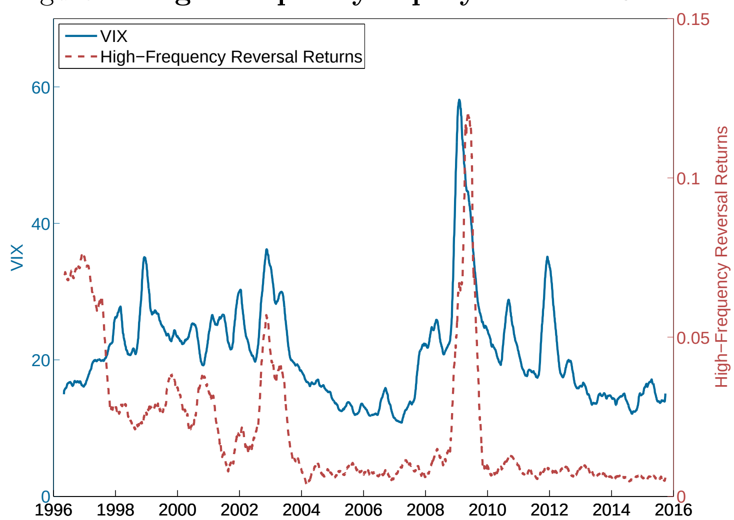
firms persists over time.

[3] In contrast, Biais, Foucault, and Moinas (2015) show that high speed technology enables fast traders to retrieve information before slow traders, generating adverse selection, and thus negative externalities.

be beneficial on average, but associated with costs in some states of the world.

To gauge the effects of electronification on market making, we estimate market-making returns in equity and corporate bond markets, following Adrian, Fleming, Shachar, Stackman, and Vogt (2015a). We first calculate minute-by-minute returns from a reversal strategy for the 30 firms in the Dow Jones Industrial Average (using the methodology described by Khandani and Lo (2007) and Nagel (2012)). Returns are based on an investment portfolio that is long past losers and short past winners, thus betting on the reversal of past trends. The literature uses such reversal profits as proxies for expected returns to market making, as market makers tend to manage their trading book in a similar fashion. As shown in Figure 4, profits on this reversal strategy declined precipitously between the mid-1990s and mid-2000s, and then stabilized at historically low levels, except for a temporary increase during the financial crisis. While market-making returns were highly correlated with the Chicago Board Options Exchange Volatility Index (VIX Index) through 2004, they were more stable than the VIX after that, except during the crisis when both the VIX and the returns increased sharply.

Figure 4: **High-Frequency Equity Market Returns**

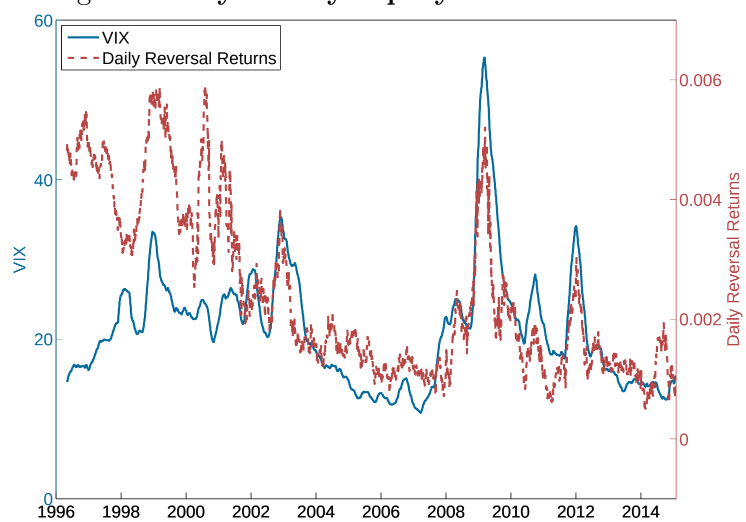


The figure plots the CBOE Volatility Index (VIX Index) alongside a proxy for high-frequency market-making returns in equities as calculated by the daily returns to a minute-by-minute reversal strategy for the 30 firms in the Dow Jones Industrial Average as described by Khandani and Lo (2007) and Nagel (2012). Three-month moving averages are shown for both series. The equity data from which the market-making returns are calculated are from the Thomson Reuters tick history; the VIX Index is from the Chicago Board Options Exchange.

The decline in high-frequency market-making returns occurred against a backdrop of increasing competition. The expected returns to high-frequency trading in the 1990s encouraged large investments in speed and led many new firms to enter the sector—as documented by Budish, Cramton, and Shim (2015). The sharp decline in high-frequency profits over the first 10 years of our sample suggests that these profits were gradually eroded by competition as the HFT sector developed. Importantly, market-making profits did not increase after capital and liquidity regulations were tightened following the crisis.

Figure 5 shows that a somewhat different picture emerges for day-to-day market-making returns. Daily reversal trading returns for the firms tracked in the Center for Research in Security Prices (CRSP) database declined between the mid-1990s and the mid-2000s and increased sharply during the crisis, with no discernible trend after the crisis. However, the figure also shows a high correlation between day-to-day market-making profits and the evolution of market volatility after the mid-2000s, a relationship not observed for higher-frequency market making. The interpretation is that higher market volatility tightens dealers' funding constraints, contributing to a widening of market-making returns. Risk-management techniques that rely directly on market volatility, such as VaR limits, can cause such funding constraints to bind and create a link between funding liquidity and market liquidity (Brunnermeier and Pedersen (2009) and Adrian and Shin (2014)).

Figure 5: **Day-to-Day Equity Market Returns**

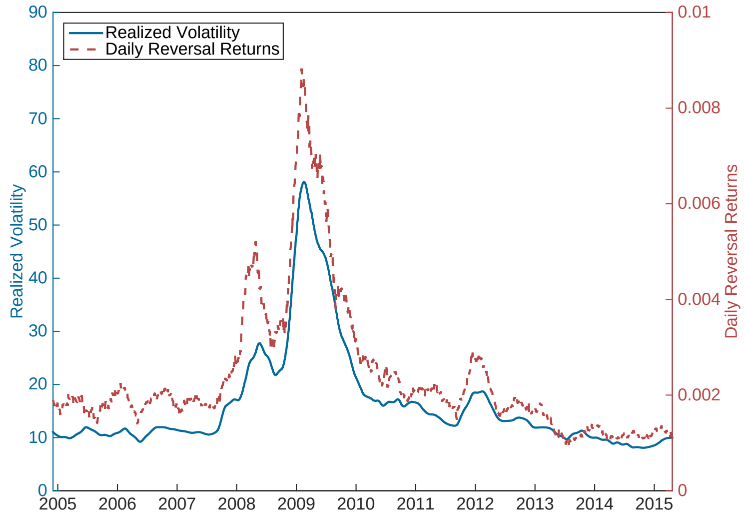


The figure plots the CBOE Volatility Index (VIX Index) alongside a proxy for daily market-making returns in equities as calculated by a day-by-day reversal strategy for the 30 firms in the Dow Jones Industrial Average as described by Khandani and Lo (2007) and Nagel (2012). Three-month moving averages are shown for both series. The equity data from which the market-making returns are calculated are from the Thomson Reuters tick history; the VIX Index is from the Chicago Board Options Exchange.

While dealers play a modest role in equity markets, they remain the predominant market makers in the corporate bond market. Moreover, while electronification has become more prevalent in corporate bond trading, such trading does not involve HFT strategies. Figure 6 shows that reversal returns for corporate bonds at the daily frequency exhibit no increase in market-making profits, and thereby do not suggest a withdrawal of market-making activity in this market. The figure also reveals a close relationship between returns to market making and corporate bond realized volatility, with returns to market making highest during high-volatility periods.

Overall, this evidence suggests that expected returns to market making remained compressed after the crisis, both in equity markets where high-frequency electronic trading is predominant, and in credit markets where electronification is not yet associated with high-frequency trading. Adrian, Fleming, Shachar, Stackman, and Vogt (2015a) present complementary evidence by investigating

Figure 6: **Day-to-Day Corporate Bond Market Returns**



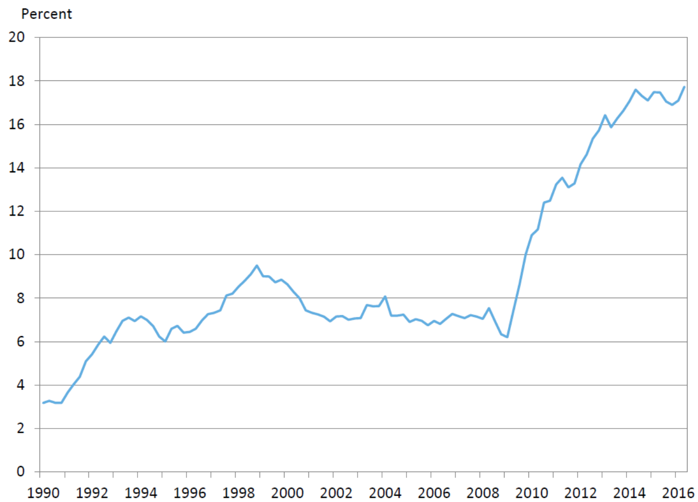
The figure plots the cross-sectionally averaged monthly realized volatility of Markit's North American Investment Grade CDX Index constituents alongside a proxy for daily market-making returns as calculated by the daily returns to a reversal strategy as described by Khandani and Lo (2007) and Nagel (2012). The reversal strategy is applied to the same index constituents. Three-month moving averages are shown for both series. The daily returns are from FINRA's TRACE database and the realized volatilities are from Markit.

the profitability of dealers. They find that post-crisis trading revenue for dealers listed on the New York Stock Exchange (NYSE) was very close to pre-crisis levels, while the volatility of trading revenue was much lower. It follows that the Sharpe ratio of trading revenue (aggregate revenue of dealers divided by the volatility of revenue) was considerably higher post-crisis. Net income for the five largest U.S. dealers in particular—Bank of America, Citigroup, Goldman Sachs, J.P. Morgan, and Morgan Stanley—was also much higher and less volatile after the crisis than before, and the Sharpe ratio of net income was nearly twice as high. These trading revenue and income figures suggest that dealers continue to play a key role in liquidity provision. This is particularly important for less liquid securities in which HFT firms are less active, such as corporate bonds and off-the-run Treasury securities, and at times of stress, when dealers have greater incentive to provide liquidity because of their customer relationships. The picture that emerges is of a change in the risk-sharing arrangement among trading institutions.

