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Unconventional Monetary Policy Had Large International Effects

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Abstract

Abstract: The Federal Reserve's unconventional monetary policy announcements in 2008-2009 substantially reduced international long-term bond yields and the spot value of the dollar. These changes closely followed announcements and were very unlikely to have occurred by chance. A simple portfolio choice model can produce quantitatively plausible changes in U.S. and foreign excess bond yields. The jump depreciations of the USD are fairly consistent with estimates of the impacts of previous equivalent monetary policy shocks. The policy announcements do not appear to have reduced yields by reducing expectations of real growth. Unconventional policy can reduce international long-term yields and the value of the dollar even at the zero bound.

JEL classifications: G12; E34; E58; E61; F31

Keywords: Large scale asset purchase, quantitative easing, event study, monetary policy, zero bound.

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1. Introduction

Following the extreme credit market disturbances in the fall of 2008, the Federal Reserve initiated two types of unconventional policies: forward guidance about future interest rates and announcements of a novel program to purchase large quantities of long-term securities to improve credit market conditions.

On December 16, 2008, and March 18, 2009, the Federal Reserve provided "forward guidance" about the federal funds rate target. More specifically, it announced that economic conditions would likely warrant exceptionally low levels of the funds rate for "some time" and "an extended period," on the respective dates.

On November 25, 2008, the Federal Reserve announced that it would purchase up to $100 billion of government-sponsored enterprise (GSE) debt and up to $500 billion in agency mortgage-backed securities (MBS) to reduce risk spreads on GSE debt and mitigate turmoil in the market for housing credit. On March 18, 2009, the Federal Open Market Committee (FOMC) announced that the Fed would purchase an additional $750 billion of agency MBS, an additional $100 billion in agency debt, and $300 billion of longer-term Treasury securities. Kohn (2009) calls these purchases "large-scale asset purchases" (LSAP).

Central banks have tried similar—but much smaller—asset purchases before. For example, the Federal Reserve famously attempted to influence the long end of the yield curve in "Operation Twist" in the early 1960s. Modigliani and Sutch (1966) found that this earlier attempt to bring down long rates was moderately successful, at best, probably because the purchases were insufficiently large and offset by new Treasury issuance (Blinder (2000)).

The recent unconventional policies are especially informative because they constitute an unusually large "natural experiment"—an isolated change in the economic environment—that illuminates market reactions and joint asset price determination. As such, researchers have studied the effect of unconventional policies on asset classes with several different methods.

Aït-Sahalia et al. (2012) take the broadest view of financial crisis policy interventions by looking at pooled and unpooled effects of different types of interventions —i.e., interest rate cuts, liquidity support, liability guarantees, and recapitalization —across countries. This bold approach presents a broad view of average effects but does not substitute for a close examination of the specific effects of heterogeneous announcements.

Several papers focus on domestic effects of asset purchase programs. Stroebel and Taylor (2012) use time series methods to argue the Federal Reserve's MBS purchases produced small or statistically insignificant effects on mortgage-Treasury spreads—not yields— that are adjusted for pre-payment and default risks. In contrast, Gagnon et al.'s (2011a, 2011b) event study finds that LSAP announcements reduced U.S. long-term yields (see also Kohn (2009) and Meyer and Bomfim (2010)). Joyce et al. (2011) find that the Bank of England's quantitative easing program had quantitatively similar bond yield effects as those found by Gagnon et al. (2011a, 2011b) for the U.S. program. Hamilton and Wu (2012) indirectly calculate the LSAP's impact with a term structure model that predicts the effects of changes in the maturity structure of U.S. debt from asset purchases/swaps. Their estimates of the effects of a large short-for-long-term debtswap are roughly consistent with the predictions of this paper's simple portfolio balance (PB) model.

In addition to influencing U.S. yields, the unconventional policies could affect international asset prices through the signaling and PB channels.[1] The signaling channel implies that the forward guidance or asset purchases would reduce expected future interest rates. On the other

[1] Kozicki et al. (2011) estimate how changes in central bank balance sheets affect international 5- and 10-year forward interest rates over 28-year samples. Ehrmann and Fratzscher (2005) find that U.S. and European money markets became more sensitive to monetary policy and macro shocks after the emergence of the European Monetary Union (EMU). Valente (2009) examines how short-term interest rates in Hong Kong and Singapore respond to the unexpected component of U.S. federal funds target announcements.

hand, the PB channel implies that a purchase of U.S. assets would tend to push down the excess yields on those securities and those of substitutes, until a new equilibrium is reached.

The primary contribution of this paper is to evaluate the unconventional policies' joint effect on nominal international long bond yields in local currencies and exchange rates with event study methods.[2] The unconventional policies significantly reduced the 10-year nominal yields of Australia, Canada, Germany, Japan, and the United Kingdom and also depreciated the USD versus the currencies of those countries. The jump depreciations of the USD are mostly consistent with the expected effects of conventional monetary shocks of equivalent stimulus. These findings reinforce and significantly extend the view of Gagnon et al. (2011a, 2011b) that central banks retain effective tools at the zero bound.

Secondarily, this paper demonstrates that the observed asset price behavior is approximately consistent with the expected effects of an asset purchase in a simple PB model under the assumption of long-run purchasing power parity. Although other plausible PB models could imply larger or smaller effects, the simple PB model used here illustrates that the PB mechanism can produce a quantitatively significant effect that is consistent with the data. This does not imply that observed effects are from a PB model or that other channels —e.g., signaling — do not contribute substantially.

The next section discusses the channels through which asset purchases can affect asset prices. Section 2 describes the policy events; Section 3 outlines the event study methods; the data are presented in Section 4. Section 5 presents the impact of the policy events on nominal asset prices. Section 6 discusses what to expect from a portfolio balance effect, and Section 7 reviews whether the actual results are consistent with such a model. Section 8 concludes.

[2] D'Amico and King (2013) find small (3.5 basis point) flow effects of LSAP operations on specific Treasury issues.

2. Channels through which unconventional policy affects yields

Forward guidance and asset purchases can potentially affect asset prices through three channels: liquidity, signaling, and PB. The liquidity channel can raise asset prices to the extent that official asset purchases improve market liquidity by providing a consistent buyer. As such, the liquidity channel is likely to have been the least important for the unconventional policy effects, as it would be operative only very early in the sample (Gagnon et al. (2011a, 2011b)).

In distinguishing the signaling and PB channels, it is useful to define the n-year yield on a bond as the sum of expected average instantaneous (overnight) rates and the term premium:

$$y_{t,t+n} = \bar{y}_{t,t+n} + TP_{t,n} \quad , \tag{1}$$

where $y_{t,t+n}$ is the yield at time t on an n-year bond, $\bar{y}_{t,t+n}$ is the average expected overnight rate over n years at time t, and $TP_{t,n}$ is the term premium on an n-year bond at time t. The term premium, which compensates investors for the risk of rising interest rates, is the major component of the U.S. Treasury risk premium, though credit and liquidity premia also contribute to MBS and agency debt risk premia.

Researchers usually motivate PB models by citing frictions—typically preferred habitat/market segmentation—that preclude perfect arbitrage between long and expected short rates (see Gagnon et al. (2011a, 2011b) and Joyce et al. (2011)).[3] These frictions permit official purchases of long-term debt to reduce yields by removing duration risk from the market, which implies that investors will demand less compensation to hold the remaining amount of that type of risk, reducing term premia. Such frictions are not unique to PB models, of course; monetary models require frictions if money is to have real effects.

[3] Gagnon et al. (2011a, 2011b) argue that the LSAP increased long-term bond prices by removing convexity (i.e., sensitivity to interest rate risk) from the public's portfolio, reducing the required rate of return to hold long-term assets. Hamilton and Wu (2012) consider the effects of the LSAP in a term structure model with preferred habitat characteristics (Vayanos and Vila (2009)).

