Does Quantitative Easing
Affect Market Liquidity?

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and

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Abstract

We argue that central bank large-scale asset purchases—commonly known as quantitative easing (QE)—can reduce priced frictions to trading through a liquidity channel that operates by changing the *shape* of the price distribution of the targeted securities. For evidence we analyze how the Federal Reserve's second QE program that included purchases of Treasury inflation-protected securities (TIPS) affected a measure of liquidity premiums in TIPS yields and inflation swap rates. We find that, for the duration of the program, the liquidity premium measure averaged 12 to 14 basis points lower than expected. This suggests that QE can improve market liquidity.

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1   Introduction

In response to the Great Recession induced by the financial crisis of 2007-2008, the Federal Reserve quickly lowered its target policy rate—the overnight federal funds rate—effectively to its zero lower bound. Despite this stimulus, the outlook for economic growth remained grim and the threat of significant disinflation, if not outright deflation, was serious. As a consequence, the Fed began purchases of longer-term securities, also known as quantitative easing (QE), as part of its new unconventional monetary policy strategy aimed at pushing down longer-term yields and providing additional stimulus to the economy.

The success of the Fed's large-scale asset purchases in reducing Treasury yields and mortgage rates appears to be well established; see Gagnon et al. (2011), Krishnamurthy and Vissing-Jorgensen (2011), and Christensen and Rudebusch (2012) among others. These studies show that yields on longer-maturity Treasuries and other securities declined on days when the Fed announced it would increase its holdings of longer-term securities. Such announcement effects are thought to be related to the effects on market expectations about future monetary policy and declines in risk premiums on longer-term debt securities.

In this paper, we argue that, in addition to announcement effects, it is also possible for QE programs to affect yields by reducing priced frictions to trading as reflected in liquidity premiums through a liquidity channel.[1,2] This effect comes about because the operation of a QE program is tantamount to introducing into financial markets a large committed buyer who is averse to large asset price declines but does not mind price increases.[3] As a consequence, for the duration of the program, the most severe downside risk of the targeted securities is effectively eliminated and the shape of their price distributions is tweaked asymmetrically to the upside. We note that this tweak may not affect the first moment of the price distribution by much. However, since liquidity premiums represent investors' required compensation for assuming the risk of potentially having to liquidate long positions prematurely at significantly disadvantageous prices, the asymmetric twist to the asset price distributions of the targeted securities should reduce their liquidity premiums. By the same logic, liquidity premiums of securities *not* targeted by the QE program are not likely to be affected by the liquidity channel. Furthermore, while such liquidity effects in principle could extend beyond the operation of the QE program provided investors perceive future large declines in the prices of the targeted securities to be countered by additional central bank purchases, they are most likely to matter when the program is in operation.

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[1]This paper is an extension of the preliminary research described in Christensen and Gillan (2012).

[2]Gagnon et al. (2011) mention a liquidity, or market functioning, channel for the transmission of QE and stipulate a mechanism that has some similarities with the liquidity channel described in this paper, but they do not provide any empirical assessment of the importance of such a channel.

[3]For example, one repeatedly stated goal of the Fed's various asset purchases programs has been to put downward pressure on long-term interest rates or, equivalently, raise the prices of long-term bonds.

The importance of the liquidity channel for a targeted class of securities could depend on several factors. First, the effect should be positively correlated with the amount purchased relative to the total market value of the targeted class of securities. Second, the intensity of the purchases, that is, the length of time it takes to acquire a given amount of the targeted securities, could play a role as well. The more intense the purchases are, the more loss absorbing capacity a QE program may provide in any given moment and the greater the reductions in the assets' downside risks are likely to be. Finally, the size of the liquidity premiums in the targeted securities should matter. Since such liquidity premiums are widely perceived to be small in the deep and liquid Treasury bond market, it may explain why the liquidity channel has gone unnoticed in the existing literature on the effects of QE.

For evidence on the liquidity channel we analyze how the Fed's second QE program (henceforth QE2), which started in November 2010 and concluded in June 2011, affected the priced frictions to trading in the market for Treasury inflation-protected securities (TIPS) and the related market for inflation swap contracts. The execution of the QE2 program provides an interesting natural experiment for studying liquidity effects in these two markets because the program included repeated purchases of large amounts of TIPS.

To further motivate the analysis and support the view that liquidity premium reductions from the QE2 TIPS purchases could exist and matter, we note that the existence of TIPS liquidity premiums is well established. Fleming and Krishnan (2012) report market characteristics of TIPS trading that indicate smaller trading volume, longer turnaround time, and wider bid-ask spreads than are normally observed in the nominal Treasury bond market (see also Campbell et al. 2009, Dudley et al. 2009, Gürkaynak et al. 2010, and Sack and Elsasser 2004). However, the degree to which they bias TIPS yields remains a topic of debate because attempts to estimate TIPS liquidity premiums directly have resulted in varying results.[4] Instead, to quantify the effects of the TIPS purchases on the functioning of the market for TIPS and the related market for inflation swaps, we use a novel measure that represents the sum of TIPS and inflation swap liquidity premiums.[5] The construction of the measure only relies on the law of one price and it provides a good proxy for the priced frictions to trading in these two markets independent of the purchase program's effect on market expectations for economic fundamentals. As such, the measure is well suited to capture the changes in TIPS and inflation swap liquidity premiums that we are interested in.

Although we view the primary channel of how QE affects market liquidity as going through liquidity premiums, we note that other measures of market functioning could have been used. Kandrac and Schlusche (2013) analyze bid-ask spreads of regular Treasuries for evidence of

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[4]Pflueger and Viceira (2013), D'Amico et al. (2014), and Abrahams et al. (2015) are among the studies that estimate TIPS liquidity premiums.

[5]As a derivative whose pricing is tied to TIPS, inflation swaps are even less liquid and contain their own liquidity premiums for that reason.

any effects from the Treasury purchases during the various Fed QE programs, but do not find any significant results. Thus, they conclude that these purchases had no effect on the functioning of the Treasury bond market. In terms of the market for TIPS, the series of TIPS bid-ask spreads available to us do not appear to be reliable, as argued in Section 5. Thus, we do not pursue an analysis similar to theirs. Fleming and Sporn (2013) study trading activity, quote incidences, and other indicators of market activity in the inflation swap market. We choose to focus on our liquidity premium measure because it quantifies the frictions to trading in the TIPS and inflation swap markets as a yield difference rather than as quantities.

Still, it remains the case that QE may reduce the frictions to trading in a broader sense. As a consequence, we explore the impact on TIPS trading volumes in our empirical analysis and find positive effects. However, we acknowledge that, in general, large-scale asset purchases such as the QE2 program have the potential to impair market functioning by reducing the amount of securities available for trading.[6] In our case, though, the Fed's TIPS purchases during QE2 were not overly concentrated in any specific TIPS (as we document), and therefore there is little reason to suspect that this effect played any major role during the period under analysis, and our results are consistent with this view.

To analyze the effect of the TIPS purchases during QE2, our empirical strategy is to construct a counterfactual estimate of what our liquidity premium measure would likely have been without the TIPS purchases. To do so, we use linear regressions to establish the historical relationship that prevailed before the introduction of QE2 between our liquidity premium measure and a set of explanatory factors that are meant to control explicitly for other sources thought to affect either TIPS and inflation swap market liquidity, specifically, or bond market liquidity more broadly. Using these pre-QE2 estimated coefficients combined with the realization of the exogenous explanatory variables during the QE2 program gives us a counterfactual path of our liquidity premium measure. The difference with respect to the actual realization suggests that the liquidity effect of the purchases was sustained and had an interesting U-shaped pattern with a peak impact of more than 30 basis points near the middle of the program. For the duration of the QE2 program, the liquidity premium measure averaged 12 to 14 basis points lower than expected depending on maturity, a reduction of about 50 percent. We interpret this finding as indicating that part of the effect from QE programs derives from improvements in the market conditions for the targeted securities, and we emphasize that the results are robust to both the choice of sample period and the specification of the regressions.

To assess whether the liquidity channel affects liquidity premiums of securities *not* targeted by the QE2 program, we repeat the analysis using short-term credit spreads of AAA-rated

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[6]Kandrac (2013, 2014) provides evidence of such negative effects on market functioning in the context of the Fed's purchases of mortgage-backed securities.

industrial corporate bonds, an asset class that the Fed under normal circumstances is not allowed to acquire and hence could not possibly be expected to purchase. As the default risk of such highly rated bonds is negligible, their credit spreads mostly represent liquidity premiums and are useful for our purposes for that reason.[7] Consistent with the theory of the liquidity channel, which emphasizes QE programs' effects on the shape of the price distributions for the targeted securities, we obtain no significant results in this exercise. Although not conclusive as we only consider one alternative asset class, we take this as evidence that the transmission of the liquidity channel is indeed limited to the purchased security classes.

In a recent paper, D'Amico and King (2013, henceforth DK) emphasize local supply effects as an important mechanism for QE to affect long-term interest rates. Under this local supply channel declines in the stock of government debt available for trading induced by QE purchases should push up bond prices (temporarily) due to preferred habitat behavior on the part of investors. DK find evidence of such purchase effects in their analysis of the Treasury market response to the $300 billion of Treasury security purchases during the Fed's first QE program, which were announced on March 18, 2009, and concluded by October 30, 2009. They report an average decline in yields in the maturity segment purchased of 3.5 basis points on days when operations occurred. Meaning and Zhu (2011) repeat the analysis of DK for the purchases of regular Treasuries included in the QE2 program. They report that a typical QE2 purchase operation reduced Treasury yields by 4.7 basis points, while the cumulative stock effect of the entire program is estimated to be 20 basis points.

To analyze whether our results could be driven by local supply effects, we replicate the approach of DK to detect effects on individual TIPS prices from the TIPS purchases in the QE2 program. However, we fail to get any significant results, which suggests that local supply effects are not likely to be able to account for our findings.

To the best of our knowledge, this paper is the first to study the liquidity channel as a separate transmission mechanism for QE to affect long-term interest rates and to document that such liquidity effects are distinct from and more persistent than the local supply channel highlighted in the existing literature.

Our findings could have important policy implications. First, for assessing the credibility of the Fed's price stability goal, it is a frequent practice to study the difference in yield between regular Treasury bonds and TIPS of the same maturity, known as breakeven inflation (BEI).[8] Figure 1 shows daily five- and ten-year BEI since 2005, also highlighted is the operation of the QE2 program. During the period of its operation, BEI first experienced a sharp increase until

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[7]See Collin-Dufresne et al. (2001) for evidence and a discussion of the weak link between corporate bond credit spreads and their default risk, frequently referred to as the credit spread puzzle, and Christensen (2008) for an overview of related research.

[8]Since October 2014, such market-based measures of inflation compensation have been mentioned explicitly in FOMC statements.
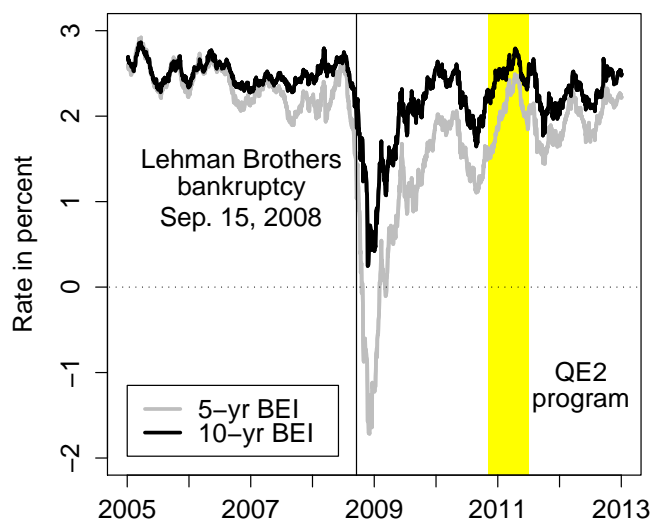
Figure 1: **TIPS Breakeven Inflation.**

the middle of the program followed by a notable downtick towards its end. Specifically, at the five-year maturity, BEI started at 1.51% on November 3, 2010, peaked at 2.49% on April 8, 2011, before retracing to 2.07% by the end of June 2011. At the ten-year maturity, BEI increased from 2.30% to 2.78% and fell back down to 2.59% between the same three dates. Based on our results, as much as one-third of the variation in BEI during this period could reflect effects arising from the QE2 TIPS purchases through the liquidity channel that, by definition, would have little to do with investors' inflation expectations or associated inflation risk premiums.[9] Thus, in determining how much the QE2 program helped boost investors' inflation expectations, it is crucial to account for the effects of the liquidity channel we unveil.

More generally, for central banks in countries with somewhat illiquid sovereign bond markets (most euro-area countries likely belong in this category), QE programs that target sovereign debt securities could be expected to reduce their liquidity premiums quite notably for the duration of the programs, which might be worthwhile to keep in mind when evaluating the effects of such QE programs. In this regard, we note that the TIPS market with a total outstanding notional of $1,078 billion as of the end of 2014 is quite comparable to the major European sovereign bond markets.[10] Thus, our analysis could provide a useful reference point

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[9]For the maximum effect of the liquidity channel on BEI to apply, it must be the case that there was no change in the liquidity premiums of inflation swaps in response to the QE2 TIPS purchases, a possibility our analysis allows for.

[10]As of December 31, 2014, the U.K. had £1,370 billion in marketable Treasury securities, the German federal government had €1,115 billion debt market instruments in circulation, the French government had

for understanding the effects of the liquidity channel in the European context.

Finally, since the Fed's TIPS purchases represented less than five percent of the TIPS market, our results suggest that even relatively modest QE programs could have large effects when the targeted security classes are illiquid.[11] Thus, the significance of the liquidity channel could matter for the design of QE programs; time frame, purchase pace, and targeted security classes are all decision variables that merit careful consideration under those circumstances.

The remainder of the paper is structured as follows. Section 2 discusses the channels of transmission of QE to long-term interest rates, paying special attention to the proposed liquidity channel. Section 3 details the execution of the TIPS purchases included in the QE2 program, while Section 4 describes the construction of the TIPS and inflation swap liquidity premium measure. Section 5 introduces the control variables we use in the empirical analysis, while Section 6 presents our results. Section 7 concludes the paper and provides directions for future research. Appendices contain additional results, a description of our adaptation of DK's approach, and an extension of our analysis to the TIPS transactions included in the Fed's maturity extension program (MEP) that operated from September 2011 through the end of 2012.

2 Transmission Channels of QE to Long-Term Rates

In this section, we first give a theoretical overview of how to think about QE and its effects on the economy. We then describe the three main channels of transmission of QE discussed in the existing literature before we introduce the novel liquidity channel that we highlight in this paper.

2.1 Theoretical Overview

Once a central bank has reduced its leading conventional policy rate to its effective lower bound, it may be forced to engage in QE to provide further monetary stimulus, if needed. This has been the reality facing several of the world's most prominent central banks in recent years.

This raises several questions relevant to monetary policy. One key question is how QE works and affects the real economic outcomes such as employment and inflation that policy-makers care about. This could matter for both design and management of QE programs and may ultimately have implications for how such programs should be wound down, a phase yet

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€1,528 billion in negotiable debt outstanding, the Italian government had €1,782 billion in outstanding debt, while the Spanish central government had €841 billion in debt.

[11]The large effects on mortgage rates of the Fed's purchases of mortgage-backed securities during its first large-scale asset purchase program, which Krishnamurthy and Vissing-Jorgensen (2011) partly attribute to improved market functioning and reduced liquidity premiums, provide another example.

to be reached by any of the major central banks that have engaged in QE.[12]

The main mechanism for QE to affect the real economy is through its impact on long-term interest rates, which are key variables in determining many important economic decisions ranging from firm investment on the business side to home and auto purchases on the household side of the economy. Therefore, to understand how QE works, we need to study its transmission channels to long-term interest rates.

At its core, QE is merely a redistribution of assets in the economy as the total outstanding stock of assets in private hands is left unchanged. In the US and the UK for example, QE has involved swapping medium- and long-term government-issued or government-backed securities for newly created reserves. In the aggregate, one could argue that not much has changed, in that one government-backed claim (Treasury securities) has been replaced by another (reserves that represent claims on the central bank, which is a branch of the government). Thus, the theoretical challenge in understanding the effects of QE is to identify conditions and circumstances under which this asset swap and the resulting change in private agents' portfolio compositions can have effects on long-term interest rates in equilibrium.

2.2 Signaling and Portfolio Balance Channels

The most straightforward way QE can affect long-term interest rates is by acting as a signaling device that changes agents' expectations about the future path for monetary policy. Christensen and Rudebusch (2012) and Bauer and Rudebusch (2014) are among the studies that emphasize the importance of the signaling channel for understanding the effects of QE.