2.4 Evolving Liquidity Demands of Large Asset Managers

As of mid-2016, mutual funds owned about 18% of corporate bonds, up from about 3% in 1990, as shown in Figure 7. The surge in ownership was strikingly rapid after 2008, suggesting that the channels of credit intermediation changed with the financial crisis. Before the crisis, shadow credit intermediation was widespread, involving maturity transformation by money market funds that funded credit. After the crisis, money market fund investments in credit vehicles such as asset-backed commercial paper conduits shrank sharply, and market-based credit intermediation shifted to bond funds. While credit intermediation by bond funds still involves some maturity transformation, such maturity transformation is far smaller than the maturity transformation of lengthy shadow credit intermediation chains that was common before the crisis.

Figure 7: **Mutual Fund Ownership of Corporate Bonds**



The figure plots corporate and foreign bonds outstanding (held in the U.S.) owned by mutual funds and exchange-traded funds as a fraction of the total amount of corporate and foreign bonds (held in the U.S.) outstanding. The data are from the Financial Accounts of the United States published by the Board of Governors of the Federal Reserve System.

Mutual funds' increased ownership of corporate bonds raises concerns about redemption risk. When mutual funds are subject to large redemptions, they can be forced to sell some of their holdings, which can cause price declines, especially for relatively illiquid bonds. Such redemption risk is reinforced when redemptions are correlated across funds. Adverse pricing conditions in secondary markets can in turn lead to a deterioration of primary markets. However, Adrian, Fleming, Shachar, and Vogt (2015b) find that net bond fund flows (fund share purchases minus fund share redemptions) as a fraction of corporate bonds outstanding has not increased over time, suggesting that redemption risk has not necessarily increased.

Even if redemption risk has not increased, the price riskiness of corporate bonds could have increased owing to self-reinforcing dynamics: when adverse news leads to lower returns, redemptions might force mutual funds to sell assets, which might reinforce the negative returns, thus generating additional redemptions (see Feroli, Kashyap, Schoenholtz, and Shin 2014). Negative returns tend to be followed by net bond fund redemptions and positive returns by net bond fund purchases, giving rise to a positive flow-performance relationship.

The flow-performance relationship for equity mutual funds is generally found to be convex: strong positive performance tends to generate an increasingly strong response of flows (see Chevalier and Ellison 1999). In contrast, Goldstein, Jiang, and Ng (2015) find a concave relationship for bond funds, so that flows react more strongly when returns are low. The concavity is more pronounced for illiquid bonds, and is stronger when market returns are negative. Moreover, the flow-performance relationship for bond funds is both statistically and economically larger than that for equity funds. These results suggest that the illiquidity of corporate bonds may generate incentives to sell quickly in response to bad news, which might amplify adverse price changes. These incentives might also give rise to self-reinforcing redemption dynamics as investors might anticipate that it pays to redeem early. In equilibrium, redemption risk might lead to higher secondary market volatility and more costly intermediation.

In contrast to mutual funds' increased ownership share of corporate bonds, dealers' ownership share of corporate bonds declined during and after the crisis, averaging 2.7% from 1990 to 2008, but just 1.2% from 2009 to 2016. The reduced ownership share raises the concern that dealers may no longer be able or willing to absorb selling pressure when redemptions force mutual funds to sell. Adrian, Fleming, Shachar, and Vogt (2015b) explore this issue by regressing weekly bond fund flows on past returns and the weekly change in dealer corporate bond positions between January 2007 and August 2015. They find that dealer positioning tends to evolve in the same direction as bond fund flows, suggesting that dealers do not typically absorb the aggregate selling pressure of bond funds. Given that dealers tend not to trade against bond fund flows, they surmise that dealers' falling corporate bond ownership share is unlikely to exacerbate redemption risk.

2.5 Changes in Expected Returns

Dealer positioning reflects the proprietary trading and risk-management motives of dealers as well as the positioning of dealer clients. To illustrate dealers' positioning, we examine the composition of dealer assets. Figure 8 shows dealers' net positions in Treasury securities and corporate bonds from 1990 to 2016. The plot reveals three key features:

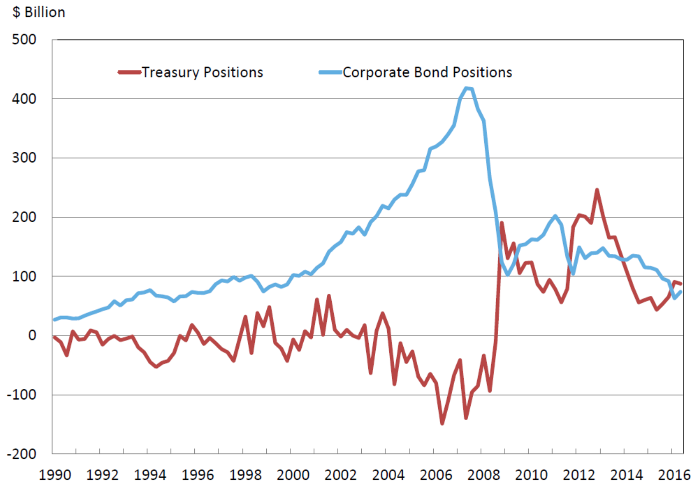
1. Dealers' net corporate positions grew quickly in the years preceding the crisis, plunged during the crisis, and stagnated after the crisis.

2. Dealers' net Treasury positions fluctuated between positive and negative between 1990 and 2016, and were negative for an extended period from 2004 to 2008.

3. In the roughly 15 years between 2001 and 2016, changes in net Treasury and corporate bond positions were negatively correlated and tended to offset, suggesting that dealers trade the credit spread.

The sharp decline in net corporate positions, in particular, raises the concern that dealers have reduced their capital commitment to market making with potentially adverse effects on market liquidity. Traditionally, dealers acted as principal, buying bonds from their customers when they wanted to sell, and holding them on their balance sheet until offsetting trades were found later, thus bearing the risk that prices fell in the interim. More recently, however, they may have shifted toward an agency model, as suggested by Barclays (2016), Bessembinder, Jacobsen, Maxwell, and Venkataraman (2016), and Choi and Huh (2016), in which dealers match offsetting orders so as to avoid holding bonds on their balance sheets. While such a shift could explain the decline in net positions, it leaves open the question as to whether liquidity is adversely affected. There are tens

Figure 8: **Dealer Corporate Bond and Treasury Positions**



The figure plots corporate bond (domestic and foreign) and Treasury security positions (held in the U.S.) of security brokers and dealers. The data are from the Financial Accounts of the United States published by the Board of Governors of the Federal Reserve.

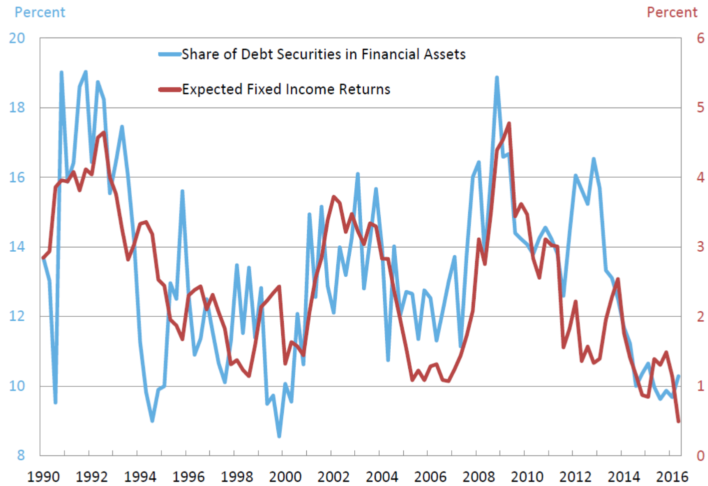
of thousands of outstanding corporate bond issues with varying maturity, seniority, and optionality characteristics, making it difficult to match demand and supply.

Across all debt securities, dealer positioning is likely managed to maximize expected returns and hence varies over time. In Figure 9, we plot debt securities as a share of dealer financial assets together with a measure of expected fixed-income returns: the sum of the 10-year Treasury term premium and the credit risk premium. The 10-year Treasury term premium, computed by Adrian, Crump, and Moench (2013), measures the interest rate risk premium embedded in a Treasury bond portfolio with a 10-year duration. The credit risk premium is measured by Moody's Baa-Aaa spread. The figure shows a tight correlation (55%) between expected fixed-income returns and dealer fixed-income positioning, with periods of sharp changes in asset valuations typically accompanied by sharp adjustments in positions. The low level of debt securities as a share of total assets prior to the financial crisis was thus associated with a compression of expected returns at that time. Similarly, the sharp rise in debt securities during the crisis corresponded with a period when expected returns were unusually high. See Adrian, Fleming, and Vogt (2015) for further analysis.

Figure 9 does suggest one exceptional period in 2012 and early 2013, when dealer positions were increasing despite ever more compressed expected returns in the bond market. Then-Governor Jeremy Stein warned at the time that fixed-income markets might be overheating, and the Financial Stability Oversight Council's 2013 annual report issued a similar warning.[4] That episode ended with the bond market selloff in mid-2013 (the taper tantrum), when yields rose abruptly and dealers quickly shed fixed-income positions (see Adrian and Fleming (2013)). In 2014, the tight link between dealer positions and expected returns returned, with both declining sharply.

[4]See `http://www.federalreserve.gov/newsevents/speech/stein20130207a.htm` and `https://www.treasury.gov/initiatives/fsoc/Documents/FSOC%202013%20Annual%20Report.pdf`

Figure 9: **Dealer Debt Security Positions and Expected Returns**



The figure shows dealers' debt securities as a percent of their total financial assets together with a measure of expected fixed-income returns. Debt securities comprise U.S. Treasury securities, corporate and foreign bonds, agency mortgage-backed securities, commercial paper, and municipal bonds. Expected returns to fixed-income securities are computed as the 10-year Treasury term premium from Adrian, Crump, and Moench (2013) plus Moody's Baa-Aaa credit spread. Data on dealer debt securities and total financial assets are from the Financial Accounts of the United States published by the Board of Governors of the Federal Reserve. The term premium data are from the Federal Reserve Bank of New York. The credit spread data are from the Board of Governors of the Federal Reserve.

3 Empirical Evidence on Market Liquidity

We proceed to assess the extent to which the changes that have roiled dealer balance sheets have affected liquidity in the U.S. Treasury and corporate bond markets. Not only do market participants' liquidity concerns center on bond markets, but the U.S. government and corporate bond markets are the largest of their kind, with debt outstanding of $13.4 trillion and $8.4 trillion, respectively, as of June 30, 2016. Liquidity is of critical importance to both markets given their roles in financing the U.S. government and corporations, as investment vehicles and, in the case of the Treasury market, as a hedging vehicle, risk-free benchmark for pricing other financial instruments, and key instrument of monetary policy.

