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The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy

ABSTRACT We evaluate the effect of the Federal Reserve's purchase of long-term Treasuries and other long-term bonds (QE1 in 2008–09 and QE2 in 2010–11) on interest rates. Using an event-study methodology, we reach two main conclusions. First, it is inappropriate to focus only on Treasury rates as a policy target, because quantitative easing works through several channels that affect particular assets differently. We find evidence for a signaling channel, a unique demand for long-term safe assets, and an inflation channel for both QE1 and QE2, and a mortgage-backed securities (MBS) prepayment channel and a corporate bond default risk channel for QE1 only. Second, effects on particular assets depend critically on which assets are purchased. The event study suggests that MBS purchases in QE1 were crucial for lowering MBS yields as well as corporate credit risk and thus corporate yields for QE1, and Treasuries-only purchases in QE2 had a disproportionate effect on Treasuries and agency bonds relative to MBSs and corporate bonds, with yields on the latter falling primarily through the market's anticipation of lower future federal funds rates.

The Federal Reserve has recently pursued the unconventional policy of purchasing large quantities of long-term securities, including Treasury securities, agency securities, and agency mortgage-backed securities (MBS). The stated objective of this quantitative easing (QE) is to reduce long-term interest rates in order to spur economic activity (Dudley 2010). There is significant evidence that QE policies can alter long-term interest rates. For example, Joseph Gagnon and others (2010) present an event study of QE1 that documents large reductions in interest rates on dates

associated with positive QE announcements. Eric Swanson (2011) presents confirming event-study evidence from the 1961 Operation Twist, where the Federal Reserve purchased a substantial quantity of long-term Treasuries. Apart from the event-study evidence, there are papers that look at lower-frequency variation in the supply of long-term Treasuries and document its effects on interest rates (see, for example, Krishnamurthy and Vissing-Jorgensen 2010).¹

Although it is clear from this body of work that QE lowers medium- and long-term interest rates, the channels through which this reduction occurs are less clear. The main objective of this paper is to evaluate these channels and their implications for policy. We review the principal theoretical channels through which QE may operate. We then examine the event-study evidence with an eye toward distinguishing among these channels, studying a range of interest rates and drawing in additional facts from various derivatives prices to help separate the channels. We furthermore supplement previous work by adding evidence from QE2 and evidence based on intraday data. Studying intraday data allows us to document price reactions and trading volume in the minutes after the main announcements, thus increasing confidence that any effects documented in daily data are due to these announcements.

It is necessary to understand the channels of operation in order to evaluate whether a given QE policy was successful. Here is an illustration of this point: Using annual data back to 1919, Krishnamurthy and Vissing-Jorgensen (2010) present evidence for a channel whereby changes in long-term Treasury supply drive the safety premiums on long-term assets with near-zero default risk. Our findings in that paper suggest that QE policy that purchases very safe assets such as Treasuries or agency bonds should work particularly to lower the yields of bonds that are extremely safe, such as Treasuries, agency bonds, and high-grade corporate bonds. But even if a policy affects Treasury interest rates, such rates may not be the most policy-relevant ones. A lot of economic activity is funded by debt that is not as free of credit risk as Treasuries or other triple-A bonds. For example, about 40 percent of corporate bonds are rated Baa or lower (for which our earlier work suggests that the demand for assets with near-zero default risk does not apply). Similarly, MBSs issued to fund household mortgages are less safe than Treasuries because of the substantial prepayment risk

1. Other papers in the literature that have examined Treasury supply and bond yields include Bernanke, Reinhart, and Sack (2004), Greenwood and Vayanos (2010), D'Amico and King (2010), Hamilton and Wu (2010), and Wright (2011).

involved. Whether yields on these less safe assets fall as much as those on very safe assets depends on whether QE succeeds in lowering default risk or the default risk premium (for corporate bonds) and the prepayment risk premium (for MBSs).

One of the principal findings of this paper is that the large reductions in mortgage rates due to QE1 appear to be driven partly by the fact that QE1 involved large purchases of agency-backed MBSs (thus reducing the price of mortgage-specific risk). In contrast, for QE2, which involved only Treasury purchases, we find a substantial impact on Treasury and agency bond rates, but smaller effects on MBS and corporate rates. Furthermore, we find a substantial reduction in default risk or the default risk premium for corporate bonds only for QE1, suggesting that the MBS purchases in QE1 may also have helped drive down corporate credit risk and thus corporate yields (possibly via the resulting mortgage refinancing boom and its impact on the housing market and consumer spending). The main effect on corporate bonds and MBSs in QE2 appears to have been through a signaling channel, whereby financial markets interpreted QE as signaling lower federal funds rates going forward. This finding for QE2 raises the question of whether the main impact of a Treasuries-only QE may have been achievable with a statement by the Federal Reserve committing to lower federal funds rates, that is, without the Fed putting its balance sheet at risk in order to signal lower future rates.

The next section of the paper lays out the channels through which QE may be expected to operate. We then, in sections II and III, present results of event studies of QE1 and QE2 to evaluate the channels. We document that QE worked through several channels. First, a signaling channel (reflecting the market inferring information from QE announcements about future federal funds rates) significantly lowered yields on all bonds, with the effects depending on bond maturity. Second, the impact of QE on MBS rates was large when QE involved MBS purchases, but not when it involved only Treasury purchases, indicating that another main channel for QE1 was to affect the equilibrium price of mortgage-specific risk. Third, default risk or the default risk premium for corporate bonds fell for QE1 but not for QE2, contributing to lower corporate rates. Fourth, yields on medium- and long-maturity safe bonds fell because of a unique clientele for safe nominal assets, and Federal Reserve purchases reduced the supply of such assets and hence increased the equilibrium safety premium. Fifth, evidence from inflation swap rates and Treasury inflation-protected securities (TIPS) shows that expected inflation increased as a result of both QE1 and QE2, implying larger reductions in real than in nominal rates. Section IV presents

regression analysis building on our previous work in Krishnamurthy and Vissing-Jorgensen (2010) to provide estimates of the expected effects of QE on interest rates via the safety channel. Section V concludes.

I. Channels

We begin by identifying and describing the various channels through which QE might operate.

I.A. Signaling Channel

Gauti Eggertsson and Michael Woodford (2003) argue that nontraditional monetary policy can have a beneficial effect in lowering long-term bond yields only if such policy serves as a credible commitment by the central bank to keep interest rates low even after the economy recovers (that is, lower than what a Taylor rule may call for). James Clouse and others (2000) argue that such a commitment can be achieved when the central bank purchases a large quantity of long-duration assets in QE. If the central bank later raises rates, it takes a loss on these assets. To the extent that the central bank weighs such losses in its objective function, purchasing long-term assets in QE serves as a credible commitment to keep interest rates low. Furthermore, some of the Federal Reserve's announcements regarding QE explicitly contain discussion of its policy on future federal funds rates. Markets may also infer that the Federal Reserve's willingness to undertake an unconventional policy like QE indicates that it will be willing to hold its policy rate low for an extended period.

The signaling channel affects all bond market interest rates (with effects depending on bond maturity), since lower future federal funds rates, via the expectations hypothesis, can be expected to affect all interest rates. We examine this channel by measuring changes in the prices of federal funds futures contracts, as a guide to market expectations of future federal funds rates.² The signaling channel should have a larger impact on intermediate-maturity than on long-maturity rates, since the commitment to keep rates low lasts only until the economy recovers and the Federal Reserve can sell the accumulated assets.

2. Piazzesi and Swanson (2008) show that these futures prices reflect a risk premium, in addition to such expectations. If short-term rates are low and employment growth is strong, the risk premium is smaller. To the extent that this risk premium is reduced by QE, our estimates of the signaling effect are too large. It is difficult to assess whether changes in short-term rates or employment growth due to QE have the same effect as non-policy-related changes in these variables, so we do not attempt to quantify any such bias.

1.B. Duration Risk Channel

Dimitri Vayanos and Jean-Luc Vila (2009) offer a theoretical model for a duration risk channel. Their one-factor model produces a risk premium that is approximately the product of the duration of the bond and the price of duration risk, which in turn is a function of the amount of duration risk borne by the marginal bond market investor and this investor's risk aversion. By purchasing long-term Treasuries, agency debt, or agency MBSs, policy can reduce the duration risk in the hands of investors and thereby alter the yield curve, particularly reducing long-maturity bond yields relative to short-maturity yields. To deliver these results, the model departs from a frictionless asset pricing model. The principal departures are the assumptions that there is a subset of investors who have preferences for bonds of specific maturities ("preferred-habitat demand") and another subset who are arbitrageurs and who become the marginal investors for pricing duration risk.

An important but subtle issue in using the model to think about QE is whether the preferred-habitat demand applies narrowly to a particular asset class (for example, only to the Treasury market) or broadly to all fixed-income instruments. For example, if some investors have a special demand for 10-year Treasuries, but not for 10-year corporate bonds (or mortgages or bank loans), then the Federal Reserve's purchase of 10-year Treasuries can be expected to affect Treasury yields more than corporate bond yields. Vayanos and Vila (2009) do not take a stand on this issue. Robin Greenwood and Vayanos (2010) offer evidence for how a change in the relative supply of long-term versus short-term Treasuries affects the yield spread between them. This evidence also does not settle the issue, because it focuses only on Treasury data.

Recent studies of QE have interpreted the model as being about the broad fixed-income market (see Gagnon and others 2010), and that is how we proceed. Under this interpretation, the duration risk channel makes two principal predictions:

- QE decreases the yield on all long-term nominal assets, including Treasuries, agency bonds, corporate bonds, and MBSs.
- The effects are larger for longer-duration assets.

1.C. Liquidity Channel

The QE strategy involves purchasing long-term securities and paying for them by increasing reserve balances. Reserve balances are a more liquid asset than long-term securities. Thus, QE increases the liquidity in the hands

of investors and thereby decreases the liquidity premium on the most liquid bonds.

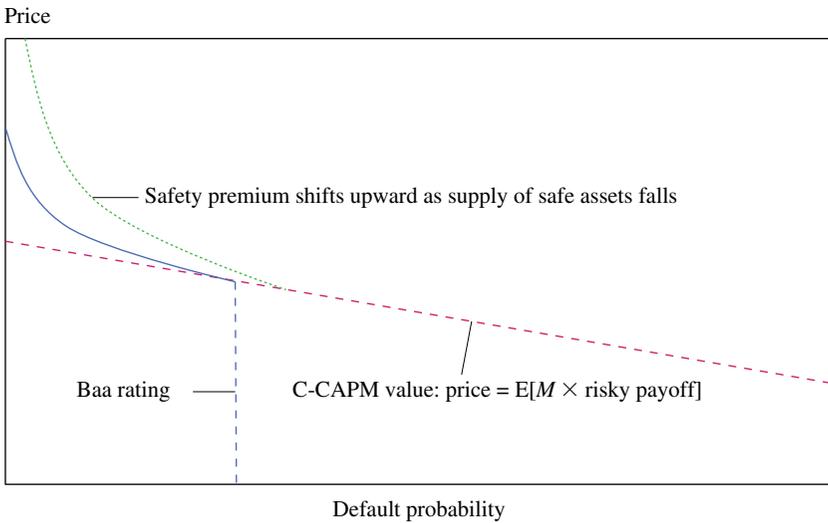
It is important to emphasize that this channel implies an *increase* in Treasury yields. That is, it is commonly thought that Treasury bonds carry a liquidity price premium, and that this premium was high during particularly severe periods of the crisis. An expansion in liquidity can be expected to reduce such a liquidity premium and increase yields. This channel thus predicts that

—QE *raises* yields on the most liquid assets, such as Treasuries, relative to other, less liquid assets.

1.D. Safety Channel

Krishnamurthy and Vissing-Jorgensen (2010) offer evidence that there are significant clienteles for long-term safe (that is, near-zero-default-risk) assets, whose presence lowers the yields on such assets. The evidence comes from relating the spread between Baa-rated and Aaa-rated corporate bonds (or agency bonds) to variation in the supply of long-term Treasuries, over the period from 1925 to 2008. In that paper we report that when there are fewer long-term Treasuries in the market, so that there are fewer long-term safe assets to meet clientele demands, the spread between Baa and Aaa bonds rises. The safety channel can be thought of as describing a preferred habitat of investors, but applying only to the space of safe assets.

The increase in yield spreads between near-zero-default-risk assets and riskier assets generated by the clientele demand for long-term safe assets is not the same as the risk premium in a standard asset pricing model; rather, it reflects a deviation from standard models. A simple way to think about investor willingness to pay extra for assets with very low default-risk is to plot an asset's price against its expected default rate. Krishnamurthy and Vissing-Jorgensen (2010) argue that this curve is very steep for low default rates, with a slope that flattens as the supply of Treasuries increases. Figure 1 illustrates the distinction. The straight line represents the value of a risky bond as determined in a consumption-based capital asset pricing model (C-CAPM). As default risk rises, the price of the bond falls. The distance from this line up to the lower of the two curves illustrates the safety premium; for bonds that have very low default risk, the price rises as a function of the safety of the bond, more so than in a standard C-CAPM setting. The figure also illustrates the dependence of the safety premium on the supply of long-term Treasuries. The distance from the straight line to the upper curve represents the safety premium for a smaller supply of safe assets. The clientele demand shifts the premium upward because of a higher marginal

Figure 1. The Safety Premium on Bonds with Near-Zero Default Risk

willingness to pay for safety when supply is lower. This dependence of the premium on the supply of long-term Treasuries is how Krishnamurthy and Vissing-Jorgensen (2010) distinguish a standard risk premium explanation of defaultable bond pricing from an explanation based on clientele-driven demand for safety.