The signaling channel affects long-term interest rates through expected overnight rates. If forward guidance or asset purchase announcements reduce expectations of the future federal funds rate—perhaps due to weaker growth forecasts—then the average expected overnight rate ($\bar{y}_t$) will decline and reduce long-term interest rates.[4]

Several papers have empirically investigated the relative importance of these channels for LSAPs. Gagnon et al. (2011a) use the Kim-Wright term structure model, swap rates, and changes in short bond rates to argue that PB channel effects produced the great majority of the yield changes from U.S. LSAP. Similarly, Joyce et al. (2011) cite swap rates to argue that U.K. bond purchases were also effective through the PB channel. Hamilton and Wu's (2012) term structure estimates also support a large PB effect. Bauer and Rudebusch (2011), however, claim that the signaling channel accounts for 30 to 65 percent of the total impact, rather than the 30 percent suggested by their interpretation of Gagnon et al.'s (2011a) analysis. Krishnamurthy and Vissing-Jorgensen (2011) find both signaling effects and a unique demand for safe long-term assets that might be considered a PB effect. In addition, these authors argue that inflation expectations affect interest rates. Li and Wei (2013) use a term structure model with observable and supply factors to find term premia effects of QE 1 and the maturity extension program. Bauer and Neely (2014) decompose QE's effect on zero-coupon foreign bond yields in local currencies with term structure models and then show that each country's bonds characteristics help determine the importance of signaling vs. PB channels. For example, the unusual sensitivity of Canadian yields to conventional U.S. monetary policy shocks is consistent with the observed strength of the signaling effect of U.S. LSAP announcements on Canadian bond yields.

[4] Bauer and Rudebusch (2011) caution that changes in expected overnight rates conservatively estimate the importance of the signaling channel because successful signaling or PB effects will raise expected output growth and thereby partially reverse declines in expected overnight rates, muting the estimated signaling effect. Evidence in Appendix C and Rosa (2013) documents that LSAP announcements increased oil prices, which suggests that unconventional policy did not signal weak growth.

3. Unconventional Policy

The Fed's unconventional policies in 2008-2009 consisted of two instances of forward guidance in FOMC statements and LSAP. The intention of the policy was to increase the availability and affordability of credit—especially for housing—with the ultimate goal of stimulating real activity by reducing medium- and long-term U.S. interest rates.

To evaluate the effects of the unconventional policies, one must examine asset price changes as announcements or other news change market expectations. Examination of press releases, FOMC member speeches, FOMC statements, and news reports confirms Gagnon et al.'s (2011a, 2011b) assessment that eight events/announcements associated with the LSAP program had potentially important information: five of those events discussed purchases or suggested future purchases; three discussed slowing and/or limiting purchases.[5] Two of the five purchase announcements were coincident with new forward guidance. Table 1 describes those eight events.

The announced purchases were of unprecedented size. Gagnon et al. (2011b) estimate that the $1.725 trillion dollar total debt purchase was 22 percent of the publicly held, long-term agency debt, fixed-rate agency MBS, and Treasury securities outstanding as of November 24, 2008, just prior to the first LSAP announcement. This calculation properly takes a fairly comprehensive view of substitutes for U.S. Treasury debt, but it excludes U.S. corporate debt, which is appropriate in view of the extreme behavior of corporate-Treasury spreads during this period. Unusually large Treasury issuance in 2009-2010 suggests that the 22 percent statistic might marginally overstate the size of the LSAP relative to the bond market.

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[5] To maintain continuity with the literature, this paper follows Gagnon et al. (2011b) in classifying events by whether they discussed purchases or sales, not by their effects on LSAP expectations or yields. Recategorizing events by their effect on expectations or yields would not change any substantive inference.

To briefly summarize the LSAP program's institutional details: The Federal Reserve Bank of New York purchased securities across the yield curve, with maturities from 3 months to 30 years, but bought Treasuries most heavily in the 4- to 10-year range, newly issued MBS with 30-year maturities, and generally "underpriced" issues. The rate of purchase was fairly steady, but increased (decreased) when liquidity was good (poor) (see Gagnon et al. (2011b)).

4. Methods

Because asset prices react relatively rapidly to news, an event study of the unconventional policy events is most appropriate for determining their effects.[6] Three key assumptions underlie the validity of the event study approach for an assessment of the effects of LSAPs.[7]

First, policymakers must determine the announcement prior to observing asset price movements within the announcement window. This assumption—which seems eminently reasonable for the announcements considered here—rules out simultaneity.

Second, all changes in expectations about the unconventional policies occur during the event windows and these changes in expectations are fully priced during the event windows. Individual policy events within the event set can be partially or fully expected, so long as those expectations were formed during earlier events in the event set.[8] This assumption seems to be plausible. News reports did not anticipate the initial LSAP release and the bond market reaction was sizeable. Additionally, it is difficult to find clear evidence of falling LSAP expectations after the final buy

[6] Rigobon and Sack (2004) point out that event study effects are identified because the ratio of the variance of the announcement shock to the asset return variance becomes arbitrarily large in a sufficiently short interval around the announcement. Alternatively, they suggest a heteroskedasticity-dependent method to identify the responses of asset prices to interest rate shocks. The method is not applicable in the present case because the monetary policy shock is not easily quantifiable and there are very few data points.

[7] Several other papers — i.e., Gagnon et al. (2011b), Joyce et al. (2011), Bauer and Neely (2014), Bauer and Rudebusch (2011) — have made very similar assumptions to use event study methodology to investigate QE1.

[8] This paper studies unconventional policy in 2008-2009, rather than other episodes, because the novelty of QE in this period meant that market expectations depended very heavily on FOMC announcements rather than other news. Therefore, it is plausible to associate all changes in expectations of the unconventional policy with a small set of FOMC events in 2008-2009. In later QE episodes, markets would be more likely to alter their QE expectations in response to macro news.

announcement on March 18, suggesting negligible expectations of further purchases.

Third, the net cumulative effect of other news during the event windows must be negligible. This assumption seems to be approximately satisfied. Appendix A details news that does not pertain to U.S. monetary policy during the event windows.

This paper calculates results for two event sets: the eight buy/sell events and all FOMC events from November 2008 through 2009. Although we consider the sum of buy and sell LSAP events to best estimate the effect of LSAP announcements, this paper also presents results for "all FOMC events" for readers who believe that a broader set of events is more appropriate. Generally, improperly excluding events that affected LSAP expectations will bias the estimates but improperly including extraneous events will produce noisy, inefficient estimates.

Although many announcement studies use very short announcement windows, unexpected or unusual news often produces protracted adjustment periods (e.g., Almeida et al. (1998), Carlson and Lo (2006) and Gagnon et al. (2011b)). Therefore, this study considers 1-day announcement windows before confirming the robustness of the inference to intraday and 2-day windows.

5. The Data

The Bank for International Settlements (BIS) provides daily data on U.S. and foreign overnight rates. Haver Analytics provides daily bond yields, U.S. TIPS-implied inflation expectations (i.e., breakeven rates), daily exchange rates, and equity index prices. The long-term interest rates are the U.S. 10-year Treasury, constant-maturity yield, Moody's Baa yield, and the Australian, Canadian, German, Japanese, and U.K. 10-year government bond yields.[9] The WSJ provides daily NY closing prices on the AUD/USD, CAD/USD, EUR/USD, JPY/USD, and GBP/USD. Bloomberg is the source for inflation swaps data for the United Kingdom and the

[9] The BIS 10-year zero coupon yields produced very similar results to the 10-year bond yields from Haver.

euro area. Tickwrite provides intraday futures prices on Australian, Canadian, German, British, Japanese, and U.S. bonds, the S&P 500, and WTI crude. Disktrading provides intraday spot exchange rate data on the AUD/USD, CAD/USD, EUR/USD, JPY/USD, and the GBP/USD.