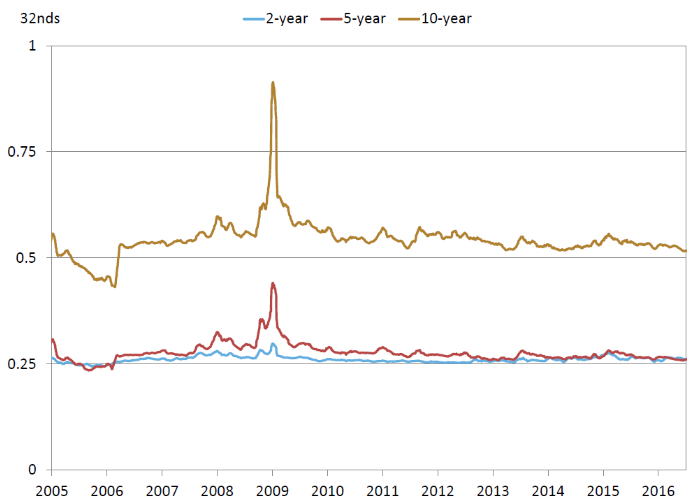
We define market liquidity as the cost of quickly converting an asset into cash (or vice versa). Liquidity has multiple dimensions, so we examine several measures for each market. We first review the time series evolution of liquidity in these markets using data from 2005 to 2016. We then consider three case studies of market stress in the post-crisis era to shed light on the resilience of market liquidity.

3.1 Evidence from the U.S. Treasury Market

We consider four common liquidity measures for the Treasury market, all calculated using high-frequency data from the interdealer market.[5] Our measures are for the most recently issued (on-the-run or benchmark) 2-, 5-, and 10-year notes, the three most actively traded Treasury securities. Our sample runs from the beginning of 2005 through June 2016, so it covers the 2007-09 financial crisis, the 2013 taper tantrum, and the October 15, 2014 flash rally.

One of the most direct liquidity measures is the inside bid-ask spread: the difference between the highest bid price and the lowest ask price for a security. The spread directly measures the cost of executing a trade of limited size, with the cost typically calculated as one-half of the bid-ask spread. As shown in Figure 10, average bid-ask spreads widened markedly during the crisis, but were narrow and stable in the years after the crisis.

Figure 10: **Bid-Ask Spreads of U.S. Treasury Securities**



The figure plots 21-day moving averages of average daily bid-ask spreads for the on-the-run notes in the interdealer market. Spreads are measured in 32nds of a point where a point equals one percent of par. The data are from BrokerTec.

While the bid-ask spread directly measures transaction costs and hence liquidity, it does not account for the depth of the market and hence how costs might vary for multiple trades or trades above the minimum size. Another limitation of the measure is that the minimum tick size (1/2 of a 32nd of a point for the 10-year note and 1/4 of a 32nd for the 2- and 5- year notes) is frequently constraining, limiting variation in the spread.[6]

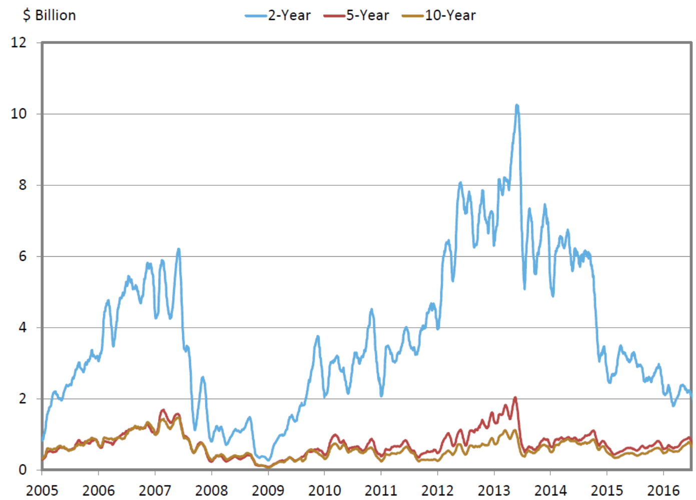
The quantity of securities that can be traded at various bid and offer prices helps account for

[5]This section draws on Adrian, Fleming, Stackman, and Vogt (2015b) and reports measures calculated using data from BrokerTec, the larger of two interdealer trading platforms for Treasuries. We first reconstruct the BrokerTec limit order book for each day and security from the platform message data. Our measures are calculated for 7 am to 5 pm eastern time and thus exclude the less liquid overnight period (see Fleming (1997)). Engle, Fleming, Ghysels, and Nguyen (2012) and Fleming and Nguyen (2013) plot time series of many of the same liquidity measures, also using BrokerTec data.

[6]Using BrokerTec tick data for 2010-2011, Fleming, Mizrach, and Nguyen (—-) find that 97% of quotes for the on-the-run 2-year note are at the minimum tick size.

the depth of the market and complements the bid-ask spread as a measure of market liquidity. We estimate depth as the quantity of securities that is explicitly bid for or offered for sale at the best five bid and offer prices in the BrokerTec limit order book. Figure 11 shows that average depth rebounded healthily after the crisis, but declined markedly during the taper tantrum and around the October 2014 flash rally and thus paints a less sanguine picture of Treasury market liquidity.

Figure 11: **Depth of U.S. Treasury Securities**



The figure plots 21-day moving averages of average daily depth for the on-the-run notes in the interdealer market. Depth is summed across the top five levels of both sides of the order book. The data are from BrokerTec.

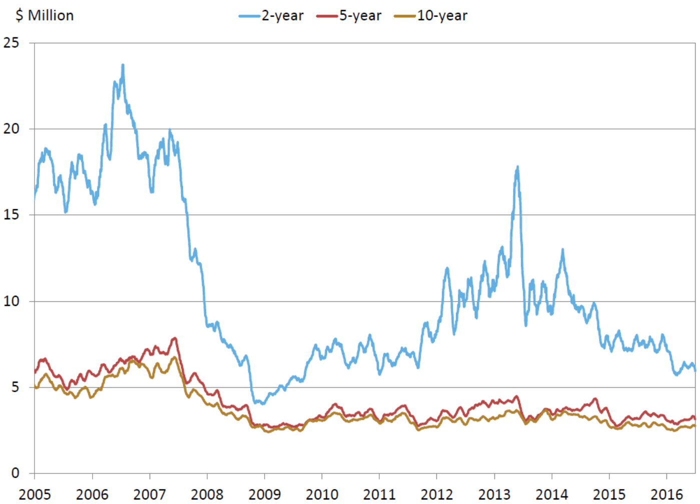
A key limitation of the depth measure is that it does not consider the spread between quoted prices, including the inside bid-ask spread, and as such does not directly capture the cost aspect of liquidity. Another important drawback of quoted depth is that market participants often do not reveal the full quantities they are willing to transact at a given price so that measured depth may underestimate true depth (see Boni and Leach (2004) and Fleming and Nguyen (2013)). Conversely, because of the speed with which orders can be withdrawn from the market, actual depth may instead be lower than what is posted in the limit order book.

An alternative measure of market depth is trade size. Trade size is an ex-post measure of the quantity of securities traded at the bid or offer price, reflecting any negotiation over quantity that takes place. Average trade size declined sharply during the crisis, increased markedly after, and then declined again during the taper tantrum and around the October 15 flash event, as shown in Figure 12.

One difficulty in interpreting trade size is that it underestimates market depth, because the quantity traded is often less than the quantity that could have been traded at a given price. The decline in trade size compared with the pre-crisis period, in particular, may reflect the increasing prevalence of high-frequency trading in the interdealer market, and not necessarily reduced liquidity. In addition, trade size does not consider the actual prices at which trades are executed and hence, like depth, does not directly measure transaction costs.

A popular measure of liquidity, suggested by Kyle (1985), considers the rise (fall) in price that

Figure 12: **Trade Sizes of U.S. Treasury Securities**



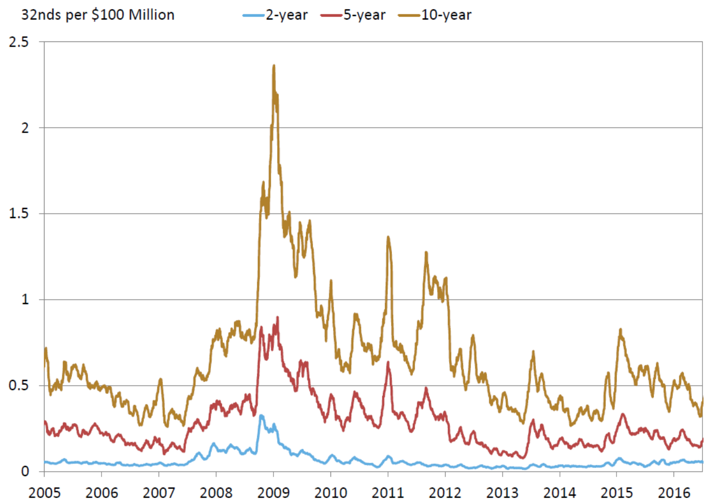
The figure shows 21-day moving averages of average daily trade size for the on-the-run notes in the interdealer market. The data are from BrokerTec.

typically occurs with a buyer-initiated (seller-initiated) trade. The "Kyle lambda", or price impact, is defined as the slope of the line that relates the price change to trade size and is often estimated by regressing price changes on net signed trading volume (positive for buyer-initiated volume and negative for seller-initiated volume) for intervals of fixed time. The measure is relevant to those executing large trades or a series of trades and, together with the bid-ask spread and depth measures, provides a fairly complete picture of market liquidity.

Measures of price impact also suggest some deterioration of liquidity over the 2013-15 period. Figure 13 plots the estimated price impact per $100 million net order flow as calculated weekly from regressions of five-minute price changes (calculated using bid-ask midpoints) on net trading volume over the same five-minute interval. Price impact rose sharply during the crisis, declined markedly after, and then increased during the taper tantrum and in the week including October 15, 2014. The measure remained somewhat elevated after October 15, but was not especially high in 2015 and 2016 by historical standards.