Beyond potential signaling effects that would affect the yields of all securities, QE programs may change the supply of or demand for a given asset, which could affect its price and hence risk premium. Such effects are usually referred to as portfolio balance effects.[13] In a recent paper, Christensen and Krogstrup (2015) introduce a distinction between supply-induced and reserve-induced portfolio balance effects.

Both types of portfolio balance effects share some common characteristics. Their existence requires market frictions or segmentation to matter so that a change in the relative market supply of an asset can have an impact on its relative price in equilibrium (a mechanism that is absent in standard models of the yield curve). To provide a theoretical justification for such effects, the seminal model introduced in Vayanos and Vila (2009) is a frequent reference. This model suggests that, when assets with otherwise near-identical risk and return characteristics are considered imperfect substitutes by some market participants (e.g., due to preferred habitat) and markets are segmented, a change in the relative market supply of an

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[12]The unwind of the small bond purchase program operated by the Swiss National Bank in 2009 and exited in 2010 is a rare exception. See Kettemann and Krogstrup (2014) for details and an analysis.

[13]This division into signaling and portfolio balance effects is a simplification. See Bauer and Rudebusch (2014) for a thorough discussion.

asset may affect its relative price (see also Tobin, 1969).

Most of the existing literature on the impact of QE on yields has focused on supply-induced portfolio balance effects where the central bank asset purchases are treated as a reduction in the market supply of the targeted assets.[14] Assuming unchanged investor demand, the prices of the targeted securities should go up or, equivalently, their yields go down.

The reserve-induced portfolio balance channel described in Christensen and Krogstrup (2015) emphasizes instead the role of the reserves created by the central bank as part of any QE program. Provided the asset purchases are executed with nonbank financial market participants, the new reserves end up expanding banks' balance sheets with reserves on the asset side matched by increased deposits on the liability side. Since only banks can hold the reserves, this reduces the duration of their portfolios. Assuming banks had optimal portfolios before the central bank asset purchases, they increase their demand for long-term assets to counter the duration reduction, which pushes up these asset prices.

As a third channel for QE to affect bond yields, DK highlight local supply effects as a potentially important transmission mechanism. The principle behind this channel is that the individual purchase operations by the central bank represent small local reductions in the available supply of government debt. To a first order, such operations are small enough individually that they should not alter investors' preferences or portfolios. If so, the demand for government debt can be assumed constant around each purchase operation. Hence, any price effects from the purchases can be characterized as resulting from movements along demand curves.

2.3 The Liquidity Channel

The novel channel we propose in this paper is for QE to have effects on the liquidity premiums that investors demand to hold any security that is less than perfectly liquid.[15] To be specific, we think of the liquidity premium of a security as representing investors' required compensation for assuming the risk of potentially having to liquidate a long position in the security prematurely at a disadvantageous price, say, in a stressed market environment when market makers and arbitrageurs are severely capital constrained.

We argue that a central bank's launch of a QE program is equivalent to introducing into financial markets a committed buyer with deep pockets who is averse to large asset price declines and does not mind (in fact, actually desires) asset price increases, and will execute a trading strategy that attempts to ensure those outcomes. This effectively eliminates the most

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[14]Gagnon et al. (2011) and Joyce et al. (2011) are among the studies that emphasize this portfolio balance channel.

[15]A perfectly liquid security can be sold any time in arbitrarily small or large amounts at no trading costs (i.e., there is no bid-ask spread) and without affecting its price. A demand deposit is close to meeting these requirements if we abstract from the default risk of large deposits, which are not government guaranteed.

severe downside risk of the securities targeted by the QE program. As a consequence, the shape of their price distributions gets an asymmetric tweak to the upside in addition to any changes to its mean from the other QE transmission channels discussed above. Ultimately, this should lower the liquidity premiums of the targeted asset classes.

The importance of the liquidity channel for a given security class is likely to be determined by several factors. First, its effect should be positively correlated with the amount purchased relative to the total market value of the security class. Second, the intensity of the purchases, that is, the length of time it takes to purchase a given amount, could play a role as well. The more intense the purchases are, the greater is the ability of a given QE program to absorb negative liquidity shocks that force owners of targeted securities to sell and exert downward pressure on the securities' prices. As a consequence, the purchase pace should have a positive correlation with the reduction in liquidity premiums. Furthermore, the size of liquidity premiums in the targeted security classes should matter. Since such liquidity premiums are widely perceived to be small in the deep and liquid Treasury bond market, that may explain why the liquidity channel has been overlooked in the existing literature.

In terms of the dynamic profile of the effect of the liquidity channel, we note that, since liquidity premiums reflect fears about the *future* resale value of securities, its effect is likely to taper off some time before the purchases are scheduled to end. In principle, though, its effect could extend beyond the operation of the QE program if investors perceive that undesirable price developments in the targeted securities would make the central bank return to the market. Still, it is clear that the liquidity effects could be expected to be strongest when the QE program is committed and in operation.

Finally, it is important to emphasize that, for the liquidity channel and the associated liquidity effects to exist, no portfolio balance effects are needed; only financial market frictions are required. Ultimately, the existence and importance of the liquidity channel may be tied to theories of limits to arbitrage capital with market makers and arbitrageurs; see Hu, Pan, and Wang (2013, henceforth HPW) for a discussion.[16] However, we leave it for future research to establish any such ties.

2.4 Identification of Liquidity Effects

In order to empirically identify effects on long-term interest rates arising through the liquidity channel, two criteria must be met. First, we need a QE program that is large, includes repeated repurchases of securities less liquid than Treasuries, and operates over a period long enough that the fears of forced resales implicit in the definition of liquidity premiums can be meaningfully affected by the purchases. Second, we must have a suitable measure of the

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[16]See Brunnermeier and Pedersen (2009) and Pasquariello (2015) for examples of theoretical models where funding liquidity and informational frictions, respectively, may affect the workings of financial markets.

priced frictions in the markets for the purchased securities.

The Fed's QE2 program meets these criteria. First, this program was large, operated over an eight-month period, and included repeated purchases of a significant amount of TIPS, which are widely perceived to be less liquid than Treasuries. Second, we devise a measure of the priced frictions in TIPS yields and inflation swap rates detailed in Section 4 that we can use to detect evidence of the liquidity channel. Still, in trying to identify effects from the liquidity channel, we acknowledge that signaling, portfolio balance, and local supply effects could be operating as well.

In principle, effects of the signaling, portfolio balance, and liquidity channels should materialize immediately following the announcement of the QE2 program and not when it is implemented thanks to the forward-looking behavior of investors. As a consequence, we look for effects related to the announcement of the program on November 3, 2010, but fail to detect any significant yield responses as documented in Appendix A. More likely, announcement effects tied to these channels materialized in the weeks and months ahead of the launch of the QE2 program as argued by Krishnamurthy and Vissing-Jorgensen (2011). Furthermore, the signaling and portfolio balance channels are thought to mainly affect the policy expectations and term premium components of bond prices, which should cancel out in the construction of our liquidity premium measure. Thus, neither of these channels are likely to be the drivers of our results. For our analysis, the key implication is that the results we report are likely to be lower bound estimates of the importance of the liquidity channel.

To address the local supply channel, we replicate the analysis of DK in an attempt to identify local supply effects in individual TIPS prices, but fail to get any significant results as documented in Appendix B. However, this may not be as surprising as it could seem. First, we argue that their regressions suffer from misspecified time fixed effects. Second and more importantly, the mechanics of the liquidity channel suggest that its effects are not limited to any specific security, but would apply to all securities at risk of being targeted by the QE program. For that reason these effects may go undetected in the type of analysis performed by DK that focuses on identifying local supply effects in individual security prices on purchase operation dates.

With signaling, portfolio balance, and local supply channels ruled out as important drivers of the variation in our measure of liquidity premiums in TIPS yields and inflation swap rates during the QE2 program, we turn our focus to the proposed liquidity channel. The remainder of the paper is dedicated to analyzing whether the TIPS purchases in the QE2 program had any effects on our liquidity premium measure consistent with this channel.

3   The TIPS Purchases in the QE2 Program

In this section, we provide a brief description of the Federal Reserve's QE2 program that included purchases of a sizable amount of TIPS.

The QE2 program was announced on November 3, 2010.[17] In its statement, the Federal Open Market Committee (FOMC) said that the program would expand the Fed's balance sheet by $600 billion through Treasury security purchases over approximately an eight-month period.[18] In addition, the FOMC had already decided in August 2010 to reinvest principal payments on its portfolio of agency debt and mortgage-backed securities in longer-term Treasury securities in order to maintain the size of the Fed's balance sheet, a policy that was maintained until September 2011.[19] As a consequence, the gross purchases of Treasury securities from November 3, 2010, until June 29, 2011, totaled nearly $750 billion, of which TIPS purchases represented about $26 billion.[20]

The uniqueness of these TIPS purchases is evident in Figure 2(a), which shows the total book value of the Fed's TIPS holdings since 2008.[21] They increased the Fed's holdings by 52.8 percent and brought the total close to $75 billion.[22] Figure 2(b) shows the market share of individual TIPS held by the Fed at the beginning of the QE2 program and at its conclusion with thin solid red lines indicating the change for each TIPS.[23] Note that the purchases were not heavily concentrated in any particular TIPS, and the Fed's TIPS holdings as a percentage of the stock of each security in general remained well below one-third.

The QE2 program was implemented with a very regular schedule. Once a month, the Fed publicly released a list of operation dates for the following 30-plus day period, indicating the relevant maturity range and expected purchase amount for each operation.[24]   There

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[17]See http://www.federalreserve.gov/newsevents/press/monetary/20101103a.htm.

[18]As of November 3, 2010, the securities held outright by the Fed totaled $2.040 trillion. By June 29, 2011, that number had increased to $2.637 trillion. In addition, on June 30, 2010, the Fed purchased another $4.9 billion of Treasury securities. Thus, by the conclusion of QE2, the actual expansion of the securities holdings was very close to the originally announced $600 billion. These data are from weekly H.4.1 releases of factors affecting reserves balances (see http://www.federalreserve.gov/releases/h41/) and do not include any unamortized premiums.

[19]The Fed has all along reinvested principal payments on its portfolio of Treasury securities in Treasuries. Since September 2011, the Fed has been reinvesting principal payments on its portfolio of agency debt and mortgage-backed securities in agency mortgage-backed securities to support the housing market.

[20]According to http://www.treasurydirect.gov, the total amount of marketable Treasury debt increased by $792 billion between the end of October 2010 and the end of June 2011. Thus, the Fed's Treasury purchases during this period nearly kept pace with the Treasury net issuance. In terms of TIPS, the net supply increased by $61 billion so that the Fed's purchases only represented an amount equal to 42 percent of the new supply.

[21]The Fed has purchased TIPS outside the QE2 program, most notably during the MEP that ran from September 2011 through 2012. The effects of these TIPS transactions are analyzed separately in Appendix D.

[22]The slight decline in mid-April 2011 is due to a maturing five-year TIPS of which the Fed was holding $2.9 billion in principal and $327 million in accrued inflation compensation.

[23]Note that a total of three TIPS were issued during the QE2 program; the five-year 4/15/2016 TIPS issued on April 29, 2011, the ten-year 1/15/2021 TIPS issued on January 31, 2011, and the thirty-year 2/15/2041 TIPS issued on February 28, 2011. As of June 29, 2011, the Fed was only holding the two latter securities.

[24]The information can be found at http://www.newyorkfed.org/markets/tot_operation_schedule.html.
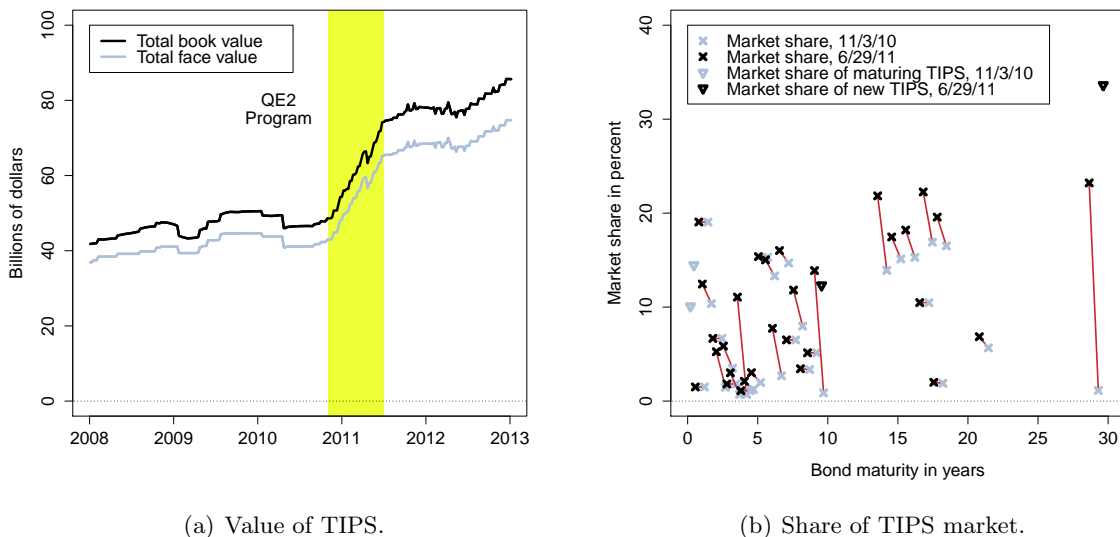
(a) Value of TIPS.

(b) Share of TIPS market.

Figure 2: **Fed's TIPS Holdings.**
Panel (a) shows the total book and face value of TIPS held in the Federal Reserve System's Open Market Account (SOMA). The difference between the two series reflects accrued inflation compensation. The data are weekly covering the period from January 2, 2008, to December 26, 2012. Panel (b) shows the market share of individual TIPS held by the Fed at the start of QE2 and at its conclusion with thin solid red lines indicating the change in the shares held. Note that two TIPS held as of November 3, 2011, matured before the end of the program, and two new TIPS were issued during the program and acquired by the Fed.

were 15 separate TIPS operation dates, fairly evenly distributed across time, each with a stated expected purchase amount of \$1 billion to \$2 billion. Table 1 lists the 15 operation dates, the total purchase amounts, and the weighted average maturity of the TIPS purchased. TIPS were the only type of security acquired on these dates, and the Fed did not buy any TIPS outside of those dates over the course of the program.[25] Furthermore, all outstanding TIPS with a minimum of two years remaining to maturity were eligible for purchase on each operation date and, as shown in Figure 2(b), the Fed did purchase TIPS across the entire indicated maturity range. Thus, there does not appear to be a need to account for price movements of specific securities related to the release of the operation schedules. Finally, market participants did not know in advance either the total amount to be purchased or the distribution of the purchases.[26] However, the auction results containing this information were released a few minutes after each auction. As the auctions closed at 11:00 a.m. Eastern time, investors had sufficient time to process the information before the close of the market on each

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[25]Also, there were no TIPS auctions by the US Treasury on any of the Fed's 15 TIPS operation dates. See Lou et al. (2013) for analysis of the effects of auctions in the regular nominal Treasury bond market.

[26]Obviously, since the actual purchase amounts all fall in the range from \$1.589 billion to \$2.129 billion, investors' perceived uncertainty about the total purchase amounts likely was lower than the width of the indicated range.

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QE2 TIPS purchase operation dates	TIPS purchases (mill.)	Weighted avg. maturity (years)
(1) Nov. 23, 2010	$1,821	9.43
(2) Dec. 8, 2010	$1,778	8.88
(3) Dec. 21, 2010	$1,725	16.09
(4) Jan. 4, 2011	$1,729	16.98
(5) Jan. 18, 2011	$1,812	14.64
(6) Feb. 1, 2011	$1,831	13.58
(7) Feb. 14, 2011	$1,589	14.16
(8) Mar. 4, 2011	$1,589	11.37
(9) Mar. 18, 2011	$1,653	17.77
(10) Mar. 29, 2011	$1,640	18.29
(11) Apr. 20, 2011	$1,729	23.17
(12) May 4, 2011	$1,679	13.62
(13) May 16, 2011	$1,660	20.49
(14) Jun. 7, 2011	$1,589	14.30
(15) Jun. 17, 2011	$2,129	5.98
Average	$1,730	14.58

Table 1: **QE2 TIPS Purchase Operations.**
The table reports the amount and weighted average maturity of TIPS purchased on the 15 TIPS operation dates during the QE2 program.

operation date.[27]

4 A Measure of Liquidity Premiums in TIPS and Inflation Swaps

In this section, we describe the measure of liquidity premiums in TIPS yields and inflation swap rates that we use as a dependent variable in our empirical analysis.

