The Costs of Quantitative Easing: Liquidity and Market Functioning Effects of Federal Reserve MBS Purchases*

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In this paper, I evaluate one of several commonly cited potential costs of quantitative easing. Specifically, I assess the effect of ongoing Federal Reserve mortgage-backed securities (MBS) purchases on MBS market liquidity. Examining several standard liquidity indicators, I find that Federal Reserve MBS purchases adversely affected average trading volume, trade sizes, and the number of trades. Bid-ask spreads remained mostly unaffected, although a spread widening in response to Fed purchases evidently emerged just after the beginning of the largest MBS purchase program. Although the marginal liquidity effects of purchases can be sizable, the economic magnitude of the effects is relatively modest when taking into account the size of Federal Reserve MBS operations. Lastly, I find no evidence of impaired price discovery in the MBS market during the time of Federal Reserve purchases.

JEL Codes: E52, E58, E65, G10.

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1. Introduction

The Federal Reserve's use of large-scale asset purchases since the recent financial crisis has been the focus of a rapidly expanding body of literature. Thus far, most studies have concentrated on evaluating the efficacy of large-scale asset purchase programs—also known as quantitative easing (QE). This focus on the efficacy of QE is understandable in light of the unprecedented nature of QE, the condition of the economy and financial markets, and the stated goals of QE.[1] Furthermore, the findings of these studies provided crucial input for the Federal Reserve and other central banks that relied on QE programs to achieve their mandates after policy rates reached their effective lower bounds in the years following the financial crisis. In fact, several central banks in advanced economies continue to rely on QE programs amid sluggish recoveries, and may look to QE in the future if there is a return to the zero lower bound.

Conversely, the potential costs of QE have garnered substantially less attention in the scholarly literature to this point. This relative inattention stands in contrast to the increased awareness of the potential risks and costs of QE expressed by policymakers as QE purchases continued. During early QE programs, Federal Reserve officials suggested potential risks, but rather than pointing to costs associated with ongoing purchases, the cited risks focused only on how to optimally implement the programs or on concerns which never materialized. For example, in August of 2010, Chairman Bernanke pointed to potential risks of Federal Reserve balance sheet expansion that included the "difficulty of calibrating and communicating policy responses," and "reduce[d] public confidence in the Fed's ability to execute a smooth exit from its accommodative policies ... lead[ing] to an undesired increase in inflation expectations" (Bernanke 2010). Downplaying the latter risk, the Chairman went

[1]Studies that evaluate the efficacy of QE programs initiated by the Federal Reserve and their effects on asset prices include Fuster and Willen (2010), Neely (2010), Gagnon et al. (2011), Hancock and Passmore (2011), Krishnamurthy and Vissing-Jorgensen (2011), Hamilton and Wu (2012), Stroebel and Taylor (2012), D'Amico and King (2013), and Kandrac and Schlusche (2013). Analyses that include other central banks' recent experience with QE include Joyce et al. (2011) and Christensen and Rudebusch (2012).

on to explain the high degree of confidence among the Federal Open Market Committee (FOMC) that exit from highly accommodative policies could be smoothly accomplished. Similarly, the minutes of the November 2010 FOMC meeting (which resulted in the announcement of QE2) note that "several participants saw a risk that a further increase in the size of the ... asset portfolio ... could cause an undesirably large increase in inflation. However, it was noted that the Committee had in place tools that would enable it to remove policy accommodation quickly if necessary to avoid an undesirable increase in inflation."

As QE programs expanded and continued to be used to support a stronger economic recovery and help ensure that inflation remained at mandate-consistent levels, potential costs of QE came into sharper focus and were more clearly defined. The first mention of concern for these potential costs within the FOMC came in the minutes of the April 2012 meeting, which state that "one participant noted the potential risks and costs associated with additional balance sheet actions." Although the FOMC continued to signal a willingness to take further action to promote a stronger recovery in its statements, the concern surrounding the costs of QE seemingly spread over the next two meetings. According to the minutes, more members began expressing interest in the potential costs of QE in June, and a more thorough discussion of the costs of large-scale asset purchases was entertained at the July/August 2012 meeting. Later that month, Chairman Bernanke enumerated several potential costs of ongoing purchases at the high-profile Economic Symposium in Jackson Hole, Wyoming. These costs included the possible impairment of market functioning, an unanchoring of inflation expectations, risks to financial stability, and the potential for Federal Reserve financial losses (Bernanke 2012). Those comments apparently reflected mounting concern within the FOMC regarding the costs of large-scale asset purchases (LSAPs), which for the first time promised to "take appropriate account of the likely efficacy and costs of such purchases," in a statement announcing the open-ended MBS purchases of the so-called QE3 program following the September 2012 FOMC meeting. Underscoring the FOMC's concern about the costs of LSAPs, the 2012 annual report of the Board of Governors included a section entitled "Efficacy and Costs of Large-Scale Asset Purchases" (Board of Governors of the Federal Reserve System 2013) in which the

potential costs identified in Chairman Bernanke's Jackson Hole speech were reiterated.[2]

In this paper, I aim to evaluate the first of four potential costs described by Chairman Bernanke and later listed in the 2012 annual report of the Board of Governors as follows:

> One potential cost of conducting additional [large-scale asset purchases] is that the operations could lead to a deterioration in market functioning or liquidity in markets where the Federal Reserve is engaged in purchasing. More specifically, if the Federal Reserve becomes too dominant a buyer in a certain market, trading among private participants could decrease enough that market liquidity and price discovery become impaired. (Board of Governors of the Federal Reserve System 2013)

Using data collected over nearly two and a half years of continuous Federal Reserve mortgage-backed securities (MBS) purchases, I test the effect of regular QE intervention on several common indicators of liquidity and market functioning in the MBS market. Notably, most of the purchases in my sample were conducted during the open-ended MBS purchases of QE3 when concerns surrounding the costs of QE appeared to grow. By examining different aspects of MBS market liquidity, I achieve a more complete picture of the liquidity effects of MBS purchases conducted as part of QE programs. Further, I consider the extent to which QE purchases coincided with any changes in price discovery in the MBS market in order to gauge the more pernicious effects of liquidity impairments induced by MBS purchases.

As mentioned previously, existing work along these lines is relatively scarce. Prior studies in this area focus predominantly on Treasury purchases by the Federal Reserve. For instance, Kandrac and Schlusche (2013) find that purchases of nominal Treasury securities as part of QE have no discernible effect on the bid-ask spreads of the traded securities. The authors show that this result persists even

[2]Policymakers' concern surrounding the market functioning effects of QE purchases were mirrored by market participants and members of the financial press. See, for example, the 2012 *Financial Times* article "QE3, the Market Functioning Fear Factor" (Garcia 2012) and Jozoff et al. (2014).

if the Federal Reserve holds sizable amounts of the purchased securities, or if purchases are large relative to the amount of the security outstanding. Christensen and Gillan (2014) present some evidence that Federal Reserve purchases of Treasury inflation-protected securities (TIPS) during QE2 did not impair TIPS market functioning, and in fact may have improved liquidity in this market. However, the liquidity and depth of the market for U.S. Treasury securities may mask liquidity impairments that would be present in less-liquid markets. Investigating the impact of QE on market functioning in the MBS market, Kandrac (2013) finds evidence that Federal Reserve MBS purchases had modest negative effects on market functioning and liquidity, and that these effects were most evident subsequent to the expansion of MBS purchases that began in September 2012 as part of QE3. Unfortunately, the author's sample period includes relatively little of QE3, so the persistence of that result could not be evaluated through the period of increasing Federal Reserve ownership of the MBS market. Moreover, some important aspects of market liquidity—such as market depth and trade immediacy—were not tested.

In this study, I use the unannounced variation in the securities purchased by the Federal Reserve to show that regular MBS purchases conducted after QE1 have negative effects on some indicators of market functioning. First, Federal Reserve purchases led to reduced third-party trading activity, with measurable reductions in trading volumes, trade sizes, and the number of trades. However, I also find that similar securities that may be viewed as substitutes see increased activity. Combined, these results could demonstrate evidence of a portfolio balance channel, through which QE is (at least in part) often claimed to work. Second, I fail to find evidence that dealers' indicative bid-ask spreads respond in a systematic way to ongoing central bank MBS purchases, though there is some indication that MBS purchases near the beginning of the QE3 period were associated with wider bid-ask spreads. Finally, I evaluate the extent to which the apparent deterioration in liquidity conditions as a result of Federal Reserve purchases coincided with impaired price discovery in the MBS market. Ultimately, I find that MBS prices responded in a normal manner to both economic news and shocks to Treasury rates throughout the sample period. To the best of the author's knowledge, these findings represent the first thorough

analysis of the liquidity and market functioning effects of ongoing Federal Reserve MBS purchases.

The remainder of the paper proceeds as follows. Section 2 describes the history of the Federal Reserve's large-scale asset purchase programs, with a focus on the pertinent details of the MBS purchases. Section 3 discusses ways in which ongoing purchases can affect market functioning, and section 4 describes the liquidity and market functioning measures that are used in the empirical analysis presented in section 5. Section 6 presents tests to evaluate changes in MBS price discovery, and section 7 concludes.

2. Background: The Federal Reserve's QE Programs and MBS Purchases

As detailed in table 1, the Federal Reserve's recent experience with MBS purchases began with the FOMC announcement on November 25, 2008 that it would initiate a program to purchase up to $500 billion of agency MBS and $100 billion of agency debt. In March of 2009, these amounts would be increased to $1.25 trillion and $200 billion, while purchases of Treasury securities were also announced. Later that year, the FOMC committed to purchase the full $1.25 trillion of agency MBS and explained that the purchase program—which came to be known as QE1—would be completed in March of 2010. Notably, the MBS market was essentially frozen at the time of the initial announcement, but by the completion of QE1 markets were functioning much more normally (Hancock and Passmore 2011). As will be discussed in more detail in the next section, a consensus emerged that the Federal Reserve's MBS purchases were an important component in the restoration of order to the agency MBS market.[3]

Although market liquidity had normalized by the end of 2010, the sluggish economic recovery prompted the FOMC to announce an additional LSAP program—known as QE2—that consisted solely of Treasury security purchases. In September of the following year

[3]See, for example, Gagnon et al. (2011), Hancock and Passmore (2011), and Krishnamurthy and Vissing-Jorgensen (2011). Additionally, Stroebel and Taylor (2012) argue that it is also possible that market participants viewed QE1 as a signal that the implicit federal government guarantees of Fannie Mae and Freddie Mac had become explicit.