Overall, we find mixed evidence on Treasury market liquidity in the post-crisis era. The appreciable declines in quoted depth in mid-2013 and late 2014 may be the strongest evidence of worsening liquidity. However, the price impact coefficients suggest a more modest deterioration, and bid-ask spreads, which directly measure the cost of trading, remained narrow by recent historical standards as of mid-2016. Trade sizes declined considerably from levels observed before the crisis, but may reflect the growth of automated trading and associated changes in order submission strategies, and are not necessarily indicative of worse liquidity.

Figure 13: **Price Impact of U.S. Treasury Securities**



The figure plots four-week moving averages of slope coefficients from weekly regressions of five-minute price changes (calculated using bid-ask midpoints) on five-minute net order flow for the on-the-run notes. The data are from BrokerTec.

3.2 Evidence from the U.S. Corporate Bond Market

We analyze some of the same measures for the U.S. corporate bond market as for the U.S. Treasury market, but our analysis is necessarily limited by the market's structure and the associated data.[7] Secondary market trading of corporate bonds is conducted over-the-counter, with most trading intermediated by dealers. There is no central limit order book, and hence limited information on quoted bid-ask spreads or depth. We therefore infer liquidity from the record of transactions as reported in FINRA's TRACE database, introduced in 2002.[8]

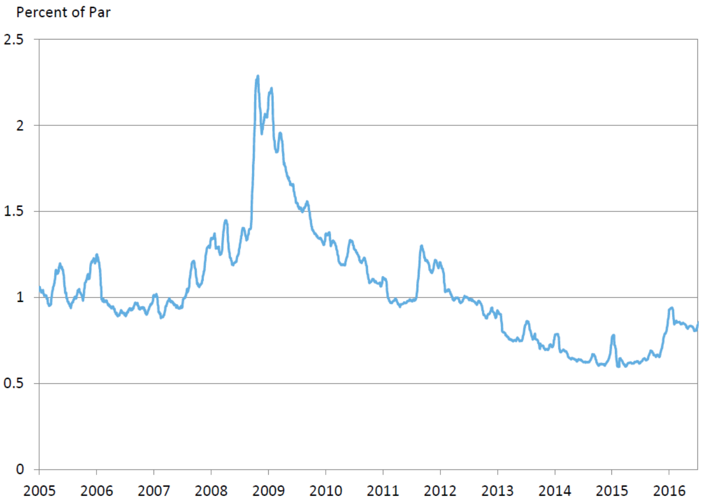
We calculate realized bid-ask spreads for each bond and day as the difference between the average price at which customers buy from dealers and the average price at which customers sell to dealers. We then calculate the average of these realized bid-ask spreads across bonds for each day. As shown in Figure 14, average bid-ask spreads widened sharply during the crisis, but then narrowed to levels lower than pre-crisis levels.

The evolution of realized bid-ask spreads is broadly robust to sub-sample and estimation approach. We find generally similar patterns when we condition on trade size, for example, as seen in Figure 15, which Edwards, Harris, and Piwowar (2007) show (and which our findings confirm) is negatively correlated with transaction costs. Similar patterns are also observed when we condition on credit rating (investment grade vs. high yield) and trading frequency. Moreover, weighting by trading volume across bonds instead of equal weighting across bonds results in appreciably lower spreads, but the same general pattern. That said, a notable distinction in Figure 15 is that spreads

[7] This section draws on Adrian, Fleming, Shachar, and Vogt (2015a) and Adrian, Fleming, Vogt, and Wojtowicz (2016a).

[8] In our analysis, we account for erroneous trade records, remove duplicated interdealer trade records, and exclude trades of Rule 144a issues, trades on weekends and holidays, and trades associated with price outliers (price $<$ \$50 or $>$ \$200) or trade size outliers (size $<$ \$1,000 or $>$ \$100 million).

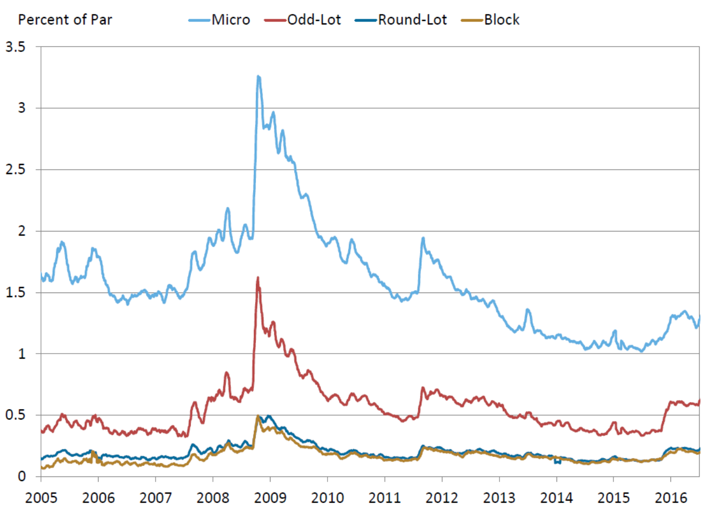
Figure 14: **Corporate Bond Bid-Ask Spreads**



The figure shows the 21-day moving average of realized bid-ask spreads for corporate bonds. The spreads are computed daily for each bond as the difference between the average (volume-weighted) dealer-to-client buy price and the average (volume-weighted) dealer-to-client sell price, and then averaged across bonds using equal weighting. The data are from FINRA's TRACE database.

are narrower after the crisis (than before the crisis) for retail (under $100,000) trades, but wider for institutional ($100,000 and above) trades, a difference also noted by Anderson and Stulz (2017).

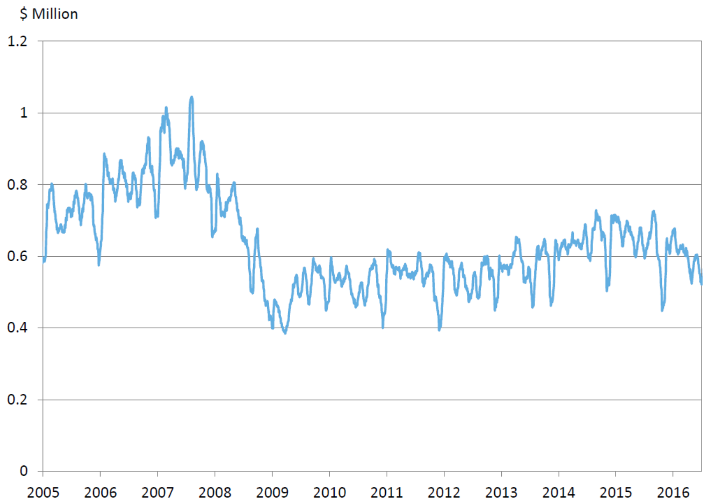
Figure 15: **Corporate Bond Bid-Ask Spreads by Trade Size**



The figure shows 21-day moving averages of realized bid-ask spreads for four different trade size groupings: micro (under $100,000), odd-lot ($100,000 to $1 million), round-lot ($1-million to $5 million), and block (above $5 million). The spreads are computed daily for each bond and trade size category as the difference between the average (volume-weighted) dealer-to-client buy price and the average (volume-weighted) dealer-to-client sell price, and then averaged (on an equal-weighted basis) across bonds. The data are from FINRA's TRACE database.

While we cannot calculate order book depth for the corporate bond market, we can look at trade size. Average trade size declined sharply during the crisis and had not recovered as of mid 2016 (see Figure 16). Some market commentators see this trend as evidence that investors find it more difficult to execute large trades and so are splitting orders into smaller trades to lessen their price impact.

Figure 16: **Corporate Bond Trade Size**



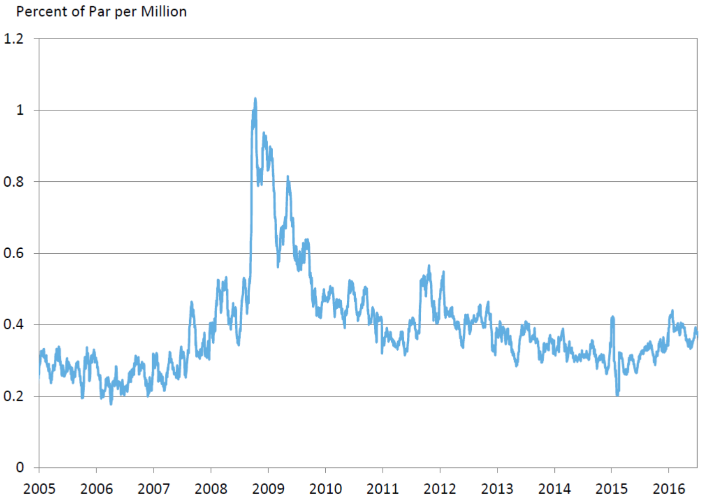
The figure shows the 21-day moving average of average trade size. Average trade size is calculated daily as total trading volume divided by the number of trades. The data are from FINRA's TRACE database.

In fact, there is evidence of higher price impact after the crisis as compared to before. We calculate price impact for each institutional trade as the price change from the previous institutional trade divided by the signed trade size (positive for customer buys and negative for customer sells). We average these estimates for each bond and day, and then average across bonds for each day. As shown in Figure 17, average price impact increased sharply during the crisis and then declined, but remained above pre-crisis levels. Anderson and Stulz (2017) also find somewhat higher price impact for large trades after the crisis than before.

Additional measures suggest ample corporate bond market liquidity. Trading volume, for example, declined during the crisis, but rebounded to record highs after (see Figure 18). Corporate bond issuance similarly plunged during the crisis, but rebounded sharply after, reaching record highs in each year from 2012 through 2016, and driving debt outstanding to ever higher levels. Some analysts note that the corporate bond turnover rate—the ratio of trading volume to debt outstanding—remains below pre-crisis levels, but it is not obvious that declining turnover amidst growing volume indicates worse liquidity.

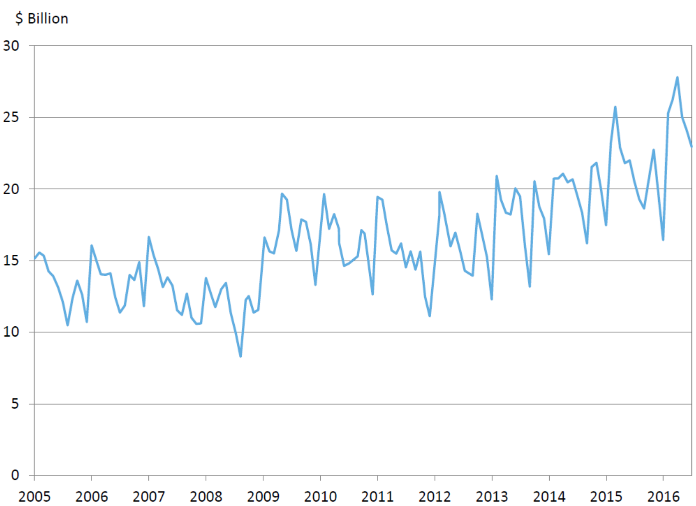
As for the Treasury market, the overall evidence on liquidity in the corporate bond market in the post-crisis era is mixed. Bid-ask spreads for retail trades declined after the crisis to levels lower than those observed pre-crisis. Moreover, trading volume and issuance rose to record highs. However, trade size declined during the crisis and did not quickly rebound after, consistent with the hypothesis that reduced liquidity has made it harder to execute large trades. Moreover bid-ask spreads and price impact for institutional trades, remained higher after the crisis than before, suggesting somewhat worse liquidity for these larger trades.

