Does Quantitative Easing Affect Market Liquidity?

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and

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Abstract

The Federal Reserve's second program of large-scale asset purchases, or quantitative easing—frequently referred to as QE2—included repeated purchases of Treasury inflation-protected securities (TIPS). Using a counterfactual analysis, we quantify the effect QE2 had on a model-free measure of combined liquidity premiums in TIPS yields and inflation swap rates. We find that, for the duration of the QE2 program, the liquidity premium measure averaged 12 to 14 basis points lower than expected, a reduction of about 50 percent. This suggests that one benefit of quantitative easing is to improve market liquidity.

JEL Classification: E43, E52, E58, G12.

Keywords: monetary policy, financial market frictions, TIPS, inflation swaps

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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, high. 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 in order to push down longer-term yields and provide 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 announcement days where the Fed indicated it was planning to 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.[1] In addition to the announcement effects, however, it is also possible that the actual purchases of longer-term securities could affect yields by increasing market liquidity and reducing liquidity premiums, at least temporarily.

In this paper, we focus on liquidity effects and analyze how the Fed's second QE program, henceforth QE2, which started in November 2010 and concluded in June 2011, affected the frictions to trading in the market for Treasury inflation-protected securities (TIPS) and the related market for inflation swap contracts.[2] The execution of the QE2 program provides an interesting natural experiment for studying liquidity effects in these two markets because the program included biweekly purchases of TIPS with no purchases of any other type of securities on the TIPS operation dates. Equally important, no TIPS were purchased outside the TIPS operation dates during the QE2 program.

To motivate the analysis and support the view that liquidity effects 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 as documented in

[1] We did look for effects related to the announcement of the QE2 program on November 3, 2010, but failed to detect any significant yield responses, see Appendix A.

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

Christensen and Gillan (2012a, henceforth CG).[3] 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 the sum of TIPS and inflation swap liquidity premiums identified by CG.[4] This measure is model-free by construction and provides a good proxy for the 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.

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 any effects from the Treasury purchases during the various Fed QE programs, but do not get 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 3. Thus, we do not pursue an analysis similar to theirs. Fleming and Sporn (2013) study trading activity, quote incidences as well as indicators of market activity in the inflation swap market. We choose to focus on the CG measure because we are interested in quantifying the effect on market functioning in terms of prices rather than quantities, and the CG measure delivers exactly that because it quantifies the frictions to trading in the TIPS and inflation swap markets as a yield difference.

In terms of how the large-scale asset purchases can affect market functioning, the primary channel is by way of reducing the frictions to trading in a broad sense—examples include, but are not limited to, increases in trading volume and trade sizes and reductions in bid-ask spreads. Still, we acknowledge that, in general, large-scale asset purchases such as the QE2 program analyzed here has the potential to impair market functioning by reducing the amount of securities available for trading.[5] However, given that the Fed's TIPS purchases during QE2 were not overly concentrated in any specific TIPS (as we document), there is little reason to suspect that this effect played any major role during the period under analysis, and our results to be detailed below are consistent with this view.

To assess 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, on one side, and a set of explanatory factors, on the other, that are meant to control explicitly for other sources thought to affect either TIPS and inflation swap market liquidity,

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

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

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

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 up to 40 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 security classes.

Our paper relates directly to two recent papers on the purchase effects of large-scale asset purchases. The paper closest to ours is the paper by D'Amico and King (2013, henceforth DK). They find evidence of 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.[6] 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. Due to the greater depth of the regular Treasury market, it is not surprising that we find liquidity effects about twice that size in the smaller markets for TIPS and inflation swaps. We also attempt to identify flow effects on TIPS prices directly by replicating the approach of DK and Meaning and Zhu (2011). However, the estimated coefficients are all insignificant and frequently have the wrong sign. We argue that this outcome is due to misspecification of the time fixed effects in their regression analysis, which does not appropriately account for the price effect of changes to expectations about economic fundamentals on the purchase dates.[7] In our analysis, we avoid the problem of how to deal with changes in expectations about economic fundamentals altogether as they cancel out in the construction of our liquidity premium measure, as argued in Section 3.

The remainder of the paper is structured as follows. Section 2 details the execution of the TIPS purchases included in the QE2 program, while Section 3 describes the construction of the TIPS and inflation swap liquidity premium measure derived in CG. Section 4 lays out our empirical strategy for estimating the effects of the QE2 TIPS purchases, and Section 5 presents our results. Section 6 concludes the paper. Appendices contain additional results,

[6] These Treasury purchases were announced on March 18, 2009, and concluded by October 30, 2009.

[7] As the purchases of Treasuries in both the QE1 and QE2 programs were much more frequent, any bias from the misspecified time fixed effects is more likely to average out in the analysis of DK and Meaning and Zhu (2011), which might explain why they get stronger 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 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 sizeable amount of TIPS.

The QE2 program was announced on November 3, 2010.[8] 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.[9] In addition, the FOMC had already decided in August 2010 to re-invest 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.[10,11] 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.[12]

The uniqueness of these TIPS purchases is evident in Figure 1(a), which shows the total book value of the Fed's TIPS holdings since 2008.[13] They increased the Fed's holdings by 52.8 percent and brought the total close to $75 billion.[14] Figure 1(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.[15] 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.

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

[9]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.

[10]The Fed has all along reinvested principal payments on its portfolio of Treasury securities in Treasuries.

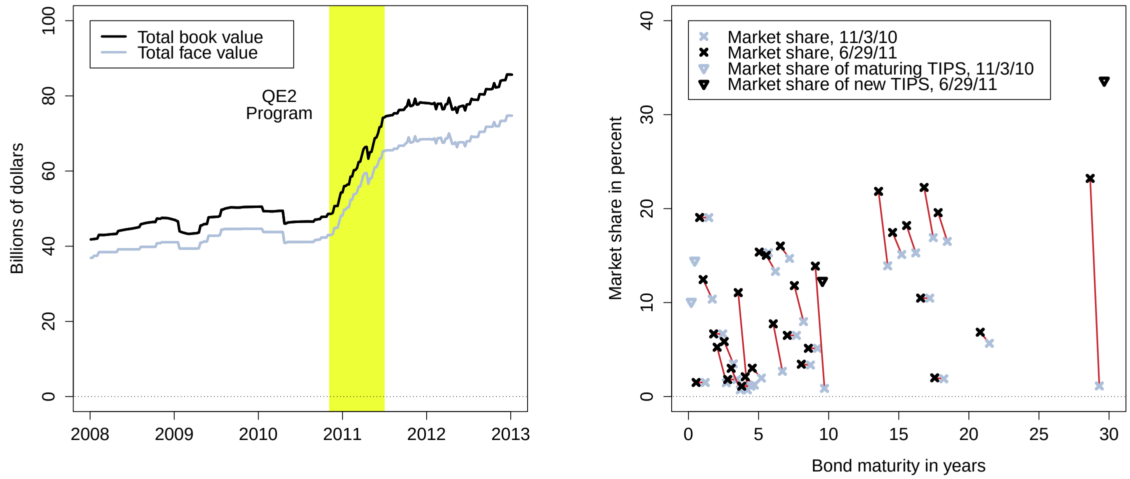
[11]Since September 2011, the Fed has been re-investing principal payments on its portfolio of agency debt and mortgage-backed securities in agency mortgage-backed securities to support the housing market.

[12]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 of which the Fed purchased 42 percent.

[13]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 E.

[14]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.

[15]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.



(a) Value of TIPS.

(b) Share of TIPS market.

Figure 1: **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 is 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.

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.[16] There 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.[17] 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 1(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

[16]The information can be found at http://www.newyorkfed.org/markets/tot_operation_schedule.html.
[17]Also, there were no TIPS auctions by the U.S. 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.

QE2 TIPS purchase operation dates	TIPS purchases (Mill.)	Weighted average maturity
(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.

the distribution of the purchases.[18] 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 operation date. This motivates the use of one-day indicator variables for the 15 TIPS purchase dates jointly in our preliminary regression analysis to be detailed in Section 5.1.

3 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 dependent variable in our empirical analysis.

Ideally, we would have liked to have a pure measure of liquidity premiums in TIPS yields and used that 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

[18]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.

and inflation. Instead, we follow CG and 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 payments are adjusted for inflation.[19] The difference in yield between regular nominal, or non-indexed, Treasury bonds and TIPS of the same maturity is referred to as breakeven inflation (BEI), 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 be equal to the BEI rate 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.[20] However, in reality as explained in CG, 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.

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 zero-coupon rates on inflation swap contracts denoted $\widehat{IS}_t(\tau)$. Due to microstructure frictions, such as bid-ask spreads and discrete-time trading in discrete denominations, 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.

[19]The U.S. Treasury uses the change in the headline consumer price index (CPI) to account for inflation compensation in TIPS.