6. The Effect of Unconventional Policy on International Asset Prices

Table 2 shows the nominal (local currency) bond yield changes around 5 LSAP buy events, 3 LSAP sell events, and the sum of 13 “control” events for U.S., Australian, Canadian, German, Japanese, and U.K. long-term bonds. Confirming Gagnon et al. (2011b), buy events are usually associated with large reductions in long-term U.S. interest rates. Specifically, the U.S. 10-year constant-maturity nominal Treasury yield fell by a cumulative total of 94 basis points (bp) around the 8 LSAP events while the Baa 10-year rate fell by 35 bp. A 50 bp rise in breakeven U.S. inflation rates —not shown in the table—implies that real 10-year Treasury yields fell by a total of 144 bp during the 8 LSAP “buy+sell” windows.

To provide perspective on the size of such changes, Table 2 also shows the probabilities (p-values) in parentheses that randomly chosen price changes of the appropriate lengths from the crisis period, July 2007 through January 2010, would exceed those of the respective event windows. The responses on policy announcement days are usually very large compared with the distribution of all 1-day yield changes and the sum of the changes over the 5 buy events is always exceedingly unlikely to be observed under the null hypothesis that there was nothing special about the policy events. That is, the p-values for the “buy sums” are close to zero.

The increase in U.S. yields on the “buy” date of January 28, 2009, deserves an explanation. Prior to this date, Federal Reserve officials had twice mentioned the possibility of purchasing Treasuries and the market probably priced in a sizeable positive probability of an actual Treasury purchase announcement on January 28. The lack of such news increased long yields by reducing market expectations for Treasury purchases. As noted previously, recategorizing this event as a "sell" would not change any inference about the overall LSAP effects.

Table 2 also shows that the three sell events did not strongly or consistently affect U.S. bond yields, presumably because they changed expectations very little. The first two sell announcements merely delayed the pace of purchases and the third only scaled back one component of the purchase by $25 billion or 1.45 percent of the total purchase.

The right-hand side of Table 2 shows that the LSAP buy announcements were also—if more remarkably—associated with large changes in nominal foreign bond yields: Australian, Canadian, German, Japanese, and British long bond yields cumulatively fell by 65, 56, 38, 18, and 43 bp during the same 5 buy event windows. Japanese long yields were already much lower than those of other countries (see Figure 1), which probably accounts for their relatively modest reaction. P-values show that the individual yield changes during buy event windows were often very large compared with typical 1-day changes during the July 2007 to January 2010 sample. Similarly, the p-values for the "buy sum" rows show that it is very unlikely that the declines observed during the policy buy days were due to chance. As with U.S. bonds, foreign bond yields either rose or did not fall much in the January 28 window and they also did not react strongly to the 3 sell events. During the "buy+sell" event windows, German and U.K. breakeven inflation rates cumulatively changed by 4 and -17 bp, implying that domestic German and U.K. real rates fell 35 and 60 bp, respectively, during those event windows.

The control sums —FOMC announcement days from November 2008 through January 2010 without significant LSAP news—are mostly positive, reflecting the generally rising bond yields in 2009, as the economy improved and the September 2008 flight-to-quality reversed. A complementary interpretation is that every Fed announcement that did not expand the LSAP marginally increased yields as buy expectations declined. This hypothesis suggests that the appropriate set of events over which to evaluate the LSAP is "all FOMC" events. If so, then the last rows of Table 2 show that the LSAP reduced nominal 10-year Treasury (Baa) yields by 60 (41) bp and foreign (local currency) nominal 10-year yields by an average of 22 bp. This is much less than the "buy+sell" sum, but still economically significant.

Table 3 shows the LSAP announcement effects on the foreign exchange value of the USD during the same event windows. The USD cumulatively declined by 3.54 to 7.76 percent—depending on the currency—over the 8 LSAP "buy+sell" days, and these declines were very large compared with sums of dollar movements over 8 randomly chosen days.[10] In contrast, the dollar depreciated far less, on average, during the windows for the 13 FOMC control events and the declines were inconsistent across exchange rates.

The evidence of a strong LSAP effect on exchange rates is consistent with evidence in Rosa (2012) who studied the effect of original, narrative measures of conventional and unconventional monetary policy shocks with a long sample, 1999-2011, and high frequency data. Rosa found a statistically significant correlation between certain LSAP buy (sell) announcements and depreciations (appreciations) of the dollar. This regression procedure does not allow one to estimate the per-dollar impact of an LSAP purchase, however, as this paper does.

Appendix B shows that these large declines in international yields and the value of the USD are fairly robust to changes in the length of the event windows from 2.5 hours to 2 days and to the inclusion of other FOMC events from November 2008 through January 2010. The procedures —i.e., window size and event set—only modestly affect the estimated asset price responses. For

[10] The largest appreciation of the dollar during these events came on December 1, 2008, when unexpectedly poor construction spending and ISM survey news pushed down U.S. and global equity markets, creating a flight to safety. That day's appreciation was especially large against the GBP, perhaps because the U.K. Chancellor of the Exchequer announced that the U.K. government would back all retail deposits of London Scottish. Analysts widely interpreted this announcement to mean that the British government would back all retail bank deposits.

example, the broadest set of events (i.e., all FOMC events) and wide windows halves the impact on foreign yields compared with the "buy+sell" events, but this change actually increases the exchange rate effect, however. Full results are omitted for brevity but available upon request.

7. What To Expect From a Portfolio Balance Effect?

Gagnon et al (2011a), Joyce et al. (2011), and Hamilton and Wu (2012) have emphasized PB effects as the primary channel through which official asset purchases affected asset prices. This section provides intuition for PB effects and describes a simple PB model that could produce a substantial portion of the asset price changes during the announcement windows.

7.1 A portfolio balance model of bond returns

PB models suggest that a change in the supply of an asset should affect its own expected return and those of assets whose returns covary with it. Intuitively, if the LSAP raises U.S. bond prices, then investors will tend to substitute toward the now relatively underpriced debt of similar quality—i.e., sovereign debt of other developed countries—driving up the price of that debt. Empirically, international bond yields/returns are closely related. Figure 1 illustrates strong comovement in U.S., Australian, Canadian, German, Japanese, and U.K. 10-year local currency bond yields. Likewise, monthly 7- to 10-year excess bond returns over the 1-month Treasury in U.S. dollars are strongly corrected, varying from 0.15 for the Canada-Japan excess return, to 0.69 for the German-U.K. excess bond return, using data from January 1985 through April 2010.

To quantify the expected PB effect from a given purchase announcement, we consider the portfolio choice of a mean-variance investor who represents all agents except the Federal Reserve/U.S. government. We assume that the investor cares about returns in U.S. goods, though this is not necessary to get qualitatively similar results.[11] The investor chooses an N-by-1 vector of portfolio weights at time t (w_t) to maximize the following constrained utility function:

$$\max_{w_t} w_t' Er_{t,t+1/12} - 0.5\gamma w_t' V w_t, \quad s.t. \quad \mathrm{w}_t' \mathbf{1} = 1 \tag{2}$$

where $Er_{t,t+1/12}$ is the N-by-1 vector of expected real (monthly) asset returns from period t to $t+1/12$, V is the N-by-N covariance matrix of the asset returns, and γ is the investor's coefficient of relative risk aversion (CRRA). The N-by-1 vector of constrained optimal portfolio weights is given by

$$w_t = z + F\widetilde{w}_t = z + F(F'VF)^{-1}F'\left[\frac{1}{\gamma}Er_{t,t+1/12} - Vz\right], \tag{3}$$

where $\widetilde{w}_t$ is the (N-1) by 1 vector of weights on asset 2 to asset N and the matrices z and F impose the constraint that the full weight vector, w_t, sums to 1. For example, if N = 3, $z' = [1 \quad 0 \quad 0]$, and $F' = \begin{bmatrix} -1 & 1 & 0 \\ -1 & 0 & 1 \end{bmatrix}$. $F'Er_{t,t+1/12}$ and $F'VF$ are the expected excess returns over the first asset —the U.S. riskless asset—and the excess return covariance matrix, respectively.[12]