Table 1. Summary of the Federal Reserve's Large-Scale Asset Purchase Programs

Large-Scale Asset Purchase Program	Assets Purchased	Announcement Date	Purchase Amount ($ Billions)	Purchase Date Range
QE1	Agency Debt	11/25/08	$172	12/5/08–3/24/10
	MBS	11/25/08	$1,250	1/5/09–3/31/10
	Treas. Securities	3/18/09	$300	3/25/09–10/29/09
Treasury Reinvestment	Treas. Securities	8/10/10	$283	8/17/10–9/30/11
QE2	Treas. Securities	11/3/10	$600	11/12/10–6/30/11
MEP	Treas. Securities	9/21/11	$667	10/3/11–12/28/12
MBS Reinvestment	MBS	9/21/11	$> \$1{,}200$[a]	10/3/11–Ongoing
QE3	MBS	9/13/12	$823	9/14/12–10/31/14
	Treas. Securities	12/12/12	$790	1/6/13–10/27/14

[a]Purchases are still being conducted under the MBS reinvestment program as of 2015:Q3.

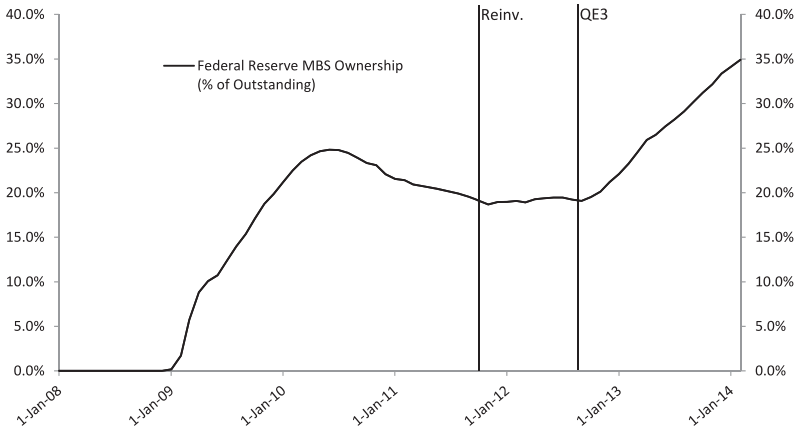
(three months after the end of QE2), the FOMC announced further balance sheet actions to help stimulate the economy. First, the FOMC decided to extend the average maturity of its Treasury securities holdings—a QE program known as the Maturity Extension Program (MEP) or "Operation Twist." Second, the FOMC decided to reinvest principal payments from its holdings of agency MBS and agency debt into agency MBS, a policy aimed at supporting conditions in mortgage markets, which would presumably also help to achieve the goal of supporting a stronger economic recovery.[4] Thus, MBS purchases were conducted in an environment of normal market functioning for the first time under the "reinvestment program" that began in October 2011.[5] Reinvestment purchases were the only source of Federal Reserve demand for MBS until, in September 2012, the FOMC agreed to purchase an additional $40 billion of agency MBS per month and to continue these purchases if the outlook for the labor market did not substantially improve. Three months later, the FOMC announced additional outright purchases of Treasury securities at a pace of $45 billion per month to continue after the completion of the MEP. Both MBS and Treasury purchases continued under this program—which came to be known as QE3—until the FOMC first agreed to decrease monthly purchases at its December 2013 meeting.

As a consequence of the aforementioned purchase programs, Federal Reserve MBS ownership as a share of total outstanding rose quite rapidly. Figure 1 demonstrates that, after the sharp rise during QE1, MBS principal payments led to a gradual decline in Federal Reserve MBS ownership as a share of the market. Upon implementation of the reinvestment program, MBS holdings remained roughly constant (both in terms of par value and as a share of MBS outstanding) until the enactment of QE3, at which point the share of MBS outstanding held in the System Open Market Account (SOMA) portfolio reached nearly 35 percent. One important question that this study aims to answer is whether QE purchases were associated

[4]This altered the existing policy—announced in August 2010 and noted in table 1—of reinvesting principal payments into Treasury securities.

[5]For the remainder of the paper, I will refer to the reinvestment program to indicate the period in which principal payments were invested into MBS, beginning in October 2011.

Figure 1. Federal Reserve MBS Holdings as a Share of Total Outstanding

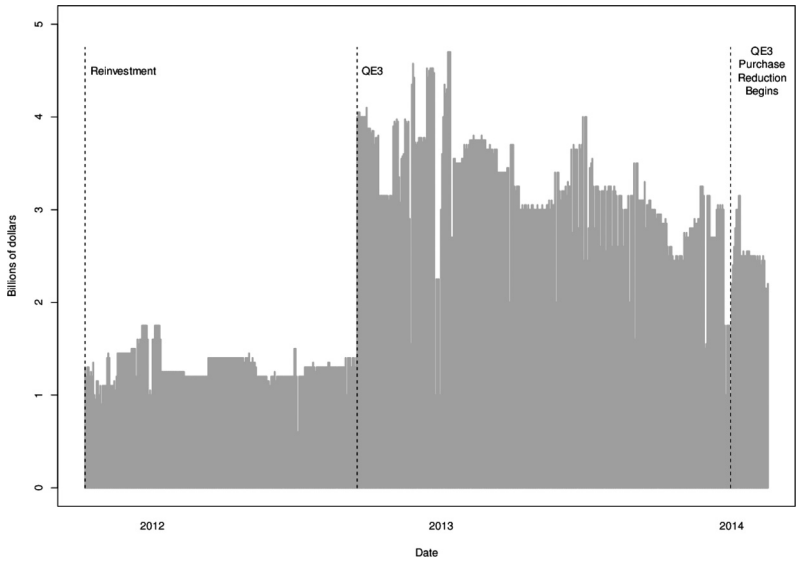


Source: Federal Reserve H.4.1. release and eMBS Inc.
Notes: Monthly totals are calculated by dividing total settled MBS holdings in the SOMA portfolio by the sum of the outstanding principal balance of fixed-rate Fannie Mae and Freddie Mac fifteen-year and thirty-year securities and fixed-rate Ginnie Mae I and Ginnie Mae II thirty-year securities.

with more severe liquidity and market functioning effects as Federal Reserve ownership of the MBS market increased.

Because the focus of the present study is on liquidity and market functioning effects of securities purchases in normal market environments, I consider only those Federal Reserve MBS purchases conducted since the start of the reinvestment period. In this way, I am able to evaluate potential costs associated with the regular use of QE outside of acute crises and market freezes, which is relevant for central banks' current tradeoff as they continue and/or contemplate QE programs. Figure 2 shows the total daily MBS purchases by the Federal Reserve that are used in this study. The substantial increase in MBS purchases following the announcement of QE3 is demonstrated quite clearly in figure 2. In addition to the new outright purchase program, however, interest rates fell for several months after the announcement of the open-ended purchases of QE3, which led to higher principal prepayments on existing MBS holdings. Consequently, total monthly MBS purchases by the Open Market Trading Desk (the Desk) rose to over $80 billion in the period just after the announcement of QE3.

Figure 2. Daily Federal Reserve MBS Purchases (Oct. 3, 2011–Feb. 20, 2014)



Source: FRBNY.
Note: Total daily MBS purchases executed by the Federal Reserve Bank of New York (FRBNY).

Though most Federal Reserve MBS purchases during QE1 were conducted by outside investment managers, all later MBS purchases were conducted by the Federal Reserve Bank of New York (FRBNY) staff at the Desk. As outlined in FRBNY operating policies and frequently asked questions (FAQs), all MBS transactions in the sample were concentrated in newly issued agency MBS in the to-be-announced (TBA) market, which is a highly liquid market that allows for the forward trading of agency MBS based on a handful of parameters under which mortgage pools can be considered interchangeable (see Vickery and Wright 2013 for more information). Furthermore, Desk MBS trades were conducted over Tradeweb, a popular electronic dealer-to-customer trading platform.[6] Through

[6]In November 2013 the Desk began a series of small-value MBS transactions conducted over FedTrade, the Desk's proprietary trading system. Given their very small size, I ignore these purchases in the sample below. In April of 2014, the Desk began conducting an increasing share of MBS purchases over FedTrade.

Tradeweb, Desk staff can solicit bids from up to four primary dealers in auctions that are conducted throughout the day. In the sample period covered by this study (October 2011 through February 2014), the Desk conducted an average of about fifteen auctions per day.

Compared with purchases of Treasury securities, the Desk released relatively little information in advance of agency MBS operations. Specifically, around the last business day of the month, the Desk posts the total amount of QE3 MBS purchases that are planned for the following calendar month, as directed previously by the FOMC.[7] Planned purchases associated with the reinvestment program expected to take place over each monthly period were announced on or around the eighth business day of the month. This delay allowed the Desk to estimate principal payments from monthly "factors" reports released by the agencies around that time. Notably, the Desk would announce neither the mix of products, coupons, and issuers nor the dates on which those purchases would occur. In a succession of FAQs posted to the FRBNY website, the Desk only indicated that "purchases will be conducted on a frequent basis over the course of each month, and will be guided by general MBS market conditions, including, but not limited to, supply and demand conditions, market liquidity, and market volatility." In practice, however, the Desk traded agency MBS on all weekdays since the start of the reinvestment period except for one day affected by Hurricane Sandy and days listed on the Securities Industry and Financial Markets Association (SIFMA) holiday calendar. The total amounts of purchased securities were made public on a weekly basis via the FRBNY website, but additional operational details, such as the price at which the trades were executed, were only released at a monthly frequency.

Table 2 provides descriptive statistics for Federal Reserve MBS purchases for the entire sample and for subperiods defined by QE regime labeled "Reinvestment" and "QE3." There are several notable features of Federal Reserve MBS purchases demonstrated in table 2. First, Fannie Mae and Freddie Mac thirty-year

[7]For much of the sample this amount was simply $40 billion per month. Coincident with the announcement of QE3 in September 2012, though, the Desk announced that it would purchase approximately $23 billion over the remainder of the month, which represents the prorated share of the agreed-upon $40 billion monthly purchase.