This same effect may be expected to play out in QE. However, there is a subtle issue in thinking about different asset classes in QE: Treasury and agency bonds are clearly safe in the sense of offering an almost certain nominal payment (note that the government “takeover” of Fannie Mae and Freddie Mac was announced on September 7, 2008, before QE1 and QE2, making agency bonds particularly safe during the period of QE1 and QE2); however, agency MBSs have significant prepayment risk, which means that they may not meet clientele safety demands. The safety channel thus predicts that

—QE involving Treasuries and agencies lowers the yields on very safe assets such as Treasuries, agencies, and possibly high-grade corporate bonds, relative to less safe assets such as lower-grade corporate bonds or bonds with prepayment risk such as MBSs.

We expect Baa bonds to be the relevant cutoff for these safety effects, for two reasons. First, such bonds are at the boundary between investment-grade and non-investment-grade securities, so that if prices are driven by clientele demands for safety, the Baa bond forms a natural threshold. Second,

and more rigorously, Francis Longstaff, Sanjay Mithal, and Eric Neis (2005) use credit default swap data from March 2001 to October 2002 to show that the component of yield spreads that is hard to explain by purely default risk information is about 50 basis points (bp) for Aaa- and Aa-rated bonds and about 70 bp for lower-rated bonds, suggesting that the cutoff for bonds whose yields are not affected by safety premiums is somewhere around the A or Baa rating.

I.E. Prepayment Risk Premium Channel

QE1 involved the purchase of \$1.25 trillion of agency MBSs. Xavier Gabaix, Krishnamurthy, and Olivier Vigneron (2007) present theory and evidence that mortgage prepayment risk carries a positive risk premium, and that this premium depends on the quantity of prepayment risk borne by mortgage investors. The theory requires that the MBS market is segmented and that a class of arbitrageurs who operate predominantly in the MBS market are the relevant investors in determining the pricing of prepayment risk. This theory is similar to Vayanos and Vila's (2009) explanation of the duration risk premium and more broadly fits into theories of intermediary asset pricing (see He and Krishnamurthy 2010).

This channel is particularly about QE1 and its effects on MBS yields, which reflect a prepayment risk premium:

—MBS purchases in QE1 lower MBS yields relative to other bond market yields.

—No such effect should be present in QE2.

I.F. Default Risk Channel

Lower-grade bonds such as Baa bonds carry higher default risk than Treasury bonds. QE may affect the quantity of such default risk as well as its price (that is, the risk premium). If QE succeeds in stimulating the economy, one can expect that the default risk of corporations will fall, and hence Baa rates will fall. Moreover, some standard asset pricing models predict that investor risk aversion will fall as the economy recovers, implying a lower default risk premium. Finally, extensions of the intermediary pricing arguments we have offered above for pricing prepayment risk can imply that increasing financial health or increasing capital in the intermediary sector can further lower the default risk premium.

We use credit default swap (CDS) rates to evaluate the importance of a default risk channel. A credit default swap is a financial derivative used to hedge against default by a firm. The credit default swap rate measures the percentage of face value that must be paid as an annual insurance premium

to insure against default on the bonds of a given firm. A 5-year CDS is such an insurance contract that expires in 5 years, and a 10-year CDS is one that expires in 10 years. We use these CDSs to infer default risk at different maturities.

I.G. Inflation Channel

To the extent that QE is expansionary, it increases inflation expectations, and this can be expected to have an effect on interest rates. In addition, some commentators have argued that QE may increase tail risks surrounding inflation.³ That is, in an environment where investors are unsure about the effects of policy on inflation, policy actions may lead to greater uncertainty over inflation outcomes. Others have argued that aggressive policy decreases uncertainty about inflation in the sense that it effectively combats the possibility of a deflationary spiral. Ultimately, this is an issue that can only be sorted out by data. We propose looking at the implied volatility on interest rate options, since a rise in inflation uncertainty will plausibly also lead to a rise in interest rate uncertainty and implied volatility. The inflation channel thus predicts that

—QE increases the fixed rate on inflation swaps as well as inflation expectations as measured by the difference between nominal bond yields and TIPS yields.

—QE may increase or decrease interest rate uncertainty as measured by the implied volatility on swaptions.

Two explanations are in order. First, a (zero-coupon) inflation swap is a financial instrument used to hedge against a rise in inflation. The swap is a contract between a fixed-rate payor and a floating-rate payor that specifies a one-time exchange of cash at the maturity of the contract. The floating-rate payor pays the realized cumulative inflation, as measured using the consumer price index, over the life of the swap. The fixed-rate payor makes a fixed payment indexed by the fixed rate that is contracted at the initiation of the swap agreement. In an efficient market, the fixed-rate payment thus measures the expected inflation rate over the life of the swap.

Second, a swaption is a financial derivative on interest rates. The buyer of a call swaption earns a profit when the interest rate rises relative to the strike on the swaption. As with any option, following the Black-Scholes model, the expected volatility of interest rates enters as an important input

3. See Charles Calomiris and Ellis Tallman, "In Fed's Monetary Targeting, Two Tails Are Better than One," *Bloomberg Business Week*, November 17, 2010 (www.businessweek.com/investor/content/nov2010/pi20101117_644007.htm).

for pricing the swaption. The implied volatility is the expected volatility of interest rates as implied from current market prices of swaptions.

I.H. Summary

The channels we have discussed and our empirical approach can be summarized with a few equations. Suppose that we are interested in the real yield on a T -year long-term, risky, illiquid asset such as a corporate bond or an MBS. Denote this yield by $r_{risky, illiq, long-term}$. Also, denote the expected average interest rate over the next T years on short-term safe and liquid nominal bonds as $E[i_{safe, liq, short-term}]$, and the expected inflation rate over the same period as π^e . Then we can decompose the long-term real yield as

$$\begin{aligned}
 (1) \quad r_{risky, illiq, long-term} &= E[i_{safe, liq, short-term}] - \pi^e \\
 &+ Duration \times P_{DurationRisk} \\
 &+ Illiquidity \times P_{Liquidity} \\
 &+ Lackofsafety \times P_{Safety} \\
 &+ DefaultRisk \times P_{DefaultRisk} \\
 &+ PrepaymentRisk \times P_{PrepaymentRisk}
 \end{aligned}$$

Each line in this equation reflects a channel we have discussed. The first line gives the expectations hypothesis terms: the long-term real yield reflects the expected average future real interest rate. The signaling channel for QE may affect $r_{risky, illiq, long-term}$ through the first line (via the term $E[i_{safe, liq, short-term}]$). Expected inflation can also be expected to affect long-term real rates. The term in the second line reflects a duration risk premium that is a function of duration and the price of duration risk, as explained above. This decomposition is analogous to the textbook treatment of the CAPM, where the return on a given asset is decomposed as the asset's beta multiplied by the market risk premium. The term in the third line is the illiquidity premium we have discussed, which is likewise related to an asset's illiquidity multiplied by the market price of liquidity. The next terms reflect the safety premium (the extra yield on the nonsafe bond because it lacks the extreme safety of a Treasury bond), a premium on default risk, and for the case of MBSs, a premium on prepayment risk.

The equation makes clear that a given interest rate can be affected by QE through a variety of channels. It is not possible to examine the change in, say, the Treasury rate alone to conclude how much QE affects interest rates more broadly, because different interest rates are affected by QE in different ways.

Our main empirical methodology for examining the various channels can be thought of as a difference-in-differences approach supplemented with information from derivatives. For example, in asking whether there is a liquidity channel that may affect interest rates, we consider the yield spread between a long-term agency bond and a long-term Treasury bond and measure how this yield spread changes over the relevant QE event. The yield decomposition from equation 1 for each of these bonds is identical, except for the term involving liquidity. That is, these bonds have the same duration, safety, default risk, and so forth, but the Treasury bond is more liquid than the agency bond. Thus, the difference in yield changes between these bonds isolates a liquidity channel. We examine how this yield spread changes over the QE event dates. We take this difference-in-differences approach in evaluating the liquidity, safety, duration risk premium, and prepayment risk channels. In addition, in some cases we use derivatives prices, which are affected by only a single channel, to separate out the effect of a particular channel. This is how we use the federal funds futures contracts, the CDS rates, the inflation swap rates, and the implied volatility on interest rate options.

II. Evidence from QE1

This section presents data from the QE1 event study and analyzes the channels through which QE1 operated. All data used throughout the paper are described in detail in the online data appendix.⁴

II.A. Event Study

Gagnon and others (2010) provide an event study of QE1 based on the announcements of long-term asset purchases by the Federal Reserve in the period from late 2008 to 2009. QE1 included purchases of MBSs, Treasury securities, and agency securities. Gagnon and others (2010) identify eight event dates beginning with the November 25, 2008, announcement of the Federal Reserve's intent to purchase \$500 billion of agency MBSs and \$100 billion of agency debt and continuing into the fall of 2009. We focus on the first five of these event dates (November 25, December 1, and December 16, 2008, and January 28 and March 18, 2009), leaving out three later event dates on which only small yield changes occurred.

4. Online appendixes for all papers in this volume may be accessed at the Brookings Papers website, www.brookings.edu/economics/bpea.aspx, under "Past Editions."

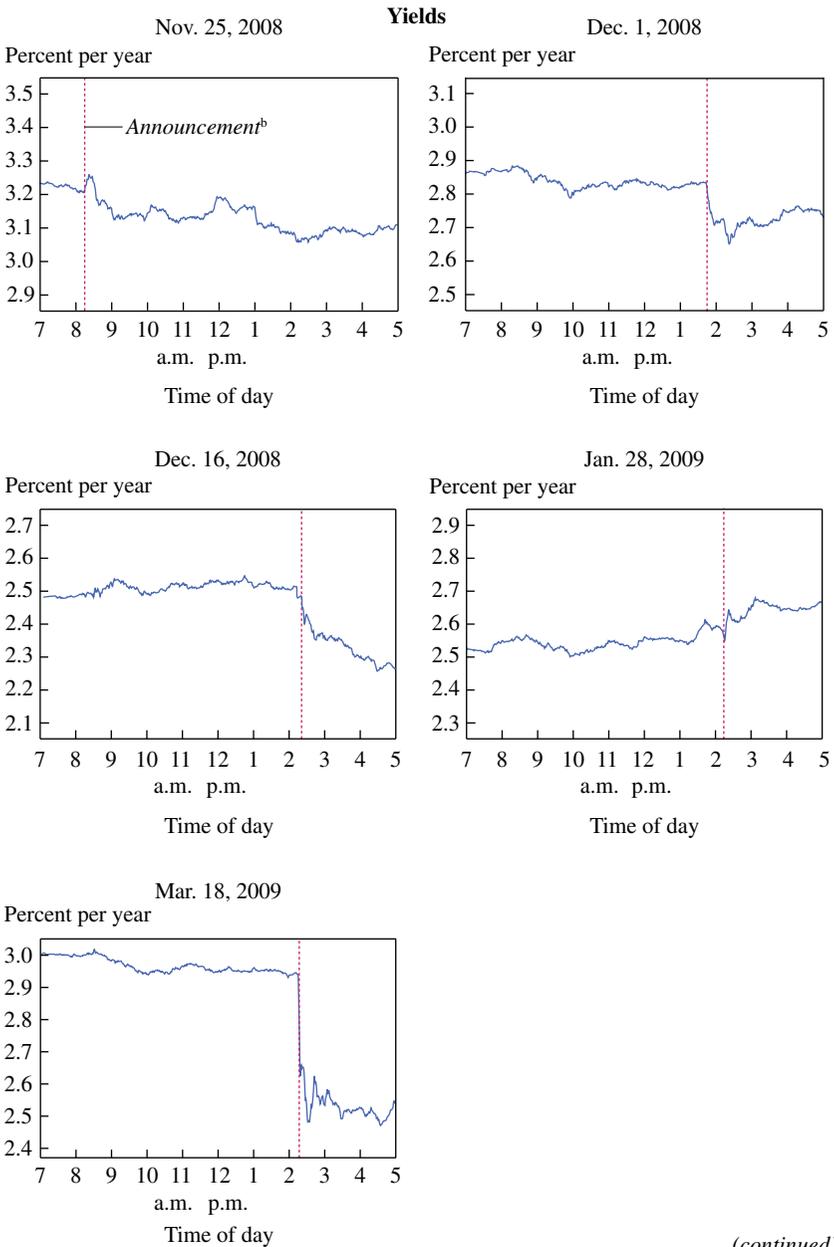
There was considerable turmoil in financial markets from the fall of 2008 to the spring of 2009, which makes inference from an event study somewhat tricky. Some of the assets we consider, such as corporate bonds and CDSs, are less liquid than Treasuries. During a period of low liquidity, the prices of such assets may react slowly to an announcement. We deal with this issue by presenting 2-day changes for all assets (from the day before to the day after the announcement). In the data, for high-liquidity assets such as Treasuries, 2-day changes are almost the same as 1-day changes. For low-liquidity assets, the 2-day changes are almost always larger than the 1-day changes.