If the Federal Reserve purchases an asset with inelastic supply (at least in the short-run), such as MBS, agency debt, or long-term Treasuries, then market clearing requires the public's portfolio holdings of that asset to decline while the public's holdings of money or a short-term liquidity asset (i.e., bank reserves) increases commensurately.[13] In other words, a combination of expected returns on the N assets must change to induce the investor to willingly hold the market-clearing portfolio. One cannot simply solve (3) for the change in returns implied by some change in weights, however, because there are N free returns but $(N-1)$ free elements of the weight vector. That is, $F(F'VF)^{-1}F'$ is not invertible. If one assumes, however, that central banks can

[11] To the extent that investors expect PPP to hold, expected real returns in U.S. and foreign goods will be the same and the base currency for the representative investor will not matter.
[12] The element of r^s corresponding to the U.S. return is zero.
[13] Doh (2010) describes the evidence on the effect of supply shifts in several contexts.

control the month-to-month real return on a short-term asset held for liquidity (bank reserves), then one can solve for the $N-1$ excess returns over the liquidity asset that make the investor willing to hold the market-clearing portfolio. This assumption seems plausible but we will see that the model's implications for exchange rate jumps do not depend on it. One can solve for the $N-1$ expected excess returns in terms of the free weights and parameters as follows:

$$F'Er_{t,t+1/12} = F'\left(Er^b_{t,t+1/12} - Er^s_{t,t+1/12} - E\pi^{US}_{t,t+1/12}\right) = \gamma[(F'VF)\tilde{w}_t + F'Vz], \quad (4)$$

where $r^b_{t,t+1/12}$ is the N-by-1 vector of international monthly nominal asset (mostly bond) returns, $r^s_{t,t+1/12}$ is the vector of monthly exchange rate changes (foreign currency per dollar), and $\pi^{US}_{t,t+1/12}$ is monthly U.S. inflation. An asset purchase that changes the public's $(N-1)$-by-1 vector of portfolio weights ($\Delta\tilde{w}_t$), but does not affect the covariance matrix of returns, would change the vector of expected excess returns over the next year, $F'Er_{t,t+1}$, as follows:

$$\Delta F'Er_{t,t+1} = \Delta E\tilde{r}^b_{t,t+1} - \Delta E\tilde{r}^s_{t,t+1} - \Delta Er^f_{t,t+1} = 12 \cdot \gamma\tilde{V}\Delta\tilde{w}_t. \quad (5)$$

where the Δ operator denotes the change in the variable at the time of the announcement, $\tilde{r}^b_{t,t+1}$ and $\tilde{r}^s_{t,t+1}$ denote the $N-1$ vectors of asset and exchange rate returns from asset 2 to N, the scalar $r^f_{t,t+1}$ is the liquidity return, $\tilde{V} = F'VF$ is the covariance of excess returns, and the right-hand side of (5) is multiplied by 12 to match the annualized returns on the left-hand side.

7.2 Comparing the model's predictions with the data

This subsection describes the model's predictions about the effect of a change in U.S. portfolio weights on U.S. and foreign bond yields and exchange rates at the time of the LSAP announcements. Equation (5) shows that a change in portfolio weights ($\Delta\tilde{w}_t$) must change a linear combination of the expected excess bond return over the liquidity asset and/or expected exchange rate return. Gagnon et al. (2011b) estimate that the November 2008-March 2009 LSAP programs reduced the expected portfolio weight on (only) U.S. bonds by about 22 percent and increased the weight on the liquidity asset by the same amount:

$$\Delta_t w_t = \begin{bmatrix} w_{t,1} + 0.22w_{t,2} \\ w_{t,2} - 0.22w_{t,2} \\ w_{t,3} \\ \vdots \\ w_{t,N} \end{bmatrix} - \begin{bmatrix} w_{t,1} \\ w_{t,2} \\ w_{t,3} \\ \vdots \\ w_{t,N} \end{bmatrix} = \begin{bmatrix} 0.22w_{t,2} \\ -0.22w_{t,2} \\ 0 \\ \vdots \\ 0 \end{bmatrix}. \tag{6}$$

The equations relating U.S. and foreign bond excess returns to the change in the portfolio weight on U.S. bonds differ slightly in that the equation for the U.S. bond lacks an exchange rate term. Using (6) in (5), the annualized expected 10-year U.S. excess bond return is

$$\frac{1}{10}\left(\Delta_t E r_{t,t+10}^{b,US} - \Delta_t E r_{t,t+10}^{f}\right) = -12 \cdot \gamma \cdot 0.22w_{t,2}\tilde{V}_{11} \quad , \tag{7}$$

where $r_{t,t+10}^{b,US}$ and $r_{t,t+10}^{f}$ are the 10-year returns on the U.S. bond and the liquidity asset from *t* to *t+10*, $0.22w_{t,2}$ is the amount of the official purchase of U.S. long bonds, and the multiplication by 1/10 converts the 10-year returns to annualized figures. The analogous expression for the change in the excess bond return of country *j* is

$$\frac{1}{10}\left(\Delta_t E r_{t,t+10}^{b,j} - \Delta_t E r_{t,t+10}^{s,j} - \Delta_t E r_{t,t+10}^{f}\right) = -12 \cdot \gamma \cdot 0.22w_{t,2}\tilde{V}_{1j}. \tag{8}$$

Equations (7) and (8) imply that the LSAP programs should reduce expected excess returns on U.S. bonds and also those of foreign bonds with positively correlated returns. The effect on the excess returns of country *j*'s bonds increases proportionately with the covariance between the dollar-denominated excess bond returns of country *j* and those of the United States.

Equation (8) uses the change in the expected rate of appreciation of the USD ($\Delta_t E r_{t,t+10}^{s,j}$), which is not directly observable. Under the assumption that the LSAP announcements do not change the expected, long-run real exchange rate, however, Appendix C on the PB model shows that the change in long-run expected exchange rate depreciation can be expressed in terms of the change in the long-run expected inflation differential and the "jump" in the exchange rate at announcement time. We take 10 years to be the long-run in the empirical work:

$$\Delta_t E r^{s,j}_{t,t+10} = \Delta_t E \pi^{j}_{t,t+10} - \Delta_t E \pi^{US}_{t,t+10} - \Delta_t s^{j}_{t}, \tag{9}$$

where s^j_t is the spot exchange rate between country j and the U.S. (foreign currency per dollar). By inserting the right-hand side of (9) into (8) for $\Delta_t E r^{s,j}_{t,t+10}$, one can express the change in the expected annual foreign excess return in dollars in terms of the PB model parameters:

$$\frac{1}{10}\left(\Delta_t E r^{b,j}_{t,t+10} + \Delta_t E \pi^{US}_{t,t+10} - \Delta_t E \pi^{j}_{t,t+10} - \Delta_t E r^{f}_{t,t+10} + \Delta_t s^{j}_{t}\right) = -12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{1j}. \tag{10}$$

One can combine (7) and (10) to express the exchange rate jump during the event windows as a function of the expected real interest rate differentials and the parameters of the PB model:

$$\Delta_t s^{j}_{t} = \left(\Delta_t E r^{b,j}_{t,t+10} - \Delta_t E \pi^{j}_{t,t+n}\right) - \left(\Delta_t E r^{b,US}_{t,t+10} - \Delta_t E \pi^{US}_{t,t+n}\right) - 10 \cdot 12 \cdot \gamma \cdot 0.22 w_{t,2}\left(\tilde{V}_{1j} - \tilde{V}_{11}\right). \tag{11}$$

We can compare the predictions of equations (7), (10), and (11) with the data in the following ways. Specifically, we can compute the right hand side of (7) ($-12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{11}$) from historical data on international 10-year excess bond returns and compare the bootstrapped distribution of that statistic to the observed change in nominal yields less breakeven inflation (hereafter expected inflation) from TIPS or inflation swaps.[14] Likewise, using (10), we can similarly compare the observed combination of the change in local currency, foreign nominal bond yield ($\Delta_t E r^{b,j}_{t,t+n}$), the expected U.S./foreign inflation differential ($\Delta_t E \pi^{US}_{t,t+n} - \Delta_t E \pi^{j}_{t,t+n}$), the liquidity return ($\Delta_t E r^{f}_{t,t+n}$) and the exchange rate "jump" ($\Delta_t s^{j}_{t}$) during the announcement windows to the distribution of the estimated statistic from the PB model ($-12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{1j}$).