Ideally, we would have liked to use a pure measure of liquidity premiums in TIPS yields in our analysis. However, empirically, it is very challenging to separate liquidity premiums from other factors that affect TIPS yields such as expectations for monetary policy and inflation. Instead, we combine the information in Treasury yields, TIPS yields, and inflation swap rates to get a handle on the size of the liquidity premiums in TIPS yields and inflation swap rates jointly as explained in the following.

To begin, note that, unlike regular Treasury securities that pay fixed coupons and a fixed nominal amount at maturity, TIPS deliver a real payoff because their principal and coupon

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[27]It is this structure of the execution of the TIPS purchases in the QE2 program that makes it a natural candidate for detecting local supply effects as we attempt in Appendix B.

payments are adjusted for inflation.[28] The difference in yield between regular nominal, or non-indexed, Treasury bonds and TIPS of the same maturity is referred to as breakeven inflation, since it is the level of inflation that makes investments in indexed and non-indexed bonds equally profitable.

In an inflation swap contract, the owner of a long position pays a fixed premium in exchange for a floating payment equal to the change in the consumer price index used in the inflation indexation of TIPS. At inception, the fixed premium is set such that the contract has a value of zero.

Since the cash flows of TIPS and inflation swaps are adjusted with the same price index, economic theory implies a connection between their pricing. Specifically, in a frictionless world, the absence of arbitrage opportunities requires the inflation swap rate to equal BEI because buying one nominal discount bond today with a given maturity produces the same cash flow as buying one real discount bond of the same maturity and selling an inflation swap contract also of the same maturity. However, in reality, the trading of both TIPS and inflation swap contracts is impeded by frictions, such as wider bid-ask spreads and less liquidity relative to the market for regular nominal Treasury bonds. As a consequence, the difference between inflation swap rates and BEI will not be zero, but instead represents a measure of how far these markets are from the frictionless outcome described above.[29]

To map this to our data, we observe a set of nominal and real Treasury zero-coupon bond yields denoted $\widehat{y}_t^N(\tau)$ and $\widehat{y}_t^R(\tau)$, respectively, where τ is the number of years to maturity. Also, we observe a corresponding set of rates on zero-coupon inflation swap contracts denoted $\widehat{IS}_t(\tau)$. As noted above, these rates differ from the unobserved values that would prevail in a frictionless world without any obstacles to continuous trading denoted $y_t^N(\tau)$, $y_t^R(\tau)$, and $IS_t(\tau)$, respectively, with the theoretical relationship:

$$IS_t(\tau) = y_t^N(\tau) - y_t^R(\tau).$$

Now, we make three fundamental assumptions:

(1) The nominal Treasury yields we observe are very close to the unobservable frictionless nominal yields, that is, $\widehat{y}_t^N(\tau) = y_t^N(\tau)$ for all t and all relevant τ. Even if not exactly true (say, for example, during the financial crisis), this is not critical as the point is ultimately about the relative liquidity between securities that pay nominal and real yields.

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[28]The US Treasury uses the change in the headline consumer price index (CPI) without seasonal adjustment to account for inflation compensation in TIPS.

[29]Note that, due to collateral posting, the credit risk in inflation swap contracts is negligible and can be neglected for pricing purposes. Also, we assume the default risk of the US government to be negligible, which is warranted for our sample that ends in June 2011 before the downgrade of US Treasury debt in August 2011. However, even for this later period, which we consider in our analysis of the Fed's MEP described in Appendix D, any significant credit risk premium is not likely to bias our measure as it would presumably affect Treasury and TIPS yields in the same way, leaving BEI effectively unchanged.

(2) TIPS are no more liquid than nominal Treasury bonds. As a consequence, TIPS yields contain a time-varying liquidity premium denoted $\delta_t^R(\tau)$, which generates a wedge between the observed TIPS yields and their frictionless counterpart given by $\widehat{y}_t^R(\tau) = y_t^R(\tau) + \delta_t^R(\tau)$ with $\delta_t^R(\tau) \geq 0$ for all t and all relevant τ.

(3) Inflation swaps are no more liquid than nominal Treasury bonds. Hence, the observed inflation swap rates are also different from their frictionless counterpart with the difference given by $\widehat{IS}_t(\tau) = IS_t(\tau) + \delta_t^{IS}(\tau)$ and $\delta_t^{IS}(\tau) \geq 0$ for all t and all relevant τ.

In support of these assumptions, we note that market size, trading volume, and bid-ask spreads all indicate that regular Treasury securities are much more liquid than both TIPS and inflation swaps.[30] It then follows that the difference between observed inflation swap and BEI rates, which defines our liquidity premium measure, is given by

$$
\begin{aligned}
LP_t(\tau) &\equiv \widehat{IS}_t(\tau) - \widehat{BEI}_t(\tau) \\
&= \widehat{IS}_t(\tau) - [\widehat{y}_t^N(\tau) - \widehat{y}_t^R(\tau)] \\
&= IS_t(\tau) + \delta_t^{IS}(\tau) - [y_t^N(\tau) - (y_t^R(\tau) + \delta_t^R(\tau))] \\
&= \delta_t^R(\tau) + \delta_t^{IS}(\tau) \geq 0.
\end{aligned}
$$

This shows that $LP_t(\tau)$ is nonnegative and equal to the *sum* of liquidity premiums in TIPS yields and inflation swap rates. Hence, $LP_t(\tau)$ quantifies how far the observed market rates are from the frictionless outcome.

4.1 Construction of the Liquidity Premium Measure

We use daily estimates of zero-coupon nominal and real Treasury bond yields as constructed by Gürkaynak et al. (2007, 2010) for our observed bond yields. For the inflation swap rates, we use daily quotes from Bloomberg. These rates are for zero-coupon inflation swap contracts, meaning they have no exchange of payment upon issuance and a single cash flow exchanged at maturity. The quoted rates represent the payment of the fixed leg at an annual rate, which we convert into continuously compounded rates using the formula $\widehat{IS}_t^c(\tau) = \ln(1 + \widehat{IS}_t(\tau))$ to make them comparable to the other interest rates. Bloomberg begins reporting quotes on inflation swap rates in early 2004, but the data are not densely populated until the end of the year. As a result, we begin the sample period on January 4, 2005, and end it on December 31, 2012, when the MEP was completed. Finally, we eliminate the few days during the sample period where quotes are not available for all maturities, which leaves us with a sample of 1,977 observations.

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[30]Driessen et al. (2014) find statistically significant liquidity effects in both TIPS yields and inflation swap rates.
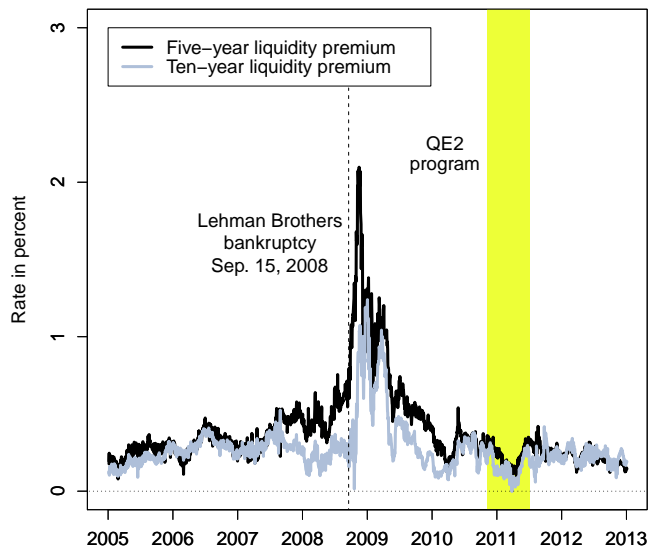
Figure 3: **Sum of Liquidity Premiums in TIPS and Inflation Swaps.**

Figure 3 shows $LP_t(\tau)$ at the five- and ten-year maturity. In the empirical analysis, we aim to quantify the liquidity effects of the TIPS purchases on the priced frictions in the markets for TIPS and inflation swaps as reflected in our liquidity measure. Importantly, in the construction of the measure, any effects of the QE2 program on bond investors' views of economic fundamentals, such as future monetary policy, inflation, and their implications for bond yields, will cancel out as they affect inflation swap rates and BEI of the same maturity equally. This is also the reason why the measure is likely affected to a minimum by signaling and portfolio balance effects.

5 Control Variables

In this section, we describe the four variables we use to control explicitly for sources that reflect either TIPS and inflation swap market liquidity, specifically, or bond market liquidity more broadly.

The first variable we consider is the VIX options-implied volatility index. It represents near-term uncertainty about the general stock market as reflected in options on the Standard & Poor's 500 stock price index and is widely used as a gauge of investor fear and risk aversion. The motivation for including this variable is that elevated economic uncertainty would imply increased uncertainty about the future resale price of any security and therefore could cause

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Figure 4: **The VIX Options-Implied Volatility Index for the S&P 500.**
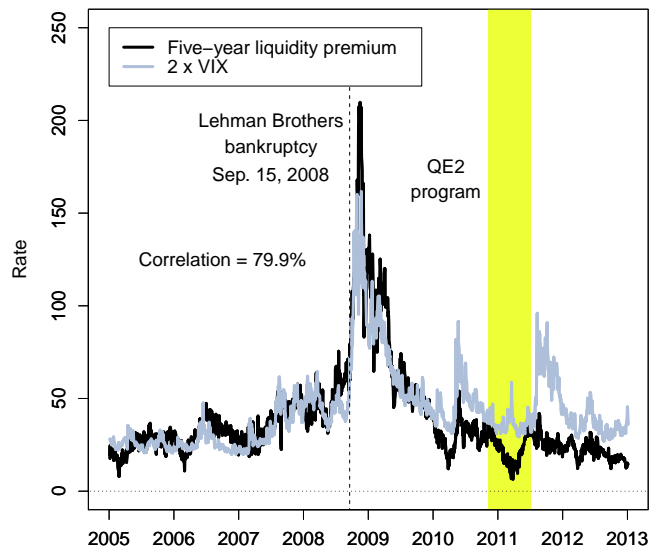Illustration of the VIX options-implied volatility index for the S&P 500 stock price index with a comparison to the five-year liquidity premium measure. Note that the former is measured in percent and multiplied by two to make its scale comparable to the latter, which is measured in basis points.

liquidity premiums that represent investors' guard against such uncertainty to go up. As shown in Figure 4, the VIX has a high, positive correlation with our liquidity premium measure as expected.

The second variable included is a market illiquidity measure introduced in the recent paper by HPW.[31] They demonstrate that deviations in bond prices in the Treasury securities market from a fitted yield curve represent a measure of noise and illiquidity caused by limited availability of arbitrage capital. Their analysis suggests that this measure is a priced risk factor across several financial markets, which they interpret to imply that it represents an economy-wide illiquidity measure that should affect all financial markets. If so, this should include the markets for TIPS and related derivatives such as inflation swaps. Indeed, Figure 5 shows that the HPW illiquidity measure tracks our five-year liquidity premium measure very closely. This suggests a very tight connection between these two measures of market frictions.

The third variable used is the yield difference between seasoned (off-the-run) Treasury securities and the most recently issued (on-the-run) Treasury security of the same maturity.[32]

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[31]The data are publicly available at Jun Pan's website: https://sites.google.com/site/junpan2/publications.
[32]We do not construct off-the-run spreads for the TIPS market since Christensen et al. (2012) show that such spreads have been significantly biased in the years following the peak of the financial crisis due to the value of the deflation protection option embedded in the TIPS contract.

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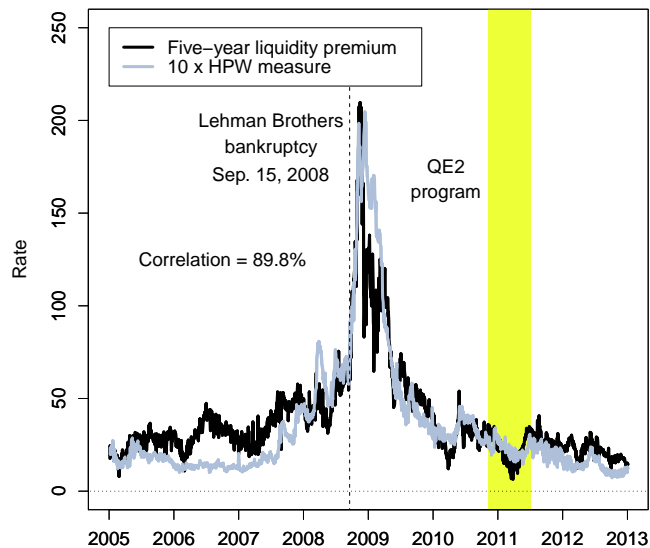
Figure 5: **The HPW Illiquidity Measure.**
Illustration of the measure of systemic or economy-wide financial market illiquidity introduced in HPW with a comparison to the five-year liquidity premium measure. Note that the former has been multiplied by ten to make its scale comparable to the latter, but both are measured in basis points.

Figures 6(a) and 6(b) illustrate these series at the five- and ten-year maturities, respectively. In each case, the off-the-run spread is compared to the corresponding liquidity premium measure of the same maturity, and in our regressions, we also match the maturity in this way. For each maturity segment in the Treasury yield curve, the on-the-run security is typically the most traded security and therefore penalized the least in terms of liquidity premiums, which explains the mostly positive spread. For our analysis, the important thing to note is that if there is a wide yield spread between liquid on-the-run and comparable seasoned Treasuries, we would expect to also see large liquidity premiums in TIPS yields and inflation swap rates relative to those in the Treasury bond market, that is, a widening of our liquidity premium measure.

The fourth variable considered is the bid-ask spreads of TIPS and inflation swap contracts. The microstructure frictions that such spreads represent could potentially account for part of the variation in our liquidity premium measure and we want to control for that effect. Figure 7 shows the four-week moving average of bid-ask spreads as reported by Bloomberg for the most recently issued five- and ten-year TIPS and the bid-ask spreads of inflation swap contracts with the same two maturities from the same source. While the bid-ask spreads of the inflation swap contracts exhibit reasonable time variation at a level consistent with numbers reported

(a) Five-year maturity.

(b) Ten-year maturity.
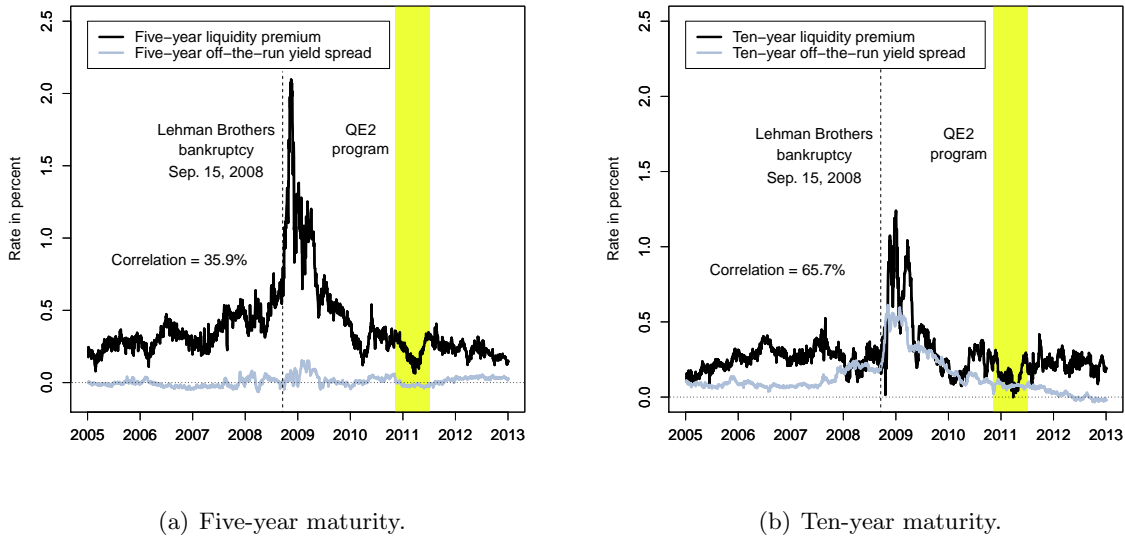
Figure 6: **Off-the-Run Treasury Par-Yield Spreads.**
Panel (a) illustrates the yield spread between the five-year off-the-run Treasury par yield from the Gürkaynak et al. (2007) database and the five-year on-the-run Treasury par yield from the H.15 series at the Board of Governors. Included is the five-year TIPS and inflation swap liquidity premium. Panel (b) illustrates the corresponding series at the ten-year maturity.

elsewhere,[33] the bid-ask spreads for the TIPS appear suspiciously low and stable before the spring of 2011.[34] For this reason we only include the bid-ask spreads for the inflation swaps in our regressions, and similar to what we did with the off-the-run yield spreads, we use the five- and ten-year bid-ask spreads in the five- and ten-year liquidity premium regressions, respectively.