The second issue that arises is that we cannot be sure that the identified events are in fact important events, or the dominant events for the identified event day. That is, other significant economic news arrives during the period and potentially creates measurement error problems for the event study. To increase our confidence that the QE1 announcements were the dominant news on the five event dates we study, we graph intraday movements in Treasury yields and trading volume for each of the QE1 event dates. Figure 2, which is based on data from BG Cantor, plots data for the on-the-run 10-year Treasury bond at each date. The yields graphed are minute-by-minute averages, and trading volumes are total volume by minute. The vertical lines indicate the minutes of the announcements, defined as the minute of the first article covering the announcement in Factiva. These graphs show that the events identify significant movements in Treasury yields and Treasury trading volume and that the announcements do appear to be the main piece of news coming out on the event days, especially on December 1, 2008, December 16, 2008, and March 18, 2009. For November 25, 2008, and January 28, 2009, the trading volume graphs also suggest that the announcements are the main events, but the evidence from the yield graphs for those days is more mixed.

Although it is likely that these five dates are the most relevant event dates, it is possible that there are other “true” event dates that we have omitted. How does focusing on too limited a set of event dates affect inference? For the objective of analyzing through which channels QE operates, omitting true event dates reduces the power of our tests but does not lead to any biases (whereas including irrelevant dates could distort inference about the channels).⁵ For estimating the overall effect of QE, omitting potentially relevant dates could lead to an upward or a downward bias, depending on how the events on the omitted dates affected the market’s perception of the probability or the magnitude of QE.

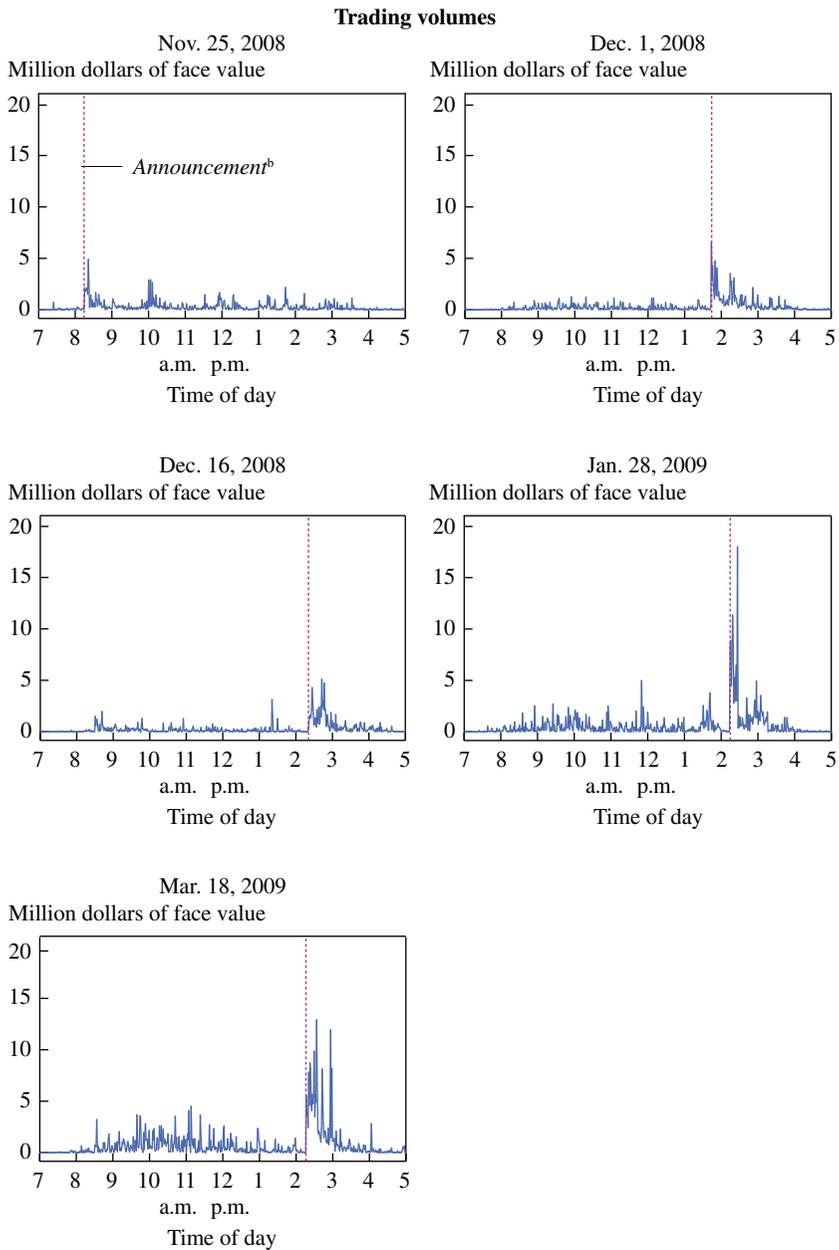
5. We thank Gabriel Chodorow-Reich for clarifying this point.

Figure 2. Intraday Yields and Trading Volumes on QE1 Event Days^a



(continued)

Figure 2. Intraday Yields and Trading Volumes on QE1 Event Days^a (Continued)



Source: BG Cantor data.
 a. Yields and trading volumes are minute-by-minute averages and total volume by minute, respectively, for the on-the-run 10-year bond on the indicated dates.
 b. Minute of the appearance in Factiva of the first article covering the QE-related announcement.

Table 1 presents data on 2-day changes in Treasury, (noncallable) agency, and agency MBS yields around the main event-study dates, spanning the period from November 25, 2008 (the 2-day change from November 24 to November 26), to March 18, 2009 (the 2-day change from March 17 to March 19). Over this period it became evident from announcements by the Federal Reserve that the government intended to purchase a large quantity of long-term securities. Across the five event dates, interest rates on long-term bonds fell across the board, consistent with a contraction-of-supply effect. We now consider the channels through which the supply effect may have worked.

In all the tables in this paper we provide tests of the statistical significance of the interest rate changes or changes in derivatives prices, focusing on the total change shown in the last row of each table (for QE1 and QE2 separately). Specifically, we test whether changes on QE announcement days differ from changes on other days. To do this, we regress the daily changes for the variable in question on six dummies: a dummy for whether there was a QE1 announcement on this day, a dummy for whether there was a QE1 announcement on the previous day, a dummy for whether there was a QE2 announcement on this day, a dummy for whether there was a QE2 announcement on the previous day, a dummy for whether there was a QE3 announcement on this day, and a dummy for whether there was a QE3 announcement on the previous day. By “QE3” we refer to the Federal Reserve’s announcement in its Federal Open Market Committee (FOMC) statement on September 21, 2011; this event happened after the Brookings Panel conference at which this paper was presented, but we analyze it briefly below. This regression is estimated on daily data from the start of 2008 to the end of the third quarter of 2011, using ordinary least squares estimation but with robust standard errors to account for heteroskedasticity. *F* tests for the QE dummy coefficients being zero are then used to assess statistical significance. When testing for statistical significance of 2-day changes, the *F* test is a test of whether the sum of the coefficient on the QE dummy (QE1 or QE2) and the coefficient on the dummy for a QE announcement (QE1 or QE2) on the previous day is equal to zero. When testing for statistical significance of 2-day changes in CDS rates, we follow a slightly different approach, described below, because of the way our CDS rate changes are constructed.

II.B. Signaling Channel

Figure 3 graphs the yields on the monthly federal funds futures contract, for contract maturities from March 2009 to October 2010. The preannouncement

Table 1. Changes in Treasury, Agency, and Agency MBS Yields around QET1 Event Dates^a
Basis points

Date	Event	Treasury yields (constant maturity)					Agency (Fannie Mae) yields					Agency MBS yields ^b	
		30-year	10-year	5-year	3-year	1-year	30-year	10-year	5-year	3-year	30-year	15-year	
Nov. 25, 2008	Initial announcement	-24	-36	-23	-15	-2	-57	-76	-57	-42	-72	-88	
Dec. 1, 2008	Bernanke speech	-27	-25	-28	-15	-13	-52	-67	-50	-33	-14	12	
Dec. 16, 2008	FOMC statement	-32	-33	-15	-4	-5	-37	-39	-26	-25	-26	-16	
Jan. 28, 2009	FOMC statement	31	28	28	19	4	33	28	27	14	31	20	
Mar. 18, 2009	FOMC statement	-21	-41	-36	-24	-9	-31	-45	-44	-35	-27	-16	
Sum of above five dates ^c		-73*	-107**	-74	-39	-25**	-144**	-200***	-150***	-123***	-107*	-88	

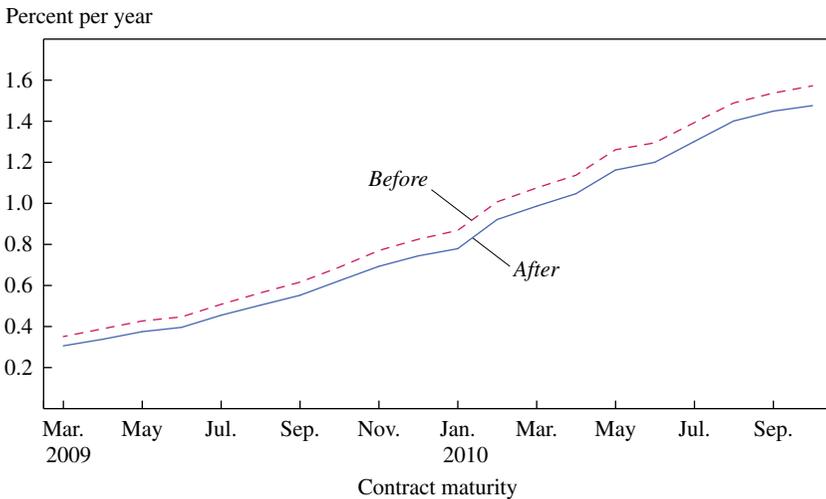
Sources: FRED, Federal Reserve Bank of St. Louis; Bloomberg.

a. All changes are over 2 days, from the day before to the day after the event. Asterisks denote statistical significance at the ***1 percent, **5 percent, and *10 percent level.

b. Averages across current-coupon Ginnie Mae, Fannie Mae, and Freddie Mac MBSs.

c. May differ from the sum of the values reported for individual dates because of rounding.

Figure 3. Yield Curves Calculated from Federal Funds Futures before and after QE1 Event Days



Source: Bloomberg data.

a. Yields are computed the day before each QE1 event date and again the day after. All the before-event yields are then averaged across events, and likewise for the after-event yields.

average yield curve is computed on the day before each of the five QE1 events and then averaged across these dates. The postannouncement average yield curve is computed likewise based on the five days after the QE1 event dates. Dividing the downward shift from the pre- to the postannouncement average yield curve by the slope of the initial average yield curve, and multiplying the result by the number of event dates, indicates how much the policy shifted the rate cycle forward in time. Evaluating the forward shift at the point and slope of the March 2010 contract, we find that the total effect of the five QE announcements is to shift anticipated rate increases later by 6.3 months. This effect is consistent with an effect through the signaling channel whereby the Federal Reserve's portfolio purchases (as well as direct indications of the stance of policy in the relevant Fed announcements) signal a commitment to keep the federal funds rate low.

Table 2 reports the 1- and 2-day changes in the yields of the 3rd-month, 6th-month, 12th-month, and 24th-month futures contracts across the five event dates. We aggregate by, for example, the 3rd month rather than a given contract month (for example, March), because it is more natural to think of the information in each QE announcement as concerning how

Table 2. Changes in Federal Funds Futures Yields around QE1 and QE2 Event Dates^a
Basis points

Date ^b	Federal funds futures, contract maturity			
	3rd month	6th month	12th month	24th month
<i>QE1</i> ^c	-6	-5	-8	-16
Nov. 25, 2008	-6	-3	-7	-20
Dec. 1, 2008	-13	-15	-10	-11
Dec. 16, 2008	-1	-1	-1	19
Jan. 28, 2009	-2	-4	-8	-11
Mar. 18, 2009	-28*	-27	-33**	-40
Sum ^d				
<i>QE2</i>				
Aug. 10, 2010				
One-day change	0	0	-2	-3
Two-day change	0	0	-3	-8
Sep. 21, 2010				
One-day change	0	-1	-3	-8
Two-day change	0	-1	-3	-8
Sum ^d				
One-day changes	0***	-1	-4***	-11***
Two-day changes	0***	-1	-5***	-16***

Source: Authors' calculations using Bloomberg data.

a. Asterisks denote statistical significance at the ***1 percent, **5 percent, and *10 percent level.

b. See table 1 for descriptions of events on QE1 dates; QE2 dates are those of FOMC statements regarding QE2.

c. All changes in yields for QE1 are 2-day changes, from the day before to the day after the event.

d. Because our significance tests are based on comparing changes on QE announcement days with changes on other days, changes on QE announcement days of zero can be statistically significant. For the 3-month federal funds futures, changes on non-QE days were on average slightly negative. Values may differ from the sum of the values reported for individual dates because of rounding.

long from today rates will be held low (on the other hand, for plotting a yield curve it is more natural to hold the contract month fixed, as we did in figure 3). For two of the four federal funds futures contracts, the 2-day changes for QE1 announcement dates are significantly more negative than on other days. The 2-day decrease in the 24th-month contract is 40 bp.

How much of an effect can the signaling channel have on longer-term rates? The difficulty in assessing this effect is that we cannot precisely measure changes in the expected future federal funds rate for horizons over 2 years, because federal funds futures contracts do not exist for those horizons. An *upper* bound on the signaling effect can be found by extrapolating the 40-bp fall in the 24th-month contract to all horizons. This is an upper bound because it is clear that at longer horizons, market expectations should reflect a normalization of the current, accommodative Federal

Reserve policy, so that signaling should not have any effect on rates at those horizons. Nevertheless, with the 40-bp number, equation 1 predicts that rates at all horizons fall by 40 bp.