Table 2. Summary of Federal Reserve MBS Purchases under Reinvestment and QE3

	Reinvestment	QE3	Full Sample
Agency Distribution			
Fannie Mae	55.3%	51.8%	52.5%
Freddie Mac	29.1%	26.8%	27.3%
Ginnie Mae	15.6%	21.5%	20.2%
Term Distribution			
30-Year	89.9%	83.2%	84.7%
15-Year	10.1%	16.8%	15.3%
Coupon Distribution			
2.0	—	1.3%	1.0%
2.5	3.1%	11.0%	9.3%
3.0	19.0%	43.5%	38.2%
3.5	57.0%	23.2%	30.4%
4.0	20.9%	19.5%	19.8%
4.5	—	1.5%	1.2%
Other Operational Details			
Total Face Value Purchased ($bil.)	306.1	1,128.7	1,434.8
Avg. Daily Purchase Amount ($bil.)	1.3	3.2	2.4
Avg. # of Trades per Day	8.6	19.1	14.9
Avg. Daily Purchase per Trade ($mil.)	152.6	166.3	163.1
Avg. # of Securities Purchased per Day	6.8	10.6	9.1
Avg. Daily Purchase per Security ($mil.)	195.6	303.5	260.7

Notes: The reinvestment period includes purchases from October 3, 2011 through September 13, 2012. The QE3 period begins September 14, 2012 and continues through February 20, 2014. The total face value purchased during QE3 includes those purchases that occurred as a result of the practice of reinvesting principal payments from agency securities into agency MBS.

securities composed the majority of purchases in each program due to their liquidity and depth. Fannie Mae and Freddie Mac thirty-year securities are also known as "class A" securities because they share monthly settlement days. Second, the variation in purchased coupons was substantial over the course of the programs, partly reflecting the fluctuation in interest rates over the course of the programs. However, 3.0 percent and 3.5 percent coupon securities composed the majority of purchases in each subperiod. Finally, other operational details are reported in the bottom of table 2, demonstrating the changes to purchase operations as a result of the introduction of QE3. Average daily purchase amounts were about 2.5 times higher during QE3, and the number of trades per day more than doubled. The number of securities purchased by the Desk per day increased notably (6.8 to 10.6), as did the average purchase per security ($196 million to $304 million). Note that here, as in the remainder of the paper, a "security" refers to a unique issuer-maturity-coupon combination (e.g., a Freddie Mac thirty-year 4.0 percent coupon). These characteristics uniquely identify a deliverable security in a TBA contract, with the other agreed-upon trade characteristics being the price, par amount, and settlement date.

3. Potential Effects of Ongoing Federal Reserve Purchases on Market Functioning

Federal Reserve securities purchases can potentially generate contrasting effects on market functioning and liquidity depending on the type of asset purchased and the market environment at the time of purchases. As briefly mentioned above, it is possible for large central bank purchases to *improve* measures of liquidity and market functioning. This outcome is most likely during a time of severe market disruption and insufficient demand for the purchased securities, such as a market freeze during or immediately following a financial crisis. As outlined in Gagnon et al. (2011), QE can provide an ongoing source of demand for illiquid assets. As a result of this persistent flow of demand, dealers and other investors may be more willing to take larger positions in the purchased securities or make markets in them more actively. In this way, QE can provide assurance to market participants that they will be able to sell assets to the Federal Reserve. Thus, even if relatively few market participants are willing

to trade, measures of liquidity such as bid-ask spreads and trading volumes may improve. This dynamic is the most likely explanation for the improvement in MBS market functioning observed during the first half of QE1. Indeed, as Krishnamurthy and Vissing-Jorgensen (2013) point out, many researchers accept that this mechanism was in operation during QE1, and Federal Reserve purchases helped to thaw the MBS market freeze.[8]

However, liquidity premiums have been relatively low since 2010. How might QE affect liquidity when there is substantially less turmoil? To answer this question, it is useful to consider the effect of QE purchases on the stock of the purchased asset available to the public. If QE purchases substantially reduce the supply of securities available to the public, QE could have deleterious consequences for market functioning. For instance, if a more scarce security trades less frequently and/or increases market makers' costs to pursue offsetting trades, lower supply engendered by QE can result in longer inventory holding periods, higher costs for market makers, and reduced overall trading as dealers and other investors become less willing to hold an increasingly scarce security. In this scenario, QE can lead to a less robust market in the purchased securities, causing measures of market functioning to deteriorate. Notably, the sheer size of the purchases required to carry out QE programs may cause deterioration in liquidity and market functioning for similar reasons, even if the supply of the traded security is ample. For instance, if market makers incur higher costs as a result of hedging or offsetting very large Federal Reserve trades, trading activity that would have otherwise taken place may be crowded out. Additionally, to the extent that MBS dealers rely on the pipeline of mortgage originators for readily available MBS supply, large Federal Reserve purchases could cover expected originations, limiting dealers' willingness or ability to trade with other counterparties.

Thus, the effect of QE on liquidity and market functioning is not theoretically clear and remains an empirical question. Moreover, as Hancock and Passmore (2015) explain, the liquidity effects of

[8]Further, theoretical work explaining the beneficial effect of central bank purchases of distressed assets is described in Cúrdia and Woodford (2011), Gertler and Karadi (2011), and He and Krishnamurthy (2013).

Federal Reserve MBS purchases may be a potentially important part of the transmission of QE to MBS yields.

4. Measures of Agency MBS Liquidity and Market Functioning

In the subsections below, I detail the indicators of liquidity and market functioning that I will later relate to Federal Reserve MBS purchases. Because there is no single measure of liquidity that receives widespread acceptance, I consider a range of indicators that are typically assumed to reflect liquidity conditions for a given market.[9]

The liquidity of a traded asset such as an MBS is often thought to consist of at least three different components. The first important component of market liquidity is "trade immediacy," or the ability to quickly trade securities. The second important component is "market depth," which measures the ability to trade without having large effects on the prices of the securities that are traded. The third component of market liquidity is known as "market breadth," which describes the ability to transact at a price that is near a security's true value.

In addition to traditional measures of market liquidity, I also examine a measure of market functioning unique to the MBS TBA market in an online appendix available on the IJCB website (http://www.ijcb.org). Although there is no clear consensus on the distinction between liquidity and market functioning in the literature and these terms are often used interchangeably, I evaluate market functioning by focusing on the extent to which MBS are delivered and settled in a normal manner. Because the Federal Reserve transacts in the forward-delivery TBA market and provides relatively limited information regarding the purchases in advance, it is possible that a scarcity of deliverable collateral can develop. Thus, it may be possible to observe effects of QE on general market functioning even if there are no implications for the components of liquidity outlined above by examining the effects of purchases on the scarcity value of purchased securities.

[9]Fleming (2003) provides an excellent summary of commonly cited measures of market liquidity, several of which are used in the present study.

4.1 Trade Sizes

Trade size is a commonly cited measure of liquidity (see, for instance, Fleming 2003) and can proxy for both market depth and trade immediacy, with lower trade sizes potentially signaling worse liquidity conditions. My source for daily security-level volumes in TBA contracts is the Financial Industry Regulation Authority (FINRA). FINRA is an independent, non-profit organization authorized by Congress to ensure transparent and fair practices in the securities industry. In 2011, prior to the beginning of the reinvestment program, the Securities and Exchange Commission approved a measure requiring broker/dealers to begin reporting asset-backed securities (ABS) and MBS transactions to the FINRA-developed Trade Reporting and Compliance Engine (TRACE).

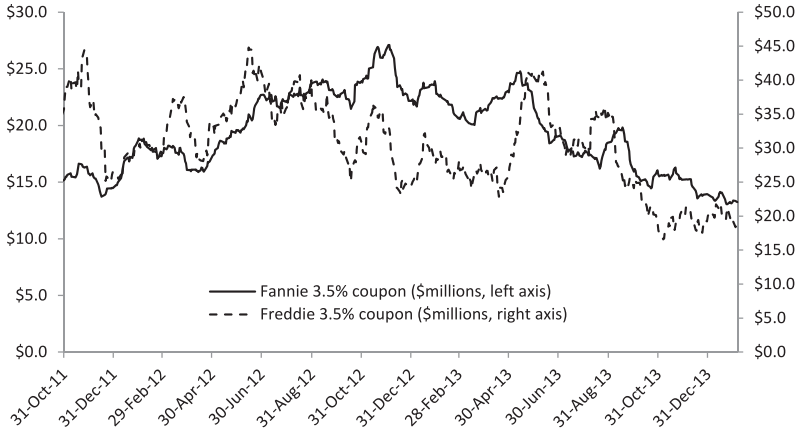
Combining the transactions in TRACE with Federal Reserve purchase data provided by the FRBNY, I construct a series of average daily trade sizes for each security excluding Federal Reserve transactions.[10] Figure 3 plots the time series of trade sizes for the Fannie Mae and Freddie Mac 3.5 percent securities over the sample period. Figure 3 demonstrates that trade sizes for these securities exhibited a slight downward trend in the latter half of the sample.

4.2 Trading Volumes

Next, I consider trading *volume* for each security. Similar to trade size, trading volume is a commonly referenced measure of liquidity, and can proxy for both market depth and trade immediacy, with lower volumes indicating worse liquidity conditions (Fleming 2003). Furthermore, changes in trade volume in response to Federal Reserve MBS purchases may reveal portfolio balance effects if investors are found to substitute out of a purchased security and into a similar security. In this sense, lower trading volume in response to Federal Reserve purchases may be viewed not as a cost of QE, but as an

[10]Note that TRACE—unlike the trading platform Tradeweb—includes dealer-to-dealer transactions in addition to dealer-to-customer transactions. As a result, Tradeweb transactions are a subset of those reported in TRACE, which covers substantially more trading activity. Using participant identification numbers supplied in the TRACE database, I am able to remove duplicate transactions that arise when two dealers transacting with one another report the same transaction as a purchase or sale.

Figure 3. Twenty-Day Moving Average of Trade Sizes for Fannie Mae and Freddie Mac Thirty-Year 3.5 Percent Coupon TBA Securities



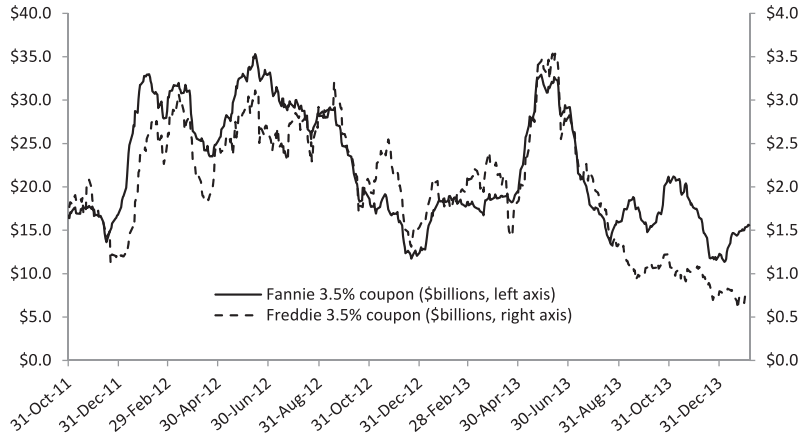
Source: TRACE.
Note: Twenty-day moving averages of trade size are reported to smooth through the TBA settlement cycle.

artifact of a mechanism through which QE is theorized to increase asset prices and lower yields.