[20]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 U.S. government to be negligible, which is warranted for our sample that ends in June 2011 before the downgrade of U.S. 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 E, any significant credit risk premium is not likely to bias our measure as it would presumably affect regular Treasury and TIPS yields in the same way, leaving BEI effectively unchanged.

Now, CG introduce three fundamental assumptions:

(1) The nominal Treasury yields we observe are very close to the unobservable nominal yields that would prevail in a frictionless world, 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 of 2008 and 2009), this is not critical as the point is ultimately about the relative liquidity between securities that pay nominal and real yields.

(2) TIPS are no more liquid than nominal Treasury bonds. As a consequence, the TIPS yields we observe 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.

CG present comprehensive evidence that these assumptions are satisfied for U.S. data; specifically, market size, trading volume, and bid-ask spreads all indicate that regular Treasury securities are much more liquid than both TIPS and inflation swaps.[21] It then follows that the difference between observed inflation swap and BEI rates is given by

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

This shows that the difference $\Delta_t(\tau)$ is non-negative and equals the *sum* of liquidity premiums in TIPS yields and inflation swap rates. Hence, $\Delta_t(\tau)$ quantifies how far the observed market rates are from the frictionless outcome. Finally, we emphasize that this is a model-independent result that relies only on the assumptions above.

Figure 2 shows this difference at the five- and ten-year maturity constructed using BEI rates from the Gürkaynak, Sack, and Wright (2007, 2010) databases of Treasury and TIPS yields combined with zero-coupon inflation swap rates from Bloomberg.[22]

[21] Driessen et al. (2014) also find statistically significant liquidity effects in both TIPS yields and inflation swap rates.

[22] As explained in CG, the inflation swap market in the United States started to be active in 2004 as the underlying TIPS market became more well established. Still, the data on inflation swap rates are not densely populated across maturities until late 2004. For this reason our sample starts in 2005. See CG for details on the construction of our measure.

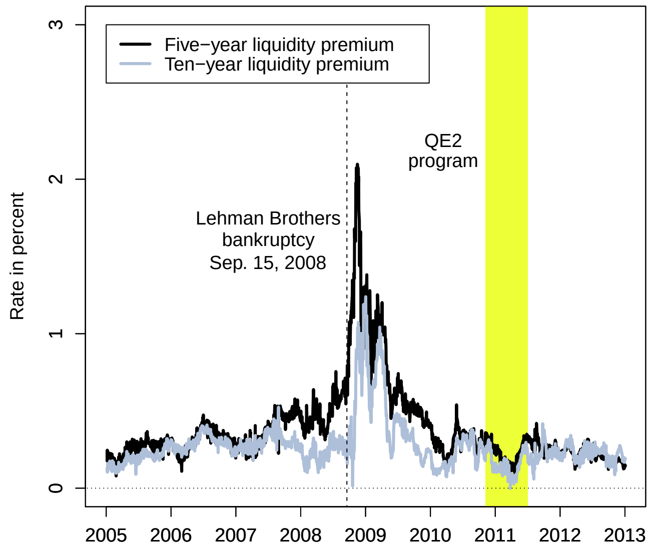


Figure 2: **Sum of Liquidity Premiums in TIPS and Inflation Swaps.**

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' view of economic fundamentals, such as future monetary policy, inflation, and their implications for bond yields, will cancel as they affect inflation swap rates and BEI of the same maturity in equal amounts.

4 Empirical Strategy

In this section, we describe how we quantify the effect of the QE2 TIPS purchases on our TIPS and inflation swap liquidity premium measure.

To isolate the effect of the QE2 TIPS purchases, we need to control explicitly for sources that could affect the measure independent of the QE2 program. To that end, we include five variables 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

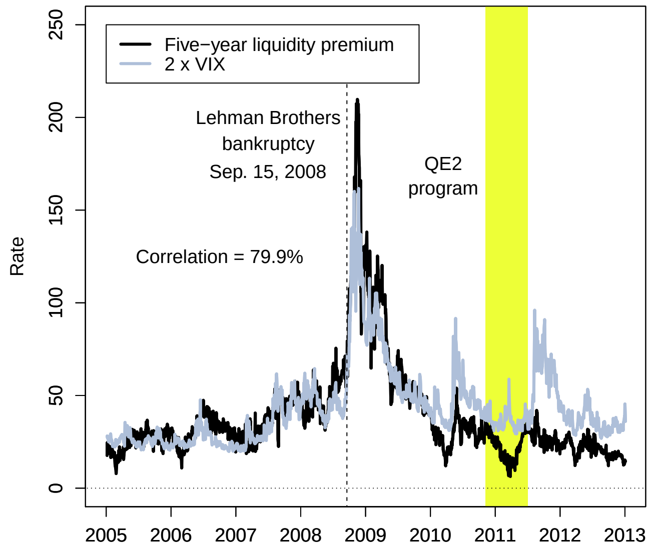


Figure 3: **The VIX Options-Implied Volatility Index for the S&P 500.**
Illustration of the VIX options-implied volatility index for the S&P 500 stock price index with a comparison to the five-year liquidity premium measure. Note that the former is measured in percent and multiplied by two to make its scale comparable to the latter, which is measured in basis points.

increased uncertainty about the future resale price of any security and therefore could cause liquidity premiums that represent investors' guard against such uncertainty to go up. As shown in Figure 3, 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 a recent paper by Hu, Pan, and Wang (2013, henceforth HPW).[23] 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 4 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

[23]The data are publicly available at Jun Pan's website: https://sites.google.com/site/junpan2/publications.

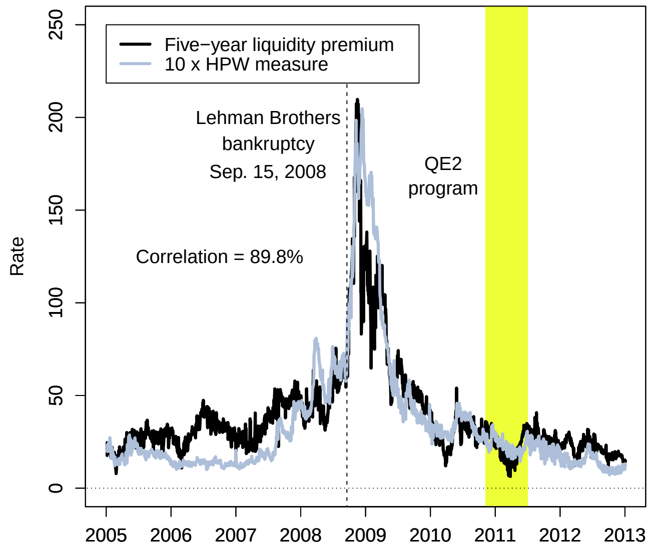
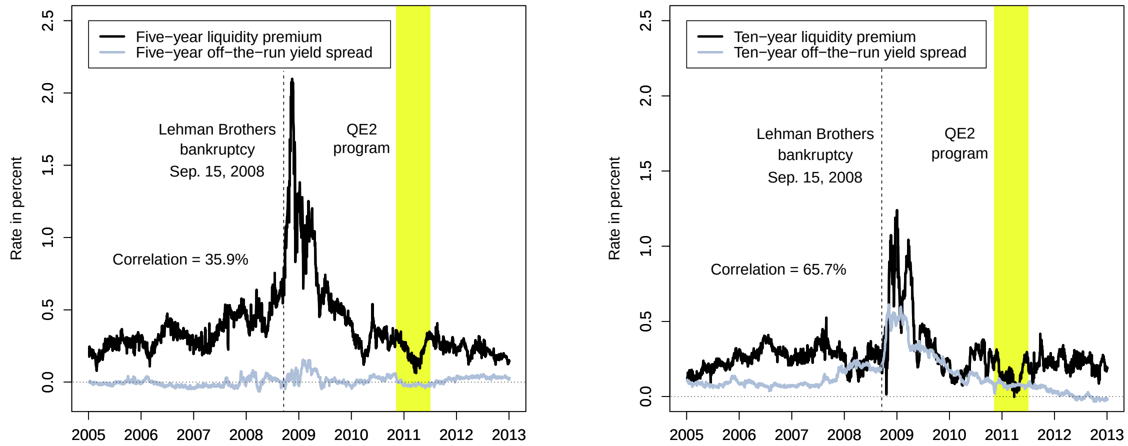


Figure 4: **The HPW Illiquidity Measure.**
Illustration of the measure of systemic or economy-wide financial market illiquidity introduced in HPW with a comparison to the five-year liquidity premium measure. Note that the former has been multiplied by ten to make its scale comparable to the latter, but both are measured in basis points.

securities and the most recently issued (on-the-run) Treasury security of the same maturity.[24] Figures 5(a) and 5(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 6 shows the four-week moving average of bid-ask spreads as reported by Bloomberg for the most

[24]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.



(a) Five-year maturity.

(b) Ten-year maturity.

Figure 5: **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.

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 elsewhere,[25] the bid-ask spreads for the TIPS appear suspiciously low and stable before the spring of 2011.[26] 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.