[14] Inflation indexed bond data and inflation swaps data provide similar inference on changes in expected inflation for cases in which both are available.

Finally, in (11), we can compute the sum of observed changes in the expected real returns to U.S. and foreign bonds during the announcement windows plus a distribution for $-10 \cdot 12 \cdot \gamma \cdot 0.22 w_{t,2}(\tilde{V}_{1j} - \tilde{V}_{11})$ from historical 10-year excess bond return data, and compare that sum to the actual exchange rate changes ($\Delta_t s_t^j$) observed during the announcement windows.

7.3 Estimating the parameters of the portfolio balance model

To examine whether an LSAP announcement can generate quantitatively important effects in the PB model, we parameterize the model with standard values of risk aversion and historical return moments. That is, we estimate E(r) and V from 303 real monthly returns in U.S. goods, 1985:02 to 2010:04, on 1-month U.S. Treasury bills (the liquidity asset), U.S., Canadian, British, Japanese, and German 10-year bond indices, and the S&P 500 and then back out estimates of the portfolio weights, w, using equation (3). To account for sampling variation in estimating $E(r)$, V and w, we bootstrapped 1000 samples of 303 observations from the return series, maintaining the contemporaneous covariance in each draw. This paper reports results for a CRRA value of 5, although other reasonable values of γ—i.e., 2 and 10— produce very similar confidence intervals.[15] Appendix D provides details on the parameters and model weights.

7.4 Limitations of the portfolio balance model's predictions

The PB modeling exercise formally illustrates the PB mechanism and assesses its quantitative significance in a model with reasonable parameters. Although the model cannot definitively prove PB effects or rule out other channels, comparing the magnitude of the model's PB effects to the observed asset price changes suggests the importance of that mechanism in the data. For example, if the portfolio-balance model implies no quantitatively significant PB effects,

[15] Although (7) and (10) seem to imply that changes in returns would be proportional to γ, in fact they are relatively insensitive to this parameter because higher values of γ also reduce the initial weight on Treasuries in equation (3).

then that would cast significant doubt on PB effects in favor of pure signaling effects. Modest PB effects in the model would be consistent with Bauer and Rudebusch's inference (2011) from term structure evidence, while large effects would support Chairman Bernanke's (2012) emphasis on such mechanisms as the primary driver of yield changes.

In comparing the model's predictions to the data, the reader should recognize some caveats.

First, as in nearly all estimated models, this exercise estimates true expected returns and covariances with realized historical moments and it assumes that these moments and the parameters of the model are constant over time.[16]

Second, the one-period (static) framework is only truly correct for a world of independently and identically distributed returns or very short investment horizons or risk aversion of one.

Third, the portfolio weights are estimated from the model with return data, rather than from actual market weights, because such estimates are model-consistent and appropriate for considering the marginal effects of changing weights. The implied portfolio weights on the liquidity asset and the German long bunds are negative, perhaps because the PB model does not account for factors such as default risk and liquidity premia. These other factors are unlikely to change much during the event windows, however, making the model-implied weights appropriate for examining LSAP effects.[17]

Fourth, the model uses a limited number of assets and excludes important assets, such as international stocks and REITs. This might not be a serious shortcoming, however. Campbell (1999) concludes that omitting assets and extending the model with intertemporal hedging

[16] The model calculations assume that V is homoskedastic, for simplicity. Using a shorter and more recent sample—from 2000 to 2010— produces wider confidence intervals that are shifted somewhat in the positive direction.

[17] Some non-LSAP news changed expected portfolio weights during the November 2008 – November 2009 period. For example, the Bank of England announced a total of about $300 billion in asset purchases during 2009 (Fawley and Neely (2013)). These events should not affect the estimates of the yield effects because they did not occur during the set of LSAP event windows.

demand does not affect substitutability of assets in this portfolio choice model. In the present exercise, the results are robust to the exclusion of the S&P 500 or Australian long bonds.

Fifth, the model assumes that purchases of shorter dated bonds and MBS and GSE debt are perfect substitutes for Treasury debt purchases. The latter assumption seems reasonable in light of the long history of lending to the GSEs at nearly Treasury rates under the understanding that the debt was implicitly back by the U.S. government. In addition, the Treasury explicitly guaranteed agency liabilities in September 2008 (see Barr (2010)). On the other hand, Krishnamurthy and Vissing-Jorgensen (2011) interpret their event study to argue that purchasing Treasuries causes different effects than purchasing MBS or GSE debt in an event study.

8. Discussion

The PB /PPP model in Section 7 expresses the U.S. real bond return, the foreign real bond returns in U.S. dollars, and the exchange rate jumps during LSAP windows in terms of the model's parameters; see equations (7), (10) and (11), respectively. This section compares the quantified model predictions with the observed asset price changes during the LSAP windows.

8.1 Portfolio balance effects and expected excess returns

Expected 10-year inflation data from TIPS and/or inflation swaps data are available only for the United States, Germany, and the United Kingdom. Therefore we can assess the consistency of the model's predictions with the data for only these three countries:

$$\frac{1}{10}\left(\Delta_t Er^{b,US}_{t,t+10} - \Delta_t Er^{f}_{t,t+10}\right) = -12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{11} \tag{7}$$

$$\frac{1}{10}\left(\Delta_t Er^{b,j}_{t,t+10} + \Delta_t E\pi^{US}_{t,t+10} - \Delta_t E\pi^{j}_{t,t+10} - \Delta_t Er^{f}_{t,t+10} + \Delta_t s^{j}_{t}\right) = -12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{1j} \ . \tag{10}$$

Table 4 compares the observed changes in U.S., German, and British excess yields (the left-hand side of (7) and (10)) for two combinations of event windows with the corresponding distribution of changes in bond returns implied by the PB model, on the right-hand side of (7) and (10).[18] The calculations in (7) and (10) that appear in Table 4 estimate the change in the expected return to the liquidity asset ($\Delta_t Er^f_{t,t+10}$) as the sums of the observed changes in the overnight U.S. interest rate for each event set. These sums were -9 and -12 bp during the "buy+sell" and "all event" sets, respectively.

Row 1 of Table 4 shows that the "buy+sell" changes in U.S., German, and British excess returns, –77, –57, and –37, are well within the distribution for excess returns implied by the PB model (Table 4). In fact, the realized changes are within 1 standard deviation of the model's point estimates. The "all event sum" for the U.S. and Germany are likewise within the implied distributions, suggesting that the results are robust to the choice of event window sets. The British "all event sum" is -79 bp, slightly below the 5th percentile of the PB implied distribution.

The expression for the "jump" in the EUR/USD and GBP/USD exchange rates— equation (11) — eliminates the need to assume that the Fed controls the liquidity return. The right-hand panel of Table 4 shows actual "buy+sell" exchange rate changes for the EUR/USD and GBP/USD are -7.76 percent and -3.54 percent, which fall within an 80 percent confidence interval of the distribution of the right hand side of (11) (see the bottom panel):

$$\Delta_t s_t^j = \left(\Delta_t Er^{b,j}_{t,t+10} - \Delta_t E\pi^j_{t,t+n}\right) - \left(\Delta_t Er^{b,US}_{t,t+10} - \Delta_t E\pi^{US}_{t,t+n}\right) - 10 \cdot 12 \cdot \gamma \cdot 0.22 w_{t,2}\left(\tilde{V}_{1j} - \tilde{V}_{11}\right). \quad (11)$$

In contrast, the "all event" jumps are much larger: the "all event" EUR/USD jumps are still within the 80 percent confidence interval but the GBP/USD jumps are below the 1st percentile. These results suggest that the exchange rate jumps are consistent with the PB model.

[18] Section 6.1's simple portfolio model predicted changes in excess bond returns in U.S. goods, but the observed changes are in nominal yields, which are average returns to maturity. A full term structure model would be necessary to formally compare returns and yields, so the comparison is an approximation.