Figure 4 plots the time series of trading volume for the same securities displayed in figure 3. As with trade size, TRACE trade data and Federal Reserve purchases are used to construct a measure of trading volume excluding Federal Reserve transactions in order to isolate private trading patterns. Figure 4 demonstrates that volumes have trended down slightly over the sample period for the Fannie Mae and Freddie Mac 3.5 percent coupon securities.[11] However, much of this effect appears to coincide with the sharp increase in interest rates through the summer of 2013. Notably, agency MBS volumes appear to exhibit a seasonal lull toward the end of each calendar year.

[11] Note that trading volume in a particular coupon will also fluctuate as a result of movements in the "current coupon," which represents the hypothetical coupon rate at which MBS trade at par. Securities with coupons closer to the current coupon tend to have more trading activity.

Figure 4. Twenty-Day Moving Average of Trading Volume for Fannie Mae and Freddie Mac Thirty-Year 3.5 Percent Coupon TBA Securities

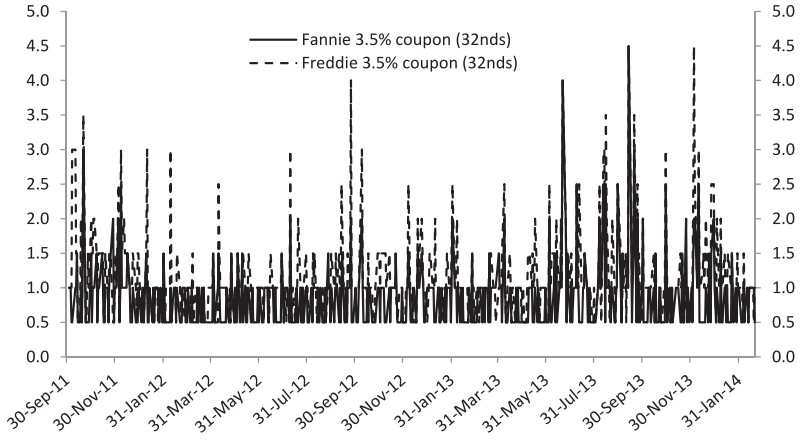


Source: TRACE.
Note: Twenty-day moving averages of trading volumes are reported to smooth through the TBA settlement cycle.

4.3 Bid-Ask Spreads

In order to measure the effect of QE purchases on market breadth, I consider changes in bid-ask spreads. The bid-ask spread for each security is compiled from data provided by Tradeweb—a popular dealer-to-customer MBS trading platform—which aggregates dealer-reported indicative quotes each day to form a composite bid-ask spread for each security. Unfortunately, the indicative nature of the quotes may make this measure a less-reliable indicator of liquidity than for other markets wherein dealers commit to transact at quoted bids and offers. Nevertheless, bid-ask spreads are one of the most commonly cited measures of market liquidity, and if the indicative spreads are assiduously reported by dealers on a best-efforts basis, a wider spread will indicate deterioration in market breadth and liquidity conditions. Figure 5 plots bid-ask spreads for the Fannie Mae and Freddie Mac 3.5 percent securities. As demonstrated in the chart, bid-ask spreads are typically 1.5 ticks (one and a half 32^{nds} of one point) or lower. The most notable increases in

Figure 5. Tradeweb Daily Composite Indicative Bid-Ask Spreads (in ticks) for Fannie Mae and Freddie Mac Thirty-Year 3.5 Percent Coupon TBA Securities



Source: Tradeweb.
Note: Bid-ask spreads, reported in ticks (32^{nds} of a point), as reported by dealers.

bid-ask spreads occurred around the time of the QE3 announcement in September 2012, during the sharp increase in interest rates in the summer of 2013, and around the end of 2013 when the reduction in asset purchases was announced.

5. Empirical Analysis

In this section, I present estimates of the effect of Federal Reserve intervention in the MBS market on the liquidity and market functioning indicators described above. In general, I proceed by regressing daily changes in each of the indicators on Federal Reserve MBS purchases. A discussion of general relevance to these analyses proceeds below to avoid excess repetition.

First, I am most interested in how Federal Reserve QE programs *as actually implemented* by the Desk affect market functioning. In other words, I do not attempt to measure the effect of a wholly unexpected and random Federal Reserve open market operation on market liquidity. Rather, I argue that if policymakers wish to assess

the cost of QE, it is important to do so in a manner that reflects the way in which purchases are actually conducted. For example, although the Desk announces neither the mix nor the settlement days of securities to be purchased each month, a combination of past trading patterns and the announcement of the total monthly purchases could lead to at least a partial anticipation of the Desk's purchases before they occur. On the other hand, many trades in the TBA market are agreed upon well over a month in advance, which could make prediction of Federal Reserve purchases much more difficult. Nevertheless, market participants' ability to anticipate some portion of Federal Reserve MBS purchases, thereby reducing the liquidity impact at the time of the trade, does not pose an issue for the present study. This is because the counterfactual outcome is less relevant for policymaking, since the costs of a fully unexpected purchase will never be realized if the Desk regularly announces purchase amounts and does not trade erratically.[12]

This framework opens up a potential concern regarding the analysis presented below. In particular, there is the possibility that the Desk's MBS purchases respond endogenously to liquidity conditions. If the Desk reacts to worsening liquidity positions by purchasing other securities, coefficient estimates will be biased. However, several factors mitigate this potential endogeneity concern. First, because my analysis is at the daily frequency, the Desk must respond to intraday liquidity conditions. This is likely impractical, as purchases are relatively large, generally occur early in the day, and would require a simultaneous response to many different liquidity indicators. Second, the first discussion of MBS market functioning and liquidity in a SOMA annual report did not appear until the 2013 report (released in early 2014). Acknowledging the concern that large QE purchases can disrupt market functioning, the report states that "the Desk closely monitored market functioning and liquidity as it increased its holdings of agency MBS." Nevertheless, there is no indication that purchases were adjusted to accommodate disruptions in market functioning. Rather, the report notes that "the market appeared to absorb the volume of the Desk's agency MBS

[12]This does not imply that current policy cannot be improved or should necessarily be maintained. In fact, as I describe below, some results suggest ways in which QE implementation can be altered to lessen market functioning effects.

operations without significant disruptions" and, despite the large volume of purchases in 2013, "there were few signs of significant market disruptions in 2013" (FRBNY 2014). Third, although the Markets Group at the FRBNY assumes responsibility for day-to-day surveillance of the Treasury securities markets (Greenspan, Levitt, and Rubin 1998), no such responsibility exists for the MBS market. However, the Desk's stated operating policy during the time period covered in this study did allow for the suspension of trading in response to deteriorating market conditions. In practice, though, the Desk traded MBS on all weekdays in the sample, with the exception of holidays and one day in the aftermath of Hurricane Sandy. Lastly, I note that if the Desk avoids purchasing securities experiencing worsening liquidity conditions (as it does for Treasury securities, as explained in the 2014 SOMA annual report), this would bias *against* finding liquidity effects of Federal Reserve purchases. Consequently, even if endogeneity issues were a concern, the magnitude of the effects reported below can be interpreted as lower bounds for purchases that are conducted without such substitution. Nevertheless, as I will describe in more detail below, I also produce results from a two-stage least-squares (2SLS) estimator to confirm the causal interpretation of the main results.

With these points in mind, I proceed below by first examining the determinants of Federal Reserve MBS purchases before turning to an analysis of the effects of the purchases on each of the liquidity and market functioning indicators described above.

5.1 Determinants of Federal Reserve Purchases

At each meeting, the FOMC issues a policy directive to the FRBNY that provides the authorization and instruction to carry out the Committee's objectives. Upon the change in the FOMC's reinvestment policy from Treasury securities into MBS after the September 2011 meeting, the FOMC changed its policy directive that previously instructed the Desk to maintain its policy of reinvesting principal payments on all domestic securities in Treasury securities. In the updated directive, the FOMC simply changed the directive to specify that the Desk should, "reinvest principal payments on all agency debt and [MBS] in ... [MBS]."

The relatively unspecific nature of the directive afforded the Desk some amount of discretion in the particular MBS that would be purchased. Consequently, the Desk could potentially base purchase decisions on any number of considerations. Importantly for the analysis conducted below, the Desk may respond to the relative liquidity of each purchasable security. As mentioned above, the desk could potentially skew purchases towards more liquid securities, thereby attenuating the estimated effect of purchases on liquidity. Conversely, the Desk could possibly choose to support the least-liquid MBS by purchasing more of these securities, which would bias the estimates in favor of finding liquidity costs of QE purchases.

To evaluate some potential predictors of Federal Reserve MBS purchases, and possibly identify an instrument that can be used to overcome any endogeneity concerns, I estimate a cross-sectional time-series regression, which allows for both contemporaneous correlation of errors across securities and autocorrelation of errors within each security. In these regressions, daily (or, for robustness, monthly) purchase amounts of individual MBS securities indexed by i, are regressed on a set of time-varying security characteristics:[13]

$$\textit{Fed Purchase}_{it} = \alpha + \beta \times \mathbf{\Phi}_{it} + \varepsilon_{it}. \tag{1}$$

The first (and third) column of table 3 reports the Prais-Winsten estimates for a regression of daily (monthly) security-level purchase amounts on ten security-specific covariates. The first covariate, *Issuance Survey Share*, is taken from a regular and confidential Desk survey of selected dealers, and measures the amount of issuance of each security that these dealers have witnessed around the survey period. As indicated, this value is converted to a proportion of total issuance and is lagged by the number of days since the last survey was conducted. Evidently, this variable exhibits a strong positive association with Federal Reserve MBS purchases. This correlation may be expected based on the Desk's online FAQs—and only public statement on the composition of purchases—that "MBS purchases will be concentrated in newly-issued agency MBS." Notably, this strong relationship to expected issuance survives controlling for the

[13]Adding a QE3 dummy increases the explanatory power of the regressions modestly, but otherwise produces identical conclusions.

Table 3. Determinants Regressions for Federal Reserve MBS Purchases

	(1)	(2)	(3)	(4)
Issuance Survey Share	0.14***	0.17***	0.48***	0.49***
	(0.01)	(0.01)	(0.04)	(0.04)
Remaining Principal	0.42		−2.59	
Balance Share	(0.77)		(4.56)	
Option-Adjusted	−0.03**		−0.04**	
Spread	(0.01)		(0.02)	
Price Volatility	0.53***		0.08	
	(0.14)		(0.90)	
Option-Adjusted	−0.21**		−0.24	
Duration	(0.08)		(0.40)	
Option-Adjusted	−0.03		0.69*	
Convexity	(0.07)		(0.40)	
Vega	−0.44***		−0.16	
	(0.06)		(0.36)	
Distance to Current	0.00		−0.04	
Coupon	(0.01)		(0.10)	
Implied Financing	0.23***		0.78*	
Rate	(0.08)		(0.45)	
AOB Transactions	0.07		0.57	
	(0.06)		(1.11)	
Observations	4,240	4,578	222	226
R-squared	0.448	0.431	0.726	0.697

Notes: This table reports Prais-Winsten estimates from regressions of Federal Reserve purchase amounts on security characteristics, which also allow for contemporaneous correlation of the errors across securities. Columns 1 and 2 estimate the regression at a daily frequency, while columns 3 and 4 estimate the regression at a monthly frequency. The constant is not reported.

second covariate, *Remaining Principal Balance Share,* which measures the relative stock of each security available to the public.