A second approach to estimating the signaling effect is to build on the observation that QE shifted the path of anticipated rate hikes by about 6 months. Signaling affects long-term rates by changing the expectations term in equation 1, $E[i_{safe,liq,short-term}]$. Consider the expectations term for a T -year bond:

$$E[i_{safe,liq,short-term}] = \frac{1}{T} \int_{t=0}^T i_t^{ff} dt,$$

where i_t^{ff} is the expected federal funds rate t years from today. Let $i_{i,prior}^{ff}$ denote the path described by the federal funds rate as expected by the market *before* the QE announcements. Suppose that QE policy then signals that the rate is going to be held at $i_{0,prior}^{ff}$ for the next X months and thereafter follow the path indicated by $i_{i,prior}^{ff}$ (such that the rate at time t with the policy in place is what the rate would have been X months earlier absent the policy). That is, QE simply shifts an anticipated rate hike cycle later by X months. Then the decrease in the expectations term for a T -year bond is

$$\Delta E[i_{safe,liq,short-term}] = \frac{1}{T} \int_{t=T-X/12}^T (i_{0,prior}^{ff} - i_{i,prior}^{ff}) dt.$$

The first point to note from this equation is that it indicates that the signaling effect is decreasing in maturity (that is, T). Here is a rough check on how large the signaling effect can be. Suppose that $i_{0,prior}^{ff}$ is zero, which is as low as the federal funds rate fell over this period. Consider the $i_{i,prior}^{ff}$ term next. The 2-year federal funds futures contract, which is the longest contract traded, indicated a yield as high as 1.8 percent over the period from November 2008 to March 2009. But expected federal funds rates out to, say, 10 years are likely to be much higher than that. Over the QE1 period the yield curve between 10 and 30 years was relatively flat, with Treasury rates at 10 and 30 years as high as almost 4 percent. Thus, consider a value of $i_{i,prior}^{ff}$ of 4 percent to get an upper bound on this signaling effect. Then the change for a 10-year bond is 20 bp, and that for a 30-year bond is about 7 bp. At the 5-year horizon, given the slope of the yield curve, $i_{i,prior}^{ff}$ is lower than 4 percent. We use 3 percent, which is based on computing average forward rates between years 4 and 7 using the 3- and 7-year Treasury yields, implying a signaling effect of 30 bp for the 5-year horizon. Our two

ways of computing the signaling effect indicate moves in the range of 20 to 40 bp out to 10 years. This effect potentially explains the moves in the CDS-adjusted Baa rates (in table 3 below) of 41 bp (long) and 25 bp (intermediate). It can also help explain the fall in the 1-year Treasury yield of 25 bp.

On the other hand, longer-term rates move much more substantially than shorter-term rates. Yields on longer-term Treasuries and agencies fall 73 to 200 bp, much more than the 1-year yield. For the corporate bonds in table 3 below, however, there is no apparent maturity effect (for a given ratings category). Thus, to understand the more substantial movements of long-term rates, we need to look to other channels and, in particular, the safety and prepayment risk channels.

II.C. Duration Risk Channel

Consistent with the duration risk hypothesis, the yields of many longer-term bonds in table 1 fall more than the yields of shorter-maturity bonds. The exceptions here are the 30-year Treasury and agency bonds, whose yields fall less than those of the 10-year bonds. Note that because mortgages amortize and carry prepayment risk, the duration on the 30-year MBS is around 7 years and is thus more comparable to that of a 10-year than that of a 30-year Treasury or agency bond. The MBS duration is from Bloomberg and calculated based on the coupon rates of the MBS series and the fact that the MBSs amortize and may prepay.

There is other evidence that the duration risk channel cannot explain. There are dramatic differences in the yield changes across the different asset classes. Agency bonds, for example, experience the largest fall in yields. The duration risk channel cannot speak to these effects, as it predicts only effects that depend on bond maturity.

The corporate bond data also cannot be explained by the duration risk channel. Table 3 presents data on corporate bond yields of intermediate (around 4 years) and long (around 10 years) duration, as well as on these same yields with the impact of changes in CDS rates taken out (the durations for the corporate series are obtained from Datastream). We adjust the yield changes using CDS changes to remove any effects due to a changing default risk premium, thereby isolating duration risk premium effects.

We construct CDS rate changes by rating category as follows. We obtain company-level CDS rates from Credit Market Analysis via Datastream. We classify companies into ratings categories based on the value-weighted average rating of the company's senior debt with remaining maturity above 1 year, using bond information from the Mergent Fixed Investment Securities

Table 3. Changes in Corporate Yields, Unadjusted and Adjusted by Credit Default Swap Rates, around QE1 Event Dates^a
Basis points

Date ^b	Corporate yields												
	Long-term						Intermediate-term						
	Aaa	Aaa	A	Baa	Ba	B	Aaa	Aaa	Aa	A	Baa	Ba	B
Nov. 25, 2008	-28	-18	-23	-19	-4	4	-17	-17	-15	-18	-18	1	-47
Dec. 1, 2008	-24	-24	-21	-17	-13	28	-21	-21	-15	-18	-8	-5	6
Dec. 16, 2008	-43	-37	-45	-39	1	-11	-19	-21	-21	-24	-27	-28	-42
Jan. 28, 2009	34	17	17	14	-16	-25	12	8	8	7	3	-32	-25
Mar. 18, 2009	-16	-21	-21	-20	-28	-39	-43	-50	-50	-39	-26	-18	-22
Sum ^c	-77	-83**	-93**	-81**	-60**	-43	-88**	-93**	-93**	-92**	-76**	-82***	-130***
<i>Credit default swap rates^d</i>													
<i>10-year maturity</i>													
Nov. 25, 2008	-1	10	-17	-13	-31	-798	-1	-6	-6	-20	-18	-32	-573
Dec. 1, 2008	1	0	9	11	21	1	1	3	13	7	28	28	33
Dec. 16, 2008	-2	-8	-18	-17	-23	-308	-2	-15	-20	-21	-40	-40	-172
Jan. 28, 2009	-3	-15	-6	-13	-26	-231	-3	-7	-9	-11	-27	-27	-255
Mar. 18, 2009	-2	-1	0	-7	-18	-18	-2	8	2	-8	-27	-27	-25
Sum ^c	-7***	-14	-32	-40*	-78*	-1,354**	-6***	-17	-33	-51**	-98*	-98*	-991**

(continued)

Table 3. Changes in Corporate Yields, Unadjusted and Adjusted by Credit Default Swap Rates, around QE1 Event Dates^a (Continued)
Basis points

Date ^b	Adjusted corporate yields ^c											
	Long-term						Intermediate-term					
	Aaa	Aa	A	Baa	Ba	B	Aaa	Aa	A	Baa	Ba	B
Nov. 25, 2008	-27	-28	-6	-6	27	802	-16	-9	2	0	33	526
Dec. 1, 2008	-25	-24	-30	-28	-34	27	-22	-18	-31	-15	-33	-27
Dec. 16, 2008	-41	-29	-27	-22	24	297	-17	-6	-4	-6	12	130
Jan. 28, 2009	37	32	23	27	10	206	15	15	16	14	-5	230
Mar. 18, 2009	-14	-20	-21	-13	-10	-21	-41	-58	-41	-18	9	3
Sum ^e	-70	-69	-61	-41	18	1,311**	-82*	-76	-59	-25	16	861**

Sources: Authors' calculations using data from Barclays, Credit Market Analysis (CMA), the Mergent Fixed Investment Securities Database (FISD), and the Trade Reporting and Compliance Engine (TRACE) of the Financial Industry Regulatory Authority.

a. All changes are over 2 days, from the day before to the day after the event. Asterisks denote statistical significance at the ***1 percent, **5 percent, and *10 percent level.

b. See table 1 for descriptions of the events on these dates.

c. May differ from the sum of the values reported for individual dates because of rounding.

d. Constructed using CMA data and ratings from FISD; changes are value-weighted averages using information on issue sizes from FISD and prices from TRACE.

e. Change in the unadjusted corporate yield minus the change in the corresponding CDS rate.

Database (FISD) and the Trade Reporting and Compliance Engine (TRACE) of the Financial Industry Regulatory Authority. For each QE date, we then calculate the company-level CDS rate change and the value-weighted average of these changes by ratings category, with weights based on the company's senior debt with remaining maturity above 1 year (weights are calculated based on market values on the day before the event day).⁶ The reason for calculating company-level CDS changes and then averaging across companies (call this "method 1"), as opposed to calculating average CDS rates across companies and then the change over time in the averages ("method 2"), is that we have CDS data for only a subset of companies: between 362 and 378 for each QE1 date (and around 338 for the two main QE2 dates we study below). This is likely many fewer than the number of companies for which bond yields are included in the corporate bond indexes from Barclays that we use. Therefore, if we used method 2, the CDS calculations for a given ratings category would be fairly sensitive to whether a particular company's bonds are down- or upgraded on a given day (and more so than the bond yield indexes). We avoid this problem by using method 1, since a given time change is then calculated using CDS rates for a fixed set of companies.

A side effect of using method 1 is that the sum of two daily CDS changes for a given ratings category (each of which averages 1-day changes across companies) will not equal the 2-day CDS change for this category (calculated by averaging 2-day changes across companies). Therefore, to assess the statistical significance of 2-day CDS changes for a given ratings category, we estimate a regression where the dependent variable is the 2-day CDS change (from date $t - 1$ to $t + 1$) and the independent variables are a dummy for whether day t is a QE1 announcement day and a dummy for whether day t is a QE2 announcement day. To keep statistical inference simple, we use data for every second day only (as opposed to using overlapping 2-day changes). We make sure that all QE announcement dates are included: if a given QE date falls on a date that would otherwise not be used, we include the QE date and drop the day before and the day after the QE date. We have CDS data only up to the end of the third quarter of 2010,

6. We drop CDS rates for AIG, the large insurance firm in which the U.S. government intervened in September 2008. According to our calculations, this firm is the largest in ratings category Baa by market value of bonds outstanding and has a very high CDS rate increase on our last QE1 date. With AIG included, the 2-day CDS changes for category Baa (summed across the five QE1 dates) are 32 bp rather than 40 bp at the 10-year horizon and 37 bp rather than 51 bp at the 5-year horizon. We are not sure whether AIG is still included in the Barclays bond indexes during this period, given the government's intervention in this firm.

so we estimate the regression using data from the start of 2008 to the end of 2010Q3. We use the same regression for 2-day changes when assessing the statistical significance of 2-day yield changes adjusted for CDS changes.

The CDS adjustment makes a substantial difference in interpreting the corporate bond evidence in terms of the duration risk channel. In particular, there is a large fall in CDS rates for lower-grade bonds on the event dates, suggesting that default risk or the default risk premium fell substantially with QE, consistent with the default risk channel (we discuss this further below). Given the CDS adjustment, the change in the yield of the Baa bond can be fully accounted for by the signaling channel. Moreover, there is no apparent pattern across long and intermediate maturities in the changes in CDS-adjusted corporate bond yields. These observations suggest that we need to look to other channels to understand the effects of QE.

II.D. Liquidity Channel

The most liquid assets in table 1 are the Treasury bonds. The liquidity channel predicts that their yields should *increase* with QE, relative to the yields on less liquid bonds. Consistent with this, Treasury yields fall much less than the yields on agency bonds, which are less liquid. That is, the agency-Treasury spread falls with QE. For example, the 10-year spread falls by $200 - 107 = 93$ basis points. This is a relevant comparison because 10-year agencies and Treasuries have similar default risk (especially since the government placed Fannie Mae and Freddie Mac into conservatorship in September 2008) and are duration matched. Thus, this spread isolates a liquidity premium. Consistent with the liquidity channel, the equilibrium price premium (yield discount) for liquidity falls substantially in economic terms. To test whether agency yield changes are statistically significantly larger than Treasury yield changes on the QE1 dates, we use the difference between agency yield changes and Treasury yield changes as the dependent variable in the regression described in section II.A. We find that this is the case, at the 5 percent level, for all maturities shown (3, 5, 10, and 30 years).

II.E. Safety Channel

The noncallable agency bonds will be particularly sensitive to the safety effect. These bonds are not as liquid as the Treasury bonds but are almost as safe. Of the channels we have laid out, (nominal) agency bond yields are mainly affected via the signaling channel, the duration risk premium channel, and the safety channel. We have argued that the duration risk premium channel is not substantial, and that the signaling channel accounts for at

most a 40-bp decline in yields on QE1 dates. The fall in 10-year agency yields is 200 bp, the largest effect in table 1. This suggests that the impact via the safety channel on agency and Treasury yields is one of the dominant effects for QE1, at least 160 bp for the 10-year bonds.⁷ To test whether agency yield changes are statistically significantly larger on the QE1 dates than the signaling channel predicts, we use the difference between agency yield changes and changes in the 24th-month federal funds futures contract yield as the dependent variable in the regression described in section II.A, and we find that this is the case, at the 5 percent level, for all maturities shown (3, 5, 10, and 30 years).

As we have just noted, the yields on Treasuries fall less than those on agencies because the liquidity effect runs counter to the safety effect, but the safety effect itself should affect Treasuries and agencies about equally.

The corporate bond evidence is also consistent with a safety effect. The CDS-adjusted yields on Aaa bonds, which are close to default free, fall much more than the CDS-adjusted yields on Baa or B bonds. The Aa and A bonds are also affected by the safety effect, but by a smaller amount, as the safety channel predicts. There is close to no effect on the non-investment-grade bonds.⁸ Finally, since agencies are safer than Aaa corporate bonds, the safety channel prediction that yields on the former will fall more than those on the latter is also confirmed in the data.