The final variable 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 7. We use the eight-week moving average to smooth out short-term volatility. This measure should have a negative effect on our liquidity premium measure as increases in TIPS trading volume should, in most cases, drive down TIPS and inflation swap liquidity premiums.

By including these five control variables, our regression results should provide a fair assessment of the effect the TIPS purchase operations had on TIPS and inflation swap liquidity

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

[26] Haubrich, Pennacchi, and Ritchken (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.

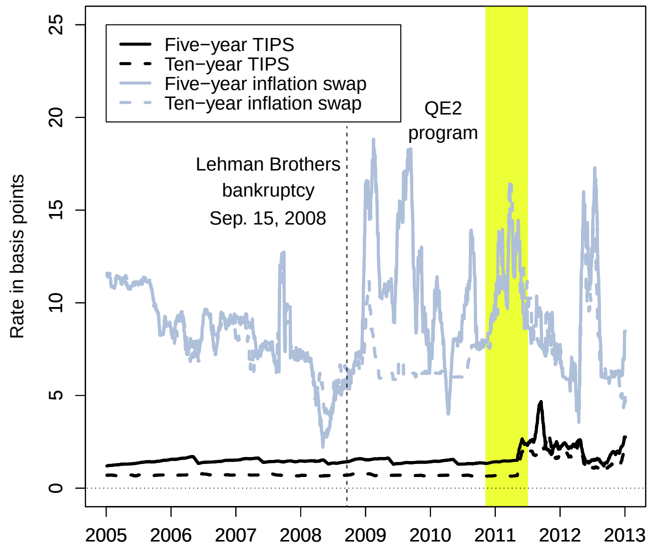


Figure 6: **Bid-Ask Spreads in the TIPS and Inflation Swap Markets.**
Illustration of the bid-ask spread as reported by Bloomberg for the most recently issued, or so-called on-the-run, five- and ten-year TIPS. Shown are also the bid-ask spreads from the inflation swap market for the five- and ten-year zero-coupon inflation swap contracts. All series are smoothed four-week moving averages and measured in basis points.

premiums.

5 Results

In this section, we first present empirical results from a set of exploratory regressions with one-day indicator variables for the QE2 TIPS purchases and discuss related robustness tests. The results suggest that the purchases had a persistent negative effect on the liquidity premium measure and motivate the subsequent set of regressions that imposes a switch in the conditional mean following the announcement of the QE2 program. We find the downward shift in the mean to be highly 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. We end the section with a replication of the approach used by DK to attempt to identify local supply effects from the TIPS purchases on TIPS prices directly.

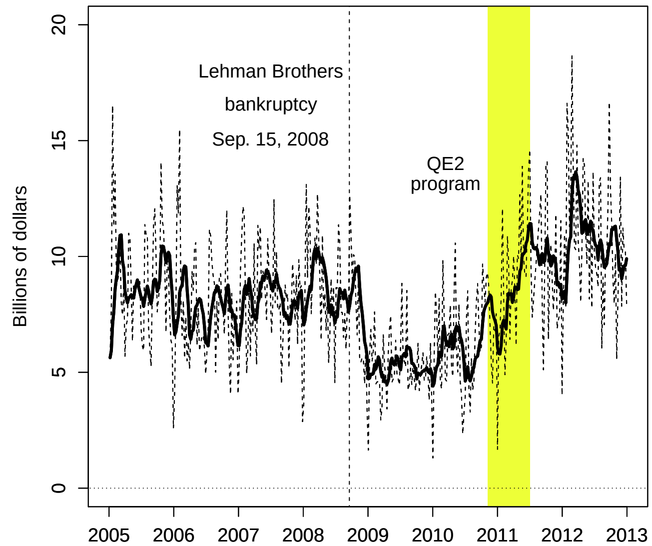


Figure 7: **TIPS Trading Volume.**
Weekly average of daily trading volume in the secondary market for TIPS (dashed black line) and the smoothed eight-week moving average (solid black line).

5.1 Exploratory Regressions

For a start we run regressions with our liquidity premium measure as the dependent variable on the five explanatory variables described in the previous section. To capture the one-day response of our liquidity premium measure to the TIPS purchase operations, we include a standard indicator variable for the 15 TIPS purchase operations jointly. This allows us to capture the difference in the closing value of the measure from the day before the TIPS purchase operations to the day of the operations. The results for these regressions are reported in Table 7 with the top and bottom panels referring to the five- and ten-year maturity, respectively. In each case, regression (7) with all five control variables is considered the baseline regression in the remainder of the section. However, regressions (1) through (6) show that the effect captured by the indicator variable is robust across different specifications of the regressions.

In the individual regressions (1)-(5), 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, while increases in the trading volume of TIPS tend to coincide with a compression of the liquidity

Explanatory variables	Dependent variable: Five-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	-5.39**	15.41**	41.08**	37.38**	89.71**	5.24**	5.82*
	(-6.99)	(32.35)	(64.69)	(15.63)	(27.95)	(6.62)	(2.42)
VIX	2.24**					0.93**	1.04**
	(70.14)					(15.50)	(17.41)
HPW measure		6.93**				4.41**	4.78**
		(78.42)				(24.23)	(26.68)
Off-the-run spread			3.94**				-1.14**
			(21.94)				(-10.51)
IS bid-ask spread				0.55*			-0.26*
				(2.26)			(-2.48)
TIPS trading volume					-6.25**		-0.19
					(-15.04)		(-0.90)
TIPS purchase dummy	-13.75**	-9.15**	-13.13*	-22.09**	-15.02*	-10.43**	-10.96**
	(-3.73)	(-2.70)	(-2.01)	(-2.96)	(-2.15)	(-3.30)	(-3.57)
Adjusted R^2	0.76	0.79	0.23	0.01	0.13	0.82	0.83

Explanatory variables	Dependent variable: Ten-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	7.68**	15.68**	13.47**	44.71**	63.29**	15.92**	31.82**
	(10.59)	(35.48)	(25.54)	(27.27)	(33.79)	(20.19)	(13.61)
VIX	0.99**					-0.02	-0.09
	(32.89)					(-0.36)	(-1.46)
HPW measure		3.36**				3.42**	3.55**
		(40.96)				(18.85)	(14.45)
Off-the-run spread			0.97**				-0.08
			(36.70)				(-1.13)
IS bid-ask spread				-1.98**			0.44**
				(-10.02)			(2.80)
TIPS trading volume					-4.57**		-2.29**
					(-18.82)		(-10.31)
TIPS purchase dummy	-10.36**	-7.82*	-5.83	-6.43	-9.23*	-7.79*	-7.87*
	(-2.98)	(-2.49)	(-1.76)	(-1.45)	(-2.27)	(-2.48)	(-2.55)
Adjusted R^2	0.41	0.51	0.46	0.06	0.18	0.51	0.54

Table 2: **Regression Results Using Standard Indicator Variables.**
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 five 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 4, 2005, to June 30, 2011, a total of 1,604 observations.

premium measures. More importantly, though, it is clear from the baseline regression (7) that the HPW measure has the strongest explanatory power of the five 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.

As for the dummy variable for the TIPS purchase operations, we find that the TIPS operations during the QE2 program had a statistically significant negative impact on the liquidity premium measure. The estimated decline in the baseline regression is 11 basis points at the five-year maturity and 8 basis points at the ten-year maturity. Considering that the averages of the five- and ten-year liquidity premium measures over the purchase period were 22.3 and 15.8 basis points, respectively, these seem like sizeable reductions of about 50 percent. We take this as a first indication that the TIPS purchases during the QE2 program could have improved TIPS and inflation swap market functioning.

We did several robustness checks regarding these preliminary results, which are reported in Appendix B. Using a two-day window, the results indicate that the point estimates do not change, while the statistical significance actually increases. We also used two separate indicator variables, one that captures the reaction of the liquidity premium measure on the days with TIPS purchases, the other for the reaction the following day. The results for these regressions suggest that the TIPS purchases had longer-lasting negative effects on our measure of liquidity premiums in the TIPS and inflation swap markets, as there is no positive coefficient for the second-day indicator variable.[27]

The intriguing question left behind by these results is whether the significant negative effects identified with the indicator variables for the 15 TIPS purchase operations during the QE2 program had a lasting downward effect on the measure of TIPS and inflation swap liquidity premiums, a question we now address.

5.2 Regressions with Switch in the Conditional Mean

To test the conjecture above, we run regressions that impose a switch in the conditional mean following the announcement of the QE2 program, that is, we use the same five 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 7 that did not impose a switch in the conditional mean. Second, for the five explanatory variables, there are only minor changes to their estimated coefficients from imposing the switch in conditional mean. This supports the choice not to allow for any switch in their interaction with the liquidity measure.