The third control reported in table 3 is the *Option-Adjusted Spread* of each security, which measures the yield spread to a Treasury security after an adjustment to take into account the embedded

prepayment option.[14] Here, the correlation is negative, which may be surprising. However, this result could potentially reflect the issue described in D'Amico and King (2013), whereby purchases may have been higher among underpriced securities whose yields were rising during the time of purchases. The fourth control is the two-week trailing *Price Volatility* of each security, which has a positive association with the purchase amount. Though this result is less robust, it might arise if larger purchases are skewed toward less-liquid and hence more price-volatile securities.

Similarly, none of the next four covariates exhibit a robust relationship to QE purchase amounts. The *Option-Adjusted Duration* is a measure of a security's price sensitivity to changes in interest rates, while the *Option-Adjusted Convexity* captures the curvature of that price/interest rate relationship. *Vega* measures the sensitivity of an MBS price to interest rate volatility (owing to the embedded prepayment option), and the *Distance to Current Coupon* measures the absolute difference between each security's coupon and the coupon of a hypothetical security that would be trading at par value on a given day.

Federal Reserve purchases are positively correlated with the *Implied Financing Rate* which, as explained in more detail in the online appendix, can proxy for the scarcity of each security, with higher values indicating a more abundant issue. Thus, this relationship is consistent with the interpretation that the Federal Reserve was purchasing fewer of the scarcest, and possibly less-liquid, MBS. The final covariate, *AOB Transactions*, reports the share of transactions that took place "at or better than" the indicative quote prevailing on the Tradeweb trading platform at the time of the trade. This variable can be considered a measure of liquidity inasmuch as it proxies for market breadth. Thus, the positive point estimate is consistent with the interpretation of the positive coefficient on the *Implied Finance Rate* described above.

As reported at the bottom of the table, this specification explains about 45 and 73 percent of the variation in daily and monthly purchase amounts, respectively, even though there are no security fixed effects. In columns 2 and 4, I show a regression that includes only

[14]This and all future controls are lagged values.

the *Issuance Survey Share.* The point estimates in both cases are similar to the corresponding richer specification, and this variable accounts for the overwhelming majority of the explanatory power of the full specification, with R-squared values that are only between 2 and 3 percentage points lower.[15]

The substantial explanatory power of the issuance survey suggests that this variable may serve as a good instrument for Federal Reserve MBS purchases insofar as a high F-statistic would be likely in any first-stage regression in which the *Issuance Survey Share* appears as an instrument. Moreover, the conditional exclusion would not be violated with such an instrument. This is due to the fact that survey responses reflect issuance estimates from a period outside of the purchase window, and are necessarily exogenous to realized changes in liquidity and market functioning in future periods. Although the correlation between survey responses and realized future issuance could be a potential concern if realized issuance affects liquidity, it is possible to control for realized issuance on the days of Federal Reserve purchases, thereby eliminating this concern and maintaining the validity of the conditional exclusion restriction. For these reasons, it is possible to instrument for QE purchases to ensure that endogeneity issues do not degrade the causal interpretation of the main results.

5.2 Trade Sizes

As a first test of the effects of QE on market liquidity, I begin by estimating the effect of Federal Reserve purchases on MBS daily average trade sizes. Specifically, I employ a cross-sectional time-series model with panel-corrected standard errors as follows:

$$\Delta \ln (TradeSize_{it}) = \beta \times Fed\ Purchase_{it} + \chi_t + \alpha + \varepsilon_{it}. \quad (2)$$

In equation (2), i indexes a security so that *Fed Purchase* represents the total amount (in billions) of security i purchased on day t. In order to capture a host of potential factors influencing differences in trade sizes across securities, I include day fixed effects, χ_t.

[15] Regressing *Fed Purchase* on the constant alone (suppressed in table 3) yields an R-squared value of only 0.09.

For example, time fixed effects can control for daily movements in interest rates, changes in MBS prepayment expectations, shifts or time trends introduced as a result of new regulations, and normal calendar effects. Additionally, because I am including only class A (Fannie Mae and Freddie Mac thirty-year) securities in the estimation of (2), day fixed effects are more likely to be correctly specified, since all of the securities have the same settlement calendar and original term to maturity. The errors in (2) are allowed to be heteroskedastic and contemporaneously correlated across panels.[16] In equation (2), trade sizes are measured excluding Federal Reserve purchases. Furthermore, securities are excluded from the sample on days in which they witnessed less than $200 million in total trading volume in either the prior or current day. The results reported below are not sensitive to the precise threshold used, but applying such a filter ensures that changes in trade sizes are defined and reflect the outcome of regular trading by market participants.

The results from the estimation of (2) are reported in the first column of table 4. The point estimate implies that a purchase of $1 billion by the Federal Reserve since the start of reinvestment reduced trade sizes by about 12 percent from the previous day on average. This represents a rather large marginal effect, though I will discuss below the economic significance of these results while taking into account the typical size of each QE operation. However, the liquidity effects may vary by QE program in light of the substantially different purchase amounts. Thus, I proceed by estimating the following regression, which multiplies *Fed Purchase* by program dummies to capture differential effects of MBS purchases across the two purchase regimes:

$$\begin{aligned}\Delta \ln (Trade\ Size_{it}) = &(\beta_{\text{Reinv}} \times Fed\ Purchase_{it}) D_{\text{Reinv}} \\ &+ (\beta_{\text{QE3}} \times Fed\ Purchase_{it}) D_{\text{QE3}} \\ &+ \gamma \Phi_{it} + \chi_t + \alpha + \varepsilon_{it}. \end{aligned} \tag{3}$$

[16]Prais-Winsten estimates of the parameters allowing for panel-specific first-order autocorrelation in the disturbances yield very similar results to those reported below.

Table 4. The Effect of Federal Reserve Purchases on Trade Size

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Fed Purchase	−11.8***					−18.5***	
	(2.32)					(5.15)	
Fed Purchase × Reinvestment		−19.8**	−21.3***	−38.7***	−37.1***		−38.9*
		(7.60)	(7.88)	(7.71)	(8.11)		(21.6)
Fed Purchase × QE3		−11.2***	−14.0***	−23.9***	−23.8***		−18.9***
		(2.43)	(2.91)	(3.08)	(3.31)		(6.50)
Issuance			−2.22**		−2.36**		−1.30
			(1.14)		(1.16)		(1.75)
Distance to Current Coupon			−0.08***		−0.05**		−0.09***
			(0.02)		(0.02)		(0.03)
Substitute Purchase × Reinvestment				50.8***	48.0***		
				(11.7)	(11.7)		
Substitute Purchase × QE3				18.2***	16.5***		
				(4.99)	(5.17)		
Observations	3,824	3,824	3,824	3,824	3,824	3,815	3,815
Securities	9	9	9	9	9	9	9
R-squared	0.194	0.194	0.197	0.200	0.201	0.194	0.196

Notes: The dependent variable in all specifications is the percent change in the average daily trade size for each security in the sample, excluding Federal Reserve purchases. *Fed Purchase* represents total daily Federal Reserve purchases of each security, measured in billions. *Reinvestment* and *QE3* dummies take a value of one for each day in the associated purchase program. *Issuance* measures the reported daily issuance of each security in billions, and *Distance to Current Coupon* is the absolute value of the difference between each security's coupon and the daily current coupon for the relevant agency, measured in percentage points. For each security, *Substitute Purchase* measures the sum of Federal Reserve purchases of MBS that have the same coupon but a different issuer. All specifications include day fixed effects and a suppressed constant. Columns 6 and 7 report 2SLS estimates.

Moreover, I include controls, Φ, in some specifications to demonstrate robustness. Control variables include daily issuance, which (together with the amount of Federal Reserve purchases) controls for the primary source of daily changes in the stock of each security available to the public.[17] As an additional control, I include the absolute value of the difference between the coupon of security i and the current coupon on day t, matched by agency. Controlling for this spread may be important, because current trading activity and banks' origination pipelines can be driven by the current coupon, with larger values likely being associated with lower trading and worse liquidity conditions.

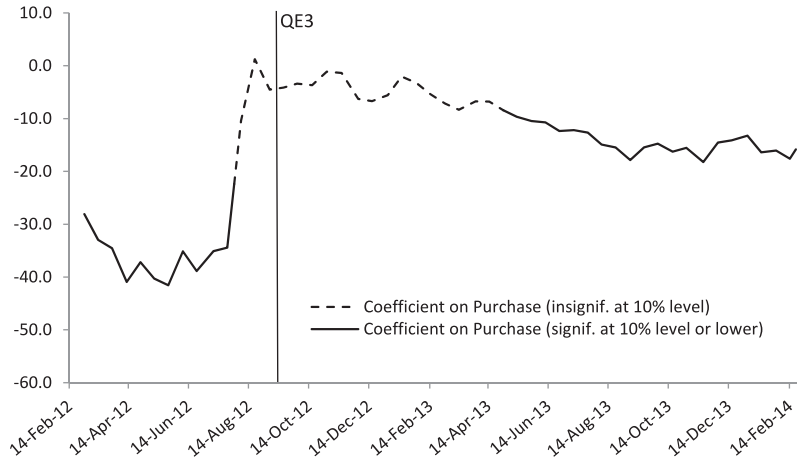
The specifications reported in columns 2 and 3 of table 4—which separate the effect of purchases for each program—indicate that the point estimate is higher for the reinvestment period. Securities with coupons that are farther from the current coupon have slightly worse liquidity, as expected. However, after controlling for the distance to the current coupon, higher daily issuance correlates, perhaps counterintuitively, with lower daily trade sizes.

Next, in order to evaluate how Federal Reserve MBS purchases affected trade sizes over time as holdings grew (see figure 1), I estimate rolling regressions over the sample period. Figure 6 plots the coefficient of interest from equation (2) using a random-effects estimator for a ninety-day rolling regression over the sample period.[18] Thus, the first point in figure 6 represents the value of the key coefficient in equation (2) generated from a regression for the first ninety days of the reinvestment program. A vertical line indicates the point at which observations from QE3 begin entering the rolling window. Figure 6 reveals that the marginal effects of Federal Reserve purchases on liquidity and market functioning were most pronounced and quite large after the start of reinvestment purchases. However, the relatively modest size of purchases during this program (see table 2) restrains the overall effect. Nevertheless, if the effect

[17] For this reason, accounting for the remaining principal balance outstanding net of Federal Reserve holdings for each security does not materially change the results.