II.F. Prepayment Risk Channel

Agency MBS yields fall by 107 bp for 30-year bonds and 88 bp for 15-year bonds (table 1). There are two ways to interpret this evidence. It could be due to a safety effect: the government guarantee behind these MBSs may be worth a lot to investors, so that these securities carry a safety premium. The safety premium then rises, as it does for the agency bonds, decreasing

7. When inferring the size of the safety channel from a comparison of agency yield changes and changes in federal funds futures, we are implicitly assuming that neither is affected by changes in the overall supply of liquidity in QE1. This is plausible if the following assumptions hold: that agencies are not (to a substantial extent) valued for their liquidity and do not change in price in response to a change in the supply of liquidity; that the federal funds futures we use are sufficiently far out in the future not to be affected by the high price of liquidity in the fall of 2008; and that the market expects any liquidity injected by QE1 to be withdrawn by the time of the federal funds futures contract used. The last two assumptions are plausible given that we focus on 24th-month federal funds futures.

8. The anomalously large moves in the CDS rates for the B category appear to be partly driven by Ford Motor Company bonds, perhaps related to news about the auto bailouts. If we drop Ford from the tabulation, the 5-year and 10-year CDS rates fall by 435 bp and 496 bp, respectively.

agency MBS yields. On the other hand, the agency MBSs carry significant prepayment risk and are unlikely to be viewed as safe in the same way as agency bonds or Treasuries (where “safety” means the almost complete certainty of nominal repayment at known dates). We think that a more likely explanation is market segmentation effects as in Gabaix, Krishnamurthy, and Vigneron (2007). The government’s purchase of MBSs reduces the prepayment risk in the hands of investors, and thereby reduces MBS yields. The effect is larger for the 30-year than for the 15-year MBSs because the longer-term bonds carry more prepayment risk.⁹

Importantly, Andreas Fuster and Paul Willen (2010) show that the large reductions in agency MBS rates around November 25, 2008, were quickly followed by reductions in mortgage rates offered by mortgage lenders to households.

II.G. Default Risk Channel

We noted earlier from table 3 that QE appears to reduce default risk or the default risk premium, which particularly affects the interest rates on lower-grade corporate bonds. The table shows that the CDS rates of the Aaa firms do not change appreciably with QE. There is a clear pattern across the ratings, going from Aaa to B, whereby firms with higher credit risk experience the largest fall in CDS rates. In terms of statistical significance, 2-day changes in CDS rates are significantly more negative around QE1 announcement days than on other days for four of the six ratings categories. This evidence suggests that QE had a significant effect on yields through changes in default risk or the default risk premium.

II.H. Inflation Channel

The above analysis focuses on nominal interest rates (in particular, on the effects on various nominal rates relative to the nominal signaling channel benchmark). To assess effects on real rates, one needs information about the impact of QE1 on inflation expectations. Table 4 presents the relevant data.

The first four columns in the table report results for inflation swaps. For example, the column labeled “10-year” shows the change in the fixed rate on the 10-year zero-coupon inflation swap, a market-based measure of

9. The fall in MBS yields may be driven by both a reduction in prepayment risk and a reduction in the risk premium required to bear prepayment risk. This is similar to the effects on corporate bond yields, where reductions in both default risk and the default risk premium play a role. We have looked at the option-adjusted spreads on MBSs, which remove the prepayment risk effects using a model, and find that these spreads fall, suggesting that the prepayment risk premium fell.

Table 4. Changes in Inflation Swap Rates, TIPS Yields, and Implied Interest Rate Volatility around QE1 Event Dates
Basis points

Date ^b	Inflation swap rates			TIPS real yield (constant maturity)			Implied interest rate volatility ^c
	30-year	10-year	5-year	1-year	20-year	10-year	
Nov. 25, 2008	1	-6	-28	48	-22	-43	5
Dec. 1, 2008	15	27	12	-40	-38	-34	-52 ^d
Dec. 16, 2008	4	37	35	-17	-45	-57	-83
Jan. 28, 2009	14	15	-6	5	15	6	13
Mar. 18, 2009	2	22	24	45	-45	-59	-43
Sum ^e	35 ^{**}	96 ^{**}	38	41	-135 ^{**}	-187 ^{**}	-160 ^{**}

Sources: FRED, Federal Reserve Bank of St. Louis; Bloomberg.

a. All changes are over 2 days, from the day before to the day after the event. Asterisks denote statistical significance at the *** 1 percent, ** 5 percent, and * 10 percent level.

b. See table 1 for descriptions of the events on these dates.

c. Volatility implied from swaptions as measured using the Barclays implied volatility index.

d. The constant-maturity TIPS data from FRED indicate that the 5-year TIPS fell by 244 bp around this event. We think this is a data error. Using data from FRED on the 5-year and 10-year underlying TIPS with remaining maturities near 5 years around QE1 (the 5-year TIPS maturing April 15, 2013, and the 10-year TIPS maturing January 15, 2014), we found yield changes of -58 bp and -46 bp, respectively. The value reported in the table is the average of these changes.

e. May differ from the sum of the values reported for individual dates because of rounding.

expected inflation over the next 10 years (see Fleckenstein, Longstaff, and Lustig 2010 for information on the inflation swap market). These data suggest that inflation expectations increased by between 35 and 96 bp, depending on maturity.

The next three columns present data on TIPS yields. We compare these yield changes with those for nominal bonds to evaluate the change in inflation expectations. Given the evidence of the existence of a significant liquidity premium on Treasuries, it is inappropriate to compare TIPS with nominal Treasuries. If investors' demand for safety does not apply to inflation-adjusted safe bonds such as TIPS, then the appropriate nominal benchmark is the CDS-adjusted Baa bond. On the other hand, if long-term safety demand also encompasses TIPS, then it is more appropriate to use the CDS-adjusted Aaa bond as the benchmark. We are unaware of any definitive evidence that settles the issue. From table 3, the CDS-adjusted yield on long-maturity Aaa bonds falls by 70 bp, while that for intermediate-maturity Aaa bonds falls by 82 bp; the corresponding numbers for Baa bonds are 41 and 25 bp. Matching the 70-bp change for the long-maturity Aaa bonds and the 41-bp change in the long-maturity Baa bonds to the 187-bp change in the 10-year TIPS, we find that inflation expectations increased by 117 or 146 bp, respectively, at the 10-year horizon. (Both are significant at the 1 percent level, using the same regression to test significance as used for 2-day CDS changes.) At the 5-year horizon, based on the 82-bp change in the CDS-adjusted intermediate-maturity Aaa bond, the 25-bp change in the corresponding Baa bond, and the 160-bp change in the TIPS, we find that inflation expectations increased by 78 or 135 bp (the first is not significant and the second is significant at the 5 percent level). Benchmarking to the Aaa bond produces results more similar to those from the inflation swaps.

Together these two sets of data suggest that the impact of Federal Reserve purchases of long-term assets on expected inflation was large and positive.

We also evaluate the inflation uncertainty channel. The last column in table 4 reports data on implied volatilities from interest rate swaptions (options to enter into an interest rate swap), as measured using the Barclays implied volatility index. The underlying maturity for the swap ranges from 1 year to 30 years, involving options that expire from 3 months to 20 years. The index is based on the weighted average of implied volatilities across the different swaptions.

Average volatility by this measure over the QE1 time period is 104 bp, so the fall of 38 bp is substantial. Thus, it appears that QE1 reduced rather than increased inflation uncertainty.

The other explanation for this fall in volatility is segmented markets effects. MBSs have an embedded interest rate option that is often hedged by investors in the swaption market. Since QE1 involved the purchase of MBSs, investors' demand for swaptions fell, and hence the implied volatility of swaptions fell. This explanation is often the one given by practitioners for changes in swaption-implied volatilities. Notice, however, that volatility is essentially unchanged on the first QE1 event date, which is the event that drives the largest changes in MBS yields. This could indicate that the segmented markets effects are not important, with volatility instead being driven by the inflation uncertainty channel.

II.1. Summary

QE1 significantly reduced yields on intermediate- and long-maturity bonds. There is evidence that this decrease in yields, particularly on the intermediate-maturity bonds, occurred via the signaling channel, with effects on 5- to 10-year bonds ranging from 20 to 40 bp. A preferred habitat for long-term safe assets, including Treasuries, agencies, and highly rated corporate bonds, appears to have generated a large impact of QE1 on the yields on these bonds, with effects as large as 160 bp for 10-year agency and Treasury bonds. For riskier bonds such as lower-grade corporate bonds and MBSs, QE1 had effects through a reduction in default risk or the default risk premium and a reduced prepayment risk premium. The 10-year CDS rates on Baa corporate bonds fell by 40 bp on the QE1 dates. These effects on CDS rates and MBS pricing could be due to reductions in risk borne by the financial sector, consistent with limited intermediary capital models, or due to impacts via a mortgage refinancing boom and its impact on the housing market and consumer spending. We find little evidence of effects via the duration risk premium channel. Finally, there is evidence that QE substantially increased inflation expectations but reduced inflation uncertainty. The increase in expected inflation was large: 10-year expected inflation was up between 96 and 146 bp, depending on the estimation approach used, implying that real interest rates fell dramatically for a wide variety of borrowers.

Finally, note that these effects are all sizable and probably much more than one should expect in general. The period from November 2008 to March 2009 was an unusual time of financial crisis in which the demand for safe assets was heightened, segmented markets effects were apparent across many markets, and intermediaries suffered from serious financing problems. In such an environment, supply changes should be expected to have a large effect on interest rates.

III. Evidence from QE2

This section presents data from the QE2 event study and analyzes the channels through which QE2 operated.

III.A. Event Study

We perform an event study of QE2 similar to that of QE1. There are two relevant sets of events in QE2. First, in its August 10, 2010, statement, the FOMC announced, “The Committee will keep constant the Federal Reserve’s holdings of securities at their current level by reinvesting principal payments from agency debt and agency mortgage-backed securities in longer-term Treasury securities.” Before this announcement, market expectations were that the Federal Reserve would let its MBS portfolio run off,¹⁰ thereby reducing reserve balances in the system and allowing the Fed to exit from its nontraditional monetary policies. Thus, the announcement of the Federal Reserve’s intent to continue QE revised market expectations. Moreover, the announcement indicated that QE would shift toward longer-term Treasuries, and not agencies or agency MBSs as in QE1. As a back-of-the-envelope computation, suppose that the prepayment rate for the next year on \$1.1 trillion of MBSs was 20 percent.¹¹ Based on this, the announcement indicated that the Federal Reserve intended to purchase \$220 billion [$\$1.1 \text{ trillion} \times 0.2$] of Treasuries over the next year, \$176 billion [$\$1.1 \text{ trillion} \times (1 - 0.2) \times 0.2$] over the subsequent year, and so on. It is unclear from the announcement how long the Federal Reserve expected to keep the reinvestment strategy in place.

The September 21, 2010, FOMC announcement reiterates this message: “The Committee also will maintain its existing policy of reinvesting principal payments from its securities holdings.”

The second type of information for QE2 pertains to the Federal Reserve’s intent to expand its purchases of long-term Treasury securities. The fourth paragraph of the September 21 FOMC statement says, “The Committee will continue to monitor the economic outlook and financial developments and is prepared to provide *additional* accommodation if needed to support the economic recovery” (emphasis added).

10. See Federal Reserve Board Chairman Ben Bernanke’s Monetary Policy Report to Congress on July 21, 2010, discussing the “normalization” of monetary policy. The issue is also highlighted in Bernanke’s testimony on March 25, 2010, on the Federal Reserve’s exit strategy.

11. The Federal Reserve’s holdings of MBSs were \$1,118 billion on August 4, 2010, and \$897 billion on August 3, 2011 (according to the H4 report of the Federal Reserve), for an annualized decline of 19.7 percent.