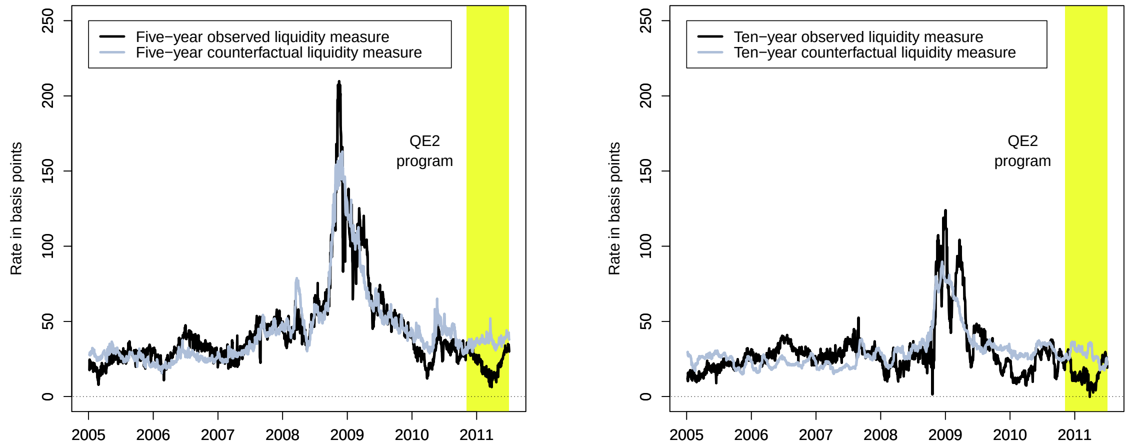
[27] Lou et al. (2013) find persistent price effects in the Treasury market from the U.S. Treasury's issuance of Treasury securities.

Explanatory variables	Dependent variable: Five-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	-3.28**	16.78**	42.53**	35.15**	86.77**	6.28**	-2.83
pre-QE2 announcement	(-4.34)	(34.32)	(64.22)	(15.08)	(27.17)	(8.16)	(-1.19)
Constant	-17.72**	6.80**	27.97**	10.74**	70.93**	-5.00**	-16.41**
post-QE2 announcement	(-14.81)	(6.73)	(14.33)	(3.10)	(17.12)	(-4.29)	(-5.78)
VIX	2.20**					0.98**	1.14**
	(71.89)					(16.85)	(19.92)
HPW measure		6.82**				4.16**	4.52**
		(78.29)				(23.48)	(26.42)
Off-the-run spread			3.74**				-1.31**
			(20.77)				(-12.55)
IS bid-ask spread				1.04**			0.14
				(4.28)			(1.32)
TIPS trading volume					-5.67**		0.48*
					(-13.52)		(2.33)
Adjusted R^2	0.93	0.94	0.76	0.70	0.73	0.95	0.95

Explanatory variables	Dependent variable: Ten-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	9.29**	16.85**	14.50**	40.66**	61.51**	16.70**	26.78**
pre-QE2 announcement	(12.83)	(36.99)	(25.91)	(23.19)	(33.03)	(21.47)	(11.45)
Constant	-1.69	8.34**	8.66**	30.94**	51.90**	8.17**	16.00**
post-QE2 announcement	(-1.48)	(8.86)	(8.60)	(11.14)	(21.49)	(6.93)	(5.68)
VIX	0.96**					0.01	0.03
	(32.80)					(0.24)	(0.45)
HPW measure		3.27**				3.23**	3.57**
		(38.80)				(18.01)	(14.92)
Off-the-run spread			0.94**				-0.19**
			(34.95)				(-2.64)
IS bid-ask spread				-1.36**			1.11**
				(-6.17)			(6.55)
TIPS trading volume					-4.21**		-2.31**
					(-17.24)		(-10.69)
Adjusted R^2	0.85	0.87	0.86	0.75	0.79	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 five 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.

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 are -14.44, -9.98, -14.56, -24.41, -15.84, -11.28, and -13.58 basis points, respectively, while the corresponding differences in the estimated constants at the ten-



(a) Five-year liquidity premium measures.

(b) Ten-year liquidity premium measures.

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

year maturity are -10.98, -8.51, -5.84, -9.72, -9.61, -8.53, and -10.79 basis points, respectively. Thus, these values are very similar to the estimated coefficients for the corresponding purchase indicator values reported in Table 7 and underscores the robustness of our findings.

More importantly, though, 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 all strongly rejected by the data at both maturities.[28] This suggests that either the announcement of the QE2 program and/or the TIPS purchases led to a statistically significant persistent shift down in the conditional mean of our liquidity measure.

5.3 Counterfactual Analysis

To better understand the timing and source(s) of the effects of the QE2 program that are behind the significant 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 (7) in Table 7 with all five 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 fixing the coefficients at those estimated values and using the subsequent realizations of the five control variables, we get an estimate of the most likely counterfactual path

[28] At the five-year maturity, the seven test sizes are 165.02, 88.89, 49.25, 108.76, 50.42, 132.81, and 183.52, respectively. At the ten-year maturity, the corresponding test sizes are 104.32, 74.44, 29.73, 38.66, 54.65, 74.27, and 95.07, respectively.

for our liquidity premium measure, had the QE2 program not included TIPS purchases.[29]

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.[30] As noted in the figure, there is a sizeable 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, maybe with the exception of the TIPS trading volume series.

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 14.47 and 12.08 basis points higher over the period of the QE2 purchase program at the five- and ten-year maturities, respectively, and up to 40 basis points higher during the middle third of the program coinciding with turmoil about sovereign debt in southern peripheral countries in the euro area that would normally have 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 used in the preliminary analysis with indicator variables for the 15 TIPS purchase operations, 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

[29] This approach shares similarities with the counterfactual analysis in Christensen et al. (2014), who assess the effects of the Fed's Term Auction Facility (TAF) introduced on December 12, 2007, designed to ease strains in short-term funding markets during the early stages of the financial crisis of 2007-2008. They estimate a dynamic term structure model with data until July 25, 2008, and generate a counterfactual outcome for LIBOR rates from December 14, 2007, to July 25, 2008, by holding their LIBOR-specific factor fixed at its pre-TAF historical mean, while the remaining factors assume their filtered values during the counterfactual period. Since our explanatory variables are observed, we avoid estimating through the counterfactual period unlike Christensen et al. (2014).

[30] 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 the ones reported in Table 3 based on the full sample with a switch in the conditional mean imposed.

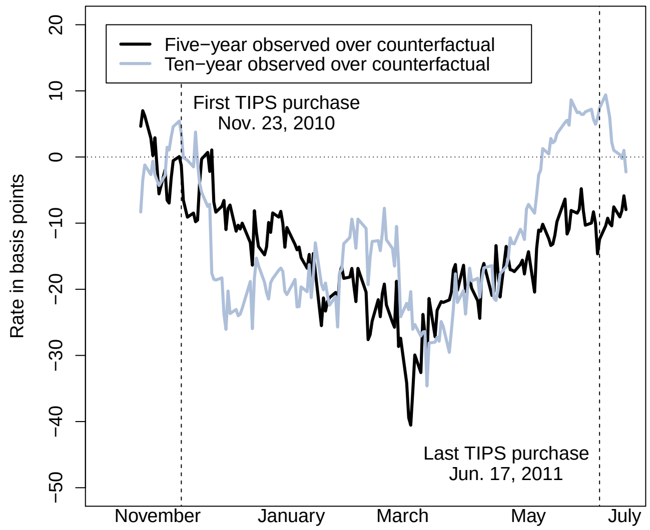


Figure 9: **Difference between Observed and Counterfactual Liquidity Premium Measures.**
Illustration of the difference between the observed and counterfactual TIPS liquidity premium measure at the five- and ten-year horizons, respectively. The sample shown covers the period from November 3, 2010, to June 30, 2011.

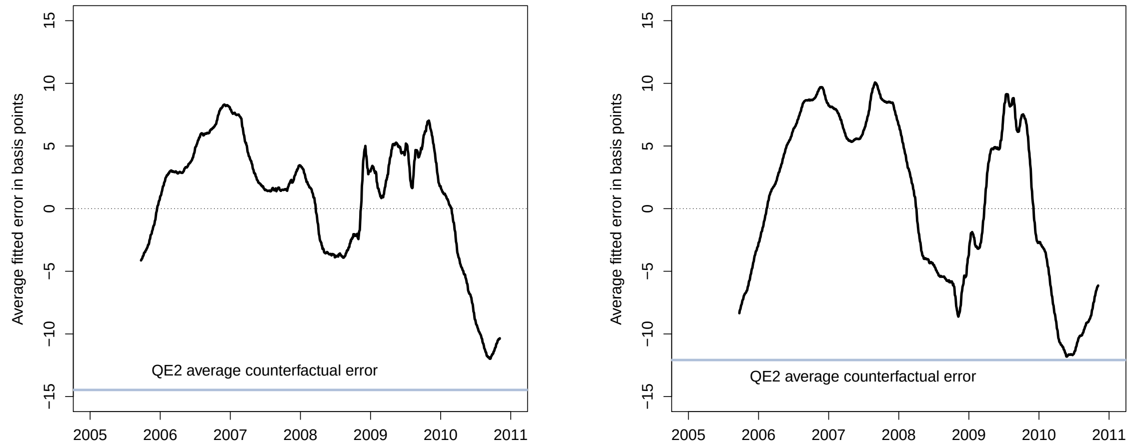
10 shows these series for the five- and ten-year maturities along with the average of the counterfactual errors during the QE2 program, indicated with solid gray horizontal lines. We note that it is unprecedented to have a sustained difference of this magnitude simultaneously at the five- and ten-year maturities.