[18] A random-effects estimator is used for each ninety-day sample due to the infeasibility of computing panel-corrected standard errors.

Figure 6. Rolling Regression—The Effect of Federal Reserve Purchases on Trade Size

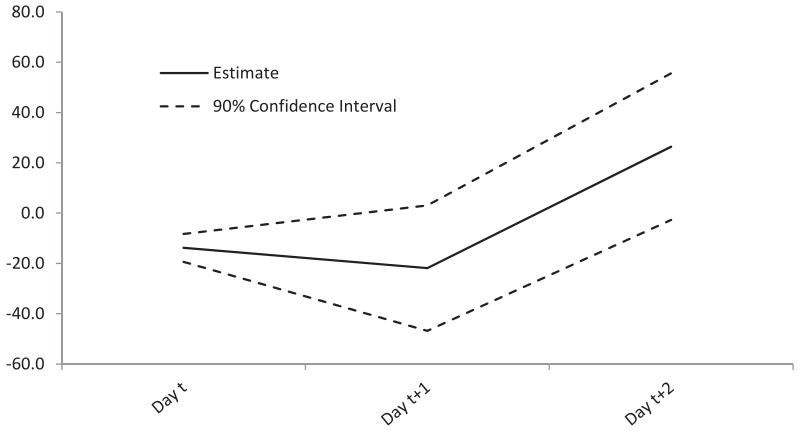


Notes: This graph plots the coefficient on the *Fed Purchase* variable in equation (3) from a rolling regression. The rolling window is ninety days and is reestimated in ten-day increments using a random-effects estimator. The final day of the rolling window is listed on the horizontal axis. Points to the right of the "QE3" line include purchases that occurred during the QE3 program. The value on the vertical axis can be interpreted as the percent change in a security's trade size as a result of a $1 billion purchase by the Federal Reserve.

of Federal Reserve purchases on trade size accumulates each day, even modest daily purchase amounts can ultimately result in a large reduction in trade sizes. In order to test the persistence of the effect identified in table 4, I demonstrate that the results from the baseline specification of equation (2) dissipate over time in figure 7. Figure 7 shows that the cumulative two-day effect of Federal Reserve purchases on trade size is no longer statistically different from zero, and the total effect on the three-day percent change in trade volumes is positive, albeit very imprecisely estimated with zero contained well within the confidence interval. In total, it appears that the effects identified in table 4 do not persist much past the day on which trades occur. Nevertheless, daily MBS QE purchases imply a sustained, if not cumulating, liquidity effect.

Columns 4 and 5 of table 4 include the volume of Federal Reserve purchases of near-substitute securities. In these specifications, I

Figure 7. Evaluating the Persistence of the Effect of Federal Reserve Purchases on Trade Size



Notes: This figure plots the coefficient on *Fed Purchase* from the first specification in table 4. The first point corresponds to the estimate provided in the table. The second point (*Day* $t+1$) reports the coefficient from the same regression, with a dependent variable (percent change in trade size) calculated over a two-day window. Similarly, the last point is produced from a regression of the three-day percent change in trade size on *Fed Purchase* and a full set of time fixed effects. Since future purchases may be correlated with purchases on day t, the multi-day horizon regressions also include the amount of the security purchased during the horizon.

include total Federal Reserve purchases of "similar" securities, which I define as those securities that have the same coupon as security i, but a different issuer. For example, total substitute purchases for the Fannie Mae thirty-year 3.5 percent coupon security include the sum of purchases of the Freddie Mac thirty-year 3.5 percent coupon. This definition of substitutable securities is likely to capture purchases of the most closely related securities. As indicated in table 4, substitute purchases have large positive effects on trade sizes. Thus, it appears that Federal Reserve purchases crowd out third-party trading activity that then finds an outlet in similar securities. Using the coefficient estimates in column 5 of table 4 along with average values for *Fed Purchase* and *Substitute Purchase* in each purchase program, it is possible to calculate the effect of average daily purchases conducted by the Desk. For the reinvestment period, average daily

purchases resulted in a statistically insignificant ($p = 0.46$) *increase* in trade size of 2.1 percent for the average security. Alternatively, the effect of average purchase operations during QE3 resulted in a statistically significant ($p = 0.05$) 3.5 percent *decrease* in trade sizes for the average security. Of course, the negative coefficient on *Fed Purchase* in each purchase regime indicates that, all else equal, securities purchased by the Desk do indeed experience adverse liquidity effects.

Lastly, the final column of table 4 reports the 2SLS estimate of the effect of Federal Reserve purchases. Here, *Fed Purchase* is instrumented with the *Issuance Survey Share* described in the previous subsection. As expected, the survey issuance is an extremely strong instrument with a first stage F-statistic (not shown) of over 900. The strength of the instrument persists even when controlling for realized daily issuance and the absolute distance to the current coupon. The 2SLS estimate shows that the results cannot be explained by an endogenous skew of purchases towards less-liquid securities and, if anything, the simple OLS estimates produce an *underestimate* of the adverse liquidity effect of MBS purchases. As explained above, this pattern could result from the desk favoring relatively more-liquid MBS. Ultimately, the results confirm the causal interpretation of the estimates described above.

5.3 Trading Volume

As a further test of the effects of Federal Reserve purchases on liquidity—and to ensure that larger trades are not simply being divided into multiple smaller trades during QE purchases—I relate purchases to daily trading volume by estimating regressions (4) and (5):

$$\Delta \ln (Trade\ Volume_{it}) = \beta \times Fed\ Purchase_{it} + \chi_t + \alpha + \varepsilon_{it} \quad (4)$$

$$\begin{aligned} \Delta \ln (Trade\ Volume_{it}) = {} & (\beta_{\text{Reinv}} \times Fed\ Purchase_{it}) D_{\text{Reinv}} \\ & + (\beta_{\text{QE3}} \times Fed\ Purchase_{it}) D_{\text{QE3}} \\ & + \gamma \Phi_{it} + \chi_t + \alpha + \varepsilon_{it}. \end{aligned} \quad (5)$$

As with the trade size regressions, I exclude Federal Reserve purchases from daily trade volume, and securities are excluded when

there was less than $200 million in total trading volume in either the prior or current day.

Table 5 displays regression results using the same specifications as those presented in table 4. The pattern of results in table 5 is very similar to the results for trade size, indicating an adverse effect of QE on market liquidity, but coefficient estimates on Federal Reserve purchases are about double the size. Of particular note, specifications 4 and 5 exhibit similar evidence of crowding out caused by Federal Reserve purchases, consistent with portfolio rebalancing effects that cause investors to move into similar securities in response to Federal Reserve purchases. Although the coefficients in table 5 again show sizable marginal effects, the estimates from the final specification in table 5 imply that the net result of average daily Federal Reserve purchases during the reinvestment period led to only about a 2.6 percent percent increase ($p = 0.54$) in trade volume for the average security. Conversely, the average net effect of a day's worth of purchases during QE3 resulted in a 3.4 percent decline ($p = 0.16$) in volume for the average security. In the 2SLS results reported in column 6, it is again evident that the adverse liquidity effects of Federal Reserve purchases are not simply explained by the possibly endogenous response of purchases to liquidity conditions.

Similar to the analysis in the previous sections, figure 8 presents the key coefficient from a rolling regression of equation (4). As with average daily trade size, volumes (excluding Federal Reserve purchases) appear to decrease in securities that see purchases by the Federal Reserve. However, the marginal effect of Federal Reserve purchases was essentially constant in the final six months of the sample, even as the Federal Reserve owned an ever-higher share of the total market. Finally, similar to the results from the previous section, figure 9 demonstrates the lack of persistence of the effect identified in table 5. However, the negative coefficient on *Fed Purchase* that persists in table 5 is again consistent with adverse liquidity effects of Federal Reserve purchases, all else equal.

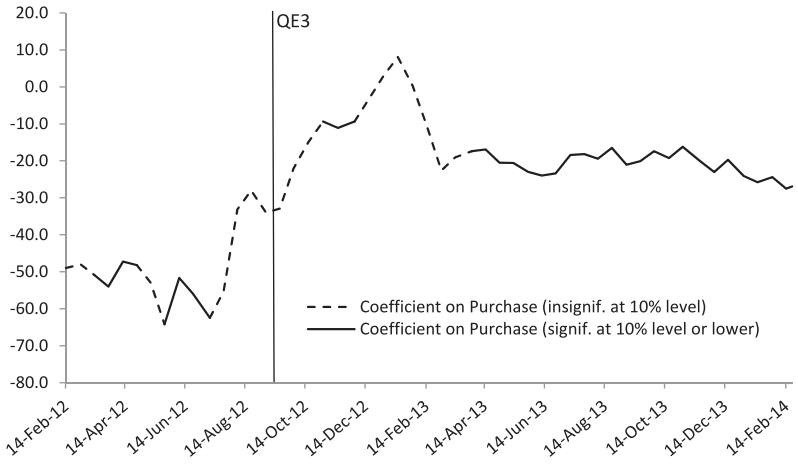
Finally, I note that the larger effect on trade volume relative to trade size implies that the number of (non-Federal Reserve) trades was also reduced by Federal Reserve MBS purchases. Indeed, unreported results confirm the adverse effect of Federal Reserve MBS transactions on the number of daily transactions. Importantly,

Table 5. The Effect of Federal Reserve Purchases on Trade Volume

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Fed Purchase	−22.3***					−32.2***	
	(3.43)					(7.83)	
Fed Purchase × Reinvestment		−49.6***	−49.6***	−87.4***	−82.8***		−84.8***
		(12.75)	(12.8)	(13.34)	(13.6)		(32.8)
Fed Purchase × QE3		−20.3***	−20.3***	−52.8***	−51.2***		−28.2***
		(3.56)	(3.6)	(4.74)	(4.99)		(9.88)
Issuance			−3.69**		−4.10**		−2.64
			(1.65)		(1.69)		(2.65)
Distance to Current Coupon			−0.12***		−0.06**		−0.13***
			(0.03)		(0.03)		(0.04)
Substitute Purchase × Reinvestment				101.8***	98.5***		
				(17.4)	(17.2)		
Substitute Purchase × QE3				46.7***	44.9***		
				(7.55)	(7.72)		
Observations	3,824	3,824	3,824	3,824	3,824	3,815	3,815
Securities	9	9	9	9	9	9	9
R-squared	0.345	0.346	0.348	0.356	0.357	0.345	0.348

Notes: The dependent variable in all specifications is the percent change in the daily trade volume for each security in the sample, excluding Federal Reserve purchases. *Fed Purchase* represents total daily Federal Reserve purchases of each security, measured in billions. *Reinvestment* and *QE3* dummies take a value of one for each day in the associated purchase program. *Issuance* measures the reported daily issuance of each security in billions, and *Distance to Current Coupon* is the absolute value of the difference between each security's coupon and the daily current coupon for the relevant agency, measured in percentage points. For each security, *Substitute Purchase* measures the sum of Federal Reserve purchases of MBS that have the same coupon but a different issuer. All specifications include day fixed effects and a suppressed constant. Columns 6 and 7 report 2SLS estimates.