8.2 Are the foreign exchange jumps consistent with the monetary stimulus?

Table 4 suggests that the observed linear combination of asset price changes in response to the LSAP announcements is consistent with the PB model. That is, the exchange rate responses are consistent with the model, given the yield changes and vice versa.

Unfortunately, the PB model is insufficiently rich to separately identify the effects on exchange rates and yields, and theoretical models are notoriously poor at explaining exchange rate movements. One can, however, ask whether the initial exchange rate reactions to the policy announcements are consistent with the typical response of equivalent conventional monetary shocks. This requires two elements: 1) The typical response of exchange rates to conventional monetary shocks; and 2) A rule-of-thumb mapping between conventional monetary surprises and the effects of the unconventional policy announcements.

To determine exchange rate reactions to monetary policy shocks, Hausman and Wongswan (2011) followed a variation of Gürkaynak et al.'s (2005) two-factor approach in regressing exchange rate changes on "target" and "path" shocks, where the target shock is the conventionally calculated Kuttner (2001) shock to the funds rate target and the path shock is the change in the 12-month ahead, implied 3-month eurodollar futures rates:

$$\Delta S_t = b_0 + b_1 \Delta \text{target}_t + b_2 \Delta \text{path}_\text{t} + u_t. \tag{12}$$

This paper estimates (12) using data from all scheduled FOMC meetings from 1994 through 2007, using 60-minute exchange rate futures changes for greater precision. The coefficient estimates in the top panel of Table 5 show that positive target and path shocks generally cause the dollar to appreciate, with the exception of target shocks for the AUD/USD.[19]

[19] These target coefficients are roughly comparable to those in the literature, though the estimates are somewhat sensitive to the frequency of the exchange rate changes and the inclusion of a few very surprising intermeeting target

Target surprises during the unconventional policy actions were very small. Instead, most of the unconventional policy shocks occurred at the medium-to-long portion of the yield curve, which suggests the need to translate those changes into conventional shocks. One such rule is suggested by Rudebusch (2010), who compares the results of Fuhrer and Moore (1995) to those of Rudebusch (2002), to argue that a given change in long term interest rates has four times the effect on output of a similarly sized short-term interest rate movement.[20] Therefore, to predict the unconventional policy effect on exchange rates during the event windows, we will use 12-month-ahead eurodollar futures changes as the path shock but we will replace the federal funds surprise in (12) with four times the observed U.S. long-rate changes during the event windows.

The lower panels of Table 5 display the results of this rule-of-thumb prediction exercise. The middle panel shows that the observed changes in the CAD/USD and AUD/USD —5.73 and 6.16 percent —were larger than the predicted changes from (12), over the "buy+sell" events. For the EUR/USD, GPB/USD and JPY/USD, however, the model does fairly well and the observed "buy+sell" exchange rate changes are well within the confidence interval for the predictions. For the "all event" set, most of the observed changes are larger than those predicted, except for the GBP/USD. In summary, most of the USD reactions to the "buy+sell" events are consistent with the usual reaction of exchange rates to conventional monetary shocks but some are larger.

9. Conclusion

This paper has illustrated that unconventional monetary policy announcements —long-term asset purchases and forward guidance—reduced expected long-term U.S. bond real and nominal yields, long-term foreign bond yields in dollars, and the value of the dollar. These price changes

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rate changes (see Faust et al. (2007) and Neely and Dey (2010)). Rosa (2012) conducts a related —but different — exercise in showing that many asset returns have similar covariances under conventional and unconventional shocks.

[20] These implied funds-rate equivalent estimates are somewhat higher than those of Dudley (2010), who suggests that the $1.725 trillion asset purchases considered here have equivalent stimulus to 1.75 to 2.6 percent of federal funds target decreases.

closely followed the announcements and were too large to have been generated by chance.

International yields declined substantially, whether measured in nominal yields (Table 2), real yields in the domestic goods, or excess returns over the U.S. riskless rate (Table 4). During the “buy+sell” event windows, nominal own-currency 10-year yield declines ranged from 63 bp for Australia to 18 bp for Japan (Table 2). Expected nominal and real 10-year Treasury yields fell by a total of 94 and 144 bp during the 8 LSAP “buy+sell” windows, respectively. Expected German and U.K. real bond yields in domestic goods also declined substantially, falling 35 and 60 bp, respectively, for “buy+sell” windows. Similarly, excess yields over the U.S. short rate, in USD, declined by 77, 57 and 37 bp for the United States, Germany, and the U.K., respectively (Table 4). These expected excess bond yield declines are consistent with the predicted effect of such an asset purchase from a simple PB model that was estimated with historical data.

The jump depreciations of the USD during the “buy+sell” announcement windows ranged from 3.5 to 7.8 percent (Table 3). These responses are consistent with past estimates of the effect of equivalent conventional monetary policy shocks for the EUR/USD, GPB/USD, and JPY/USD (Table 5). Observed CAD/USD and AUD/USD changes were larger than would be predicted.

The announcements of minor delays or reductions in the LSAP had much smaller effects than did the announcements associated with buys because they affected expectations much less. Neither did the policy announcements consistently influence international overnight interest rates. Likewise, FOMC announcements that were not associated with unconventional policies had small and inconsistent average effects on asset prices, especially at high frequency.

Equity and oil prices do not appear to support the hypothesis that yields fell because the policy announcements reduced expected real growth. Rather, it seems likely that the policies influenced long rates both by reducing expected future short rates and through a PB effect on term premia. Bauer and Neely (2014) formally investigate the relative importance of these effects in local currencies with dynamic term structure models.

Some observers have interpreted the March-to-June 2009 increases in international yields as indicating that the unconventional policy's effects were short-lived and therefore not useful. In fact, the parallel rise in equity and oil prices over the same period suggests that such policies successfully increased confidence and risk appetites. While markets may have initially under or overestimated the policies' impact, the efficient markets hypothesis implies that the initial impact is the best point estimate of their long-run effect.

The success of the unconventional policies in reducing long-term interest rates and the value of the dollar shows that central banks are not toothless when short rates hit the zero bound. The reduction in foreign bond yields and the value of the USD probably stimulated the U.S. economy through export channels, for example. From an international perspective, these findings imply that central banks should coordinate their unconventional policies to avoid contradictory or overly stimulative effects.