By including these four control variables, the regression results should provide a fair assessment of the effect the QE2 TIPS purchases had on our measure of TIPS and inflation swap liquidity premiums.

6 Empirical Results

In this section, we first present empirical results from a set of standard regressions that document the explanatory power of the control variables for the variation in our liquidity premium measure. Since we have ruled out the local supply channel as documented in Appendix B, we start out looking for more persistent effects consistent with the liquidity channel by using

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[33]For example, these numbers are close to the order of transaction costs in the inflation swap market reported by Fleckenstein et al. (2014) based on conversations with traders.

[34]Haubrich et al. (2012) report bid-ask spreads for ten-year TIPS, which are higher than the Bloomberg data, in particular around the peak of the financial crisis in the fall of 2008 and early 2009. Unfortunately, their series ends in May 2010 and cannot be used for our analysis.
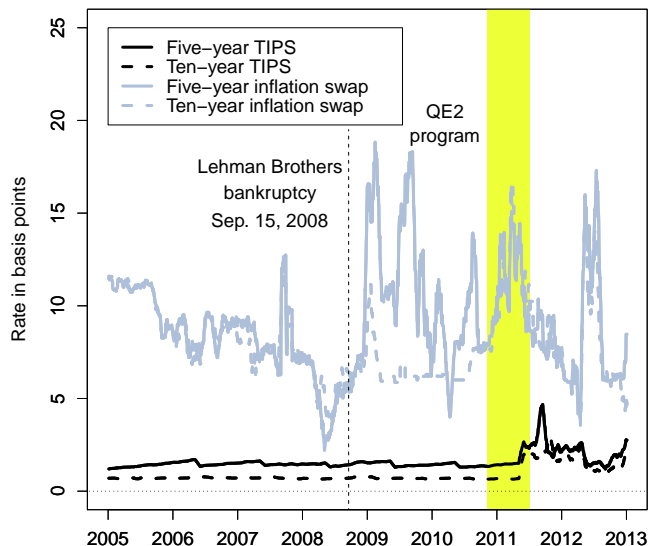
Figure 7: **Bid-Ask Spreads in the TIPS and Inflation Swap Markets.**
Illustration of the bid-ask spread as reported by Bloomberg for the most recently issued, or so-called on-the-run, five- and ten-year TIPS. Shown are also the bid-ask spreads from the inflation swap market for the five- and ten-year zero-coupon inflation swap contracts. All series are smoothed four-week moving averages and measured in basis points.

regressions that impose a switch in the conditional mean following the announcement of the QE2 program. We find a downward shift in the mean that is statistically significant and proceed to a counterfactual analysis that aims at quantifying what our liquidity premium measure would likely have been without the QE2 TIPS purchases. After having documented a reduction in the priced frictions in the markets for TIPS and inflation swaps during the period QE2 operated, we provide evidence of its positive effects on TIPS trading volumes. We then go on to repeat our analysis using short-term credit spreads of AAA-rated industrial corporate bonds to study whether the effects of the liquidity channel extend beyond the targeted securities. We end the section by entertaining the possibility of the European sovereign debt crisis as an alternative explanation for our results.

6.1 Standard Regressions

To begin, we run standard regressions with our liquidity premium measure as the dependent variable on the four explanatory variables described in the previous section. The results from these regressions are reported in Table 2, with the top and bottom panels referring to the five- and ten-year maturity, respectively.

Explanatory variables	Dependent variable: Five-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-5.59**	15.28**	40.95**	37.67**	5.16**	4.19**
	(-7.24)	(32.18)	(64.76)	(15.72)	(6.50)	(3.37)
VIX	2.24**				0.93**	1.04**
	(69.99)				(15.37)	(17.57)
HPW measure		6.94**			4.44**	4.80**
		(78.46)			(24.32)	(26.73)
Off-the-run spread			3.96**			-1.11**
			(22.06)			(-10.28)
IS bid-ask spread				0.50*		-0.27**
				(2.04)		(-2.62)
Adjusted R^2	0.75	0.79	0.23	0.00	0.82	0.83

Explanatory variables	Dependent variable: Ten-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	7.53**	15.57**	13.37**	45.02**	15.85**	15.53**
	(10.39)	(35.35)	(25.49)	(27.69)	(20.09)	(8.99)
VIX	0.99**				-0.03	-0.06
	(32.90)				(-0.43)	(-1.03)
HPW measure		3.37**			3.44**	3.03**
		(41.04)			(18.95)	(12.19)
Off-the-run spread			0.97**			0.17*
			(36.86)			(2.39)
IS bid-ask spread				-2.03**		0.01
				(-10.39)		(0.05)
Adjusted R^2	0.40	0.51	0.46	0.06	0.51	0.51

Table 2: **Results of Standard Regressions.**
The top panel reports the results of standard regressions with the TIPS and inflation swap liquidity premium measure at the five-year maturity as the dependent variable and four measures of market functioning as explanatory variables. The bottom panel reports the corresponding results when the ten-year liquidity premium measure is the dependent variable. T-statistics are reported in parentheses. Asterisks * and ** indicate significance at the 5 percent and 1 percent levels, respectively. The data are daily covering the period from January 4, 2005, to June 30, 2011, a total of 1,604 observations.

In the individual regressions (1) to (4), the explanatory factors have the expected sign with a single exception at the ten-year maturity, where the inflation swap bid-ask spread has a negative coefficient. Thus, as anticipated, positive changes in both the VIX and the off-the-run yield spread are associated with increases in the liquidity premium measures. More importantly, though, it is clear from regression (6), which is considered the baseline regression in the remainder of the section, that the HPW measure has the strongest explanatory power of the four considered variables as it remains highly statistically significant at both maturities even when all variables are included. In contrast, the estimated coefficients of the other variables are much reduced, several lose significance, and some even switch sign. This suggests that they are marginal factors in explaining the variation in the liquidity premium measure

once the contribution of the HPW measure is accounted for.

6.2 Regressions with a Switch in the Conditional Mean

The mechanics of the liquidity channel described in Section 2.3 suggest that the TIPS purchases included in the QE2 program should reduce the liquidity premiums of TIPS, and as a derivative priced off of TIPS, the liquidity premiums of inflation swaps are likely to be negatively affected as well. Both effects would show up as a reduction in our liquidity premium measure.

To test whether, indeed, there were such negative effects consistent with the liquidity channel on our liquidity premium measure, we run regressions that impose a switch in the conditional mean following the announcement of the QE2 program, that is, we use the same four explanatory variables as before but allow the constant term to take on one value for the pre-QE2 announcement period and another value for the post-QE2 announcement period.

Table 3 reports the results from these regressions. First, we note the large increase in the adjusted R^2 values relative to the results reported in Table 2 without a switch in the conditional mean. Second, for the four explanatory variables, there are only minor changes to their estimated coefficients from imposing the switch in the conditional mean. This supports the choice not to allow for any switch in their effects on the liquidity premium measure. Third, the difference in the estimated constant terms represents a measure of the persistent negative effect of the QE2 TIPS purchases on our liquidity premium measure. At the five-year maturity, these differences range from -9.98 basis points to -24.41 basis points, while the differences at the ten-year maturity range from -5.84 basis points to -10.98 basis points.

Finally, the hypothesis that there was no change in the constant term following the announcement of the QE2 program can be tested with a standard test that follows the $F(1,N–p–1)$-distribution, where N is the number of observations and p is the number of parameters in the unrestricted regression. These tests are rejected by the data at both maturities.[35] Although not a strong test, the results still suggest that the TIPS purchases in the QE2 program led to a persistent shift down in the conditional mean of our liquidity measure.

6.3 Counterfactual Analysis

To better understand the timing and source(s) of the effects of the QE2 program that are behind the downward shift in the mean of our liquidity premium measure documented above, we perform a counterfactual analysis. For this purpose, we use the baseline regression (6) in Table 2 with all four control variables included, but estimate the coefficients on the sample ending on November 2, 2010, the day before the announcement of the QE2 program. By

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[35]At the five-year maturity, the six test sizes range from 49.25 to 178.92, while the test sizes at the ten-year maturity are in the range from 29.73 to 104.32.

Explanatory variables	Dependent variable: Five-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant pre-QE2 announcement	-3.28** (-4.34)	16.78** (34.32)	42.53** (64.22)	35.15** (15.08)	6.28** (8.16)	1.98 (1.66)
Constant post-QE2 announcement	-17.72** (-14.81)	6.80** (6.73)	27.97** (14.33)	10.74** (3.10)	-5.00** (-4.29)	-11.00** (-6.71)
VIX	2.20** (71.89)				0.98** (16.85)	1.12** (19.79)
HPW measure		6.82** (78.29)			4.16** (23.48)	4.53** (26.44)
Off-the-run spread			3.74** (20.77)			-1.33** (-12.77)
IS bid-ask spread				1.04** (4.28)		0.06 (0.58)
Adjusted R^2	0.93	0.94	0.76	0.70	0.95	0.95

Explanatory variables	Dependent variable: Ten-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant pre-QE2 announcement	9.29** (12.83)	16.85** (36.99)	14.50** (25.91)	40.66** (23.19)	16.70** (21.47)	9.94** (5.56)
Constant post-QE2 announcement	-1.69 (-1.48)	8.34** (8.86)	8.66** (8.60)	30.94** (11.14)	8.17** (6.93)	-0.69 (-0.28)
VIX	0.96** (32.80)				0.01 (0.24)	0.06 (0.93)
HPW measure		3.27** (38.80)			3.23** (18.01)	3.04** (12.53)
Off-the-run spread			0.94** (34.95)			0.06 (0.90)
IS bid-ask spread				-1.36** (-6.17)		0.72** (4.19)
Adjusted R^2	0.85	0.87	0.86	0.75	0.87	0.88

Table 3: **Results of Regressions with a Switch in Conditional Mean.**
The top panel reports the results of regressions with the TIPS and inflation swap liquidity premium measure at the five-year maturity as the dependent variable and four measures of market functioning as explanatory variables in addition to a constant term that is allowed to switch value following the announcement of the QE2 program on November 3, 2011. The bottom panel reports the corresponding results when the ten-year liquidity premium measure is the dependent variable. T-statistics are reported in parentheses. Asterisks * and ** indicate significance at the 5 percent and 1 percent levels, respectively. The data are daily covering the period from January 4, 2005, to June 30, 2011, a total of 1,604 observations.

fixing the coefficients at those estimated values and using the subsequent realizations of the four control variables, we get an estimate of the most likely counterfactual path for our liquidity premium measure, had the QE2 program not included TIPS purchases. In spirit, this exercise is close to Gagnon et al. (2011), who estimate a regression model of the ten-year term premium over the period from January 1985 to June 2008 and use it to assess the term premium effect of the Fed's first QE program that operated from November 2008 to March 2010. In a similar vein, Li and Wei (2013) estimate a dynamic term structure model with
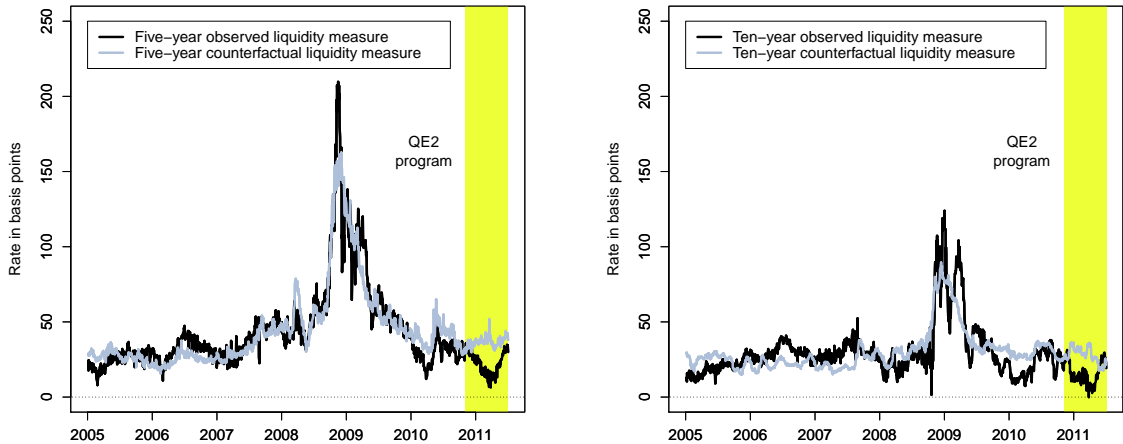
(a) Five-year liquidity premium measures.　　　　(b) Ten-year liquidity premium measures.

Figure 8: **Observed and Counterfactual Liquidity Premium Measures.**

supply factors on data from March 1994 to July 2007 and use the estimated factor loadings to evaluate the term premium effects of the Fed's QE1, QE2, and MEP.

Figure 8 shows the realized liquidity premium measure at the five- and ten-year maturities as well as the corresponding estimated counterfactual paths constructed in this way.[36] As noted in the figure, there is a sizable wedge between the counterfactual path and the actual realization during the period from November 3, 2010, until June 30, 2011. Importantly, this counterfactual differs from a more ambitious counterfactual analysis of what would have happened without the introduction of the entire QE2 program. One key difference is that the QE2 program likely affected the controlling bond liquidity variables we use. However, for the narrow question about the effect of the TIPS purchases, which accounted for less than 5 percent of the total QE2 program, we can relatively safely assume that the control measures would not have been much different without the TIPS purchases.

Figure 9 puts the difference between the actual realization and the counterfactual path into sharper focus for the duration of the QE2 program. Our counterfactual exercise indicates that the average of our liquidity premium measure would have been 13.50 and 12.14 basis points higher over the period of the QE2 purchase program at the five- and ten-year maturities, respectively. In particular, the measure would have been more than 30 basis points higher during the middle third of the program, which coincides with turmoil about sovereign debt in southern peripheral countries in the euro area that would normally have

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[36]The estimated coefficients from these regressions are reported in Appendix C. We note that the estimated coefficients for the explanatory variables are very similar to the ones reported in Table 3 based on the full sample with a switch in the conditional mean.
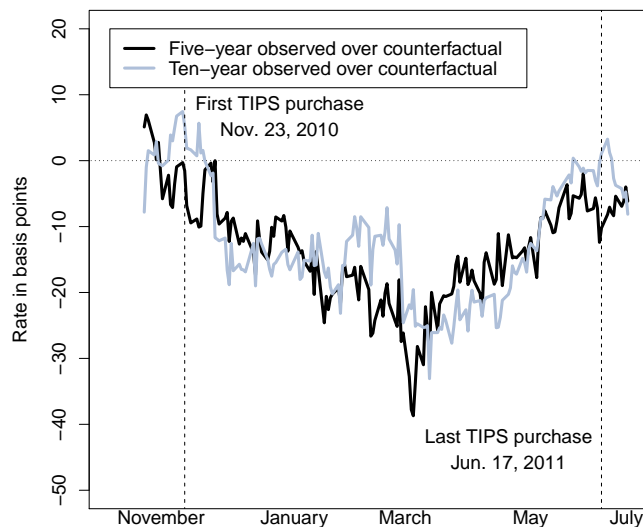
Figure 9: **Difference between Observed and Counterfactual Liquidity Premium Measures.**
Illustration of the difference between the observed and counterfactual TIPS liquidity premium measure at the five- and ten-year horizons, respectively. The sample shown covers the period from November 3, 2010, to June 30, 2011.

pushed our liquidity premium measure higher. Interestingly, the realized measure declines relative to the counterfactual over the first third of the program and then increases back to its level at the program start in a fairly symmetric fashion, indicating that market participants repeatedly priced the liquidity premiums of TIPS and inflation swaps lower for the first half of the program before gradually returning to pre-program levels. Furthermore, the estimated coefficients and fit for the pre-program period are consistent with those for the entire sample, confirming the robustness of the counterfactual construction.

To provide context for the difference between the observed and counterfactual path over the period from November 3, 2010, to June 30, 2011, we calculate the moving average of the in-sample fitted errors from the regression used in the construction of the counterfactual path over periods of similar length as the QE2 period (165 daily observation dates). Figure 10 shows these series for the five- and ten-year maturities along with the average of the counterfactual errors during the QE2 program, indicated with solid gray horizontal lines. We note that it is unprecedented to have a sustained difference of this magnitude simultaneously at the five- and ten-year maturities.