Figure 17: **Corporate Bond Price Impact**



The figure shows the 21-day moving average of price impact for institutional ($100,000 and above) trades. Price impact is calculated for each such trade as the price change from the previous institutional trade divided by the signed trade size (positive for customer buys and negative for customer sells). These are averaged daily on an equal-weighted basis for each bond and then averaged across bonds using equal weighting. The data are from FINRA's TRACE database.

Figure 18: **Corporate Bond Trading Volume**



The figure shows average daily trading volume by month across all publicly traded non-convertible corporate debt, medium-term notes, and yankee bonds (excluding issues with maturities of one year or less and certificates of deposit). The data are from the Securities Industry and Financial Markets Association and based on data from FINRA's TRACE database.

3.3 Case Studies of Market Liquidity Events

We present three case studies of market behavior during times of stress in the post-crisis era to better understand the resilience of market liquidity. The first is the 2013 taper tantrum, when fixed-income markets sold off, reportedly in anticipation of the end of the Federal Reserve's large scale asset purchases. The second is the flash rally in the U.S. Treasury market on October 15, 2014, when Treasury yields declined sharply and then rebounded within a short 12-minute window.

The third is the liquidation of Third Avenue's high-yield Focused Credit Fund (FCF) in December 2015.

3.3.1 Dealer Balance Sheet Capacity and Market Liquidity during the Taper Tantrum

Long-term interest rates increased substantially in 2013 after hitting record lows in 2012. The sharpest increase occurred between May 2 and July 5 of 2013, with the 10-year Treasury yield rising from 1.63% to 2.74% (see Adrian and Fleming (2013)). Market liquidity deteriorated during this episode, as shown in Figures 11 and 13 by the sharp drop in market depth and increase in price impact between May and June 2013, especially following then Federal Reserve Chairman Ben Bernanke's testimony before the Joint Economic Committee on May 22 and the June 18-19 Federal Open Market Committee meeting. Some market participants suggested that constraints on dealer balance sheet capacity impaired liquidity during the selloff, increasing the magnitude and speed of the rise in interest rates and volatility.[9] Dealers intermediate between buyers and sellers, putting capital at risk in order to absorb changes in client supply and demand. The less capacity a dealer has to absorb supply and demand imbalances, the higher volatility and the lower market liquidity are likely to be. In this section, we review the evidence on what motivated dealer behavior during the episode and whether dealer balance sheet capacity amplified the selloff.

To gauge dealer willingness to add interest rate risk exposure and buffer the selling pressures from their customers, Adrian, Fleming, Goldberg, Lewis, Natalucci, and Wu (2013) examine dealers' positions in U.S. Treasury securities, agency debt, agency MBS, and corporate securities, as reported to the Federal Reserve by the primary dealers. During the selloff, dealers markedly reduced their net positions (the difference between long and short positions) in these securities, particularly agency debt and agency MBS, suggesting that they had decided to limit their outright exposures rather than absorb inventory from customers looking to sell. Moreover, the biggest decline in dealers' long positions in 2013 occurred between May 8 and July 17, suggesting that dealers reduced their market-making activities during the selloff. Outside of 2013, instances since 1990 in which there were larger changes in both long and short positions are limited to a small number of periods at the height of the financial crisis in 2008, during the bond market selloff of 1994, and around the financial market turmoil of 1998.

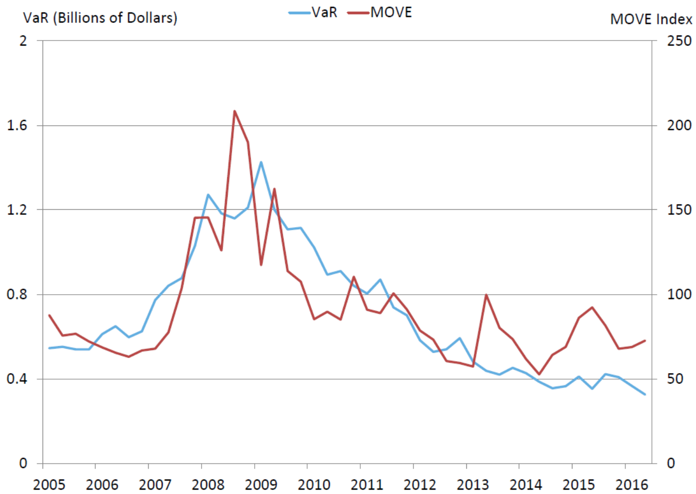
Another indicator of risk taking is value-at-risk (VaR), which measures the worst expected loss over a given time horizon at a given confidence level. Figure 19 shows that the sum of firm-wide VaR across eight large U.S. dealers trended downward after the crisis.[10] The figure also shows that VaR tends to move in tandem with market volatility, as proxied by the Merrill Lynch Option Volatility Estimate (MOVE) Index, so that the decline in VaR after the crisis is associated with the decline in volatility.

Interestingly, dealer VaR did not increase during the 2013 selloff, even though volatility rose

[9] See, for example, "The great unwind: Buy-side fears impact of market-making constraints," Risk, July 30, 2013.

[10] VaR is reported at either the 95% or 99% level, depending on the firm. For those firms for which the 95% confidence level is reported, we scale the VaR to the 99% level using the Gaussian assumption, as in Adrian and Shin (2014).

Figure 19: **Dealer VaR and Interest Rate Volatility**



The figure plots the sum of firm-wide VaR across eight large U.S. firms (Bank of America, Bear Stearns, Citibank, Goldman Sachs, JP Morgan, Lehman Brothers, Merrill Lynch, Morgan Stanley) and the Merrill Lynch Option Volatility Estimate (MOVE) Index, a measure of implied interest rate volatility. The data are from Bloomberg.

Table 1: **Dealers' Net Positions and Balance Sheet Constraints during the 2013 Selloff**

The table presents pairwise correlations between dealers' changes in net positions in U.S. Treasury securities, agency debt, agency MBS, and corporate securities during the May-July 2013 selloff and dealers' changes in balance sheet constraints over the same period. Calculations are based on Federal Reserve supervisory VaR data, company reports for major U.S. chartered bank holding company affiliated dealers, and the Federal Reserve's FR 2004 statistical release.

Measure of Dealer Constraint (Period over which Constraint Changes)	Correlation between Change in Net Position and Change in Dealer Constraint
Change in interest rate VaR (May 1 to July 10, 2013)	63%
Change in tier 1 capital ratio (March 31 to June 30, 2013)	-34%
Change in tier 1 leverage ratio (March 31 to June 30, 2013)	-87%

sharply, suggesting that dealers might have actively managed their risk exposures to insulate their firm-wide VaR from price moves. In fact, an analysis of the cross-sectional behavior of dealers highlights the observation that firms that reduced their net fixed-income positions more during the selloff tended to experience a larger decline in their interest rate VaR, as shown in Table 1. Furthermore, dealers that reduced their positions more experienced larger increases in their tier 1 capital and tier 1 leverage ratios in the second quarter of 2013. That is, a reduction in net positions by some dealers appears to have been associated with a reduction in risk taking.

The finding that dealers reduced their fixed-income positions during the selloff, and that the reduction was associated with reduced risk taking as measured by VaR and regulatory capital ratios, is compatible with two alternative explanations. The first is that dealers were unable to provide market liquidity because of capital constraints. The second is that dealers decided to manage their balance sheets more conservatively at a time when investors were repricing interest rate risk rapidly. That is, dealers may have been able but unwilling to provide market liquidity.

Table 2: **Dealer Changes in Net Positions and Balance Sheet Constraints prior to the 2013 Selloff**

The table presents pairwise correlations between dealers' changes in net positions in U.S. Treasury securities, agency debt, agency MBS, and corporate securities during the May-July 2013 selloff and dealers' constraints shortly before the selloff. Calculations are based on Federal Reserve supervisory VaR data, company reports for major U.S. chartered bank holding company affiliated dealers, and the Federal Reserve's FR 2004 statistical release.

Measure of Dealer Constraint (Date prior to Selloff)	Correlation between Change in Net Position and Constraint prior to Selloff
VaR gap (May 1, 2013)	-60%
Basel III tier 1 common ratio buffer (March 31, 2013)	-83%
Tier 1 capital ratio (March 31, 2013)	-74%
Tier 1 leverage ratio (March 31, 2013)	-6%

If the constraints explanation were correct, then dealers facing tighter balance sheet constraints before the selloff would have been expected to reduce their net positions more than other dealers during the selloff. The evidence presented in Table 2 is not consistent with that hypothesis. In particular, U.S. dealers with a higher VaR gap (which measures the difference between a dealer's VaR and its VaR limit), a higher Basel III tier 1 common ratio buffer (which measures the difference between a dealer's measured ratio and proposed ratio requirement), and higher tier 1 capital and tier 1 leverage ratios before the selloff tended to reduce their net positions more during the selloff. That is, dealers with greater ability to take on risk prior to the selloff actually sold off more. This relationship suggests that dealer behavior during the selloff was not driven by regulatory constraints.

Instead, the evidence supports the second hypothesis: Dealers were less willing to employ their balance sheets as market participants reassessed fixed-income valuations and repriced interest rate risk in response to heightened uncertainty around the stance of monetary policy. Prior to the selloff, the term premium—the risk premium investors demand for bearing duration risk—had been very low, or even negative, for some time, and interest rate volatility had been at historically low levels. Some investors (including dealers) may have viewed valuations as stretched and may have been waiting for a trigger for the market to reverse. Events in May and June 2013 may have provided the trigger, and dealers responded by cutting their risk exposures and shrinking their inventories.