Figure 8. Rolling Regression—The Effect of Federal Reserve Purchases on Trade Volume



Notes: This graph plots the coefficient on the *Fed Purchase* variable in equation (5) from a rolling regression. The rolling window is ninety days and is reestimated in ten-day increments using a random-effects estimator. The final day of the rolling window is listed on the horizontal axis. Points to the right of the "QE3" line include purchases that occurred during the QE3 program. The value on the vertical axis can be interpreted as the percent change in a security's daily trading volume as a result of a $1 billion purchase by the Federal Reserve.

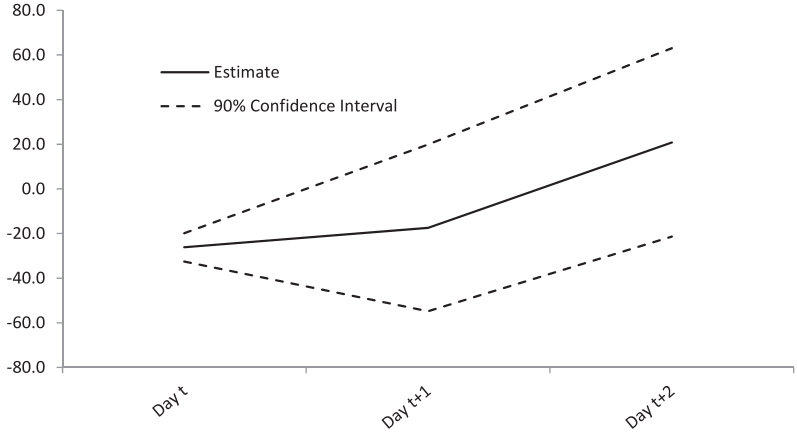
the number of trades in a market is also viewed as a measure of liquidity (Fleming 2003) and thus the effect of Federal Reserve purchases on trades serves as further confirmation of the finding that QE purchases can reduce liquidity conditions for purchased securities.

5.4 Bid-Ask Spread

As a final test of the effects of Federal Reserve purchases on liquidity, I consider one of the most commonly cited measures of liquidity across asset classes—bid-ask spreads—and estimate the following regressions:

$$\Delta(Bid - Ask_{it}) = \beta \times Fed\ Purchase_{it} + \chi_t + \alpha + \varepsilon_{it} \qquad (6)$$

Figure 9. Evaluating the Persistence of the Effect of Federal Reserve Purchases on Trade Volume



Notes: This figure plots the coefficient on *Fed Purchase* from the first specification in table 5. The first point corresponds to the estimate provided in the table. The second point (*Day* t+1) reports the coefficient from the same regression, with a dependent variable (percent change in trade volume) calculated over a two-day window. Similarly, the last point is produced from a regression of the three-day percent change in trade volume on *Fed Purchase* and a full set of time fixed effects. Since future purchases may be correlated with purchases on day t, the multi-day horizon regressions also include the amount of the security purchased during the horizon.

$$\begin{aligned}\Delta(Bid - Ask_{it}) = &(\beta_{\text{Reinv}} \times Fed\ Purchase_{it})D_{\text{Reinv}} \\ &+ (\beta_{\text{QE3}} \times Fed\ Purchase_{it})D_{\text{QE3}} \\ &+ \gamma\Phi_{it} + \chi_t + \alpha + \varepsilon_{it}. \qquad (7)\end{aligned}$$

In equations (6) and (7), the dependent variable is the change in the end-of-day composite bid-ask spread as reported by Tradeweb, measured in 32^{nds} of a point, also referred to as "ticks." Point estimates of the estimation results, presented in table 6, indicate that during the reinvestment program, $1 billion of Federal Reserve purchases increased bid-ask spreads by between 0.03 and 0.09 ticks, while the increase during the QE3 period is much smaller at only 0.003 to 0.04 ticks. Although these estimates do not achieve statistical significance in any of the specifications, standard errors would be biased upward if the indicative nature of the bids and asks reported to Tradeweb

Table 6. The Effect of Federal Reserve Purchases on Bid-Ask Spreads

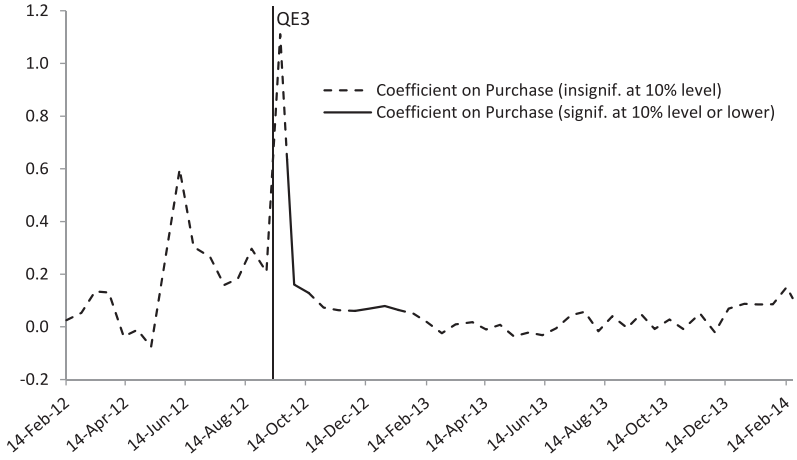
	(1)	(2)	(3)	(4)	(5)	(6)
Fed Purchase	0.043				0.033	
	(0.083)				(0.131)	
Fed Purchase × Reinvestment		0.088	0.025	0.027		0.052
		(0.189)	(0.198)	(0.197)		(0.497)
Fed Purchase × QE3		0.039	0.003	0.017		−0.011
		(0.089)	(0.090)	(0.122)		(0.167)
Issuance			0.032	0.032		0.030
			(0.026)	(0.026)		(0.047)
Distance to Current Coupon				0.000		0.000
				(0.001)		(0.001)
Observations	4,778	4,778	4,778	4,778	4,726	4,726
Securities	10	10	10	10	10	10
R-squared	0.191	0.191	0.191	0.191	0.198	0.198

Notes: The dependent variable in all specifications is the change in the end-of-day composite bid-ask spread as reported by Tradeweb. *Fed Purchase* represents total daily Federal Reserve purchases of each security, measured in billions. *Reinvestment* and *QE3* dummies take a value of one for each day in the associated purchase program. *Issuance* measures the reported daily issuance of each security in billions, and *Distance to Current Coupon* is the absolute value of the difference between each security's coupon and the daily current coupon for the relevant agency, measured in percentage points. All specifications include day fixed effects and a suppressed constant. Columns 5 and 6 report 2SLS estimates.

introduce error in the measured spread. Nevertheless, these results are similar to those achieved by Steeley (2015), who finds that purchase activity of U.K. government bonds by the Bank of England (BoE) have no association with bid-ask spreads, although the share of each security held by the BoE appears to exhibit a negative relationship with bid-ask spreads. Other control variables—shown in the third and fourth columns of table 6—demonstrate no relationship to changes in bid-ask spreads. Lastly, the fifth column of table 6 shows a similarly statistically insignificant result for the 2SLS estimate of the baseline regression, though I note that there is an efficiency loss with an instrumental-variables approach.

In figure 10, I again plot the results from a rolling regression of the baseline specification, represented by equation (6). The most

Figure 10. Rolling Regression—The Effect of Federal Reserve Purchases on Bid-Ask Spreads



Notes: This graph plots the coefficient on the *Fed Purchase* variable in equation (7) from a rolling regression. The rolling window is ninety days and is reestimated in ten-day increments using a random-effects estimator. The final day of the rolling window is listed on the horizontal axis. Points to the right of the "QE3" line include purchases that occurred during the QE3 program. The value on the vertical axis can be interpreted as the change (in ticks) in a security's bid-ask spread as a result of a $1 billion purchase by the Federal Reserve.

notable feature of the rolling regression is the spike in the response of the bid-ask spread to Federal Reserve purchases at the start of the QE3 period.[19] Moreover, rolling regressions reveal statistically significant effects of Federal Reserve purchases in the months following the start of QE3. The magnitude of the effect over this time indicates that $1 billion in purchases increased bid-ask spreads by as much as a half of a tick in the period just after QE3 purchases began. Overall, it appears that there is some evidence from bid-ask spreads that Federal Reserve purchases induced worse liquidity conditions immediately after the start of QE3, but the effect was relatively short-lived.

[19]This result is not driven by outliers. Removing bid-ask changes that are in the top 1 percent of the sample in absolute value yields nearly identical results.

6. Price Discovery in the MBS TBA Market

The previous section presents evidence that Federal Reserve MBS purchases are associated with worse liquidity and market functioning. Although poor liquidity conditions can lead to higher costs for some market participants, liquidity deterioration would become most costly if it precipitated impairment in price discovery. Indeed, interference with price discovery in the MBS market could be seen as a possibly substantial cost of QE given the importance of U.S. debt markets to the transmission of monetary policy. For example, if the Federal Reserve wished to put downward pressure on interest rates through a commitment to keep short-term interest rates near zero for an extended period of time, this would normally be reflected in lower interest rates, including MBS yields and primary mortgage rates. If, however, MBS prices did not fully respond to lower interest rates due to substantial liquidity impairments, primary mortgage rates may not fall as much as they otherwise would, muting the efficacy of monetary policy.

Thus, having documented the negative liquidity effects of Federal Reserve MBS purchases in the previous section, I now evaluate the evolution of price discovery in the MBS market during the course of QE purchases. Specifically, I test the extent to which MBS prices responded normally to fundamentals during QE programs using two different methods.