Overall, the results and time series patterns from the counterfactual analysis suggest that

| (a) Five-year maturity. | (b) Ten-year maturity. |
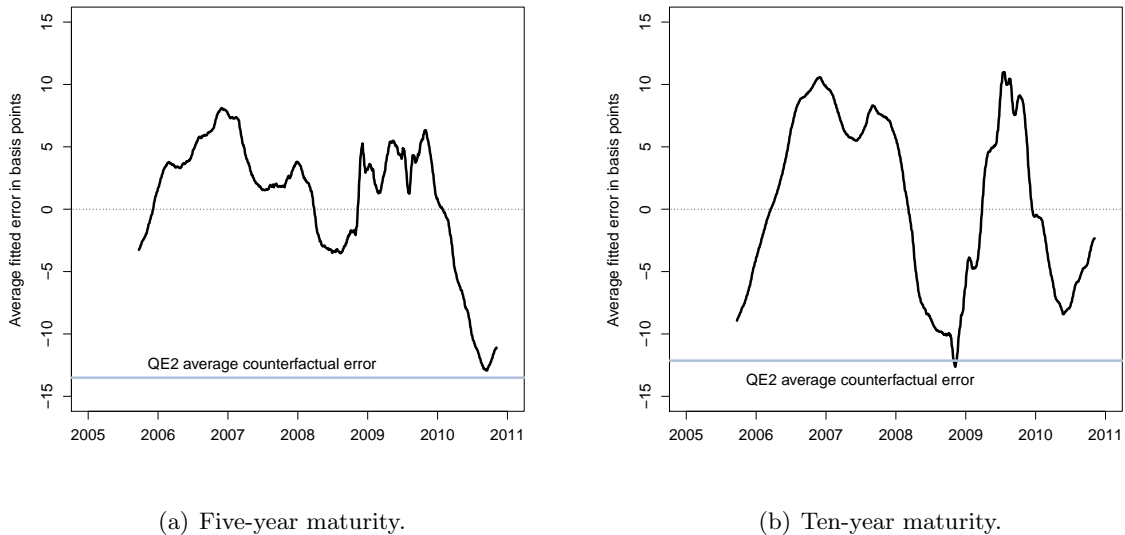
Figure 10: **Moving Average of Fitted Errors.**
Illustration of the moving average of fitted errors over periods containing 165 observation dates from the benchmark regression with data ending on November 2, 2010. The shown series cover the period from September 21, 2005, to November 2, 2010, a total of 1,275 observations. The average of the counterfactual errors over the QE2 period from November 3, 2010, to June 30, 2011, is shown with a solid grey line.

the QE2 TIPS purchases and their duration pushed the liquidity premium measure to levels well below where it would otherwise have been.[37]

6.3.1 Autoregressive Counterfactual Analysis

As is evident from Figure 10, the residuals from the regressions used in the counterfactual analysis above are serially correlated. A simple Durbin-Watson test gives values of 0.29 and 0.14 at the five- and ten-year maturity, respectively, which indicates that the positive serial correlation is statistically significant.

To address this problem, we include the lagged value of our liquidity premium measure in the regressions, that is, we use an AR(1) specification. Thus, we run regressions of the following type:

$$LP_t(\tau) = \beta_0 + \rho LP_{t-1}(\tau) + \beta^T X_t + \varepsilon_t, \tag{1}$$

where $LP_t(\tau)$ is our TIPS and inflation swap liquidity premium measure at the τ-year maturity and X_t represents the exogenous explanatory variables. As in the previous section, we estimate the regressions on the sample from January 5, 2005, to November 2, 2010, which delivers the

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[37]For robustness, we repeated the counterfactual analysis using samples starting in January 3, 2007, and July 1, 2009, respectively, and obtained results qualitatively similar to those reported in Figures 9 and 10.

Explanatory variables	Dependent variable: Five-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-0.30	1.38**	0.86**	1.01*	0.43	0.09
	(-1.00)	(5.13)	(3.17)	(2.08)	(1.22)	(0.16)
AR(1) coefficient	0.92**	0.92**	0.98**	0.98**	0.90**	0.89**
	(93.65)	(87.26)	(180.60)	(202.94)	(79.12)	(74.13)
VIX	0.17**				0.12**	0.15**
	(6.91)				(4.09)	(5.06)
HPW measure		0.54**			0.34**	0.46**
		(6.69)			(3.71)	(4.72)
Off-the-run spread			0.05			-0.19**
			(1.05)			(-3.74)
IS bid-ask spread				-0.03		-0.02
				(-0.60)		(-0.31)
Adjusted R^2	0.97	0.97	0.97	0.97	0.97	0.97

Explanatory variables	Dependent variable: Ten-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.33	0.95**	0.66**	1.35**	1.00**	0.51
	(1.41)	(4.54)	(3.16)	(2.64)	(3.36)	(0.77)
AR(1) coefficient	0.95**	0.94**	0.95**	0.97**	0.94**	0.94**
	(123.37)	(111.43)	(119.46)	(160.78)	(111.40)	(109.51)
VIX	0.05**				-0.01	-0.00
	(4.59)				(-0.26)	(-0.07)
HPW measure		0.22**			0.24**	0.23**
		(5.84)			(3.59)	(2.63)
Off-the-run spread			0.06**			0.01
			(5.02)			(0.21)
IS bid-ask spread				-0.07		0.05
				(-1.16)		(0.85)
Adjusted R^2	0.95	0.95	0.95	0.95	0.95	0.95

Table 4: **Regression Results for Pre-QE2 Period with AR(1) Specification.**
The top panel reports the results of regressions with the TIPS and inflation swap liquidity premium measure at the five-year maturity as the dependent variable and an AR(1) term and four measures of market functioning as explanatory variables. The bottom panel reports the corresponding results when the ten-year liquidity premium measure is the dependent variable. T-statistics are reported in parentheses. Asterisks * and ** indicate significance at the 5 percent and 1 percent levels, respectively. The data are daily covering the period from January 5, 2005, to November 2, 2010, a total of 1,438 observations.

estimated coefficients $\widehat{\beta}_0$, $\widehat{\rho}$, and $\widehat{\beta}$ reported in Table 4 that describe the statistical relationship before the introduction of the QE2 program.

Given the autoregressive specification, the counterfactual analysis is performed in a slightly different way. Based on the historical dynamic relationship implied by the estimated coefficients in equation (1) and reported in Table 4, we analyze whether the shocks to the liquidity premium measure during QE2 were statistically significantly more negative than in the pre-QE2 period. If so, it would suggest that the QE2 TIPS purchases exerted downward pressure

on our liquidity premium measure.

Focusing on regression (6) in Table 4, we calculate realized residuals relative to the counterfactual prediction for the period from November 3, 2010, to June 30, 2011, using

$$\varepsilon_t^R = LP_t(\tau) - \widehat{\beta}_0 - \widehat{\rho}LP_{t-1}(\tau) - \widehat{\beta}^T X_t. \tag{2}$$

Since the residuals from the regressions in Table 4 have fatter tails than the normal distribution (mainly due to the financial crisis), we use a Wilcoxon test of the hypothesis that the mean of the realized residuals in equation (2) is identical to the mean of the residuals in the pre-QE2 regression with the alternative being a lower mean of the realized residuals in light of our previous results. At the five-year maturity, the Wilcoxon test is -1.77 with a p-value smaller than 0.0001, while at the ten-year maturity the test is -0.63 with a p-value of 0.0029. Thus, at both maturities, the results indicate that the shocks to our liquidity premium measure experienced during the QE2 program were significantly more negative than what would have been predicted based on the historical dynamic relationships. Therefore, consistent with our previous results, we conclude that the TIPS purchases included in the QE2 program exerted a persistent downward pressure on the frictions to trading in the TIPS and inflation swap markets as captured through our measure of the sum of their respective liquidity premiums.[38]

6.4   Analysis of TIPS Trading Volumes

In this section, we analyze whether the QE2 TIPS purchases had positive effects on TIPS trading volumes in addition to reducing TIPS and inflation swap liquidity premiums as documented so far.

The dependent variable in the analysis is the weekly average of the daily trading volume in the secondary market for TIPS as reported by the Federal Reserve Bank of New York and shown in Figure 11(b).[39] We use the eight-week moving average to smooth out short-term volatility. Abrahams et al. (2015) use the ratio of primary dealers' Treasury transaction volumes relative to TIPS transaction volumes as an input in their construction of a TIPS illiquidity factor. For that reason we include the Treasury transaction volume series in our regressions, also measured as an eight-week moving average. In addition, we include the same four explanatory variables we have been using throughout this section, but now measured as weekly averages to align those daily series with the weekly trading volume data. Finally, as in the previous sections, we are interested in generating a counterfactual path for what the

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[38]For robustness, we also repeated the autoregressive counterfactual analysis using samples starting January 3, 2007, and July 1, 2009, respectively. Again, we obtained results qualitatively similar to those reported for the full sample.

[39]The trading volume data are available at: http://www.newyorkfed.org/markets/statrel.html.
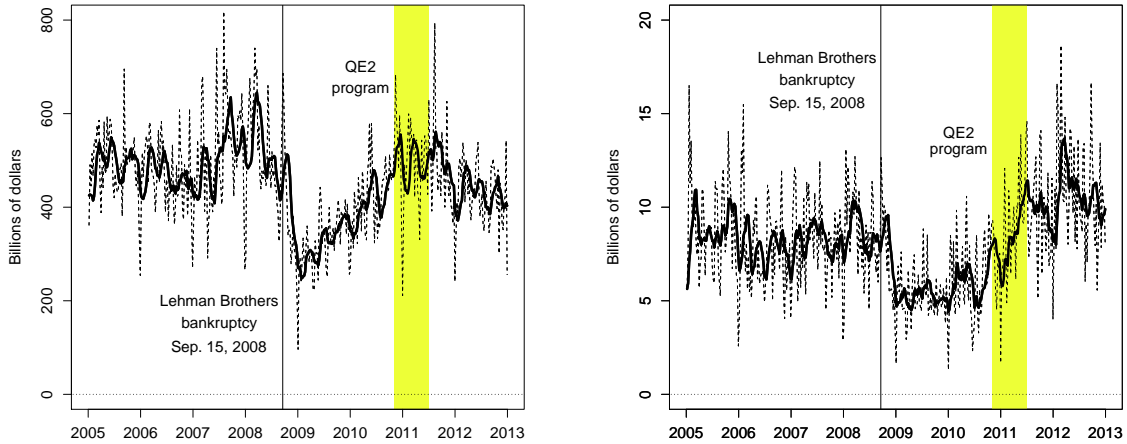
(a) Treasury trading volume.　　　　　　　(b) TIPS trading volume.

Figure 11: **Treasury and TIPS Trading Volumes.**
Panel (a) shows the weekly average of daily trading volume in the secondary market for Treasury coupon bonds (dashed black line) and the smoothed eight-week moving average (solid black line). Panel (b) shows the weekly average of daily trading volume in the secondary market for TIPS (dashed black line) and the smoothed eight-week moving average (solid black line).

TIPS trading volume series likely would have been without the QE2 TIPS purchases. Thus, we run the regressions on the pre-QE2 part of the sample from January 5, 2005, to November 3, 2010.

The results of the regressions are reported in Table 5. First, we note that, indeed, the trading volumes of nominal Treasury securities have significant positive effects on TIPS trading volumes. Also, the VIX is a second important factor in explaining TIPS trading volumes and it has a negative coefficient as financial market uncertainty tends to put downward pressure on TIPS trading volumes. On the other hand, the HPW measure that is crucial in accounting for variation in liquidity premiums appears to be less critical when it comes to explaining trading volumes as its estimated coefficient switches sign once the VIX and the Treasury trading volume series are added to the model. Finally, as before, the off-the-run spread and the inflation swap bid-ask spread are secondary factors without significant coefficients in the baseline regression (7).[40]

The fit of the baseline regression (7) and the counterfactual path for the TIPS trading volume series generated from it are shown in Figure 12. We note that during the second half of the QE2 program there is a notable uptick in the TIPS trading volumes far above the levels expected by the counterfactual. We test whether the mean of the in-sample residuals is

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[40]The results in Table 5 are based on regressions with the off-the-run spread and the inflation swap bid-ask spread measured at the five-year maturity, but similar results are obtained with the ten-year maturity series.

Explanatory variables	Dependent variable: TIPS trading volume						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	1.64**	8.72**	8.09**	8.51**	9.45**	2.92**	4.03**
	(4.44)	(50.61)	(66.73)	(65.19)	(34.75)	(6.43)	(5.96)
Nominal Treasury	0.01**					0.01**	0.01**
trading volume	(15.98)					(13.78)	(9.70)
VIX		-0.06**				-0.06**	-0.05**
		(-8.41)				(-4.67)	(-3.82)
HPW measure			-0.16**			0.12**	0.18**
			(-7.29)			(2.99)	(3.46)
Off-the-run spread				-0.06**			-0.03
				(-10.16)			(-1.90)
IS bid-ask spread					-0.22**		-0.03
					(-7.73)		(-1.17)
Adjusted R^2	0.46	0.19	0.15	0.25	0.16	0.50	0.51

Table 5: **TIPS Trading Volume Regression Results for Pre-QE2 Period.**
The table reports the results of regressions with the eight-week moving average of the weekly TIPS trading volume series as the dependent variable and five measures of market functioning as explanatory variables. T-statistics are reported in parentheses. Asterisks * and ** indicate significance at the 5 percent and 1 percent levels, respectively. The data are weekly covering the period from January 5, 2005, to November 3, 2010, a total of 304 observations.

identical to the QE2 counterfactual prediction errors with a Wilcoxon test, which is rejected with a p-value of 0.01975. This shows that the deviations from the counterfactual are statistically significant, and it suggests that the QE2 TIPS purchases had a positive effect on TIPS trading volumes.

6.5   Liquidity Effects in Corporate Bond Markets

As a final exercise, we study whether the effects from the liquidity channel extend beyond the targeted securities, which in the case of QE2 were Treasuries and TIPS. We do this by examining highly rated industrial corporate bond credit spreads. Again, our counterfactual construction lends itself to an analysis of liquidity effects in corporate bond markets. Now, our hypothesis is that the liquidity channel should have no effect as the Fed did not buy any corporate bonds and financial market participants knew this.

The dependent variable in this exercise is the excess yield of AAA-rated US industrial corporate bonds over comparable Treasury yields.[41] In choosing the maturity, we face a trade-off. On one side, we would ideally like to match the maturity of our liquidity premium measure to be consistent with the previous analysis. However, the credit risk of even AAA-rated industrial bond issuers cannot be deemed negligible at a five- to ten-year horizon. On the other hand, if we focus on very short-term debt where the credit risk is entirely negligible,

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[41]The corporate bond yield data are from Bloomberg; see Christensen et al. (2014) for details.
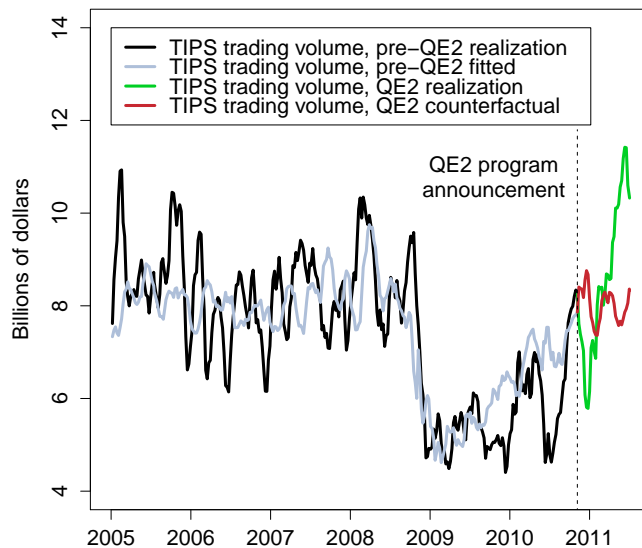
Figure 12: **Fitted and Counterfactual TIPS Trading Volume Series.**
Illustration of the smoothed eight-week moving average of the weekly average of daily trading volume
in the secondary market for TIPS (solid black line during pre-QE2 period and solid green line during
the QE2 period). Also shown are the fitted value during the pre-QE2 period (solid grey line) and the
counterfactual path for the QE2 period (solid red line), both constructed from regression (7) in Table
5.

we are far from the desired maturity range. We believe using the two-year credit spread
strikes a reasonable balance, and the results are not sensitive to this particular choice. As
the credit risk component of such highly rated shorter-term corporate bond yields is minimal,
the yield spread largely reflects the premium bond investors require for being exposed to the
lower trading volume and larger bid-ask spreads in the corporate bond market vis-à-vis the
liquid Treasury bond market.