3.3.2 The Treasury Flash Event of October 15, 2014

On October 15, 2014, the U.S. Treasury securities market experienced an unusually high level of volatility and a rapid round-trip in prices. The benchmark 10-year Treasury note traded in a 37 basis point range, only to close 6 basis points below its opening level. Moreover, between 9:33 and 9:45 a.m. ET, without a clear cause, the 10-year yield declined 16 basis points and then rebounded. Such a large price change and reversal in so short a time with no obvious catalyst is unprecedented in the recent history of the Treasury market.

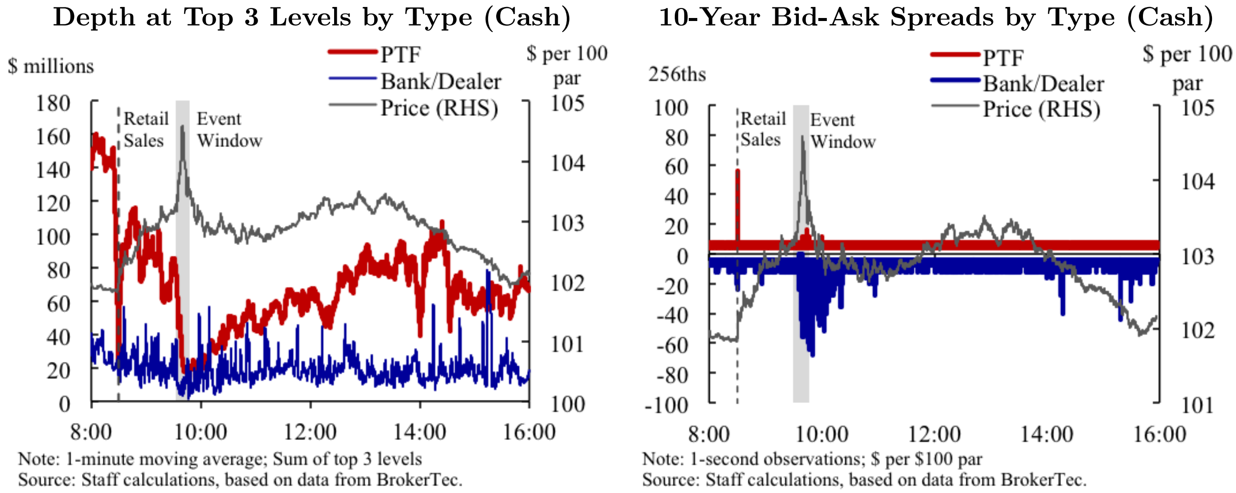
As explained in the Joint Staff Report (2015), principal trading firms (PTFs) and bank-dealers, in that order, accounted for the largest shares of trading volume in both the cash and futures markets on both October 15 and control days. Moreover, during the event window, the relative share of PTF trading activity increased as prices and volume rose sharply. Though the share of trading shifted toward PTFs, both PTFs and bank-dealers experienced an increase in trading volume given the sharp increase in overall volume. As the prices quickly retraced their previous increases, the share of PTF trading activity declined somewhat from its elevated levels and the share of bank-dealer activity rose.

PTFs and bank-dealers took actions to reduce their risk exposure to volatility during the event window. PTFs continued to provide the majority of order book depth and a tight spread between bid and ask prices, but reduced their limit order quantities (Figure 20). In contrast, bank-dealers widened their bid-ask spreads such that they only provided limit orders at some distance from the top of the book.

Despite the surge in trading volume during the event window, available data do not show a large change in net position of any specific participant type at that time. However, an imbalance between the volume of buyer-initiated trades and seller-initiated trades is observed, primarily driven by PTFs, with more buyer-initiated trades as prices rose, and more seller-initiated trades as prices fell (Figure 21, left panel). A similar breakdown of the net passive trade flow by participant type shows that PTFs were large net passive sellers during the first part of the event window and large net passive buyers during the second part of the window (Figure 21, right panel). Notably, the PTF pattern of passive flows closely mirrors the pattern of PTF aggressive flows, such that, as a group, PTFs' net position remained largely unchanged throughout the event window, suggesting that they were deploying multiple types of trading strategies. In contrast, net passive bank-dealer flows are not indicative of significant market-making activity during the event window.

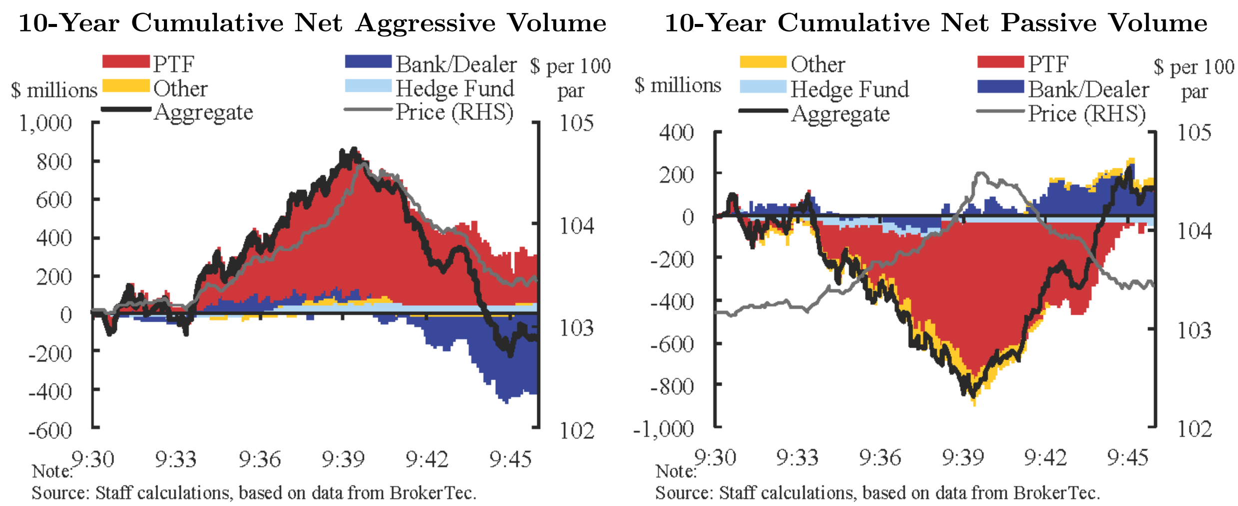
While the Joint Staff Report (2015) revealed no single cause for the price behavior during the event window, it did highlight a number of important developments in the market before and during the event window, including a significant increase in trading volume, sizeable changes in

Figure 20: **Liquidity during the October 15, 2014 Treasury Flash Event**



The figure reproduces Figures 3.15 and 3.23 from the Joint Staff Report (2015) on the October 15, 2014, Treasury market flash event. The left panel shows limit order book depth at the top three levels in the on-the-run 10-year note as provided by principal trading firms (PTFs) and banks/dealers. The right panel shows bid-ask spreads in the 10-year note as calculated separately for quotes provided by PTFs and banks/dealers. The data are from BrokerTec.

Figure 21: **Net Trading Volume during the October 15, 2014 Treasury Flash Event**



The figure reproduces Figures 3.5 and 3.7 from the Joint Staff Report (2015) on the October 15, 2014, Treasury market flash event. The left panel shows cumulative net aggressive trading volume in the on-the-run 10-year Treasury note by participant type during the 9:30 to 9:45 a.m. event window. The right panel shows cumulative net passive trading volume in the note over the same interval. The data are from BrokerTec.

market participation, a decline in market depth, and shifts in net order flow, which together provide insight into the nature of the event. The analysis also revealed that changes to the Treasury market structure in recent years have been significant. These changes are likely important context for understanding the unusual volatility that day and for assessing the risk of such an event recurring.

3.3.3 Third Avenue's Liquidation and Corporate Bond Liquidity in 2015

Third Avenue's high-yield Focused Credit Fund (FCF) announced liquidation on December 9, 2015 drawing widespread attention in asset markets. Events of this kind have the potential to increase the demand for market liquidity, as investors revise expectations, reassess risk exposures, and fulfill the need to trade. Moreover, portfolio effects and general fears of contagion may increase the demand for liquidity in assets only remotely related to a liquidating firm's direct holdings. In this section, we examine whether FCF's announced liquidation affected liquidity and returns in broader corporate bond markets.

In the weeks and months preceding its liquidation, FCF experienced an ever-increasing outflow of investor assets, similar to a run. The investor redemptions followed poor fund performance and forced FCF to try to sell assets to meet those redemptions. This created a direct and mechanical need for immediacy in the segment of the corporate bond market in which FCF specialized. There are at least two reasons to think that the corporate bond market in aggregate might experience liquidity strains in such a scenario.

First, a publicized risk event like FCF's announced liquidation may raise expectations of redemptions at other funds. To meet those expected redemptions, fund managers (all else equal) may prefer more liquid bonds, which they can sell at a moment's notice and with low cost. Similarly, these managers may have a preference for safe bonds that can prevent their funds' values from declining further during a flight to safety. If fund managers have these motives in aggregate, the market can become temporarily one-sided, leading to shortages of safe and liquid bonds and hence strains on market liquidity more broadly.

Second, FCF's liquidation occurred against a backdrop of heightened uncertainty in corporate bond markets. Rising credit spreads, increased costs for default insurance, declining commodity prices, uncertainty about global demand, and a possible change in the Federal Reserve's monetary policy stance were all common themes affecting markets at the time. Against that backdrop, a highly observable shock like FCF's liquidation could lead to a broad-based repricing of risk and a subsequent need to hedge and reduce exposures, further increasing the demand for immediacy.

To assess how FCF's closure affected broader market liquidity, Adrian, Fleming, Vogt, and Wojtowicz (2016b) examine the corporate bond market liquidity measures discussed earlier. They first sort bonds into quintiles of performance, as measured by their returns on December 11, 2015, so as to group bonds by their price sensitivity to news about Third Avenue.[11] Bonds with the worst returns on December 11 tended to (1) have higher spreads to Treasury securities, (2) have higher yields at issuance, and (3) be high yield to a greater extent. These findings support the view that FCF's announced closure triggered a wider sell-off of risky assets.

Bonds with the worst returns on December 11 also exhibited somewhat worse liquidity that day, with wider bid-ask spreads and higher price impact. However, in the months prior, this group of bonds had already been suffering steady losses and was consistently less liquid than bonds in

[11] Note that while FCF's liquidation was announced December 9, the news did not become public until late on December 10, and market commentary suggests that the initial market reaction came December 11.

the other performance quintiles. Thus, the event appeared to have the greatest (negative) effects on price and bid-ask spreads for bonds that were less liquid to begin with. Moreover, the liquidity effects were modest in magnitude and did not spill over into the broader universe of corporate bonds.