Overall, the results and time series patterns from the counterfactual analysis suggest that it was the QE2 TIPS purchases and their duration rather than any effects from the announcement of the QE2 program that pushed the liquidity premium measure to levels well below where it would otherwise have been.[31]

5.3.1 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.

[31]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. They are available upon request.



(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.

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:

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

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 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 as explained in the following. 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 (7) in Table 4, we calculate realized residuals relative to the coun-

Explanatory variables	Dependent variable: Five-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	-0.30	1.38**	0.86**	1.01*	0.64	0.43	-1.99**
	(-1.00)	(5.13)	(3.17)	(2.08)	(0.77)	(1.22)	(-1.63)
AR(1) coefficient	0.92**	0.92**	0.98**	0.98**	0.98**	0.90**	0.89**
	(93.65)	(87.26)	(180.60)	(202.94)	(192.00)	(79.12)	(73.91)
VIX	0.17**					0.12**	0.16**
	(6.91)					(4.09)	(5.36)
HPW measure		0.54**				0.34**	0.46**
		(6.69)				(3.71)	(4.73)
Off-the-run spread			0.05				-0.19**
			(1.05)				(-3.68)
IS bid-ask spread				-0.03			0.02
				(-0.60)			(0.46)
TIPS trading volume					0.02		0.20
					(0.16)		(1.92)
Adjusted R^2	0.97	0.97	0.97	0.97	0.97	0.97	0.99

Explanatory variables	Dependent variable: Ten-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	0.33	0.95**	0.66**	1.35**	1.72*	1.00**	1.29
	(1.41)	(4.54)	(3.16)	(2.64)	(2.56)	(3.36)	(1.39)
AR(1) coefficient	0.95**	0.94**	0.95**	0.97**	0.97**	0.94**	0.93**
	(123.37)	(111.43)	(119.46)	(160.78)	(145.52)	(111.40)	(103.41)
VIX	0.05**					-0.01	-0.00
	(4.59)					(-0.26)	(-0.15)
HPW measure		0.22**				0.24**	0.26**
		(5.84)				(3.59)	(2.88)
Off-the-run spread			0.06**				-0.01
			(5.02)				(-0.23)
IS bid-ask spread				-0.07			0.07
				(-1.16)			(1.11)
TIPS trading volume					-0.11		-0.10
					(-1.43)		(-1.20)
Adjusted R^2	0.95	0.95	0.95	0.95	0.95	0.95	0.99

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 five 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.

terfactual 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.[32]

5.4 Local Supply Effects in the TIPS Market

The results presented so far 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, TIPS BEI would widen leading to a decline in our liquidity premium measure. In this section, 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 11, 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

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

(a) Treasury yields.

(b) TIPS yields.

Figure 11: **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.

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.[33] 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 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.[34] 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,

[33] All details are provided in Appendix D.

[34] 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.

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 5: **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 with TIPS with less than ten years to maturity, and one subsample with 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.

denoted $R^n(t)$, on a set of variables:

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

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 5 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 the two subsamples with TIPS with less/more than ten years to maturity.[35] Overall, the results are surprising in light of our previous results. Most of the coefficients of the purchase elasticities do not even have the right sign, and none of them are statistically significant at conventional levels. In short, it is hard 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 ar-

[35]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 1(b).

bitrageurs who trade away profit opportunities along the yield curve are capital constrained; thus, only taking on the most profitable trades, not necessarily all available arbitrages. As noted in Figure 2, 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.[36] 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.[37] 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.[38] 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 DK's approach 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-by-day variation for its identification.

6 Conclusion

In this paper, 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.

[36]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.

[37]Figure 11(b) shows that the TIPS curve did experience several level shifts during the QE2 program.

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

To quantify the frictions in the markets for these two types of financial claims, we use the model-independent measure of the sum of liquidity premiums in TIPS yields and inflation swap rates derived in CG. 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 binary event variables for the purchases dates, regressions with switches in the conditional mean, and a counterfactual analysis all suggest that the TIPS purchases reduced liquidity premiums in the markets for TIPS and inflation swaps. Specifically, the 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 on-going and expected to continue.

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, most likely due to misspecification of the time fixed affects in their regressions. An alternative interpretation of 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, our analysis does not identify what part of the documented improvement in market functioning arises from reductions in the price of liquidity and what part reflects improvements in liquidity itself. We leave it to future work to disentangle these two effects.

Finally, another underresearched area is the extent to which the improvement in market functioning from QE asset purchases extends beyond the safest assets such as Treasuries, TIPS, and mortgage-backed securities. In particular, the impact on the functioning of corporate bond markets would be interesting to study because any improvement in the efficiency of their pricing would translate into tangible economic benefits as firms would be able to obtain external financing at lower cost and in greater volume. Again, we leave this important question for future research.

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**
CG 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 6: **Market Response to QE2 Announcement.**
The table reports the one-day response of nominal Treasury yields, real TIPS yields, TIPS breakeven inflation, and inflation swap rates 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, Sack, and Wright (2007, 2010), while the inflation swap rates are from Bloomberg.

Table 6 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 CG measure little affected. To put the reported yield changes into perspective, we note that the standard deviation of daily changes in the CG measure over the period from January 4, 2005, to November 2, 2010, is 5.4 basis points at the five-year maturity and declines monotonely with maturity reaching 4.0 basis points at the ten-year maturity. We take this as evidence that there are no statistically significant effects to account for related to the announcement of the QE2 program.

Appendix B: Robustness Check of Indicator Variable Regressions

In this appendix, we carry out a number of additional regressions that serve as robustness checks of our baseline regressions with a one-day indicator variable for the 15 TIPS purchase dates.

Our first robustness check is to replace the one-day response indicator variable with a two-day indicator variable. Table 7 summarizes the results from these regressions. Using a two-day window, the results indicate that the point estimates do not change much, while the statistical significance actually increases. As such, the interpretation and the magnitude remain intact with a two-day response window. Furthermore, all other coefficients barely change. In a related robustness check, we use two separate indicator variables, one that captures the reaction of the liquidity premium measure on the days with TIPS purchases, and another for the reaction the following day. If the purchases only push down the liquidity premium measure temporarily on the days of the TIPS purchases, we should expect to see a reversal already the following day, that is, the dummy variable for the second-day response should have a positive coefficient. The results from these regressions are reported in Table 8. They show that the TIPS purchases had longer-lasting negative effects on our measures of liquidity premiums in the TIPS and inflation swap markets as there is no positive coefficient for the second-day dummy. Note, its estimated coefficient has the same sign and is only slightly smaller than the coefficient of the first-day indicator variable.

As an alternative, we weight the indicator variable for each operation date by the ratio of the amount of TIPS purchased relative to the market value of the entire TIPS market. In general, the results do not differ much from our baseline result in the sense that the sign and significance of the purchase indicator variable are little affected. As neither the amount of TIPS purchased nor the value of the TIPS market varied much across time, the total-purchase-weighted dummy exhibits only modest time variation (shown with solid black bars in Figure 12), which explains its similarity to the results from using a standard indicator variable. Instead, we proceed to include two weighted indicator variables in each regression. The first variable is weighted by the fraction of TIPS purchased with four to six years remaining to maturity relative to the total market value of TIPS in that maturity range. The second variable repeats this using the eight- to ten-year maturity range. The weights for the two indicator variables are shown in Figure 12 with dark and light gray bars, respectively, while the regression results are reported in Table 9.

We note that the indicator variable weighted based on the fraction of the four- to six-year TIPS market purchased is uniformly insignificant and most of the time has the wrong sign. On the other hand, the indicator variable weighted based on the fraction of the eight- to ten-year TIPS market purchased has the right sign in all regressions, and is highly statistically significant and about the same size at both maturities in regression (7). Combined with the significance of the standard indicator variables reported in Table 7, this suggests that the effects of purchases in one maturity segment may be able to spill over into neighboring maturity segments and is consistent with similar findings for the regular Treasury bond market reported by DK. Additionally, the estimated coefficients in this case can be interpreted quite nicely. For the ten-year maturity segment, the liquidity premiums in the TIPS and inflation swap markets decline by about 14 basis points for each percentage point of that segment of the TIPS market purchased. Purchases of that magnitude also depress the liquidity premium measure at the five-year maturity by about the same magnitude.