We continue to rely on the same four explanatory variables and use the pre-QE2 sample to
establish the historical relationship between the dependent and explanatory variables. These
regression results are reported in Table 6. We note that the VIX, the HPW, and the off-the-
run spread are all individually highly significant and with positive coefficients. On the other
hand, the bid-ask spread of inflation swaps has a significant but counterintuitive negative
coefficient in these regressions.[42]

The fit of the baseline regression (6) and the counterfactual path for the AAA credit spread
series generated from it are shown in Figure 13. We note the very close in-sample fit during

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[42]The results in Table 6 are based on regressions with the off-the-run spread and the inflation swap bid-ask
spread measured at the five-year maturity, but similar results are obtained with the ten-year maturity series.

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Explanatory variables	Dependent variable: Two-year AAA credit spread					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-6.73**	16.24**	50.18**	83.74**	11.13**	51.11**
	(-4.64)	(18.74)	(50.29)	(24.31)	(7.52)	(28.11)
VIX	2.74**				0.48**	0.60**
	(46.64)				(4.24)	(7.07)
HPW measure		8.98**			7.69**	8.42**
		(58.16)			(22.45)	(32.69)
Off-the-run spread			4.86**			-0.98**
			(17.76)			(-6.25)
IS bid-ask spread				-3.39**		-4.96**
				(-9.40)		(-32.55)
Adjusted R^2	0.60	0.70	0.18	0.06	0.71	0.84

Table 6: **Regression Results for AAA Credit Spread during Pre-QE2 Period.**
The table reports the results of regressions with the two-year AAA-rated US industrial corporate bond credit spread as the dependent variable and four measures of market functioning as explanatory variables. T-statistics are reported in parentheses. Asterisks * and ** indicate significance at the 5 percent and 1 percent levels, respectively. The data are daily covering the period from January 4, 2005, to November 2, 2010, a total of 1,439 observations.

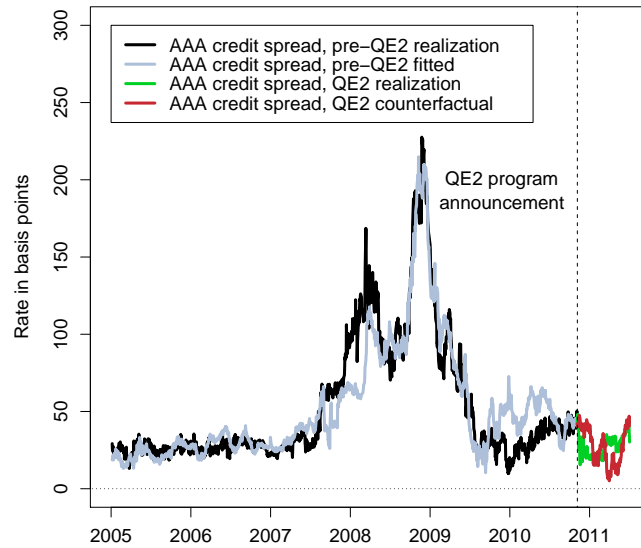Figure 13: **Fitted and Counterfactual AAA Credit Spread Series.**
Illustration of the two-year AAA-rated US industrial corporate bond credit spread (solid black line during pre-QE2 period and solid green line during the QE2 period). Also shown are the fitted value during the pre-QE2 period (solid grey line) and the counterfactual path for the QE2 period (solid red line), both constructed from regression (6) in Table 6.

the pre-QE2 period and the equally small difference between the realized and counterfactual AAA credit spread in the QE2 period. On average, the AAA credit spread was slightly higher during the QE2 period than indicated by the regression model. This shows that there is no significant unusual variation in the AAA credit spread during the QE2 program once we control for the variation in the four explanatory variables. Thus, for the QE2 program to have had any effects on the AAA credit spread, those effects would have to be second-round effects that materialize by the QE2 program lowering financial market frictions more broadly as captured through the VIX and HPW measures. Detecting these types of more broad-based effects on financial market liquidity from the operation of QE programs is outside the analysis in this paper and is left for future research.

6.6 The European Sovereign Debt Crisis as an Alternative Explanation

One potential alternative story for our findings is centered around the European Sovereign debt crisis. Evidence in favor of this story is the spike in the VIX observed in Figure 4 during the operation of QE2, which coincides with some key events in the Greek debt crisis. Under this alternative story those events led to increased risk aversion, hence higher VIX, and at the same time to a flight to higher quality assets including TIPS that depressed our liquidity premium measure and made it deviate from its otherwise stable relationship with the VIX.

In countering this alternative story, we note that we do not disagree with the view that the spike in the VIX in the spring of 2011 in all likelihood is caused by events related to Greece and the broader European sovereign debt crisis. However, we see it as a poor explanation for variation in TIPS trading during this period for several reasons.

The timing of the story does not line up well with the data. First, the decline in our liquidity premium measure starts in late 2010, while the spikes in the VIX tied to the Greek debt crisis do not occur until March 2011. Second, the unusually low values of the liquidity premium measure tapers off towards June 2011 *right before* the Greek debt crisis moves into a much more severe phase in the second half of 2011 where there were truly outsized and prolonged spikes in the VIX that dwarf the March 2011 spike. During this period there is little evidence of unusual variation in the liquidity premium measure even though, under this alternative story, flight to higher quality assets like TIPS should presumably have been even more intense. Based on these observations we conclude that the European sovereign debt crisis does not represent an alternative credible story that can account for our findings.

7 Conclusion

In this paper, we argue that one channel of transmission for central bank large-scale asset purchases to long-term interest rates comes about through a reduction of the priced frictions

in the targeted security classes.

For evidence, we analyze the effects the TIPS purchases included in the Fed's QE2 program had on the functioning of the market for TIPS and the related market for inflation swaps. To quantify the frictions in the markets for these two types of financial claims, we use a model-independent measure of the sum of liquidity premiums in TIPS yields and inflation swap rates constructed from the difference between inflation swap rates and BEI. This measure is ideal for our purposes as it is unaffected by how the QE2 program and its implementation might have changed investors' expectations for economic fundamentals such as inflation and monetary policy.

Our results from regressions with a switch in the conditional mean and a counterfactual analysis both suggest that the TIPS purchases reduced liquidity premiums in the markets for TIPS and inflation swaps. Specifically, our counterfactual analysis indicates that the purchases persistently depressed the liquidity premium measure by an average of 12 to 14 basis points for the duration of the QE2 program from what we would otherwise have expected it to be. In our view, this represents a considerable reduction. Furthermore, and critical to our interpretation, the liquidity premium effects dissipated towards the end of the QE2 TIPS purchases. This leads us to conclude that one benefit of QE programs is to improve financial market functioning by reducing liquidity premiums through a liquidity channel. However, our results also show the limitation of such liquidity effects in that they appear to only be sustained as long as QE purchases are ongoing and expected to continue. Furthermore, such liquidity effects appear, indeed, to be limited to the targeted securities as we find no effects on the liquidity premiums of AAA-rated US industrial corporate bonds.

In an attempt to identify local supply effects in individual TIPS prices from the QE2 TIPS purchases, we adapted the approach of DK. However, our analysis did not yield any significant results. The interpretation we offer for this finding is that the liquidity effects we document are general in nature and not tied to any specific TIPS, which would make them go undetected in the analysis of DK. Clearly, a better understanding of the connection between the liquidity effects we document and potential local supply effects would be desirable, but we leave it for future research. Furthermore, we find that reductions in the priced frictions go hand-in-hand with improvements in actual liquidity as measured by TIPS trading volumes. However, more research is needed to better understand the nature and mechanics of the liquidity channel we unveil in this paper.

Our findings could have important policy implications. On a practical note, for understanding BEI and the underlying variation in investors' inflation expectations during the QE2 program, it is crucial to account for the effects we document associated with the liquidity channel. Second, for central banks in countries with somewhat illiquid sovereign bond markets, QE programs targeting sovereign debt could be quite effective in lowering liquidity premi-

ums in addition to any benefits arising from other transmission channels. More generally, it appears that even relatively modest QE programs could have large effects if the targeted security classes are illiquid. Thus, the significance of the liquidity channel could matter for the design of QE programs; time frame, purchase pace, and targeted security classes would all be variables that could make a meaningful difference for the effectiveness of a QE program provided liquidity premiums in the targeted securities are of nontrivial magnitude.

As a final thought, we note that the QE program launched by the European Central Bank in January 2015 could provide rich cross-country data for studying questions related to the liquidity channel highlighted in this paper thanks to the length, size, and implementation of that particular QE program. We encourage others to undertake this type of research in the future.

Appendix A: Event Study of QE2 Announcement Effects

Response		Maturity					
		5-year	6-year	7-year	8-year	9-year	10-year
Nominal yields	Nov. 2, 2010	122	159	195	227	256	282
	Nov. 3, 2010	118	156	192	227	258	286
	Change	**-4**	**-3**	**-2**	**0**	**2**	**4**
TIPS yields	Nov. 2, 2010	-28	-9	10	27	41	54
	Nov. 3, 2010	-33	-12	8	26	42	56
	Change	**-5**	**-4**	**-2**	**-1**	**0**	**2**
TIPS BEI rates	Nov. 2, 2010	150	168	185	201	215	227
	Nov. 3, 2010	151	168	185	201	216	230
	Change	**1**	**0**	**0**	**1**	**1**	**2**
Inflation swap rates	Nov. 2, 2010	183	199	216	228	238	251
	Nov. 3, 2010	185	199	215	229	237	248
	Change	**2**	**0**	**-1**	**1**	**-1**	**-3**
LP measure	Nov. 2, 2010	32	32	31	28	23	23
	Nov. 3, 2010	34	31	30	28	21	18
	Change	**2**	**0**	**-1**	**0**	**-2**	**-6**

Table 7: **Market Response to QE2 Announcement.**
The table reports the one-day response of nominal Treasury yields, real TIPS yields, TIPS breakeven inflation, inflation swap rates, and the LP measure at six maturities to the announcement of QE2 on November 3, 2010. All numbers are measured in basis points and reported in continuously compounded equivalents. The Treasury and TIPS yields are from Gürkaynak et al. (2007, 2010), while the inflation swap rates are from Bloomberg.

Table 7 summarizes the market reaction to the announcement of the QE2 program on November 3, 2010, using a one-day event window. The key observation is the rather muted response of medium- and long-term Treasury and TIPS yields. Importantly for our analysis, this converts into an even more muted response of TIPS breakeven inflation and inflation swap rates that leave the liquidity premium measure little affected. To put the reported yield changes into perspective, we note that the standard deviation of daily changes in the measure over the period from January 4, 2005, to November 2, 2010, is 5.4 basis points at the five-year maturity and declines monotonically with maturity reaching 4.0 basis points at the ten-year maturity. We take this as evidence that there are no statistically significant effects related to the announcement of the QE2 program that need to be accounted for.

Appendix B: Local Supply Effects in the TIPS Market

In this appendix, we describe our adaptation of DK's analysis to attempt to identify local supply effects in the TIPS market.

First, we introduce notation and define the fundamental statistical objects, which are as follows:

(i). N is the total number of TIPS in existence during the QE2 program.

(ii). $O^n(t)$ equals the notional amount of security n outstanding at t, $n \in \{1, \ldots, N\}$.

(iii). $Q^n(t)$ equals the dollar amount of security n purchased at t, $n \in \{1, \ldots, N\}$.

(iv). $R^n(t) = \frac{P^n(t) - P^n(t-1)}{P^n(t-1)}$ is the daily percentage price change of security n at time t, $n \in \{1, \ldots, N\}$.

(v). T^n is the maturity date of security n, $n \in \{1, \ldots, N\}$.

The second step is to calculate the variables used in the subsequent regressions. Similar to DK, for each security n, we define buckets of substitutes, but limit the number to three buckets due to the smaller number of TIPS trading relative to the number of securities in the market for regular Treasuries.

The first bucket is denoted $S_0(n)$ and only contains security n. For this bucket, two variables are defined:

(i). $O_0^n(t) = O^n(t)$ is the notional amount of security n outstanding.

(ii). $Q_0^n(t) = Q^n(t)$ is the amount of security n purchased at time t.

The second bucket is denoted $S_1(n)$ and contains all securities with maturities within two years of the maturity of security n, that is, $S_1(n) = \{m : |T^m - T^n| \leq 2\}$. Following DK we refer to these securities as the near substitutes for security n.

Finally, the third bucket is denoted $S_2(n)$ and contains all securities with a difference in maturity of more than two years relative to the maturity of security n, that is, $S_2(n) = \{m : |T^m - T^n| > 2\}$. Again, using language similar to DK, we refer to these securities as the far substitutes for security n.

Related to the last two buckets, the following variables are defined:

(i). $O_i^n(t) = \sum_{m \in S_i(n)} O^m(t)$ is the notional amount outstanding of bucket i substitutes for security n at time t, $i \in \{1, 2\}$.

(ii). $Q_i^n(t) = \sum_{m \in S_i(n)} Q^m(t)$ is the amount of bucket i substitutes for security n purchased at time t, $i \in \{1, 2\}$.

As in DK, we use normalized variables in the regressions:

(i). $q_0^n(t) = \frac{Q_0^n(t)}{O_0^n(t) + O_1^n(t)}$ is the amount of security n purchased at time t relative to the notional amount outstanding of security n itself and its near substitutes.

(ii). $q_i^n(t) = \frac{Q_i^n(t)}{O_0^n(t) + O_1^n(t)}$ is the amount of bucket i substitutes for security n purchased at time t relative to the notional amount outstanding of security n itself and its near substitutes, $i \in \{1, 2\}$.

Finally, similar to DK, we run regressions of the daily percentage price change of each TIPS security on a set of variables:

$$R^n(t) = \gamma_0 q_0^n(t) + \gamma_1 q_1^n(t) + \gamma_2 q_2^n(t) + \delta(t) + \alpha^n + \varepsilon^n(t),$$

where

- γ_0 is security n's price elasticity to own purchases,

- γ_1 is security n's price elasticity to purchases of near substitutes,

- γ_2 is security n's price elasticity to purchases of far substitutes,

- $\delta(t)$ represents time fixed effects, and

- α^n represents security fixed effects.
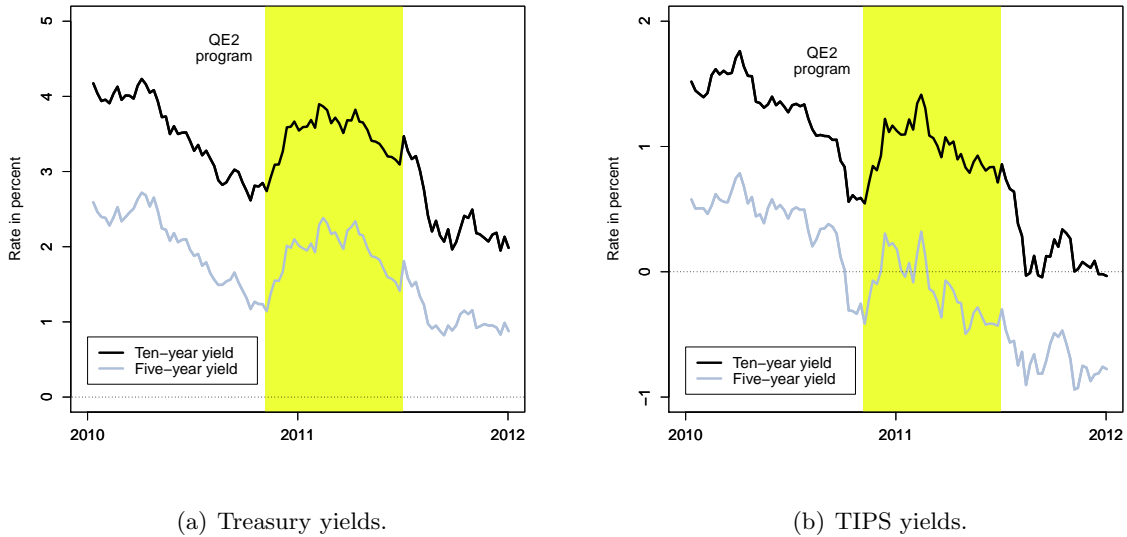
(a) Treasury yields. (b) TIPS yields.

Figure 14: **Treasury and TIPS Yields.**
Panel (a) illustrates the five- and ten-year Treasury yields from the Gürkaynak et al. (2007) database over the 2010-2011 period. Panel (b) illustrates the five- and ten-year TIPS yields from the Gürkaynak et al. (2010) database over the same period.