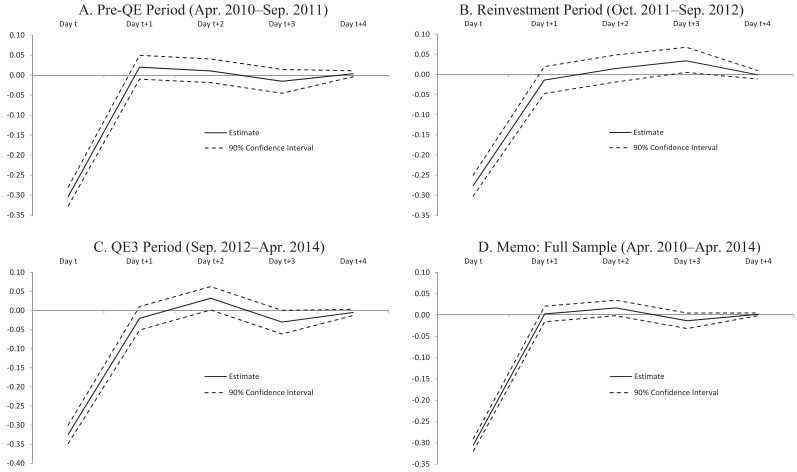
As an initial test of MBS price discovery, I first estimate a standard vector autoregression of the following form:

$$y_t = \alpha + \sum_{i=1}^{3} \beta_i y_{t-i} + \varepsilon_t, \tag{8}$$

where y_t is a vector consisting of the daily change in the five-year Treasury yield and the percentage change in the price of the Fannie Mae thirty-year 3.5 percent coupon TBA security, which was regularly traded throughout the sample period.[20] If price discovery diminished during ongoing Federal Reserve QE purchases, impulse

[20] All of the analysis and conclusions of this section hold if the change in the Fannie Mae thirty-year current coupon is used in place of the price change of the 3.5 percent TBA contract.

Figure 11. Impulse Responses of MBS Prices to a Shock to the Five-Year Treasury Yield



Notes: Each panel plots a one-week impulse response function for the percent change in price of the Fannie Mae 3.5 percent coupon to an orthogonalized 5 basis point shock to the five-year U.S. Treasury yield. Each panel corresponds to a different estimation period, as indicated. Vertical axes are in percent.

response functions (IRFs) of MBS prices to shocks in the five-year Treasury yield could become more drawn out over time, indicating that MBS prices take more time to reflect changes in Treasury yields. Several earlier studies have noted the potential that price discovery in fixed income markets could extend to a period beyond a single day. For example, Joyce et al. (2011) use a two-day window for their event-study analysis, and Krishnamurthy and Vissing-Jorgensen (2011) note that prices of assets may react more slowly during a period of low liquidity. Thus, if liquidity conditions deteriorate sufficiently, MBS prices could take more time to reflect changes evident in the more liquid U.S. Treasury market.

In figure 11, I plot Cholesky-orthogonalized IRFs from the estimation of equation (9) for several different sample periods. The first sample period—shown in panel A—limits the sample to the eighteen-month period after the completion of QE1 MBS purchases but prior to the initiation of the MBS purchases under the reinvestment program. During this time, a shock of 5 basis points to the five-year

Treasury yield resulted in a contemporaneous decline in the price of the Fannie Mae 3.5 percent coupon security of approximately 0.3 percent. The IRFs estimated over the reinvestment and QE3 subperiods are presented in panels B and C, respectively, and demonstrate a very similar pattern. However, in contrast to the pre-QE period, the point estimate of the MBS price change for the second day after the shock to the five-year Treasury yield remains negative during MBS QE purchase periods. Furthermore, the MBS price response three days after the shock is positive and marginally statistically significant during reinvestment. Ultimately, these differences appear relatively minor if not statistically insignificant, and the IRFs estimated across subsamples do not clearly indicate worsening price discovery in the MBS market during the time of Federal Reserve MBS purchases.

As a second test of price discovery during Federal Reserve MBS market intervention, I estimate a time-series regression in which I regress price changes in the Fannie Mae 3.5 percent coupon on an economic surprise index:

$$\Delta \ln(\text{Price}_t) = \alpha + \beta \times \text{Economic Surprise Index}_t + \varphi \times \text{Economic Surprise Index}_{t-1} + \varepsilon_t. \quad (9)$$

Similar to the previous exercise, I estimate equation (9) for sample periods corresponding to the pre-QE, reinvestment, and QE3 periods. If the response of MBS prices to economic surprises changed dramatically during the course of the Federal Reserve's MBS purchases, this could indicate impaired price discovery. In particular, if the lagged value of the economic surprise index does not load in the pre-QE period, but does yield significant explanatory power for MBS price changes during QE purchases, weakened price discovery could be inferred.

To construct an index of economic surprises, I compare regular economic releases with the median expectation from a Bloomberg survey of economic forecasters. Mathematically, I compute the economic surprise index as follows:

$$\text{Economic Surprise Index}_t = \sum_j \frac{v_{jt} - \tilde{x}_{jt}}{\sigma_{jt}}, \quad (10)$$

where v_{jt} represents the initial print of economic indicator j on day t, $\tilde{x}$ is the median forecast from a survey conducted by Bloomberg, and σ is the standard deviation of the survey forecasts. As indicated by the summation operator, the standardized economic surprises of different economic indicators are added together on days in which more than one release occurs. I use five monthly economic indicators to construct the economic surprise index: non-farm payrolls, retail sales, industrial production, personal income, and personal spending. Thus, the economic surprise index takes a value of zero for days in which none of the aforementioned indicators were released, and a value equal to the standardized surprise for days on which releases occur.

Table 7 reports the results from estimating equation (9) over the pre-QE, reinvestment, and QE3 subperiods. The estimates shown in the first column of each time period demonstrate that MBS prices responded to economic surprises with the expected sign in all three subperiods. Although the strength of the response was slightly weaker during the reinvestment period, lagged economic surprises were not related to MBS price changes in any of the three regimes.

To demonstrate how MBS prices responded to economic indicators individually, I decompose the economic surprise index into its individual components, and report the results in the second column beneath each sample period. Perhaps predictably, surprises in non-farm payrolls are significant in each subperiod. Moreover, surprises in retail sales—another important and timely economic indicator—also appear to influence MBS prices. However, the strength of the price response to retail sales surprises weakened during the reinvestment period compared with the pre-QE period, and (though the point estimate was similar to the reinvestment period) failed to achieve conventional levels of statistical significance during QE3 purchases. The insignificance of retail sales and the stronger response to non-farm payroll surprises during QE3 could indicate a shift in focus by market participants during this period. This explanation seems plausible in light of the FOMC's explicit commitment to tie QE3 purchases to the outlook for employment.

Overall, the evidence presented in this section suggests that there is little, if any, indication that price discovery in the MBS market changed during the ongoing Federal Reserve purchases.

Table 7. The Effect of Surprises in Economic Indicators on MBS Prices

	Pre-QE (Apr. '10–Sep. '11)		**Reinvestment (Oct. '11–Sep. '12)**		**QE3 (Sep. '12–Apr. '14)**		**Memo: Full Sample (Apr. '10–Apr. '14)**	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Economic Surprise Index$_t$	-0.078^{***} (0.027)		-0.056^{***} (0.018)		-0.070^{***} (0.018)		-0.070^{***} (0.013)	
Economic Surprise Index$_{t-1}$	-0.013 (0.027)		0.002 (0.018)		0.001 (0.018)		-0.004 (0.013)	
Non-farm Payroll Surprise		-0.080^{*} (0.045)		-0.115^{***} (0.029)		-0.217^{***} (0.033)		-0.134^{***} (0.022)
Retail Sales Surprise		-0.173^{**} (0.07)		-0.078^{*} (0.041)		-0.076 (0.048)		-0.112^{***} (0.033)
Industrial Production Surprise		-0.020 (0.056)		0.019 (0.041)		-0.008 (0.037)		-0.08 (0.027)
Personal Income Surprise		-0.144 (0.092)		0.026 (0.058)		0.005 (0.036)		-0.029 (0.033)
Personal Spending Surprise		-0.024 (0.070)		0.014 (0.056)		0.057 (0.054)		0.000 (0.037)
Observations	378	378	239	239	404	404	1,021	1,021
Adjusted R-squared	0.017	0.032	0.030	0.060	0.031	0.105	0.028	0.042
Durbin-Watson Statistic	2.16	2.15	1.92	1.94	1.97	1.98	2.09	2.08

Notes: The dependent variable in all specifications is the percent change in the price of the Fannie Mae 3.5 percent coupon security. *Economic Surprise Index* is calculated by differencing the announced value of an economic indicator from the median expected forecast from a Bloomberg survey, and dividing by the standard deviation of the survey responses. The individual components of the index are reported in additional rows of the table.

7. Conclusions

As has become evident in more recent debates surrounding QE, rigorous analyses of the potential costs of large-scale asset purchases are required if central banks are to rely on these programs to achieve their mandates. Indeed, an assessment of the potential costs associated with QE should be an important consideration when deciding to begin, continue, or cease these programs.

One important potential cost of QE is the possibility that continuous large purchases by the central bank may deteriorate liquidity and market functioning. Since the global financial system relies on deep and liquid markets for U.S. debt securities, liquidity impairment can be tremendously costly. Moreover, sufficiently large disruptions in price discovery could potentially impede the transmission of monetary policy. Thus, empirical evaluations of the effect of QE on market functioning, liquidity, and price discovery are required for policymakers to make informed decisions regarding the use of ongoing asset purchases. Yet, the effect of central bank purchases on market liquidity in normal environments is not theoretically clear, and studies examining the potential costs of QE are scarce, even as major central banks continue QE programs.

This paper attempts to help fill this gap in the literature by examining one potential cost associated with ongoing QE purchases. I show that Federal Reserve MBS purchases since 2011 have led to deterioration in measures of liquidity and market functioning, particularly in the months after the commencement of a new purchase program. Measures of trade sizes, trade volumes, and the number of trades all showed notable declines that were contemporaneous with recent Federal Reserve MBS purchases. Additionally, bid-ask spreads appear to have briefly widened as a result of Federal Reserve purchases shortly after QE3 purchases began. Conditional on Desk operating policy, however, the magnitude of the liquidity and market functioning effects of Federal Reserve purchases appears to be quite modest. Furthermore, the influence of Federal Reserve purchases on bid-ask spreads disappeared entirely a few quarters after the start of the reinvestment program and/or QE3, as investors and dealers were evidently able to adjust to the purchase programs. Lastly, the magnitude of the market functioning and liquidity effects of MBS QE purchases appear to be unrelated to the overall share of MBS

outstanding held by the Federal Reserve, though this does not preclude a relationship at ownership rates well above those observed during QE3.

Ultimately, it appears that Federal Reserve QE purchases have noticeable effects on market functioning, but when taking account of the size of purchases in the QE operations considered here, these effects appear to be relatively modest in size, short-lived, or both. Moreover, I demonstrate that the liquidity-impairing effects of Federal Reserve MBS purchases did not coincide with a deterioration of price discovery in the MBS TBA market. Throughout the ongoing QE programs, MBS prices responded normally to both surprises in economic indicators and shocks to U.S. Treasury yields, suggesting that the liquidity and market functioning costs of regular QE purchases did not impede price discovery.

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