To explain the difference in the results for the two weighted dummies, Figure 12 shows the weights for each of the 15 operation dates. Note that the purchases of four- to six-year TIPS were small, with few exceptions, even relative to the total size of that maturity segment. Hence, it appears reasonable that purchases of such tiny magnitudes have essentially no effect on the size of liquidity premiums in the markets for these securities. In the eight- to ten-year maturity segment, on the other hand, purchases were much more material and, on several occasions, represented more than 1 percent of the entire market in that maturity segment. With purchases of that magnitude, it is not surprising that our liquidity measure responds, and significantly so, in

Explanatory variables	Dependent variable: Five-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	-5.19**	15.55**	41.22**	37.10**	89.46**	5.36**	5.08*
	(-6.74)	(32.59)	(64.66)	(15.54)	(27.90)	(6.79)	(2.12)
VIX	2.23**					0.94**	1.05**
	(70.29)					(15.60)	(17.59)
HPW measure		6.92**				4.40**	4.76**
		(78.45)				(24.20)	(26.71)
Off-the-run spread			3.92**				-1.16**
			(21.83)				(-10.69)
IS bid-ask spread				0.61*			-0.22*
				(2.47)			(-2.12)
TIPS trading volume					-6.20**		-0.13
					(-14.91)		(-0.64)
TIPS purchase dummy	-13.61**	-9.76**	-13.50**	-22.50**	-15.23**	-10.75**	-11.42**
	(-5.21)	(-4.06)	(-2.90)	(-4.25)	(-3.07)	(-4.80)	(-5.22)
Adjusted R^2	0.76	0.80	0.24	0.01	0.13	0.82	0.83

Explanatory variables	Dependent variable: Ten-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	7.84**	15.80**	13.57**	44.37**	63.14**	16.01**	31.40**
	(10.81)	(35.65)	(25.60)	(26.87)	(33.74)	(20.33)	(13.44)
VIX	0.98**					-0.02	-0.08
	(32.87)					(-0.33)	(-1.32)
HPW measure		3.35**				3.40**	3.56**
		(40.90)				(18.80)	(14.50)
Off-the-run spread			0.97**				-0.09
			(36.54)				(-1.25)
IS bid-ask spread				-1.93**			0.51**
				(-9.66)			(3.17)
TIPS trading volume					-4.53**		-2.30**
					(-18.69)		(-10.38)
TIPS purchase dummy	-10.35**	-8.16**	-5.79*	-6.87*	-9.34**	-8.14**	-8.42**
	(-4.20)	(-3.66)	(-2.45)	(-2.16)	(-3.23)	(-3.64)	(-3.80)
Adjusted R^2	0.41	0.52	0.46	0.06	0.19	0.52	0.55

Table 7: **Regression Results Using Standard Indicator Variables with a Two-Day Window.**

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 five 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 two-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 4, 2005, to June 30, 2011, a total of 1,604 observations.

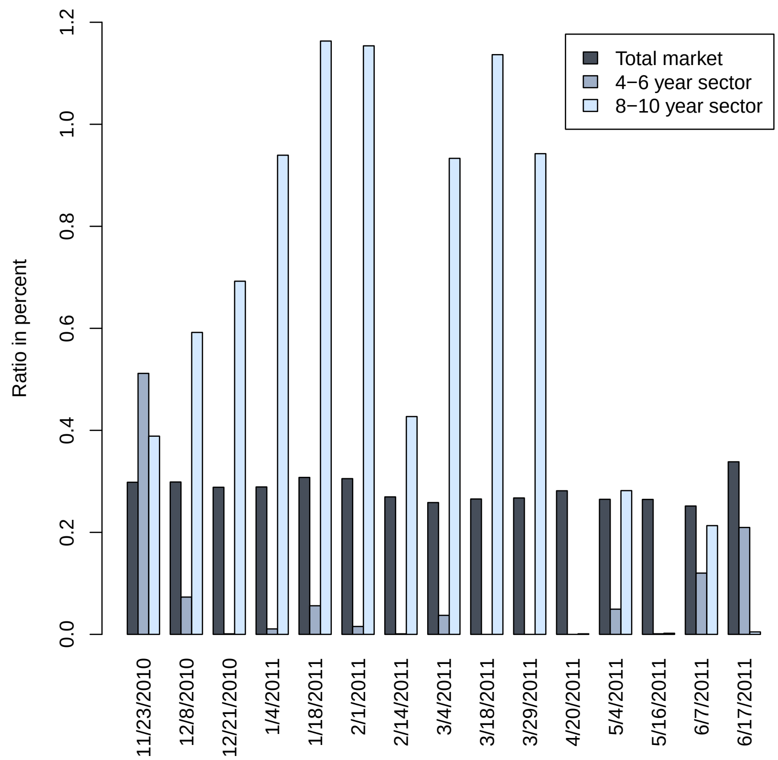


Figure 12: **Ratio of TIPS Purchased Relative to Total TIPS Market.**
Illustration of the ratio of TIPS purchased in each of the 15 TIPS purchase operations during the QE2 program. The solid black bars indicate the amount purchased relative to the market value of the entire TIPS market. The dark grey bars indicate the amount of four- to six-year TIPS purchased relative to the market value of all four- to six-year TIPS outstanding. The light grey bars indicate the amount of eight- to ten-year TIPS purchased relative to the market value of all eight- to ten-year TIPS outstanding.

Explanatory variables	Dependent variable: Five-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	-5.19**	15.55**	41.22**	37.10**	89.46**	5.36**	5.08*
	(-6.74)	(32.58)	(64.64)	(15.54)	(27.89)	(6.79)	(2.12)
VIX	2.23**					0.94**	1.05**
	(70.26)					(15.60)	(17.59)
HPW measure		6.92**				4.40**	4.76**
		(78.43)				(24.19)	(26.70)
Off-the-run spread			3.92**				-1.16**
			(21.82)				(-10.69)
IS bid-ask spread				0.61*			-0.22*
				(2.47)			(-2.12)
TIPS trading volume					-6.20**		-0.13
					(-14.90)		(-0.64)
Day 1 TIPS purchase dummy	-13.89**	-9.26**	-13.30*	-22.43**	-15.21*	-10.56**	-11.24**
	(-3.78)	(-2.74)	(-2.03)	(-3.01)	(-2.18)	(-3.35)	(-3.68)
Day 2 TIPS purchase dummy	-13.33**	-10.26**	-13.70*	-22.58**	-15.24*	-10.95**	-11.59**
	(-3.62)	(-3.04)	(-2.10)	(-3.04)	(-2.18)	(-3.48)	(-3.79)
Adjusted R^2	0.76	0.80	0.24	0.01	0.13	0.82	0.83

Explanatory variables	Dependent variable: Ten-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	7.84**	15.80**	13.57**	44.38**	63.14**	16.01**	31.41**
	(10.80)	(35.64)	(25.59)	(26.86)	(33.73)	(20.33)	(13.43)
VIX	0.98**					-0.02	-0.08
	(32.86)					(-0.33)	(-1.32)
HPW measure		3.35**				3.40**	3.56**
		(40.89)				(18.80)	(14.50)
Off-the-run spread			0.97**				-0.09
			(36.53)				(-1.25)
IS bid-ask spread				-1.93**			0.51**
				(-9.66)			(3.17)
TIPS trading volume					-4.53**		-2.30**
					(-18.68)		(-10.37)
Day 1 TIPS purchase dummy	-10.47**	-7.92*	-5.91	-6.67	-9.35*	-7.89*	-8.20**
	(-3.02)	(-2.52)	(-1.78)	(-1.51)	(-2.30)	(-2.51)	(-2.66)
Day 2 TIPS purchase dummy	-10.23**	-8.41**	-5.67	-7.06	-9.33*	-8.39**	-8.64**
	(-2.95)	(-2.68)	(-1.71)	(-1.60)	(-2.29)	(-2.67)	(-2.81)
Adjusted R^2	0.41	0.52	0.46	0.06	0.18	0.51	0.55

Table 8: **Regression Results Using Two One-Day Standard Indicator Variables.** 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 five measures of market functioning as explanatory variables. Included are two standard binary dummy variables, one for the 15 dates on which TIPS purchase operations took place, another for the day after the 15 purchase dates. 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.

a downward direction.