The results presented in the main text suggest that the QE2 TIPS purchases led to a sustained reduction in the frictions to trading in the markets for TIPS and inflation swaps. However, the exact channel through which the effects came about is not identified. At face value, the purchases could have lowered liquidity premiums in both markets. Alternatively, if there are local supply effects from the purchases, this would tend to push down TIPS yields, while nominal yields and inflation swap rates presumably would be unaffected in that case. As a consequence, BEI would widen leading to a decline in our liquidity premium measure. In this appendix, to shed light on this latter alternative channel, we attempt to estimate any direct effects on TIPS prices from the QE2 TIPS purchases by replicating the approach of DK.

Assuming the purchased securities are held for a considerable period of time, QE purchases are effectively equivalent to a reduction in the available stock of the targeted securities. The empirical question is whether fluctuations in the supply of government debt should affect yields. Under the expectations hypothesis and in standard term structure models, such supply effects are ruled out. However, models with imperfect asset substitutability or preferred-habitat investors allow for local supply effects on bond yields (see DK for a detailed discussion). Still, as is evident from Figure 14, which shows the changes in the five- and ten-year Treasury and TIPS yields around the time of the QE2 program, the naked eye is a poor guide for detecting such supply effects as both nominal and real yields increased on net during the QE2 program, but the latter less than the former causing BEI to widen as well. Thus, a statistical model is needed to tease out any effects from the asset purchases against this backdrop of generally rising yields. By using security-level data one might hope to be able to identify local supply effects and how they vary across securities with different maturities and liquidity characteristics. To do so, we replicate the approach of DK as briefly summarized in the following. However, we note up front that, unlike the analysis so far, the key element in their approach is to control appropriately for changes in expectations about monetary policy and other economic fundamentals that may affect TIPS prices independent of QE2. Below we will discuss the complications this may entail.

To begin, we follow DK and conduct the regressions in price changes. Second, we drop all TIPS with

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Purchases	All TIPS	<10 years to maturity	> 10 years to maturity
Own	-0.023	0.080	-0.035
	(-0.83)	(0.950)	(-1.990)
Near substitutes	-0.068	-0.068	-0.036
(maturity w/in 2 years of own)	(-1.470)	(-0.910)	(-1.100)
Far substitutes	0.008	0.001	0.004
(maturity more than 2 years from own)	(0.560)	(0.030)	(0.460)
# Obs.	427	284	143
# CUSIPs	30	20	10
Adjusted R^2	0.733	0.762	0.953

Table 8: **Flow Effects on Day of Purchase.**

The table reports the results of regressions of the flow effects from the QE2 TIPS purchases as described in the text. The first column reports the results of using all available TIPS with more than two years to maturity, while the following two columns report the result of splitting that sample into one subsample for TIPS with between two and ten years to maturity, and one subsample for TIPS with more than ten years to maturity. T-statistics are reported in parentheses. Asterisks * and ** indicate significance at the 5 percent and 1 percent levels, respectively.

less than two years remaining to maturity at the beginning of the QE2 program because TIPS near maturity have rather erratic price behavior due to the seasonality and general unpredictability of shocks to the headline consumer price index.[43] Third, unlike DK, we only have three maturity buckets related to each security, namely (1) the security itself, (2) the near substitutes with maturities within two years of that of the security, and (3) the far substitutes whose maturities are more than two years from that of the security.

Next, we run regressions of the daily percentage price change of each TIPS security n, denoted $R^n(t)$, on a set of variables:

$$R^n(t) = \gamma_0 q_0^n(t) + \gamma_1 q_1^n(t) + \gamma_2 q_2^n(t) + \delta(t) + \alpha^n + \varepsilon^n(t), \qquad (3)$$

where $q_0^n(t)$ represents the normalized amount purchased of security n itself, $q_1^n(t)$ is the normalized amount purchased of near substitutes for security n, while $q_2^n(t)$ is the normalized amount purchased of far substitutes for security n. Thus, the corresponding coefficients can be interpreted as elasticities where γ_0 is security n's price elasticity to own purchases, γ_1 is its price elasticity to purchases of near substitutes, and γ_2 is its price elasticity to purchases of far substitutes. Finally, $\delta(t)$ and α^n represent time and security fixed effects, respectively.

Table 8 reports the regression results for the full sample using all available TIPS with more than two years to maturity as well as the results from two subsamples, one for TIPS with between two and ten years to maturity, the other for TIPS with more than ten years to maturity.[44] We note that all estimated purchase elasticities are insignificant and frequently do not even have the right sign. In short, we are not able to detect any local supply effects in TIPS prices directly.

Various explanations could account for this outcome. First, as emphasized by DK, according to the theory of local supply effects in bond markets (see Vayanos and Vila 2009), they are more likely to matter when liquidity and market functioning is poor, that is, when the arbitrageurs who trade away profit opportunities along the yield curve are capital constrained and are taking on only the most profitable trades, not necessarily

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[43]For similar reasons, TIPS with less than two years to maturity are discarded in the construction of the Gürkaynak et al. (2010) TIPS yield curve.

[44]We split the sample around the ten-year maturity point as there is a discrete jump in TIPS outstanding with remaining maturity above ten years, as can also be seen in Figure 2(b).

all available arbitrages. As noted in Figure 3, our measure of TIPS and inflation swap market functioning had reached pre-crisis levels well before the announcement of the QE2 program. Thus, it is indeed possible that market functioning could have been restored and local supply effects would be small for that reason.[45] In addition, we think that there are issues with the specification of the time fixed effects represented by $\delta(t)$. This specification provides a poor proxy for changes in the shape of the yield curve on purchase dates. For example, a level shift in the TIPS yield curve will affect the prices of long-maturity TIPS in a very different way than the prices of short-maturity TIPS.[46] By contrast, the time fixed effect imposes an identical price response across all TIPS. Furthermore, the bias from this misspecification might be more severe in our case than in the analysis of DK for two reasons. First, our pool of TIPS is smaller and more heterogeneous than their sample of regular Treasuries that is dominated by securities with three to ten years remaining to maturity.[47] Second, the limited number of purchase dates in our analysis could matter as well since it allows for less averaging of any errors induced by the misspecified time fixed effects.

To summarize, we believe there are compelling reasons why we are not able to identify any purchase effects on individual TIPS prices from the QE2 TIPS purchases using the approach of DK, despite the clear results we obtain when we analyze the effects on our TIPS and inflation swap liquidity measure. However, we stress that there is not necessarily a contradiction between the two sets of results. One key difference is that our approach based on the liquidity measure is unaffected by changes in expectations about economic fundamentals, unlike the method used by DK which could be severely biased by them. Furthermore, our results suggest that the QE2 TIPS purchase operations led to a reduction in the general frictions to trading in the market for TIPS and the related market for inflation swaps that may not be tied to any specific TIPS. Finally, the liquidity effects we detect are persistent and not limited to a few days around each TIPS purchase operation. Hence, they may go undetected in the approach used by DK that relies on day-to-day variation for its identification.

To provide further evidence that local supply effects are not likely to be the driver of our results, we run our regressions in first differences with purchase date indicator variables. The results reported in Table 9 show that there is no significant response effects in our TIPS and inflation swap liquidity premium measure on the 15 dates with TIPS purchase operations. Thus, the effects we document are persistent and not tied to any specific purchase operations, which is consistent with the mechanics underlying the liquidity channel as described in Section 2.3.

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[45]Using an approach similar to DK, Kandrac and Schlusche (2013) analyze the effects of Treasury securities purchases on Treasury bond prices in all the Fed's QE programs. They find that effects do appear to fade in the later programs.

[46]Figure 14(b) shows that the TIPS curve did experience several level shifts during the QE2 program.

[47]The closer securities are in terms of maturity, the smaller is the room for error from the misspecification of the time fixed effects.

Explanatory variables	Dependent variable: Five-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.01	0.01	0.01	0.01	0.01	0.01
	(0.06)	(0.06)	(0.06)	(0.05)	(0.06)	(0.05)
VIX	0.02				0.03	0.04
	(0.27)				(0.45)	(0.67)
HPW measure		-0.51			-0.54	-0.39
		(-1.13)			(-1.19)	(-0.84)
Off-the-run spread			-0.30**			-0.29*
			(-2.15)			(-2.04)
IS bid-ask spread				-0.50		-0.048
				(-1.36)		(-1.30)
TIPS purchase dummy	0.26	0.22	0.28	0.33	0.21	0.31
	(0.27)	(0.23)	(0.30)	(0.34)	(0.22)	(0.33)
Adjusted R^2	0.00	0.00	0.00	0.00	0.00	0.00

Explanatory variables	Dependent variable: Ten-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.00	0.01	0.00	0.00	0.01	0.00
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
VIX	-0.10*				-0.08	-0.07
	(-2.04)				(-1.56)	(-1.51)
HPW measure		-1.10**			-1.02**	-0.93**
		(-3.23)			(-2.94)	(-2.67)
Off-the-run spread			-0.30**			-0.26*
			(-2.82)			(2.45)
IS bid-ask spread				-0.03		-0.05
				(-0.08)		(-0.13)
TIPS purchase dummy	-0.28	-0.38	-0.22	-0.28	-0.36	-0.29
	(-0.39)	(-0.53)	(-0.31)	(-0.39)	(-0.51)	(-0.41)
Adjusted R^2	0.00	0.01	0.00	0.00	0.01	0.01

Table 9: **Regressions in First Differences Using Standard Indicator Variables.**
The top panel reports the results of regressions in first differences with the TIPS and inflation swap liquidity premium measure at the five-year maturity as the dependent variable and four measures of market functioning as explanatory variables. Included is a standard binary dummy variable for the 15 dates on which TIPS purchase operations took place using a one-day event window. The bottom panel reports the corresponding results when the ten-year liquidity premium measure is the dependent variable. T-statistics are reported in parentheses. Asterisks * and ** indicate significance at the 5 percent and 1 percent levels, respectively. The data are daily covering the period from January 5, 2005, to June 30, 2011, a total of 1,603 observations.

Appendix C: Regression Results Used in Counterfactual Analysis

Explanatory variables	Dependent variable: Five-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-3.47**	16.79**	42.51**	33.21**	6.03**	0.02
	(-4.43)	(32.99)	(61.09)	(13.24)	(7.51)	(0.02)
VIX	2.21**				1.01**	1.16**
	(69.74)				(16.48)	(19.64)
HPW measure		6.82**			4.09**	4.47**
		(75.18)			(22.03)	(25.08)
Off-the-run spread			3.77**			-1.43**
			(19.78)			(-13.14)
IS bid-ask spread				1.25**		0.22*
				(4.78)		(2.09)
Adjusted R^2	0.77	0.80	0.21	0.01	0.83	0.85

Explanatory variables	Dependent variable: Ten-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	9.29**	16.86**	14.45**	39.62**	16.92**	4.96*
	(12.32)	(35.70)	(24.92)	(20.03)	(20.83)	(2.48)
VIX	0.96**				-0.01	0.07
	(31.45)				(-0.09)	(1.13)
HPW measure		3.27**			3.28**	2.89**
		(38.80)			(17.48)	(11.42)
Off-the-run spread			0.94**			0.13
			(33.80)			(1.72)
IS bid-ask spread				-1.22**		1.26**
				(-4.90)		(6.50)
Adjusted R^2	0.41	0.51	0.44	0.02	0.51	0.52

Table 10: Regression Results for Pre-QE2 Period.
The top panel reports the results of regressions with the TIPS and inflation swap liquidity premium measure at the five-year maturity as the dependent variable and four measures of market functioning as explanatory variables. The bottom panel reports the corresponding results when the ten-year liquidity premium measure is the dependent variable. T-statistics are reported in parentheses. Asterisks * and ** indicate significance at the 5 percent and 1 percent levels, respectively. The data are daily covering the period from January 4, 2005, to November 2, 2010, a total of 1,439 observations.

In the construction of our counterfactual, we rely on the historical connection between our liquidity premium measure and the four explanatory variables we use. Table 10 reports the results for the baseline regressions using the pre-QE2 part of our data sample, that is, the sample from January 4, 2005, to November 2, 2010. The estimated coefficients reported under regression (7) in the table are the ones used in the counterfactual analysis in Section 6.3.

Appendix D: The TIPS Purchases and Sales during the MEP

In this appendix, we provide a brief description of the Federal Reserve's maturity extension program (MEP) that included purchases and sales of a sizable amount of TIPS.

The MEP program was announced on September 21, 2011. At first, it was intended to run through June 2012 and involve buying $400 billion of Treasury securities with more than 6 years to maturity financed by selling a similar amount of Treasury securities with less than 3 years to maturity. At the June 2012 FOMC meeting it was decided to continue the MEP through the end of 2012 at which point it would total more than $600 billion in purchases and sales of securities. Similar to the QE2 program, the MEP involved transactions in TIPS the effects of which we briefly detail and analyze below.
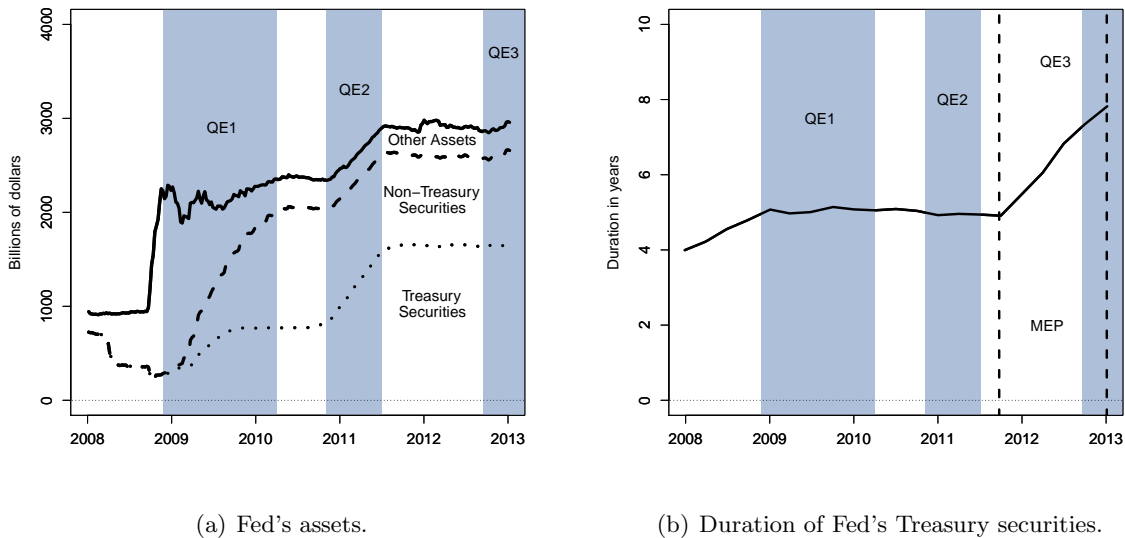

(a) Fed's assets.

(b) Duration of Fed's Treasury securities.

Figure 15: **The Fed's Assets and the Duration of Its Treasury Securities.**

For a start, though, Figure 15 shows how the Fed's asset holdings have changed since 2008. We note that the first asset purchase program (QE1) consisted of a modest expansion of its Treasury securities holdings combined with substantial purchases of mortgage-backed securities (MBS). During the QE2 program it was only the Treasury holdings that increased, while the MEP analyzed in this appendix barely changed the size of the Fed's balance sheet. However, obviously, it did achieve the intended goal of increasing the average maturity of the Fed's securities holdings. This is illustrated in Figure 15(b), which shows the change in the average duration of the Fed's nominal Treasury securities since 2008.[48] The weighted average duration increased from about five years to almost eight years over the course of the MEP.

Like the QE2 program, the MEP was implemented with a fairly regular schedule. Once a month, the Fed publicly released a list of operation dates for the following 30-plus day period, indicating the relevant maturity range and expected purchase and sale amount for each operation.[49] There were 15 separate TIPS purchase operation dates, effectively once a month, each with a stated expected purchase amount of $1 billion to $2 billion. TIPS were the only type of asset purchased on these dates. In addition, there were 10 separate TIPS

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[48]The durations are calculated based on real-time quarterly estimation of the shadow-rate term structure model analyzed in Christensen et al. (2015). This model respects the zero lower bound for yields, which has been a prominent characteristic of the Treasury yield curve since 2009.

[49]The information can be found at http://www.newyorkfed.org/markets/tot_operation_schedule.html.