This paragraph includes new language relative to the corresponding paragraph in the August 10, 2010, FOMC statement, which read, “The Committee will continue to monitor the economic outlook and financial developments and will employ its policy tools as necessary to promote economic recovery and price stability.” The new language in the September 21 statement follows the third paragraph of that statement in which the FOMC reiterates its intention to maintain its target for the federal funds rate and reiterates its policy of reinvesting principal payments from its securities holdings. The new language was read by many market participants as indicating new stimulus by the Federal Reserve, and particularly an expansion of its purchases of long-term Treasuries. For example, Goldman Sachs economists, in their market commentary on September 21, 2010, refer to this language and conclude that the Federal Reserve intended to purchase up to \$1 trillion of Treasuries.¹²

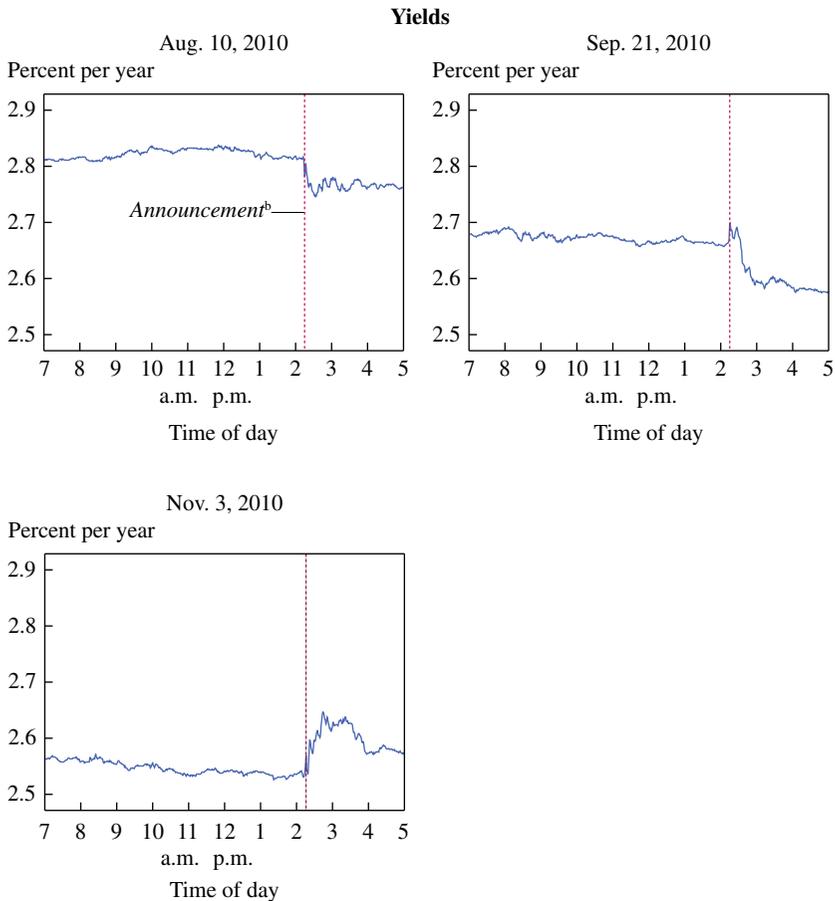
The following announcement from the November 3, 2010, FOMC statement makes such an intention explicit: “The Committee will maintain its existing policy of reinvesting principal payments from its securities holdings. In addition, the Committee intends to purchase a further \$600 billion of longer-term Treasury securities by the end of the second quarter of 2011.”

The November 3 announcement was widely anticipated. A *Wall Street Journal* survey of private sector economists in early October 2010 found that they expected the Federal Reserve to purchase about \$750 billion in QE2.¹³ We have noted above the expectation, as of September 21, 2010, by Goldman Sachs economists of \$1 trillion of purchases. Based on this, one would expect the November 3 announcement to have little effect. (Estimates in the press varied widely, but the actual number of \$600 billion was within the range of numbers commonly mentioned.)

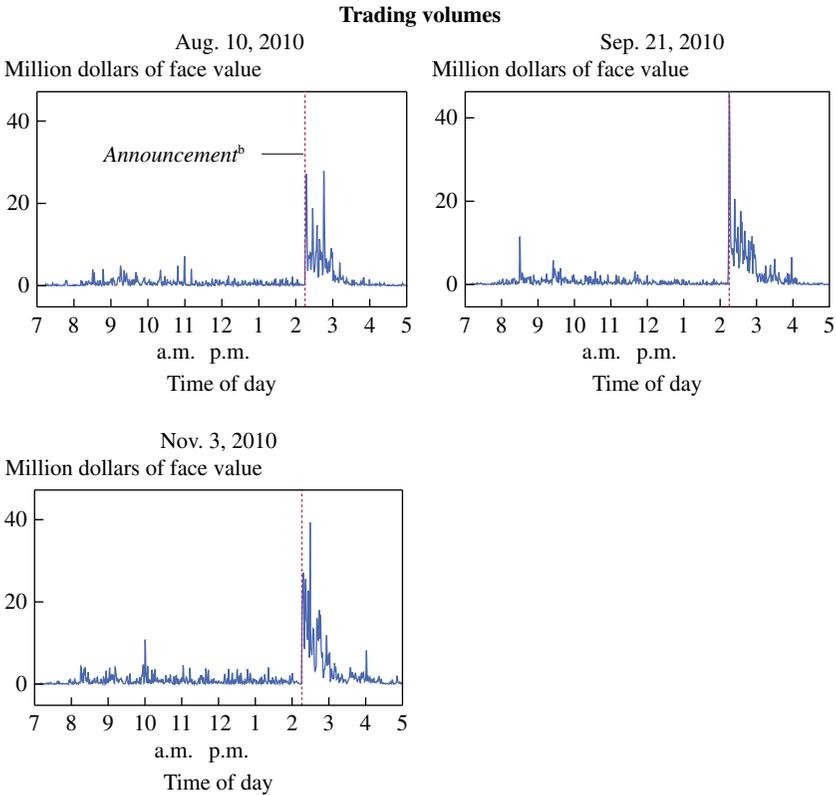
Figure 4 presents intraday data on the 10-year Treasury bond yield around the announcement times of the above FOMC statements. The August 10 announcement appears to have contained significant news for the Treasury market, reducing the yield in a manner that suggests that market expectations regarding QE were revised upward. The reaction to the September 21 announcement is qualitatively similar. After the November 3 announcement, Treasury yields increased but then fell somewhat. This reaction suggests that markets may have priced in more than a \$600 billion QE announcement.

12. “FOMC Rate Decision—Fed Signals Willingness to Ease Further if Growth or Inflation Continue to Disappoint,” Goldman Sachs newsletter, New York, September 21, 2010.

13. Jon Hilsenrath and Jonathan Cheng, “Fed Gears Up for Stimulus,” *Wall Street Journal*, October 26, 2010.

Figure 4. Intraday Yields and Trading Volumes on QE2 Event Days^a

In our event study, we aggregate across the August 10 and September 21 events, which seem clearly to be driven by upward revisions in QE expectations. We do not add in the change from the November 3 announcement, as it is unclear whether only the increase in yields after that announcement or also the subsequent decrease was due to QE2. (Furthermore, the large 2-day reaction to the November 3 announcement may not have been due to QE2, since a lot of it happened the morning of November 4, around the time new numbers were released for jobless claims and productivity.) As noted in section II.A, given our objective of understanding the channels of QE, it is important to focus on events that we can be sure are relevant to QE.

Figure 4. Intraday Yields and Trading Volumes on QE2 Event Days^a (*Continued*)

Source: BG Cantor data.

a. Yields and trading volumes are minute-by-minute averages and total volume by minute, respectively, for the on-the-run 10-year bond on the indicated dates.

b. Minute of the appearance in Factiva of the first article covering the QE-related announcement.

Additionally, we present information for both 1-day changes and 2-day changes, but we focus on the 1-day changes in our discussion. The reason is that market liquidity had normalized by the fall of 2010, and looking at the 2-day changes would therefore likely add noise to the data.

III.B. Analysis

Table 5 provides data on the changes in Treasury, agency, and agency MBS yields over the event dates. Table 6 provides data on changes in corporate bond yields, CDS rates, and CDS-adjusted corporate yields.

The effects of QE2 on yields are consistently much smaller than the effects found for QE1. This could be partially due to omission of relevant

Table 5. Changes in Treasury, Agency, and Agency MBS Yields around QE2 Event Dates^a
Basis points

Date	Treasury yields (constant maturity)					Agency (Fannie Mae) yields					Agency MBS yields ^b				
	30-year	10-year	5-year	3-year	1-year	30-year	10-year	5-year	3-year	1-year	30-year	10-year	5-year	3-year	15-year
Aug. 10, 2010															
One-day change	-1	-7	-8	-3	-1	-2	-7	-8	-4	-1	-1	-4	-8	-4	-4
Two-day change	-8	-14	-10	-3	-1	-8	-13	-9	-7	-4	-4	-7	-9	-4	-8
Sep. 21, 2010															
One-day change	-8	-11	-9	-5	0	-8	-11	-9	-6	-8	-11	-9	-6	-8	-8
Two-day change	-13	-16	-10	-5	-1	-14	-16	-10	-6	-4	-16	-10	-6	-4	-5
Nov. 3, 2010															
One-day change	16	4	-4	-2	0	13	5	-5	-3	5	-10	-14	-8	-4	-4
Two-day change	11	-10	-11	-6	-1	4	-10	-14	-8	-10	-10	-14	-8	-10	-9
Sum of Aug. 10 and Sep. 21 ^c															
One-day change	-9*	-18***	-17***	-8***	-1	-9***	-17***	-17***	-10***	-17***	-17***	-17***	-10***	-9*	-12***
Two-day change	-21***	-30***	-20***	-8***	-2	-22***	-29***	-20***	-13***	-29***	-29***	-20***	-13***	-8	-13**

Sources: FRED, Federal Reserve Bank of St. Louis; Bloomberg.

a. Dates are those of FOMC statements regarding QE2. Asterisks denote statistical significance at the ***1 percent, **5 percent, and *10 percent level.

b. Averages across current-coupon Ginnie Mae, Fannie Mae, and Freddie Mac MBSs.

c. May differ from the sum of the values reported for individual dates because of rounding.

Table 6. Changes in Corporate Yields, Unadjusted and Adjusted by Credit Default Swap Rates, around QE2 Event Dates^a

Basis points

Date	Corporate yields											
	Long-term					Intermediate-term						
	Aaa	Aa	A	Baa	Ba	B	Aaa	Aa	A	Baa	Ba	B
Aug. 10, 2010												
One-day change	0	3	1	1	-3	-9	-4	-2	-2	-3	0	6
Two-day change	-10	-5	-7	-7	-3	-5	-8	-5	-6	-6	9	23
Sep. 21, 2010												
One-day change	-9	-9	-9	-8	-7	2	-9	-9	-10	-10	-4	-3
Two-day change	-13	-12	-13	-11	-15	1	-10	-8	-10	-11	-3	2
Nov. 3, 2010												
One-day change	10	11	12	9	28	-1	-2	-2	-1	-1	-1	-5
Two-day change	5	2	4	-1	22	-10	-10	-11	-13	-14	-12	-18
Sum of Aug. 10 and Sep. 21 ^b												
One-day change	-9	-6	-8	-7	-10***	-7	-13***	-11**	-12**	-13**	-4	3**
Two-day change	-23***	-17*	-20***	-18**	-18***	-4	-18***	-13**	-16**	-17***	6	25
Credit default swap rates												
	10-year maturity					5-year maturity						
Aug. 10, 2010												
One-day change	-1	5	2	2	4	4	1	5	3	4	5	9
Two-day change	0	10	7	7	16	23	1	15	7	9	20	26
Sep. 21, 2010												
One-day change	2	-3	0	0	2	4	-1	-1	0	0	4	4
Two-day change	3	0	2	2	9	8	1	3	3	4	11	12
Sum of Aug. 10 and Sep. 21 ^b												
One-day change	2	2	2	2	6	8	0	4	3	4	9	13
Two-day change	3	10	10**	8*	25***	31	2*	18*	10**	13***	31***	38

(continued)

Table 6. Changes in Corporate Yields, Unadjusted and Adjusted by Credit Default Swap Rates, around QE2 Event Dates^a (Continued)

Basis points

Date	Adjusted corporate yields ^d											
	Long-term					Intermediate-term						
	Aaa	Aa	A	Baa	Ba	B	Aaa	Aa	A	Baa	Ba	B
Aug. 10, 2010												
One-day change	1	-2	-1	-1	-7	-13	-5	-7	-5	-7	-5	-3
Two-day change	-10	-15	-14	-14	-19	-28	-9	-20	-13	-15	-11	-3
Sep. 21, 2010												
One-day change	-11	-6	-9	-8	-9	-2	-8	-8	-10	-10	-8	-7
Two-day change	-16	-12	-15	-13	-24	-7	-11	-11	-13	-15	-14	-10
Sum of Aug. 10 and Sep. 21 ^b												
One-day change	-11	-8**	-10*	-9	-16***	-15	-13***	-15***	-15***	-17***	-13***	-10
Two-day change	-26***	-27***	-30***	-26***	-43***	-35	-20***	-31***	-26***	-30***	-25***	-13

Sources: Authors' calculations using data from Barclays, Credit Market Analysis (CMA), the Mergent Fixed Investment Securities Database (FISD), and the Trade Reporting and Compliance Engine (TRACE) of the Financial Industry Regulatory Authority.

a. Dates are those of FOMC statements regarding QE2. Asterisks denote statistical significance at the ***1 percent, **5 percent, and *10 percent level.

b. May differ from the sum of the values reported for individual dates because of rounding.

c. Constructed using CMA data and ratings from FISD; changes are value-weighted averages using information on issue sizes from FISD and prices from TRACE. Data for the November 3 event are unavailable.

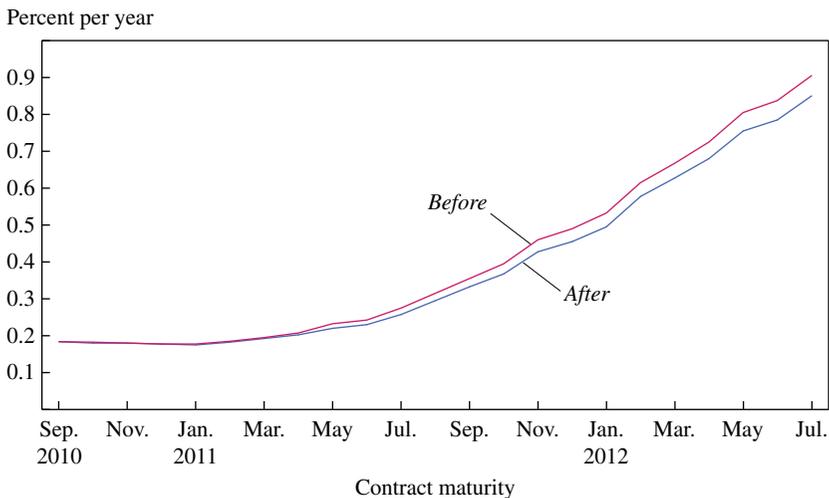
d. Change in the unadjusted corporate yield minus the change in the corresponding CDS rate.

additional event dates for QE2. We considered various additional events (for example, speeches by Federal Reserve officials) but, using intraday Treasury yield data, did not find any days with dramatic Treasury yield declines right around the events. This does not mean that considering only a few QE2 event dates captures all of the impact of QE2, but only that the market may have updated its perceptions about QE2 not only on Federal Reserve announcement dates but also on dates of bad economic news. Decomposing the yield impact of, for example, a GDP announcement into its “standard effects” and its indirect effect due to its impact on the likelihood of QE is difficult, and we do not pursue it.