4 Directions for Further Research

While we do not uncover strong evidence of a widespread worsening of market liquidity, our findings are not unqualified due to data and methodological limitations. We therefore consider directions for future research that could help overcome these shortcomings. Our discussion focusses on five areas: 1) additional data, 2) methodological improvements, 3) endogeneity, 4) liquidity risk, and 5) funding liquidity.

4.1 Additional Data

A major challenge in accurately measuring market liquidity is inadequate data. For example, in the corporate bond market, trade price and limited trade size information are publicly disseminated through FINRA's TRACE system, but the aggregate corporate bond limit order book is mostly latent. Thus, information on the quantity that could have been traded at the transaction price or other prices is not reported. Moreover, buyer and seller search costs as well as interactions that did not result in a trade are not reported. In recent years, electronic trading venues for corporate bonds have started to collect such data, but these venues represent only a small portion of total corporate bond trading volume and hence may not be representative of broader liquidity conditions.

Fragmented markets present a further challenge to obtaining comprehensive liquidity data. A given asset may trade in scattered liquidity pools or trading venues, each with different order types or trading environments designed to attract various clienteles. Data on liquidity conditions in one liquidity pool may not be representative of liquidity conditions elsewhere. In the interdealer Treasury market, for example, on-the-run securities trade on well-lit interdealer brokerage (IDB) platforms with extraordinary liquidity and data. However, significant trading in the full range of Treasuries occurs in the dealer-to-customer (DtC) market, which is known to be less liquid, but for which liquidity data are less readily available (Fleming, Keane, and Schaumburg (2016)). Thus, while high-quality liquidity measures can be calculated in the IDB market for on-the-run Treasury securities, these may not be representative of liquidity conditions in the DtC market, particularly for off-the-run securities.

Along similar lines, derivatives markets offer alternative methods for replicating cash flows and creating synthetic risk exposures. Thus liquidity challenges in cash markets may be mitigated by creating synthetic positions through futures, options, or swaps. The effect of including these alternative channels for transferring risk directly affects certain liquidity measures. For instance, the Amihud (2002) price impact measure represents illiquidity as the ratio of absolute returns to dollar trading volume, so the omission of, say, Treasury futures trading volume, may lead to an underestimate of liquidity. A comprehensive study of liquidity conditions should consider the joint, or co-liquidity, of a given asset and its close substitutes.

4.2 Methodological Improvements

Liquidity measures that work well in some markets do not necessarily extend to other markets. As an example, consider the problem of computing depth in the corporate bond market. The equivalent of top-of-book depth in this setting is the largest quantity an investor can trade at the best bid or offer price. While an investor may assess this quantity by inquiring with individual dealers, the investor's assessment is neither publicly recorded nor disseminated to other market participants. The problem is compounded by the fact that depth available to investor A for a specific security may not be the same depth available to investor B at roughly the same time. Such differences can arise in the absence of anonymous limit order book trading and may reflect investors' differential information content of order flow or varying treatment from dealers, reflecting client relationships (Di Maggio, Kermani, and Song (2015)).

Facing limited information, researchers construct proxies from observable data to infer properties of unobservable data. For example, Dick-Nielsen, Feldhütter, and Lando (2012) impute round-trip costs from TRACE trades to indirectly infer information akin to bid-ask spreads. Similarly, Bessembinder, Jacobsen, Maxwell, and Venkataraman (2016) use indicator variable regressions to estimate unobserved liquidity variables. However, these methods necessarily require securities to trade, which poses a sample selection problem: if only liquid securities trade, then only liquid securities make it into the liquidity calculations and estimates are biased toward higher liquidity.

It follows that broad aggregates of standard market liquidity measures may mask pockets of illiquidity. Adrian, Fleming, Wojtowicz, and Vogt (2016) attempt to address this concern in the corporate bond market by computing liquidity metrics conditional on certain bond characteristics. They find that retail bid-ask spreads were narrower after the crisis than before, on average, but that institutional bid-ask spreads were wider. In terms of credit rating, they find that price impact and spreads improved for investment grade bonds, but were essentially unchanged for high-yield bonds, on average. Sommer and Pasquali (2016) provide guidance on which bond characteristics tend to correlate with liquidity, including credit quality, maturity, amount issued, age, coupon rate, price volatility, and central bank eligibility.

Market participants have informally referred to the concentration of liquidity in certain subsets of the bond market as a "liquidity bifurcation," with trading conditions favorable only for the largest, most recognizable issuers, and most recently issued bonds. Studying the causes and consequences of liquidity bifurcation more closely could be an interesting area of research. For example, liquidity bifurcation can potentially be rationalized by a model of capital-constrained investors (Brunnermeier and Pedersen (2009)) who seek to avoid capital intensive positions in high-margin securities. Because margins for high-yield bonds tend to be larger than those for investment grade bonds, a higher concentration of liquidity in investment grade bonds is consistent with this theory, but is in need of further investigation.

Another important issue concerns strategic quoting. There are indications that certain crossvenue HFT firms display depth in related markets without the intention of delivering the total quantity displayed. For instance, Dobrev and Schaumburg (2015) present evidence that trades against resting quotes in the Treasury futures market are followed by almost instantaneous reductions in depth in the Treasury cash market. Their analysis implies that depth is not summable across trading venues, in the sense that the displayed total depth across trading venues is not the actual quantity available for trade. This type of behavior reinforces the need to further study traditional liquidity measures like market depth in light of recent changes in market structure and investor composition.

4.3 Endogeneity

The endogenous response of market participants to changing liquidity conditions can also create biases in traditional liquidity measures. Both academic and private sector researchers note that post-crisis regulations may have induced dealers to shift from a principal model of market making to an agency model (e.g., Barclays (2016), Bessembinder, Jacobsen, Maxwell, and Venkataraman (2016), and Choi and Huh (2016)). In a principal model, dealers intermediate buyers and sellers through time by temporarily warehousing securities in their inventory and are compensated for the opportunity cost of capital and the inventory risks incurred through the bid-ask spread. In an agency model, no inventory risks are incurred because buyers and sellers are directly matched and the bid-ask spread is presumably narrower. Thus, in a regime where capital-constrained dealers endogenously avoid carrying large inventories, bid-ask spreads may narrow, suggesting an improvement of liquidity conditions. However, in this setting, the investor now bears inventory risk during the time it takes the market maker to locate the other side of the trade, suggesting that liquidity has not improved. Traditional liquidity measures may therefore need to be adjusted for biases or at least interpreted with caution.

A further challenge to measuring future, or expected, liquidity comes from the observation that liquidity can endogenously appear during risk events. When a shock arrives, investors with different risk appetites, constraints, opinions, and mandates enter the market to fulfill the need to trade. During such episodes, liquidity can improve as buyers and sellers arrive in the market at the same time, essentially offsetting the demand for immediacy on both sides of the market. An example of this phenomenon occurs regularly as a result of Treasury auctions, which lead to higher volatility and also trigger trading. These observations have several implications. First, not all increases in volatility necessarily correspond to a deterioration in liquidity, although the effect may be nonlinear: moderate increases in volatility may come with higher liquidity, while large increases in volatility may result in worse liquidity. Second, the argument that a poor liquidity environment will necessarily exacerbate volatility is perhaps oversimplified, as it assumes that liquidity provision, if low, remains exogenously low. Third, current measures of liquidity may not be indicative of future levels of liquidity, as liquidity is time-varying and responsive to the economic environment.

Conversely, in the absence of a shock, investors may wait to transact, suggesting that investors' decision to pay for immediacy services or wait to trade at a later date is endogenous. This mechanism is described by Grossman and Miller (1988), who theoretically show that realized trades are the equilibrium outcome determined by the supply and demand for immediacy. Thus in environments in which investors can afford to wait to trade (e.g., when expected volatility is low), the price for immediacy services (and hence the returns to providing liquidity) can decline. An implication is that infrequent trading may simply reflect low expected volatility, which will affect the reliability of inter-trade durations as a measure of liquidity.

4.4 Liquidity Risk

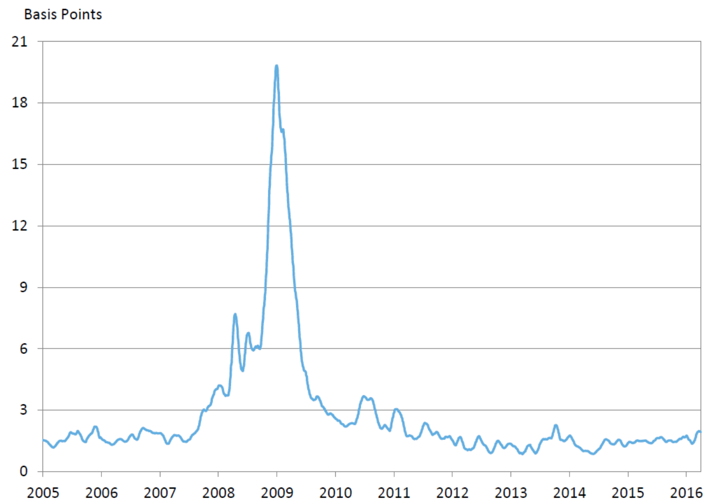
The October 15, 2014 flash rally in the U.S. Treasury market and the May 2010 equity market flash crash highlight that market liquidity and pricing are subject to infrequent but significant disruptions [e.g., CFTC and SEC (2010) and Joint Staff Report (2015)]. Adrian, Fleming, Stackman, and Vogt (2015a) and Adrian, Fleming, Shachar, Stackman, and Vogt (2015b) model illiquidity dynamics as consisting of a continuous Gaussian component plus an infrequent jump component (capturing liquidity risk) and find that jump-like changes in illiquidity tend to occur at times of high volatility. The authors also find somewhat elevated liquidity risk, as measured by the illiquidity jump intensity, in equities and Treasuries, but not corporate bonds. These disparate findings may be reconciled by the fact that high-frequency trading, which is a common feature in markets that experience flash events, has not taken hold in the corporate bond market as it has in the U.S. Treasury and equity markets. The authors' method for classifying liquidity jumps is based on daily measures of liquidity and may be improved by using higher frequency intra-day measures.