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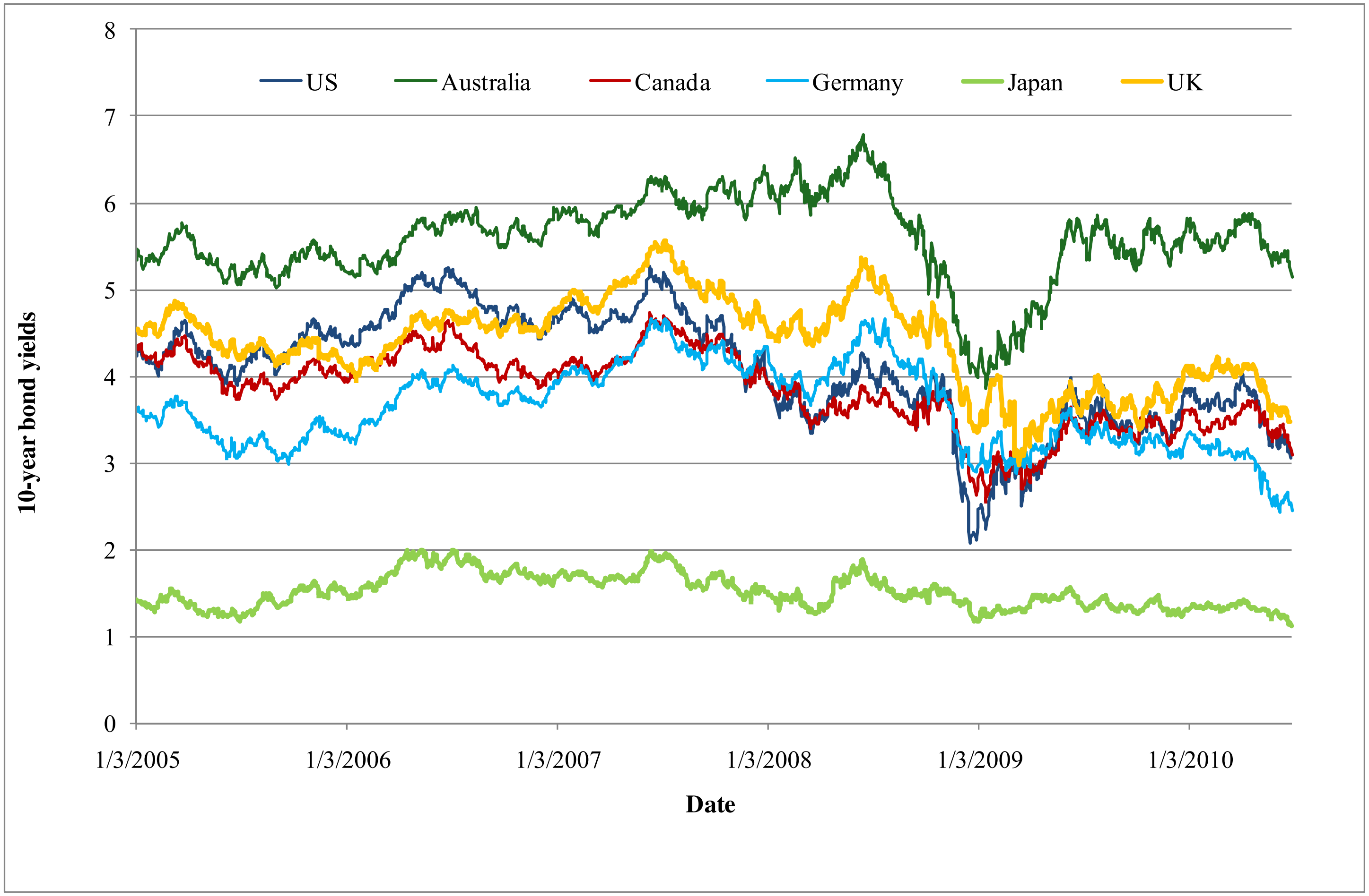
Figure 1: Nominal yields on 10-year government bonds



Notes: The figure depicts nominal yields, in the respective currencies, on 10-year sovereign debt for the U.S., Australia, Canada, Germany, Japan, and the U.K. The source is Haver Analytics.

Table 1: Announcements associated with the LSAP programs

Announcements or suggestions of future purchases.

Date	Event	Time	Bloomberg time	Event	Other significant news in the event window
11/25/2008	Initial LSAP announcement	08:15	08:08	Fed announces purchases of $100 billion in GSE debt and up to $500 billion in MBS.	FOMC minutes released on November 24.
12/1/2008	Bernanke Speech	13:40	13:45	Chairman Bernanke mentions that the Fed could purchase long-term Treasuries.	U.K. government effectively backs all retail bank deposits in the U.K. Construction spending and ISM announcements come in weaker than expected. NBER dating committee officially declares a recession.
12/16/2008	FOMC Statement	14:15	14:21	The FOMC statement mentions possible purchase of long-term Treasuries and expects "exceptionally low levels of the federal funds rate for some time."	Federal funds rate target reduced from 1 percent to a 0-25 bp target range.
1/28/2009	FOMC Statement	14:15	14:16	FOMC statement says that it is ready to expand agency debt and MBS purchases, as well as to purchase long-term Treasuries.	The term asset lending facility (TALF) will be implemented.
3/18/2009	FOMC Statement	14:15	14:17	FOMC will purchase an additional $750 billion in agency MBS and increase its purchases of agency debt and long-term Treasuries by $100 and $300 billion, respectively. FOMC expects "exceptionally low levels of the federal funds rate for an extended period."	
Announcements of limited or reduced purchases					
8/12/2009	FOMC Statement	14:15	14:16	The FOMC will slow the pace of the LSAP, making the full purchase by the end of October instead of mid-September.	
9/23/2009	FOMC Statement	14:15	14:16	FOMC will slow the purchases of agency MBS and agency debt, finishing the purchases by the end of 2010Q1. Treasury purchases will still be finished by October 2009.	
11/4/2009	FOMC Statement	14:15	14:19	Amount of agency debt to be halted at $175 billion, instead of $200 billion.	The Reserve Bank of Australia raises its policy rate by 25 bp on November 4, 2009.

Notes: The table describes the 8 events associated with LSAP announcements. The columns denote the date of the announcement, the nature of the event, the time of the event in U.S. Eastern time, the time of the first Bloomberg story on the event, a brief description of the event, and a brief description of other possibly significant news events in a 3-day event window from t-1 through t+1.

Table 2: Effect of the LSAP on U.S. and foreign long-term bond yields

	U.S. 10YR	Moody's Baa	Australia 10YR	Canada 10YR	Germany 9-10YR	Japan 10YR	U.K. 10YR	Foreign Average
Buy Events								
11/25/2008	-24	-9	-10	-10	2	-2	-7	-5.4
	(0.01)	(0.18)	(0.19)	(0.06)	(0.72)	(0.52)	(0.22)	(0.15)
12/1/2008	-21	-19	-9	-18	-8	-5	-14	-10.8
	(0.01)	(0.02)	(0.26)	(0.00)	(0.15)	(0.15)	(0.04)	(0.01)
12/16/2008	-16	-15	-18	-12	-16	-8	-17	-14.2
	(0.04)	(0.04)	(0.03)	(0.03)	(0.01)	(0.03)	(0.01)	0.00
1/28/2009	12	14	-4	7	-1	1	3	1.2
	(0.13)	(0.06)	(0.64)	(0.17)	(0.83)	(0.80)	(0.63)	(0.74)
3/18/2009	-51	-23	-24	-23	-15	-4	-8	-14.8
	0.00	(0.01)	(0.01)	(0.00)	(0.01)	(0.22)	(0.19)	0.00
Buy Sum	-100	-52	-65	-56	-38	-18	-43	-44
	0.00	(0.00)	(0.00)	0.00	(0.00)	(0.02)	(0.01)	0.00
Sell Events								
8/12/2009	1	10	-17	2	5	-2	0	-2.4
	(0.90)	(0.15)	(0.04)	(0.74)	(0.32)	(0.52)	(1.00)	(0.54)
9/23/2009	-2	-2	3	-1	-8	0	-6	-2.4
	(0.83)	(0.82)	(0.75)	(0.91)	(0.15)	(1.00)	(0.34)	(0.53)
11/4/2009	7	9	16	5	2	2	6	6.2
	(0.38)	(0.22)	(0.05)	(0.36)	(0.72)	(0.52)	(0.30)	(0.11)
Sell Sum	6	17	2	6	-1	0	0	1.4
	(0.66)	(0.16)	(0.91)	(0.52)	(0.94)	(1.00)	(0.99)	(0.84)
Buy+Sell Sum	-94	-35	-63	-50	-39	-18	-43	-42.6
	0.00	(0.09)	(0.01)	(0.00)	(0.01)	(0.04)	(0.02)	(0.00)
Control Sum	34	-6	37	3	34	9	22	21
	(0.22)	(0.83)	(0.21)	(0.89)	(0.08)	(0.43)	(0.33)	(0.14)
All Event Sum	-60	-41	-26	-47	-5	-9	-21	-21.6
	(0.09)	(0.23)	(0.49)	(0.06)	(0.84)	(0.54)	(0.46)	(0.23)

Notes: The table shows one-day nominal U.S. and foreign long-term yield changes, in bp, around 8 LSAP news events and 13 FOMC control events, as well as sums over those event windows. The "p-values" in parentheses below the yield changes show the proportions of n-day yield changes from July 2007 through January 2010 that were larger in absolute value than the actual change in the n-day period around the event. The 13 control events consist of all FOMC meeting statements and minutes releases from November 2008 through January 2009 that are not "buy" or "sell" events.