The fact that the effects of QE2 are fairly small makes it more difficult to discern all of the various channels involved in QE2 than in QE1. That said, we offer some conclusions regarding the channels:

—There is significant evidence of the signaling channel. The 12th-month federal funds futures contract (table 2) falls by 4 bp. The 24th-month contract falls by 11 bp. Extrapolating out from this 24th-month contract suggests that we can explain moves in longer-term rates of up to 11 bp following our first approach outlined in our discussion of signaling for QE1. Turning to our second approach, we show in figure 5 the average pre- and post-QE2

Figure 5. Yield Curves Calculated from Federal Funds Futures before and after QE2 Event Days^a



Source: Bloomberg data.

a. Yields are computed the day before each QE2 event date and again the day after. All the before-event yields are then averaged across events, and likewise for the after-event yields.

yield curves from the federal funds futures contracts. The graph suggests a shift forward in time of the anticipated rate hike cycle. We can again estimate how large this shift is. Because the slope of the futures curve from figure 5 is not constant, the computation is sensitive to exactly which point one uses to evaluate the time shift. Using the slope and vertical shift at July 2012, we estimate that the time shift is 3.2 months, whereas using the slope and vertical shift at July 2011, we estimate it at 2.1 months. The latter implies a fall in 5-year rates of 11 bp, a fall in 10-year rates of 7 bp, and a fall in 30-year rates of 2 bp. A time shift of 3.2 months implies a fall in 5-year rates of 16 bp, a fall in 10-year rates of 11 bp, and a fall in 30-year rates of 4 bp. The fall of 16 bp in the 5-year rate from this computation is too large relative to the 11-bp upper bound from our first approach, suggesting that the computation at 2.1 months is more plausible.

These numbers appear to be in line with the CDS-adjusted corporate bond yield changes as well as the agency MBS yield changes. Note also that the intermediate-term corporate rates (those for bonds of about 4 years' duration) in table 6 fall more than the long-term rates (10 years' duration) and that the 15-year agency MBS yields (3 years' duration) in table 5 fall more than the 30-year yields (7 years' duration). Both moves are consistent with the signaling channel. Thus, the signaling channel can plausibly explain all of the movements in the corporate bond rates and the agency MBS yields. The only exceptions are the long-term Ba and B categories, where the CDS rates appear to rise sharply with no corresponding effects on bond yields. We are unsure of what is driving the divergence between CDS rates and bond yields for these categories.

—Given that MBS yield changes are fully accounted for by the signaling channel, there is no evidence of a prepayment risk channel for QE2. This is as would be expected given that QE2 did not involve MBS purchases. Similarly, there does not appear to be a substantial duration risk premium channel. Given that the size of the signaling channel is roughly the same as the decline in the CDS-adjusted corporate rates, there is no additional yield decline to be explained by a duration risk premium reduction.

—There is evidence for a safety channel. Yields on 10-year agency and Treasury bonds, both of which have near-zero default risk, fall more than the CDS-adjusted corporate bond yields. With a signaling effect for 10-year bonds of between 7 and 11 bp, and a fall in 10-year Treasury and agency bond yields of 17 to 18 bp, the safety effect is between 6 and 11 bp for the 10-year agency bonds and Treasuries.

—There does not appear to be a liquidity channel. Treasury and agency yields fall by nearly the same amounts, so that their spread, which we use

to measure liquidity, appears unchanged. This result is plausible because liquidity premiums in bond markets were quite low in late 2010, as market liquidity conditions had normalized. Consider the following data (as of August 10, 2010):

<i>Maturity</i>	<i>Yield (basis points)</i>	
	<i>Treasury bill</i>	<i>Tier 1 nonfinancial commercial paper</i>
1 week	13	20
1 month	15	19
3 months	15	27

The yield discount on the more liquid 1-week bill relative to the 1-month bill is only 2 bp, and the yield discount on the more liquid 3-month bill relative to 3-month commercial paper is only 12 bp. The latter premium also reflects some credit risk and tax effects. Part of the reason why liquidity premiums are so low is that government policy had already provided a large supply of liquid assets to the private sector. The Federal Reserve had already increased bank reserves substantially. At the end of the third quarter of 2008, reserve balances totaled \$222 billion. At the end of the second quarter of 2010, reserve balances totaled \$973 billion, and the government increased the supply of Treasury bills from \$1,484 billion to \$1,777 billion over this same period.¹⁴ These arguments suggest that the effects on liquidity premiums should be negligible via the liquidity channel.

—There is no evidence for a credit risk channel as CDS rates rise, especially for lower-grade bonds. This may indicate that QE2 (unlike QE1) did not have a substantial stimulating effect on the economy. It is possible that CDS rates rose (rather than simply remained unchanged) because the market inferred from the Federal Reserve's decision to pursue QE2 that the economy was in worse shape than previously thought.

—Table 7 provides data on inflation swaps and TIPS yields for the event dates. Inflation expectations rise with QE2. The rate on the 10-year inflation swap rises by 5 bp, while that on the 30-year inflation swap rises by 11 bp. The 10-year TIPS yield falls by 25 bp. Comparing this number with

14. Federal Reserve, Flow of Funds Accounts of the United States, table L.109 (depository institution reserves), and U.S. Treasury, Monthly Statement of the Public Debt of the United States, various issues.

Table 7. Changes in Inflation Swap Rates, TIPS Yields, and Implied Interest Rate Volatility around QE2 Event Dates^a
Basis points

Date	Inflation swaps			TIPS real yield (constant maturity)			Implied interest rate volatility ^b
	30-year	10-year	5-year	1-year	20-year	10-year	
Aug. 10, 2010							
One-day change	5	-1	-3	0	-7	-9	-8
Two-day change	-2	0	-3	-4	-5	-9	-5
Sep. 21, 2010							
One-day change	6	6	6	-1	-13	-16	-14
Two-day change	6	4	7	9	-18	-20	-18
Nov. 3, 2010							
One-day change	6	-3	2	1	8	1	-6
Two-day change	1	-11	4	14	12	-5	-14
Sum of Aug. 10 and Sep. 21 ^c	11***	5	3	-1	-20***	-25***	-22***
One-day change	4	4	4	5	-23***	-29***	-23***
Two-day change							

Sources: FRED, Federal Reserve Bank of St. Louis; Bloomberg.

a. Dates are those of FOMC statements regarding QE2. Asterisks denote statistical significance at the ***1 percent, **5 percent, and *10 percent level.

b. Volatility implied from swaptions as measured using the Barclays implied volatility index.

c. May differ from the sum of the values reported for individual dates because of rounding.

the CDS-adjusted declines in yields on long-term Aaa and Baa bonds implies that inflation expectations rise by 14 bp or 16 bp, respectively, at the 10-year horizon. The implied volatility on swaptions falls by 3 bp, indicating a slight decrease in inflation uncertainty.

III.C. Summary and Discussion

The QE2 data suggest three primary channels for this Treasuries-only policy. The signaling channel lowered yields on 5-year bonds by 11 to 16 bp and on 10-year bonds by 7 to 11 bp, depending on the estimation method used. The safety channel lowered yields on low-default-risk 10-year bonds by an additional 6 to 11 bp. Furthermore, there is significant evidence of an increase in inflation expectations (5 to 16 bp over the 10-year horizon), suggesting that real interest rates fell for all borrowers. The main effect on the nominal rates that are most relevant for households and many corporations—mortgage rates and rates on lower-grade corporate bonds—was thus through the signaling and inflation channels, rather than from a portfolio balance effect via the QE2 Treasury purchases.

Our finding that signaling played a primary role in QE2 is consistent with the market's reaction to the August 9, 2011, FOMC statement, which said that "the Committee currently anticipates that economic conditions—including low rates of resource utilization and a subdued outlook for inflation over the medium run—are likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013." From August 8 to August 9, Treasury rates declined by 12, 20, 20, and 12 bp at maturities of 3, 5, 10, and 30 years, respectively. An important question is thus whether the Federal Reserve could have achieved the signaling and inflation impact on yields seen in the Treasuries-only policy of QE2 from a commitment like that in the August 9, 2011, statement, and thus without taking on additional balance sheet risk.

It is also interesting to contrast the channels in the QE2 policy with those in the QE1 policy, and to consider the Federal Reserve's QE3 action on September 21, 2011, in this light. We find that the main channel in lowering MBS rates (and thus household mortgage rates) and corporate borrowing rates in QE1 is a portfolio balance effect via the MBS purchases during a time of market stress (and its associated effects on the housing market and the real economy). We also find a smaller, but still sizable, signaling effect in QE1. The QE2 channel for MBS and corporate borrowing rates appears to be entirely through the signaling effects. QE3 involves both purchases of long-dated Treasuries (funded by corresponding sales of shorter-maturity Treasuries) as well as investments in agency MBSs. The

two relevant parts of the September 21, 2011, FOMC statement are the following: “The Committee intends to purchase, by the end of June 2012, \$400 billion of Treasury securities with remaining maturities of 6 years to 30 years and to sell an equal amount of Treasury securities with remaining maturities of 3 years or less,” and “the Committee will now reinvest principal payments from its holdings of agency debt and agency mortgage-backed securities in agency mortgage-backed securities.”

Our analysis of QE1 and QE2 suggests that the impact of QE3 on MBS and corporate borrowing rates should occur through a signaling effect and a portfolio balance effect based on the MBS purchases. The latter effect should be smaller than during QE1, because market conditions were less stressed in September 2011 than in late 2008 and early 2009, and MBS purchases were larger in QE1 than in QE3.

From September 20 to September 21, 2011, long-term interest rates decline substantially and across the board. The largest decline, 23 bp, is in the 30-year MBS (as previously, this is based on averaging the yields on current-coupon Fannie Mae, Ginnie Mae, and Freddie Mac securities); the yield on the comparable-duration 10-year Treasury declines by 7 bp, that on the 10-year agency by 2 bp, and long-term corporate rates from the Aaa to the Baa category by between 15 and 17 bp. These moves are plausibly affected by an MBS risk premium channel, with attendant effects for corporate borrowing rates, as in QE1. On the other hand, the market responses differ in three other ways from those following QE1. First, the federal funds futures contract barely moves (the 24th-month contract falls by 1 bp), suggesting a negligible signaling channel. It is possible that the August 9, 2011, statement reduced the amount of room remaining for rate reductions via the signaling channel. Second, default risk rises, with 10-year investment-grade CDS rates rising by 9 bp and high-yield CDS rates rising by 1 bp. (We do not have firm-level CDS data for the QE3 period. The CDS numbers reported are based on data from Markit obtained via Datastream.) The rise in perceived default risk despite an observed decrease in corporate bond yields is unlike what happened in QE1 and is puzzling to us. One possible answer is that other news affecting financial markets that day also moved asset prices. When we look at intraday asset price changes, we find that Treasury and MBS rates decline sharply within minutes after the announcement. That same day the S&P 500 index declines by around 3 percent, but the bulk of this decline occurs a full hour after the FOMC announcement. Thus, it is possible that bad news affected the market later in the day, driving up CDS rates and driving down all yields. We do not have intraday data on corporate bond yields and CDS rates with which

to evaluate this hypothesis. Finally, unlike in both QE1 and QE2, inflation expectations measured from inflation swaps are down 8 bp at the 30-year horizon and 4 bp at the 10-year horizon. It is possible that since QE3 involved no change in the monetary base, markets perceived the operation not to be inflationary. Moreover, both the increased default risk and the decrease in inflation expectations could be driven by the markets updating their odds of a slowdown in economic growth.¹⁵

IV. Regression Analysis of the Safety Channel

The event-study evidence is useful in identifying channels for QE. Although it provides guidance on the magnitudes of the effects through QE, it is hard to interpret the numbers precisely, because event-study measures are dependent on the dynamics of expectations through the event. That is, the asset market reaction depends on the change in the expectation of QE over the event. We have no direct way of precisely measuring such a change, nor can we determine whether the event study is likely to over- or understate the effects of QE. In addition, the QE1 event occurred in highly unusual market conditions, so that it is hard to extrapolate numbers from that period to more normal conditions. As such, it is valuable to find alternative approaches to estimating the impact of QE. In this section we use regression analysis to provide such estimates, focusing on the long-term safety channel.