4.5 Funding Liquidity

Theoretical asset pricing models, such as the one proposed in Brunnermeier and Pedersen (2009), suggest a feedback loop or "spiral" connecting market liquidity and funding liquidity: Good funding liquidity allows increased trading, which in turn improves market liquidity and lowers volatility. Lower volatility then allows lenders to lower margin requirements or haircuts applied to collateral in repo transactions, which then further improves funding liquidity. Conversely, tightened funding liquidity dissuades capital-constrained investors from taking positions, adversely affecting market liquidity. A potential consequence is an increased concentration of market liquidity in the least capital-intensive assets. From a measurement perspective, the tight link between funding liquidity and market liquidity suggests further studying their joint evolution, as opposed to each in isolation.

One measure in the Treasury market closely linked to both market liquidity and funding liquidity gauges the "noisiness" of Treasury yields around a smoothed yield curve, as described in Hu, Pan, and Wang (2013) (also see Fleming (2000)). We calculate this measure as the average absolute yield curve fitting error for coupon-bearing securities from the Nelson-Siegel-Svensson model of Gürkaynak, Sack, and Wright (2007). Large pricing differences suggest unexploited profit opportunities, which could reflect constraints on market-making capacity and/or poor liquidity. As shown in Figure 22, such pricing differences spiked during the crisis, but were relatively low and stable in the years after the crisis.

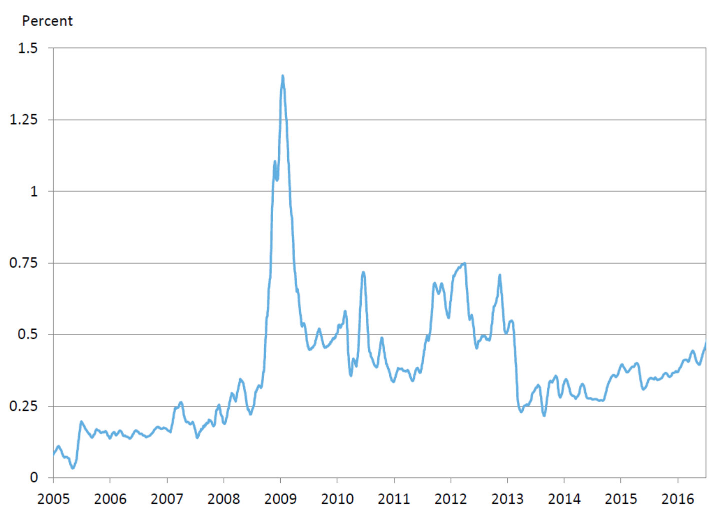
Figure 22: **Spline Errors of U.S. Treasury Securities**



The figure shows the 21-day moving average of absolute yield curve fitting errors for 2- to 10-year coupon securities from the Nelson-Siegel-Svensson model of Gürkaynak, Sack, and Wright (2007). The data are from the Board of Governors of the Federal Reserve System.

A second measure closely tied to both market liquidity and funding liquidity is the Refcorp spread: the yield spread between bonds of the Resolution Funding Corporation and Treasury securities with similar cash flows. Longstaff (2004) argues that since Refcorp bonds and Treasury securities are equally creditworthy, but Refcorp bonds are less liquid, the Refcorp spread solely reflects the value of the liquidity difference. As shown in Figure 23, the Refcorp spread also spiked during the crisis, and was close to post-crisis lows in the 2013-16 period, albeit somewhat above pre-crisis levels.

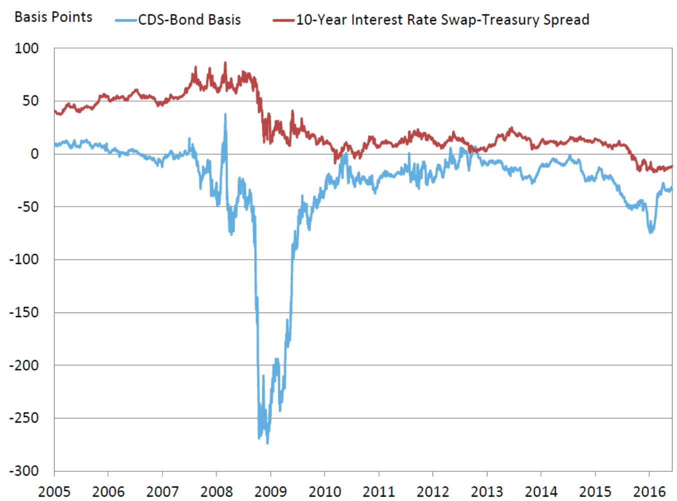
Figure 23: **The RefCorp/U.S. Treasury Spread**



The figure shows the 21-day moving average of the Refcorp spread, which is the difference in yield between a 10-year Resolution Funding Corporation zero-coupon bond and a 10-year zero-coupon Treasury bond. The data are from Bloomberg.

Alternative funding liquidity measures also warrant attention. Figure 24 plots the spread between the 10-year interest rate swap and the 10-year Treasury yield. Swap rates represent the value of a stream of payments indexed to LIBOR, so their pricing depends on the credit risk of LIBOR-panel banks. Treasuries, in contrast, price in the credit risk of the U.S. government, and should therefore command lower yields. Indeed, the swap spread has typically been positive. However, such spreads were negative at times in 2010, and also turned negative in late 2015 (where they remained through mid-2016). Such negative swap spreads are often cited as evidence of less plentiful funding liquidity (Dudley (2016)), and are sometimes attributed to regulatory balance sheet constraints on banks, hedging demands, and foreign central bank activities.

Figure 24: **Funding Cost Measures**

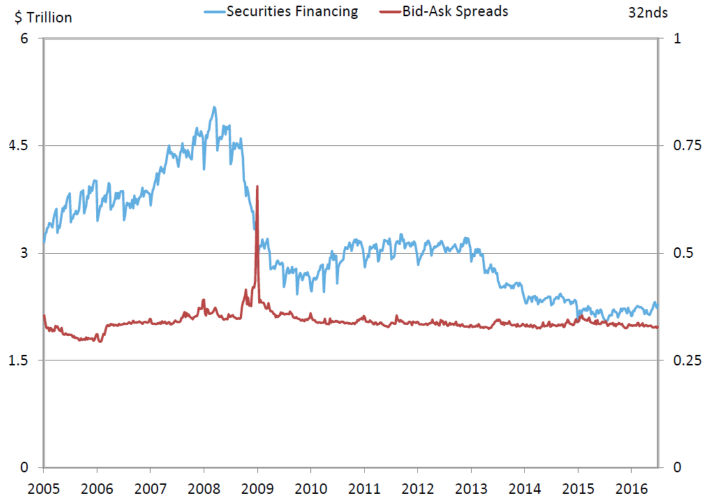


The figure plots the 10-year interest rate swap spread and the CDS-bond basis for investment grade bonds. The 10-year swap spread is computed as the difference between the 10-year swap rate and the 10-year constant maturity Treasury yield, both from the Board of Governors of the Federal Reserve System. The CDS-bond basis is from J.P. Morgan, and is computed for investment grade corporate bonds as the average difference between each bond's market CDS spread (interpolated to the bond maturity) and the theoretical CDS spread implied by the bond yield.

Figure 24 shows another measure of market dislocation based on the CDS-bond basis. The CDS-bond basis is calculated for investment grade bonds as the average difference between each bond's market CDS spread and the theoretical CDS spread implied by the bond yield. The basis was close to zero, but generally positive, before the crisis, plunged to extreme negative values during the crisis before rebounding, and has generally been at moderate negative levels since the crisis. Boyarchenko, Gupta, Steele, and Yen (2016) find that increased funding costs tied to balance sheet constraints are an important determinant of this apparent arbitrage opportunity, with regulatory changes forcing dealers to hold more capital against such trades.

A potential link between market liquidity and funding liquidity is illustrated in Figure 25. We use primary dealers' total financing of U.S. Treasury securities, agency debt securities, and agency MBS as an indicator of funding liquidity, and Treasury security bid-ask spreads as an indicator of market liquidity. The figure suggests that the two metrics were correlated during the financial crisis, with bid-ask spreads rising as securities financing declined. The metrics otherwise show little comovement, although this may reflect the fact that Treasury bid-ask spreads are often constrained

Figure 25: **Dealer Securities Financing and Treasury Bid-Ask Spreads**



The figure plots aggregate primary dealer securities financing (defined as securities out) for U.S. Treasury securities, agency debt securities, and agency MBS and a geometric average of the 5-day moving averages of average daily bid-ask spreads for the on-the-run 2-, 5-, and 10-year Treasury notes in the interdealer market. Financing data are from the Federal Reserve's FR2004 statistical release and bid-ask spreads are from BrokerTec.

by the minimum tick size, especially during normal times. Note that this evidence of a relationship is only suggestive; there are many ways of measuring funding and market liquidity, and many theoretically plausible arguments for their linkages.

5 Conclusion

Dealer business models have changed markedly since the financial crisis, as reflected in the total balance sheet size of the dealer sector. While dealers' total assets grew exponentially prior to the crisis, they declined sharply during the crisis and then stagnated, in concurrence with the deleveraging of dealer balance sheets. While deleveraging is an intended consequence of tighter capital regulations, the associated contraction of dealer assets could have adverse effects for market liquidity. Identification of causal effects is challenging, however, because the regulations were announced and implemented at a time when dealers' risk-management practices were changing, liquidity demands of asset managers were evolving, the electronification of markets was increasing, and expected returns to market making were changing.

Despite the many factors affecting dealer business models, we do not uncover clear evidence of a widespread worsening of liquidity in two markets in which dealers remain important market makers. Bid-ask spreads in the interdealer Treasury market thus remained narrow and stable in the years after the crisis. Order book depth and price impact showed signs of reduced liquidity after early 2013, but remained within normal historical ranges and far from crisis levels. In the corporate bond market, bid-ask spreads narrowed after the crisis to levels lower than those before the crisis for retail trades, while trading volume and issuance increased to record highs. In contrast, bid-ask spreads and price impact for institutional trades remained above pre-crisis levels in the years after the crisis. In response to three market shocks in the post-crisis era, we find that bond market liquidity remained resilient and within historical norms.

Our analysis therefore suggests that the post-crisis stagnation of dealer balance sheets has not markedly impaired bond market liquidity. We caution, however, that this inference is not beyond question because of data and methodological limitations. We discuss directions for future research that could potentially overcome these shortcomings. First, we review the need for additional data sources to deepen and broaden coverage of fragmented bond markets. Second, we outline the importance of new methods for drawing inferences about liquidity in the presence of incomplete data. Third, we discuss how endogeneities can lead to biases in traditional liquidity measures like bid-ask spreads and depth. Finally, we draw distinctions and interactions between market liquidity, liquidity risk, and funding liquidity.

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