Explanatory variables	Dependent variable: Five-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	-5.44**	15.37**	41.06**	37.38**	90.01**	5.23**	6.20**
	(-7.05)	(32.32)	(64.72)	(15.60)	(28.06)	(6.60)	(2.58)
VIX	2.24**					0.93**	1.04**
	(70.12)					(15.46)	(17.34)
HPW measure		6.94**				4.42**	4.78**
		(78.46)				(24.26)	(26.70)
Off-the-run spread			3.95**				-1.14**
			(21.98)				(-10.49)
IS bid-ask spread				0.55*			-0.27*
				(2.23)			(-2.54)
TIPS trading volume					-6.29**		-0.23
					(-15.16)		(-1.09)
TIPS purchase dummy	-9.45	13.51	-10.36	-9.42	5.70	5.31	5.86
4-6 year segment	(-0.37)	(0.58)	(-0.23)	(-0.18)	(0.12)	(0.24)	(0.28)
TIPS purchase dummy	-16.33**	-12.68**	-15.84	-25.26*	-23.01*	-13.61**	-14.05**
8-10 year segment	(-3.25)	(-2.75)	(-1.78)	(-2.49)	(-2.43)	(-3.17)	(-3.37)
Adjusted R^2	0.76	0.79	0.23	0.00	0.13	0.82	0.83

Explanatory variables	Dependent variable: Ten-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	7.65**	15.65**	13.44**	44.73**	63.50**	15.91**	32.05**
	(10.55)	(35.47)	(25.54)	(27.34)	(33.95)	(20.19)	(13.75)
VIX	0.99**					-0.02	-0.09
	(32.90)					(-0.40)	(-1.50)
HPW measure		3.36**				3.43**	3.57**
		(41.01)				(18.90)	(14.52)
Off-the-run spread			0.97**				-0.09
			(36.76)				(-1.17)
IS bid-ask spread				-1.98**			0.46**
				(-10.08)			(2.90)
TIPS trading volume					-4.59**		-2.33**
					(-18.98)		(-10.49)
TIPS purchase dummy	10.51	21.74	23.48	7.25	22.21	21.95	28.12
4-6 year segment	(0.44)	(1.00)	(1.03)	(0.24)	(0.79)	(1.01)	(1.34)
TIPS purchase dummy	-14.14**	-12.05**	-9.77*	-9.21	-16.94**	-12.03**	-14.37**
8-10 year segment	(-2.99)	(-2.82)	(-2.16)	(-1.54)	(-3.06)	(-2.81)	(-3.44)
Adjusted R^2	0.41	0.51	0.46	0.06	0.19	0.51	0.55

Table 9: **Regression Results Using Maturity-Weighted Indicator Variables.**
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 five measures of market functioning as explanatory variables. Included is a dummy variable for the 15 dates with TIPS purchase operations weighted by the amount of TIPS purchased in the 4-6 year segment relative to the total market value of all TIPS outstanding in that maturity sector. A similar dummy variable for the 8-10 year segment is also included. 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.

Appendix C: Regression Results Used in Counterfactual Analysis

Explanatory variables	Dependent variable: Five-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	-3.47**	16.79**	42.51**	33.21**	91.85**	6.03**	-7.41**
	(-4.43)	(32.99)	(61.09)	(13.24)	(26.05)	(7.51)	(-2.76)
VIX	2.21**					1.01**	1.20**
	(69.74)					(16.48)	(19.91)
HPW measure		6.82**				4.09**	4.44**
		(75.18)				(22.03)	(25.01)
Off-the-run spread			3.77**				-1.41**
			(19.78)				(-13.00)
IS bid-ask spread				1.25**			0.36**
				(4.78)			(3.15)
TIPS trading volume					-6.35**		0.72**
					(-13.69)		(3.13)
Adjusted R^2	0.77	0.80	0.21	0.01	0.11	0.83	0.85

Explanatory variables	Dependent variable: Ten-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	9.29**	16.86**	14.45**	39.62**	65.93**	16.92**	27.04**
	(12.32)	(35.70)	(24.92)	(20.03)	(32.59)	(20.83)	(10.37)
VIX	0.96**					-0.01	0.02
	(31.45)					(-0.09)	(0.33)
HPW measure		3.27**				3.28**	3.62**
		(38.80)				(17.48)	(14.64)
Off-the-run spread			0.94**				-0.20**
			(33.80)				(-2.70)
IS bid-ask spread				-1.22**			1.68**
				(-4.90)			(8.93)
TIPS trading volume					-4.80**		-2.91**
					(-18.06)		(-12.38)
Adjusted R^2	0.41	0.51	0.44	0.02	0.18	0.51	0.57

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 five 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 five 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 5.3.

Appendix D: Replication of D'Amico and King (2013)

In this appendix, we describe our adaptation of DK's analysis of flow effects from QE purchases.

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:

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

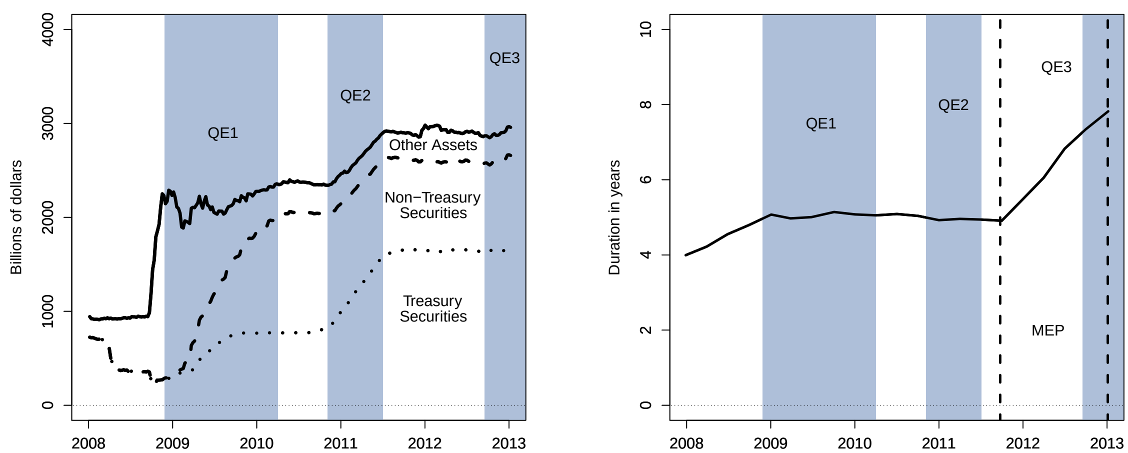
where

- 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.

Appendix E: 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 sizeable 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 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 13: **The Fed's Assets and the Duration of Its Treasury Securities.**

For a start, though, Figure 13 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 13(b), which shows the change in the average duration of the Fed's nominal Treasury securities since 2008.[39] 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.[40] 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

[39] The durations are calculated based on real-time quarterly estimation of the shadow-rate term structure model analyzed in Christensen, Lopez, and Rudebusch (2013). This model respects the zero lower bound for yields, which has been a prominent characteristic of the Treasury yield curve since 2009.

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

MEP TIPS purchase operation dates	TIPS purchases (Mill.)	Weighted average maturity	Response of			
			Liquidity measure		VIX	HPW measure
			Five-year	Ten-year		
(1) Oct. 5, 2011	$1,861	22.77	-0.75	-1.15	-1.54	0.04
(2) Nov. 3, 2011	$1,916	25.62	-0.05	-1.77	-0.34	-0.39
(3) Dec. 12, 2011	$1,872	25.02	2.41	-6.09	-0.71	0.36
(4) Jan. 10, 2012	$1,905	28.56	-0.66	-0.91	-0.38	-0.51
(5) Feb. 10, 2012	$1,926	26.98	-0.98	0.31	2.16	0.14
(6) Mar. 14, 2012	$1,272	27.53	-2.11	-4.67	0.51	0.09
(7) Apr. 3, 2012	$1,765	19.01	2.62	-1.63	0.02	0.08
(8) May 9, 2012	$1,565	15.44	6.49	10.87	1.03	-0.08
(9) Jun. 15, 2012	$1,730	16.29	1.75	-4.85	-0.57	-0.15
(10) Jul. 10, 2012	$1,809	21.08	-0.81	2.77	0.74	0.03
(11) Aug. 9, 2012	$1,947	24.58	-0.60	-1.79	-0.04	-0.03
(12) Sep. 10, 2012	$1,979	26.77	1.73	2.77	1.90	-0.25
(13) Oct. 11, 2012	$1,819	24.67	-1.46	0.45	-0.70	-0.03
(14) Nov. 9, 2012	$1,939	25.49	-0.06	-0.13	0.12	0.27
(15) Dec. 11, 2012	$1,829	23.01	0.60	0.22	-0.48	0.14
Average	$1,809	23.52	0.54	-0.37	0.11	-0.02

Table 11: **Market Response on 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 table also reports the one-day response of the five- and ten-year liquidity premium measure described in Section 3. In addition, the table shows the response of two of the daily time series used as control variables. The TIPS purchase amounts are reported in millions of dollars, the weighted average maturities are measured in years, the VIX is reported in percent, and the remaining numbers are measured in basis points.