MEP TIPS purchase operation dates	TIPS purchases (Mill.)	Weighted avg. maturity (years)
(1) Oct. 5, 2011	$1,861	22.77
(2) Nov. 3, 2011	$1,916	25.62
(3) Dec. 12, 2011	$1,872	25.02
(4) Jan. 10, 2012	$1,905	28.56
(5) Feb. 10, 2012	$1,926	26.98
(6) Mar. 14, 2012	$1,272	27.53
(7) Apr. 3, 2012	$1,765	19.01
(8) May 9, 2012	$1,565	15.44
(9) Jun. 15, 2012	$1,730	16.29
(10) Jul. 10, 2012	$1,809	21.08
(11) Aug. 9, 2012	$1,947	24.58
(12) Sep. 10, 2012	$1,979	26.77
(13) Oct. 11, 2012	$1,819	24.67
(14) Nov. 9, 2012	$1,939	25.49
(15) Dec. 11, 2012	$1,829	23.01
Average	$1,809	23.52

Table 11: **The MEP TIPS Purchase Operation Dates.**
The table reports the amount and weighted average maturity of TIPS purchased on the 15 TIPS purchase operation dates during the MEP. The TIPS purchase amounts are reported in millions of dollars, while the weighted average maturities are measured in years.

MEP TIPS sale operation dates	TIPS sales (Mill.)	Weighted avg. maturity (years)
(1) Oct. 17, 2011	$1,456	2.17
(2) Nov. 9, 2011	$1,376	1.20
(3) Dec. 7, 2011	$1,353	0.74
(4) Jan. 5, 2012	$1,367	0.73
(5) Feb. 7, 2012	$1,407	1.68
(6) Mar. 5, 2012	$1,415	1.66
(7) Apr. 9, 2012	$1,289	0.37
(8) May 2, 2012	$1,427	2.15
(9) Jun. 11, 2012	$1,146	2.24
(10) Oct. 19, 2012	$1,198	2.87
Average	$1,343	1.58

Table 12: **The MEP TIPS Sale Operation Dates.**
The table reports the amount and weighted average maturity of TIPS sales on the 10 TIPS sale operation dates during the MEP. The TIPS sale amounts are reported in millions of dollars, while the weighted average maturities are measured in years.

sale operation dates distributed with sale operations once a month from October 2011 to June 2012 plus a final sale operation in mid-October 2012. These all had indicated expected sale amounts of $1 billion to $1.5 billion.

One complicating factor in analyzing the MEP relative to the QE2 program is that not all TIPS were

eligible in each operation. The sales were targeting TIPS with less than 3 years to maturity,[50] while the purchases were targeted at TIPS with more than 6 years to maturity. However, given that this would remain true throughout the operation of the MEP, this should show up as an announcement effect when the MEP was first introduced in September 2011, but not change from day to day during the implementation of the program. Thus, we proceed with an analysis similar to the one we used to analyze the effects of the QE2 program.

Table 11 lists the 15 TIPS purchase operation dates during the MEP, while Table 12 reports the corresponding statistics for the 10 TIPS sale operation dates. The MEP TIPS purchases totaled $27.1 billion, all of which involved TIPS with more than 6 years to maturity. The MEP TIPS sales totaled $13.4 billion and only included TIPS with less than 3.5 years to maturity. Thus, the net TIPS purchases in the MEP were $13.7 billion stretched out over a 15-month period. In comparison, the QE2 program involved almost twice the amount of net TIPS purchases and took less than half the time to implement.[51] Hence, based on these statistics, the QE2 program can be viewed as four times more intense than the MEP in terms of the operations related to the TIPS market. All else equal, this would suggest that liquidity channel effects from the MEP could be expected to be substantially smaller than the effects we reported for the QE2 program.

Pre-MEP Regressions

To generate the most likely counterfactual outcome for our liquidity premium measure during the operation of the MEP, we run the regressions with data up until September 20, 2011, the day before the MEP was first announced. Table 13 reports the results of these regressions. Given that this is only a short period after the end of the QE2 program already analyzed, it is not surprising that the estimated coefficients are close to those reported in Table 10 and used in the QE2 counterfactual exercise.

The average difference between the observed and counterfactual series at the five- and ten-year maturities are -1.58 basis points and 8.34 basis points, respectively. Thus, the outcome of the counterfactual exercise is murky and not statistically significant.

To summarize, we conclude that the TIPS purchases and sales that were part of the MEP do not appear to have had any significant sustained effects on our measure of liquidity premiums in the TIPS and inflation swap markets.

To explain these results when set against our clear findings of effects from the QE2 TIPS purchases, it appears that several factors could be at play. First, the MEP TIPS operations were overall much less intense than the QE2 TIPS purchases. Therefore, the effects are likely to be smaller and harder to detect. Second, the MEP TIPS operations involved purchases *and* sales for most of the period, which blur the signals we are trying to extract. Finally, the TIPS purchases and sales were located in maturity segments far from the five- and ten-year maturities that we track in our analysis. Specifically, the average of the weighted average maturities of the TIPS sold was 1.58 years, while the average of the weighted average maturities of the TIPS purchased was 23.52 years. Thus, both purchases and sales happened predominantly at maturities well outside the range captured by our liquidity premium series. Since all three effects tend to make it more difficult to establish a connection between the MEP TIPS operations and our liquidity measure, it may not be all that surprising that the results are much less clear in these exercises. This also explains why we choose to focus solely on the QE2 TIPS purchases in the main part of the paper.

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[50]Except for the sale of $572 million of a 3.24-year TIPS on October 19, 2012, all TIPS sold during the MEP had maturities less than 3 years.

[51]The QE2 TIPS purchases ran from November 23, 2010, to June 17, 2011, a 206-day period, while the MEP TIPS operations were implemented from October 5, 2011, to December 11, 2012, a 433-day period.

Explanatory variables	Dependent variable: Five-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-4.29**	15.16**	40.62**	37.00**	7.24**	6.49**
	(-5.17)	(32.96)	(66.30)	(15.72)	(9.60)	(5.27)
VIX	2.13**				0.69**	0.78**
	(62.59)				(12.90)	(14.77)
HPW measure		6.95**			5.13**	5.51**
		(80.00)			(31.27)	(33.63)
Off-the-run spread			3.98**			-1.04**
			(22.50)			(-9.54)
IS bid-ask spread				0.53*		-0.25*
				(2.17)		(-2.44)
Adjusted R^2	0.70	0.79	0.23	0.00	0.81	0.82

Explanatory variables	Dependent variable: Ten-year measure					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	8.07**	15.33**	13.26**	44.90**	16.07**	15.67**
	(11.02)	(35.79)	(26.28)	(28.00)	(21.82)	(9.25)
VIX	0.94**				-0.06	-0.09
	(31.17)				(-1.24)	(-1.69)
HPW measure		3.39**			3.56**	3.02**
		(41.86)			(22.23)	(12.48)
Off-the-run spread			0.98**			0.20**
			(37.86)			(2.92)
IS bid-ask spread				-2.05*		-0.01
				(-10.67)		(-0.03)
Adjusted R^2	0.37	0.51	0.46	0.06	0.51	0.52

Table 13: **Regression Results for Pre-MEP Period.**

The top panel reports the results of regressions with the TIPS and inflation swap liquidity premium measure at the five-year maturity as the dependent variable and four measures of market functioning as explanatory variables. The bottom panel reports the corresponding results when the ten-year liquidity premium measure is the dependent variable. T-statistics are reported in parentheses. Asterisks * and ** indicate significance at the 5 percent and 1 percent levels, respectively. The data are daily covering the period from January 4, 2005, to September 20, 2011, a total of 1,660 observations.

Appendix E: TIPS Purchases outside QE2 and the MEP

TIPS purchase operation dates	TIPS purchases (mill.)	Weighted avg. maturity (years)
(1) Apr. 16, 2009	$1,619	11.74
(2) May 26, 2009	$1,562	2.16
(3) Jul. 16, 2009	$1,525	3.30
(4) Aug. 30, 2010	$398	10.20
(5) Sep. 28, 2010	$655	10.86
(6) Oct. 10, 2010	$788	10.74
Average	$1,091	8.17

Table 14: **TIPS Purchase Operation Dates outside QE2 and the MEP.**
The table reports the amount and weighted average maturity of TIPS purchased on the six TIPS purchase operation dates outside QE2 and the MEP. The TIPS purchase amounts are reported in millions of dollars, while the weighted average maturities are measured in years.

Table 14 contains information for the six TIPS purchase operations that were included as part of the Treasury securities purchases in the QE1 program in 2009 and during the re-investment program that was initiated in the months before the announcement of the QE2 program. The total amount purchased was $6.1 billion. The three TIPS purchase operations in 2009 were close in size to the ones during QE2, but six weeks apart instead of biweekly. On the other hand, the three TIPS purchase operations in the fall of 2010 had a frequency not that different from the schedule operated during QE2, but the purchased amounts were about one-third of the purchase amounts during QE2. Thus, in both cases, the intensity of the TIPS purchases was but a fraction of that experienced during the QE2 program and for that reason we choose not to analyze these TIPS purchases further.

References

Abrahams, Michael, Tobias Adrian, Richard K. Crump, and Emanuel Moench, 2015, "Decomposing Real and Nominal Yield Curves," *Federal Reserve Bank of New York Staff Reports* #570.

Bauer, Michael D. and Glenn D. Rudebusch, 2014, "The Signaling Channel for Federal Reserve Bond Purchases," *International Journal of Central Banking*, Vol. 10, No. 3, 233-289.

Brunnermeier, Markus K. and Lasse Heje Pedersen, 2009, "Market Liquidity and Funding Liquidity," *Review of Financial Studies*, Vol. 22, No. 6, 2201-2238.

Campbell, John Y., Robert J. Shiller, and Luis M. Viceira, 2009, "Understanding Inflation-Indexed Bond Markets," *Brookings Papers on Economic Activity*, Spring, 79-120.

Christensen, Jens H. E., 2008, "The Corporate Bond Credit Spread Puzzle," Federal Reserve Bank of San Francisco, *Economic Letter* 2008-10.

Christensen, Jens H. E. and James M. Gillan, 2012, "Do Fed TIPS Purchases Affect Market Liquidity?" Federal Reserve Bank of San Francisco, *Economic Letter* 2012-07.

Christensen, Jens H. E. and Signe Krogstrup, 2015, "Transmission of Quantitative Easing: The Role of Central Bank Reserves," Working Paper 2014-39, Federal Reserve Bank of San Francisco.

Christensen, Jens H. E., Jose A. Lopez, and Glenn D. Rudebusch, 2012, "Extracting Deflation Probability Forecasts from Treasury Yields," *International Journal of Central Banking*, Vol. 8, No. 4, 21-60.

Christensen, Jens H. E., Jose A. Lopez, and Glenn D. Rudebusch, 2014, "Do Central Bank Liquidity Facilities Affect Interbank Lending Rates?" *Journal of Business and Economic Statistics*, Vol. 32, No. 1, 136-151.

Christensen, Jens H. E., Jose A. Lopez, and Glenn D. Rudebusch, 2015, "A Probability-Based Stress Test of Federal Reserve Assets and Income," *Journal of Monetary Economics*, Vol. 73, 26-43.

Christensen, Jens H. E. and Glenn D. Rudebusch, 2012, "The Response of Interest Rates to U.S. and U.K. Quantitative Easing," *Economic Journal*, Vol. 122, F385-F414.

Collin-Dufresne, Pierre, Robert S. Goldstein, and J. Spencer Martin, 2001, "The Determinants of Credit Spread Changes," *Journal of Finance*, Vol. 56, No. 6, 2177-2207.

D'Amico, Stefania, Don H. Kim, and Min Wei, 2014, "Tips from TIPS: The Informational Content of Treasury Inflation-Protected Security Prices," Finance and Economics Discussion Series 2014-24, Board of Governors of the Federal Reserve System.

D'Amico, Stefania and Thomas B. King, 2013, "The Flow and Stock Effects of Large-Scale Treasury Purchases: Evidence on the Importance of Local Supply," *Journal of Financial Economics*, Vol. 108, No. 2, 275-564.

Driessen, Joost, Theo E. Nijman, and Zorka Simon, 2014, "The Missing Piece of the Puzzle: Liquidity Premiums in Inflation-Indexed Markets," Manuscript. Department of Finance, Tilburg University.

Dudley, William C., Jennifer Roush, and Michelle Steinberg Ezer, 2009, "The Case for TIPS: An Examination of the Costs and Benefits," *Federal Reserve Bank of New York Economic Policy Review*, Vol. 15, No. 1, 1-17.

Fleckenstein, Mathias, Francis A. Longstaff, and Hanno Lustig, 2014, "The TIPS-Treasury Bond Puzzle," *Journal of Finance*, Vol. 69, No. 5, 2151-2197.

Fleming, Michael J. and Neel Krishnan, 2012, "The Microstructure of the TIPS Market," *Federal Reserve Bank of New York Economic Policy Review*, Vol. 18, No. 1, 27-45.

Fleming, Michael J. and John R. Sporn, 2013, "Trading Activity and Price Transparency in the Inflation Swap Market," *Federal Reserve Bank of New York Economic Policy Review*, Vol. 19, No. 1, 45-57.

Gagnon, Joseph, Matthew Raskin, Julie Remache, and Brian Sack, 2011, "Large-Scale Asset Purchases by the Federal Reserve: Did They Work?" *International Journal of Central Banking*, Vol. 7, No. 1, 3-43.

Gürkaynak, Refet S., Brian Sack, and Jonathan H. Wright, 2007, "The U.S. Treasury Yield Curve: 1961 to the Present," *Journal of Monetary Economics*, Vol. 54, No. 8, 2291-2304.

Gürkaynak, Refet S., Brian Sack, and Jonathan H. Wright, 2010, "The TIPS Yield Curve and Inflation Compensation," *American Economic Journal: Macroeconomics*, Vol. 2, No. 1, 70-92.

Hamilton, James D. and Jing Wu, 2012, "The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment," *Journal of Money, Credit, and Banking*, Vol. 44, No. 1 (Supplement), pp. 3-46.

Haubrich, Joseph, George Pennacchi, and Peter Ritchken, 2012, "Inflation Expectations, Real Rates, and Risk Premia: Evidence from Inflation Swaps," *Review of Financial Studies*, Vol. 25, No. 5, 1588-1629.

Hu, Grace Xing, Jun Pan, and Jiang Wang, 2013, "Noise as Information for Illiquidity," *Journal of Finance*, Vol. 68, No. 6, 2341-2382.

Joyce, Michael A. S., Ana Lasaosa, Ibrahim Stevens, and Matthew Tong, 2011, "The Financial Market Impact of Quantitative Easing in the United Kingdom," *International Journal of Central Banking*, Vol. 7, No. 3, 113-161.

Kandrac, John, 2013, "Have Federal Reserve MBS Purchases Affected Market Functioning?," *Economics Letters*, Vol. 121, 188-191.

Kandrac, John, 2014, "The Costs of Quantitative Easing: Liquidity and Market Functioning Effects of Federal Reserve MBS Purchases," Manuscript, Board of Governors of the Federal Reserve System.

Kandrac, John and Bernd Schlusche, 2013, "Flow Effects of Large-Scale Asset Purchases," *Economics Letters*, Vol. 121, 330-335.

Kettemann, Andreas and Signe Krogstrup, 2014, "Portfolio Balance Effects of the Swiss National Bank's Bond Purchase Program," *Journal of Macroeconomics*, Vol. 40, 132-149.

Krishnamurthy, Arvind and Annette Vissing-Jorgensen, 2011, "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy," *Brookings Papers on Economic Activity*, Fall 2011, 215-265.

Li, Canlin and Min Wei, 2013, "Term Structure Modeling with Supply Factors and the Federal Reserve's Large-Scale Asset Purchase Programs," *International Journal of Central Banking*, Vol. 9, No. 1, 3-39.

Lou, Dong, Yan Hongjun, and Jinfan Zhang, 2013, "Anticipated and Repeated Shocks in Liquid Markets," *Review of Financial Studies*, Vol. 26, No. 8, 1890-1912.

Meaning, Jack and Feng Zhu, 2011, "The Impact of Recent Central Bank Asset Purchase Programmes," *BIS Quarterly Review*, December, 73-83.

Pasquariello, Paolo, 2015, "Government Intervention and Arbitrage," Manuscript, Department of Finance, Ross School of Business, University of Michigan.

Pflueger, Carolin E. and Luis M. Viceira, 2013, "Return Predictability in the Treasury Market: Real Rates, Inflation, and Liquidity," Manuscript, Harvard Business School.

Sack, Brian and Robert Elsasser, 2004, "Treasury Inflation-Indexed Debt: A Review of the U.S. Experience," *Federal Reserve Bank of New York Economic Policy Review*, Vol. 10, No. 1, 47-63.

Tobin, James, 1969, "A General Equilibrium Approach to Monetary Theory," *Journal of Money, Credit and Banking*, Vol. 1, No. 1, 15-29.

Vayanos, Dimitri and Jean-Luc Vila, 2009, "A Preferred-Habitat Model of the Term Structure of Interest Rates," NBER Working Paper 15487.