15. Another interesting case study for QE is that of the United Kingdom in 2009–10, examined by Joyce and others (2010). Like QE2 in the United States, QE in the United Kingdom during this period consisted of purchases of long-term government bonds, totaling £200 billion in the U.K. case. Joyce and others (2010) document that QE led to large reductions in government bond yields, smaller effects on investment-grade bonds, and more erratic effects on non-investment-grade corporate bonds. They find quite small effects on derivatives measures of future policy rates (to capture the signaling effects). The authors do not consider the effects on MBS rates, CDS rates, or expected inflation. It would be interesting to revisit the U.K. QE evidence explicitly in the framework of our channels approach. Regarding our long-term safety channel, a few observations from the U.K. experience are striking. Joyce and others (2010, chart 7) find that on the first QE event date, yields on gilts (government bonds) moved dramatically out to a maturity of 15 years, with sharply smaller effects on yields just longer than the 15-year maturity, suggesting that the market did not expect bonds beyond that maturity to be purchased. On the second QE event date, the Bank of England announced that the maturities purchased would be 5 to 25 years. On that date, yields on bonds from 15 to 25 years' maturity declined sharply more than yields on bonds between 5 and 15 years, and yields on bonds just above 5 years declined much more than yields on bonds just below 5 years. This suggests the presence of investors with preferred-habitat demand for very safe bonds of particular maturities, and the absence of sufficient arbitrage activity from other investors to smooth out the impact of announced gilt purchases across the yield curve.

IV.A. Regressions

We build on the regression analysis in Krishnamurthy and Vissing-Jorgensen (2010) to estimate the effect of a purchase of long-term securities via the safety channel. We focus on the safety channel because it appears from the event studies to be a dominant effect, and because long time series of historical data exist that allow us to elaborate on this channel.

The regression approach we have taken in prior work can be explained through figure 1. Consider the yield (or price) difference between a low-default-risk bond, such as a Treasury bond, and a Baa-rated bond. This yield difference includes both a default risk premium due to standard risk considerations and a safety premium due to clientele demands for particularly safe assets. We disentangle the default risk and the safety premium by observing that the safety premium is decreasing in the supply of safe assets, including Treasuries, whereas the default risk component can be controlled for using empirical default measures. The empirical approach is to regress the Baa-Treasury spread on the supply of Treasuries as well as on standard measures of default.

As we explain in Krishnamurthy and Vissing-Jorgensen (2010), the Baa-Treasury spread reflects both a liquidity premium, since Treasuries are much more liquid than corporate bonds, and a safety premium. The Baa-Treasury spread is thus likely to overstate the safety premium.¹⁶ We therefore also consider the spread between Baa- and Aaa-rated corporate bonds (as we did for QE). The coefficient from the Baa-Aaa regression is a pure read on the safety premium, because Baa and Aaa corporate bonds are equally illiquid. However, it is an underestimate of the safety effect as may be reflected in Treasuries or agencies, because although Aaa corporate bonds are safe, they still contain more default risk than Treasuries or agencies. For example, Moody's reports that over 10 years, the historical average default probability of a corporate bond that is rated Aaa today is 1 percent (whereas it is likely close to zero for Treasuries and around 8 percent for Baa bonds). We note that an alternative spread to capture the price of long-term safety would be that between Treasury yields and duration-matched federal funds futures (following our approach to estimating the safety channel for QE, with the exception that agency yields could not be used historically because

16. Note that, as discussed above, in QE the liquidity effect of changes in Treasury supply works to increase Treasury yields relative to yields on less liquid assets, because the QE Treasury purchases were financed by reserves and thus represented an increase in the supply of liquidity. In general, however, a reduction in the supply of Treasuries available to investors will not be associated with a change in reserves and will thus reduce the supply of liquidity and reduce Treasury yields relative to yields on less liquid assets such as corporate bonds.

of their higher risk before the government takeover). However, data on federal funds futures contracts are not available far enough back in time to allow meaningful regressions in annual data.

In Krishnamurthy and Vissing-Jorgensen (2010), we mainly focus on the effect of changes in the total supply of Treasuries, irrespective of maturity, on bond yields. For evaluating QE, we are interested more in asking how a change in the supply of long-term Treasuries (and agency bonds) will affect yields. Accordingly, we construct a maturity-based measure of debt supply as follows. For each Treasury issue in the Center for Research in Security Prices' Monthly U.S. Treasury Database, we compute the market value of that issue multiplied by the duration of the issue divided by 10.¹⁷ We normalize by 10 to express the supply variable in "10-year equivalents." We then sum these values across Treasury issues with remaining maturity of 2 years or more. We denote the sum as LONG-SUPPLY. We also construct the (unweighted) market value across all Treasury issues (TOTAL-SUPPLY), including those with a remaining maturity of less than 2 years.

We then regress the spread between the Moody's Baa corporate bond yield and the long-term Treasury yield (Baa-Treasury), or between Moody's Baa and Aaa corporate bond yields, on $\ln(\text{LONG-SUPPLY}/\text{GDP})$ instrumented by $\text{TOTAL-SUPPLY}/\text{GDP}$ and squares and cubes of $\text{TOTAL-SUPPLY}/\text{GDP}$. The regression includes as default controls stock market volatility (the standard deviation of weekly stock returns over the preceding year) and the slope of the yield curve (the 10-year Treasury yield minus the 3-month yield). Data sources are as described in detail in Krishnamurthy and Vissing-Jorgensen (2010). The regressions are estimated via two-stage least squares, with standard errors adjusted for an AR(1) correlation structure. It is important to instrument for LONG-SUPPLY because the maturity structure of government debt is chosen by the government in a way that could be correlated with spreads. TOTAL-SUPPLY is strongly related to LONG-SUPPLY and is plausibly exogenous to the safety premium. (See Krishnamurthy and Vissing-Jorgensen 2010 for further details of the estimation method.) The regressions are estimated using annual data from 1949 to 2008. The regression is

$$\text{spread}_t = \text{default controls}_t + \beta \ln(\text{LONG-SUPPLY}_t/\text{GDP}_t) + \varepsilon_t,$$

17. We use monthly data on prices and bond yields from the CRSP Monthly U.S. Treasury Database to empirically construct the derivative of price with respect to yield (see the online data appendix). The derivative is then used to compute the duration.

instrumented by TOTAL-SUPPLY/GDP and squares and cubes of TOTAL-SUPPLY/GDP. The term $\beta \ln(\text{LONG-SUPPLY}/\text{GDP})$ is the premium of interest in this regression. We evaluate the effect of a QE by evaluating this premium term at the pre-QE and post-QE values of LONG-SUPPLY.

The resulting β coefficient is -0.83 (t statistic = -5.83) for the Baa-Treasury spread. For the Baa-Aaa spread, the coefficient is -0.32 (t statistic = -3.02).

IV.B. Estimates for QE1

Gagnon and others (2010) report that, in 10-year equivalents, the Federal Reserve had purchased \$169 billion of Treasuries, \$59 billion of agency debt, and \$573 billion of agency MBSs by February 1, 2010. The Treasury purchases were complete at \$300 billion, whereas \$164 billion of up to \$200 billion of agency securities had been purchased. We scale up the agency number to $\$59 \text{ billion} \times (200/164) = \72 billion of 10-year equivalents.

Agency debt and Treasury debt are almost equally safe during the QE period, whereas agency MBSs carry prepayment risk. Thus, if we consider only the Treasuries and agencies purchased and ask what effect this will have on the Baa-Aaa spread using the regression coefficient of -0.32 , we find that the effect is 4 bp (we also use the fact that at the end of 2008, before the QE purchases, LONG-SUPPLY equaled \$1,983 billion and GDP for 2008 was \$14,291.5 billion). As we have noted, this is smaller than the true safety effect, because Aaa corporate bonds are not as safe as either agencies or Treasuries. As an upper bound, even if we use the Baa-Treasury coefficient (which includes a liquidity premium), the estimate is 11 bp. Although the event study may not identify the precise economic impact of QE via the long-term safety channel, for reasons discussed earlier, our regression estimates still appear quite small. This suggests that had QE1 taken place at an “average” demand for safety (as estimated by our regressions), its effects via the safety channel would have been much smaller than what we observed.

IV.C. Estimates for QE2

In QE2 the Federal Reserve announced that it would purchase \$600 billion of Treasuries and roll over the maturing MBSs in its portfolio into long-term Treasuries. We suggested earlier that the latter translates to a purchase of \$220 billion over the next year, and \$176 billion for the following year, if the policy was kept in place. For the sake of argument, let us

suppose that the market expects the policy to be in place for only one year; then the total effect is to purchase \$820 billion of Treasuries.

An \$820 billion Treasury purchase can have a large effect on safety premiums. Moreover, QE2 occurred during more normalized market conditions, so that estimates based on the -0.32 coefficient are likely to be appropriate during this period. The \$820 billion of Treasuries translates to \$511 billion of 10-year equivalents, based on the planned maturity breakdown provided by the Federal Reserve Bank of New York.¹⁸ Based on these numbers, and using the -0.32 coefficient, we find that QE2 should have increased the safety premium by 8 bp. Using the upper-bound coefficient of -0.83 , we estimate an effect of 20 bp. These numbers are roughly comparable to the magnitude of the safety channel for QE2 we estimated using the event-study approach.

V. Conclusion

We have documented that the Federal Reserve's purchases of long-term Treasuries and other long-term bonds (QE1 in 2008–09 and QE2 in 2010–11) significantly lowered nominal interest rates on Treasuries, agencies, corporate bonds, and MBSs, but with magnitudes that differed across bond types, across maturities, and across QE1 and QE2. There are several primary channels for these effects. Three of these were operative in both QE1 and QE2, and the other three only in QE1. For both QE1 and QE2 we find significant evidence for, first, a signaling channel that drives down the yield on all bonds (with larger effects on intermediate- than on long-term bonds); second, a long-term safety channel through which yields on medium- and long-maturity safe bonds fall because a unique clientele exists for extremely safe nominal assets, and Federal Reserve purchases reduce the supply of such assets and hence increase the equilibrium safety premium; and third, an inflation channel, with evidence from both inflation swap rates and TIPS showing that expected inflation increased, implying larger reductions in real than in nominal rates. The three additional channels for QE1 are, first, an MBS risk premium channel that lowers yields on MBSs (QE affected MBS yields by more than the signaling effect for QE1 but not for QE2, indicating that another main channel for QE is to affect the equilibrium price of mortgage-specific risk if QE involves purchases of MBSs); second, a default risk or default risk premium channel that lowers

18. Federal Reserve Bank of New York, "FAQs: Purchases of Longer-Term Treasury Securities" (www.newyorkfed.org/markets/opolicy/operating_policy_101103.html).

yields on corporate bonds; and third, a liquidity channel through which QE financed by reserves increases yields on the most liquid bonds relative to less liquid bonds of similar duration. We find no evidence for an impact of QE on the duration risk premium.

Our results have three main policy implications. First, it is inappropriate for central banks to focus only on Treasury rates as a policy target, because changes in Treasury rates are driven by safety effects that do not carry over to mortgage and lower-grade corporate borrowing rates. Second, the beneficial effects of QE for mortgage and lower-grade corporate rates of the Federal Reserve's asset purchases are highest when these purchases involve non-Treasury assets such as MBSs. Last, a Treasuries-only policy such as QE2 has effects primarily through a signaling channel, whereby the market lowers its anticipation of future federal funds rates. An important question is thus whether the Federal Reserve could have achieved the signaling impact via a direct commitment as in the August 9, 2011, FOMC statement, and thus without taking on additional balance sheet risk.

The principal contribution of our work relative to other research on QE in the United States (D'Amico and King 2010, Gagnon and others 2010, and Hamilton and Wu 2010) is that by analyzing the differential impact of QE on a host of interest rates and derivatives, we shed light on the channels through which QE affects interest rates. Although the prior literature does not discuss the channels for QE in as much detail as we do, it points to the operation of QE through two potential channels: the signaling channel as well as a "portfolio balance channel." Brian Sack, executive vice president of the Federal Reserve Bank of New York's Markets Group, which oversees open market operations, describes the portfolio balance channel as follows:

By purchasing a particular asset, the Fed reduces the amount of the security that the private sector holds, displacing some investors and reducing the holdings of others. In order for investors to be willing to make those adjustments, the expected return on the security has to fall. Put differently, the purchases bid up the price of the asset and hence lower its yield. *These effects would be expected to spill over into other assets that are similar in nature, to the extent that investors are willing to substitute between the assets.* These patterns describe what researchers often refer to as the portfolio balance channel. (Sack 2009, emphasis added)

In thinking about the portfolio balance channel, it is key to understand which assets are substitutes for those that the Federal Reserve is purchasing. Compared with prior work, we have fleshed out the portfolio balance channel in more detail. We have considered specific finance theory-based versions of the portfolio balance channel, each of which indicates how certain assets

may substitute for others in terms of their duration risk, prepayment risk, default risk, degree of extreme safety, and liquidity. One portfolio balance channel that emerges as substantial for both QE1 and QE2 works partially through a safety channel affecting extremely safe long- and medium-term bonds. Investors have a unique demand for low-default-risk assets of particular maturities. When the Federal Reserve purchases a large quantity of such assets, investors bid up the price on the remaining low-default-risk assets, decreasing their yields. The safety channel highlights the substitutability of assets within a (low) default-risk class. In other words, the safety channel can be thought of as a preferred habitat for particular maturities, but applying only to low-default-risk assets. This channel differs from the duration risk channel. Under the duration risk channel, in which the key dimension of substitutability is duration risk, QE has an effect on long-term rates by reducing the duration risk held by investors, and thereby reducing the term premium on longer-term assets. When the Federal Reserve removes duration from the portfolios of investors, they substitute by purchasing other long-duration assets to make up for the lost duration. Longer-duration assets, which substitute better for the removed duration than do short-duration assets, fall the most in yield. We do not find support for the operation of the duration risk channel. Instead, the role of duration appears to be through a preferred-habitat demand for particular maturities.

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