MEP TIPS sale operation dates	TIPS sales (Mill.)	Weighted average maturity	Response of			
			Liquidity measure		VIX	HPW measure
			Five-year	Ten-year		
(1) Oct. 17, 2011	$1,456	2.17	-7.56	-5.76	-1.83	0.18
(2) Nov. 9, 2011	$1,376	1.20	3.82	3.63	-3.35	0.19
(3) Dec. 7, 2011	$1,353	0.74	0.17	5.50	0.54	0.25
(4) Jan. 5, 2012	$1,367	0.73	-0.61	-0.67	-0.74	-0.01
(5) Feb. 7, 2012	$1,407	1.68	0.37	-1.05	-0.11	0.04
(6) Mar. 5, 2012	$1,415	1.66	1.34	5.06	0.76	-0.35
(7) Apr. 9, 2012	$1,289	0.37	-0.95	0.31	2.11	-0.21
(8) May 2, 2012	$1,427	2.15	0.34	1.23	0.28	-0.02
(9) Jun. 11, 2012	$1,146	2.24	5.29	4.12	2.33	-0.19
(10) Oct. 19, 2012	$1,198	2.87	-1.51	6.44	2.03	0.18
Average	$1,343	1.58	0.07	1.88	0.20	0.01

Table 12: **Market Response on 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 table also reports the one-day response of the five- and ten-year liquidity premium measure described in Section 3. In addition, the table shows the response of two of the daily time series used as control variables. The TIPS sale amounts are reported in millions of dollars, the weighted average maturities are measured in years, the VIX is reported in percent, and the remaining numbers are measured in basis points.

sale operation dates distributed with sale operations once a month from October 2011 to June 2012 plus a final smaller 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,[41] 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, the reaction of the TIPS and inflation swap liquidity premium measure we analyze, and the response of two of the control variables in our empirical analysis. 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.[42] 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.

Baseline Regressions

The results for the baseline regressions used to assess the effects of the MEP TIPS transactions are reported in Table 13. Note that the sample period now runs from January 4, 2005, to December 31, 2012. Since the MEP involved both TIPS purchases and sales, we include a set of indicator variables for the TIPS purchase dates and a set of indicator variables for the TIPS sale dates. Three things stand out relative to our findings for the QE2 program. First, we notice the lack of significance of the indicator variables, which is particularly notable once we include several controlling factors. Second, the magnitudes of the estimated coefficients for the indicator variables are, in general, much smaller than what we obtained in the analysis of the QE2 program. Finally, the coefficients of the indicator variables mostly have the wrong sign.

Based on these findings we conclude that there are no significant direct purchase or sale effects detectable during the operation of the MEP. Still, there could be some more longer lasting effects that our regressions based on indicator variables are not able to capture. For that reason, we also make a counterfactual analysis similar to the one applied to the QE2 program. This is described in the following.

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 14 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, consistent with the results from the preliminary

[41] 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.

[42] 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)	(7)
Constant	-5.14**	14.37**	36.77**	31.59**	87.16**	8.35**	13.02**
	(-6.19)	(37.48)	(63.16)	(15.98)	(35.94)	(12.47)	(6.93)
VIX	2.05**					0.47**	0.60**
	(59.10)					(10.81)	(13.76)
HPW measure		7.04**				5.84**	5.90**
		(90.22)				(43.50)	(42.69)
Off-the-run spread			2.98**				-1.01**
			(17.52)				(-11.28)
IS bid-ask spread				0.80**			-0.24**
				(3.88)			(-2.74)
TIPS trading volume					-5.99**		-0.57**
					(-20.45)		(-3.66)
TIPS purchase dummy	-14.65**	-2.27	-24.29**	-16.19*	-2.84	-4.24	-0.37
	(-3.48)	(-0.73)	(-3.72)	(-2.32)	(-0.44)	(-1.40)	(-0.12)
TIPS sale dummy	-18.02**	-2.29	-22.49**	-14.61	-0.41	-5.11	-1.70
	(-3.50)	(-0.60)	(-2.82)	(-1.71)	(-0.05)	(-1.38)	(-0.48)
Adjusted R^2	0.64	0.81	0.14	0.01	0.18	0.82	0.83

Explanatory variables	Dependent variable: Ten-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	8.20**	16.05**	16.06**	39.29**	54.88**	15.68**	27.44**
	(12.48)	(44.68)	(39.86)	(29.79)	(37.94)	(24.29)	(13.91)
VIX	0.90**					0.03	0.05
	(32.92)					(0.67)	(1.27)
HPW measure		3.31**				3.24**	3.52**
		(45.32)				(25.03)	(16.35)
Off-the-run spread			0.87**				-0.20**
			(38.80)				(-3.34)
IS bid-ask spread				-1.46**			-0.04
				(-9.22)			(-0.37)
TIPS trading volume					-3.39**		-1.27**
					(-19.39)		(-7.22)
TIPS purchase dummy	-4.15	1.75	5.38	-5.61	2.82	1.63	2.75
	(-1.25)	(0.60)	(1.72)	(-1.38)	(0.74)	(0.56)	(0.95)
TIPS sale dummy	-5.61	1.72	5.18	-5.16	4.05	1.55	2.99
	(-1.38)	(0.48)	(1.35)	(-1.04)	(0.87)	(0.44)	(0.85)
Adjusted R^2	0.35	0.51	0.43	0.04	0.16	0.51	0.52

Table 13: **Regression Results for MEP Using Standard Indicator Variables.** 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 five measures of market functioning as explanatory variables. Included is a standard binary dummy variable for the 15 dates on which MEP TIPS purchase operations took place using a one-day event window and a similar dummy variable for the 10 dates on which MEP TIPS sale operations occurred. 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 December 31, 2012, a total of 1,977 observations.

Explanatory variables	Dependent variable: Five-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	-4.29**	15.16**	40.62**	37.00**	89.34**	7.24**	13.74**
	(-5.17)	(32.96)	(66.30)	(15.72)	(29.14)	(9.60)	(6.06)
VIX	2.13**					0.69**	0.78**
	(62.59)					(12.90)	(14.77)
HPW measure		6.95**				5.13**	5.43**
		(80.00)				(31.27)	(32.93)
Off-the-run spread			3.98**				-1.10**
			(22.50)				(-10.01)
IS bid-ask spread				0.53*			-0.36**
				(2.17)			(-3.38)
TIPS trading volume					-6.21**		-0.76**
					(-15.84)		(-3.80)
Adjusted R^2	0.70	0.79	0.23	0.00	0.13	0.81	0.82

Explanatory variables	Dependent variable: Ten-year measure						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	8.07**	15.33**	13.26**	44.90**	63.02**	16.07**	31.63**
	(11.02)	(35.79)	(26.28)	(28.00)	(35.15)	(21.82)	(14.14)
VIX	0.94**					-0.06	-0.06
	(31.17)					(-1.24)	(-1.12)
HPW measure		3.39**				3.56**	3.48**
		(41.86)				(22.23)	(14.58)
Off-the-run spread			0.98**				-0.08
			(37.86)				(-1.18)
IS bid-ask spread				-2.05*			0.37*
				(-10.67)			(2.38)
TIPS trading volume					-4.54**		-2.23**
					(-19.78)		(-10.50)
Adjusted R^2	0.37	0.51	0.46	0.06	0.19	0.51	0.55

Table 14: **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 five 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.

regressions with indicator variables for the operation dates, the outcome of the counterfactual exercise is murky and not statistically significant.

To summarize, we conclude that the TIPS purchases and sales that was part of the MEP does 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 is maybe not 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.

Appendix F: TIPS Purchases outside QE2 and the MEP

TIPS purchase operation dates	TIPS purchases (Mill.)	Weighted average maturity	Response of			
			Liquidity measure		VIX	HPW measure
			Five-year	Ten-year		
(1) Apr. 16, 2009	$1,619	11.74	-3.28	-5.80	-0.38	-0.48
(2) May 26, 2009	$1,562	2.16	-2.64	0.46	-2.01	-0.50
(3) Jul. 16, 2009	$1,525	3.30	1.71	0.66	-0.47	-0.90
(4) Aug. 30, 2010	$398	10.20	6.07	7.41	2.76	-0.17
(5) Sep. 28, 2010	$655	10.86	-1.18	0.45	0.06	-0.05
(6) Oct. 10, 2010	$788	10.74	0.47	0.42	-1.78	-0.08
Average	$1,091	8.17	0.19	0.60	-0.30	-0.36

Table 15: **TIPS Purchase Operation Dates outside QE2 and the MEP.** The table reports the amount and weighted average maturity of TIPS purchased on the 6 TIPS purchase operation dates outside QE2 and the MEP. The table also reports the one-day response of the five- and ten-year liquidity premium measure described in Section 3. In addition, the table shows the response of two of the daily time series used as control variables. The TIPS purchase amounts are reported in millions of dollars, the weighted average maturities are measured in years, the VIX is reported in percent, and the remaining numbers are measured in basis points.

Table 15 contains information for the six TIPS purchase operations that was 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 prior to 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 were but a fraction of that experienced during the QE2 program and for that reason we choose not to analyze these TIPS purchases further.

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