Table 3: Effect of the LSAP on the foreign exchange value of the USD

	AUD/USD	CAD/USD	EUR/USD	JPY/USD	GBP/USD	Average Δ in FX rate
Buy Dates						
11/25/2008	-0.17	-0.62	-1.27	-1.57	-2.28	-1.18
	(0.87)	(0.40)	(0.08)	(0.06)	(0.02)	(0.06)
12/1/2008	2.59	0.74	0.85	-2.49	3.85	1.11
	(0.05)	(0.33)	(0.19)	(0.01)	0.00	(0.07)
12/16/2008	-4.41	-2.53	-3.02	-2.18	-2.13	-2.86
	(0.02)	(0.01)	0.00	(0.02)	(0.02)	(0.00)
1/28/2009	-0.19	-0.92	0.39	1.43	-0.30	0.08
	(0.84)	(0.24)	(0.52)	(0.09)	(0.64)	(0.88)
3/18/2009	-2.52	-1.77	-3.60	-2.41	-1.68	-2.40
	(0.05)	(0.05)	0.00	(0.02)	(0.05)	(0.00)
Buy Sum	-4.71	-5.10	-6.65	-7.23	-2.55	-5.25
	(0.11)	(0.01)	(0.00)	(0.00)	(0.15)	(0.00)
Sell Dates						
8/12/2009	-0.54	-1.25	-0.44	0.14	-0.16	-0.45
	(0.58)	(0.14)	(0.48)	(0.84)	(0.78)	(0.39)
9/23/2009	0.36	0.59	0.38	0.12	0.10	0.31
	(0.71)	(0.41)	(0.53)	(0.86)	(0.88)	(0.55)
11/4/2009	-0.84	-0.39	-1.05	0.28	-0.92	-0.59
	(0.38)	(0.57)	(0.14)	(0.70)	(0.19)	(0.27)
Sell Sum	-1.03	-1.06	-1.11	0.53	-0.99	-0.73
	(0.60)	(0.45)	(0.36)	(0.70)	(0.43)	(0.45)
Buy+Sell Sum	-5.73	-6.16	-7.76	-6.70	-3.54	-5.98
	(0.12)	(0.01)	(0.00)	(0.01)	(0.12)	(0.00)
Control Sum	-7.38	-6.84	-1.98	1.49	-6.14	-4.17
	(0.12)	(0.03)	(0.45)	(0.63)	(0.04)	(0.06)
All Event Sum	-13.11	-13.00	-9.74	-5.20	-9.68	-10.15
	(0.03)	(0.00)	(0.01)	(0.19)	(0.01)	(0.00)

Notes: The table shows one-day exchange rate (FX per USD) changes in percentage points around 8 LSAP news events and 13 FOMC control events, as well as sums over those event window sets. The "p-values" in parentheses below the yield changes show the proportions of n-day changes from July 2007 through January 2010 that were larger in absolute value than the actual change in the n-day period around the event. The 13 control events consist of all FOMC meeting statements and minutes releases from November 2008 through January 2009 that are not "buy" or "sell" events.

Table 4: Predicted foreign bond returns and observed foreign yield changes

		Δ in 10-year annual excess bond returns (bp)			Δ in FX (percent)	
		U.S.	German	U.K.	EUR/USD	GBP/USD
Empirical	buy+sell event sum	-77	-57	-37	-7.76	-3.54
	all event sum	-46	-30	-79	-9.74	-9.68
	5th Percentile	-122	-105	-77	-10.05	-7.64
PB Implied	10th Percentile	-106	-91	-67	-9.82	-7.25
Distribution	Point Estimate	-59	-51	-38	-9.06	-5.49
	90th Percentile	-9	-7	-6	-7.50	-3.18
	95th Percentile	5	4	3	-6.96	-2.25

Notes: The top panel of the table shows the observed changes in excess domestic yields in U.S. dollars, in bp, for 2 sets of event window sums for U.S., German, and U.K. yields. The observed changes are constructed from bond yield changes less changes in the liquidity return plus the inflation differential plus foreign exchange jumps, equations (7) and (10). The bottom panel shows the statistics of the bootstrapped distribution of the predictions from the PB model. That is, the top-left panel shows the left-hand side of (7) for the U.S. and the left-hand side of (10) for German and U.K. data. For each row in the top-left panel, the exchange rate change, $\Delta_t s_t$, is the actual change in that row of the top right-hand panel. For example, the German "buy+sell Event Sum" for the change in 10-year real bond yields in U.S. goods uses -7.76 as the exchange rate change. The top-right hand panel shows the observed exchange rate change from the left-hand side of (11). The bottom panel shows estimates of the distribution of the right-hand side of these equations—(7), (10), and (11)—for comparison.

$$\frac{1}{10}\left(\Delta_t E r^{b,US}_{t,t+10} - \Delta_t E r^{f}_{t,t+10}\right) = -12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{11} \quad (7)$$

$$\frac{1}{10}\left(\Delta_t E r^{b,j}_{t,t+10} + \Delta_t E \pi^{US}_{t,t+10} - \Delta_t E \pi^{j}_{t,t+10} - \Delta_t E r^{f}_{t,t+10} + \Delta_t s^{j}_{t}\right) = -12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{1j} \quad (10)$$

$$\Delta_t s^{j}_{t} = \left(\Delta_t E r^{b,j}_{t,t+10} - \Delta_t E \pi^{j}_{t,t+10}\right) - \left(\Delta_t E r^{b,US}_{t,t+10} - \Delta_t E \pi^{US}_{t,t+n}\right) - 10 \cdot 12 \cdot \gamma \cdot 0.22 w_{t,2}\left(\tilde{V}_{1j} - \tilde{V}_{11}\right) \quad (11)$$

Table 5: The predicted effect on exchange rates from conventional monetary shocks and observed jumps

		AUD/USD		CAD/USD		EUR/USD		GBP/USD		JPY/USD	
Regression statistics		coef	(t-stat)	coef	(t-stat)	coef	(t-stat)	coef	(t-stat)	coef	(t-stat)
	constant	-1.84	-(0.87)	-1.39	-(0.92)	-3.81	-(1.48)	-1.20	-(0.61)	-0.92	-(0.46)
	Funds Shock	-0.14	-(0.34)	0.24	(0.82)	1.62	(3.24)	1.27	(3.36)	0.99	(2.52)
	ED12	1.14	(4.61)	0.75	(4.29)	0.87	(2.88)	0.63	(2.75)	0.63	(2.65)
buy+sell sum	predicted FX Δ	-0.75		-1.75		-7.26		-5.50		-4.43	
	[lower, upper bounds]	[-3.11,	1.62]	[-3.43,	-0.07]	[-10.15,	-4.38]	[-7.68,	-3.32]	[-6.70,	-2.16]
	observed FX Δ	-5.73		-6.16		-7.76		-6.70		-3.54	
all event sum	predicted FX Δ	-1.37		-1.74		-5.70		-4.03		-3.31	
	[lower, upper bounds]	[-4.33,	1.59]	[-3.84,	0.36]	[-9.31,	-2.09]	[-6.76,	-1.30]	[-6.15,	-0.47]
	observed FX Δ	-13.11		-13.00		-9.74		-5.20		-9.68	

Notes: The top panel of the table shows the results from regressing exchange rate futures returns (1400 to 1500, EST) on target and path shocks (federal funds surprise and 12-month-ahead eurodollar futures rate changes), similar to the exercise in Hausman and Wongswan (2011). The middle and bottom panels show the predicted exchange rate change from unconventional policy, using 4 times the observed change in long rates as the federal funds shock and the observed change in 12-month-ahead eurodollar futures rates from the dates of the 2 event sets, the "buy+sell Events" and the "all event" sum, respectively.

Appendix A: Non-policy News During the Policy Event Windows

The event study methodology will be biased to the extent that non-policy news in the policy event windows importantly influences asset prices. To determine the importance of non-policy news during these event windows, I searched news sources for incidents of macroeconomic and other non-policy news. The daily Dow Jones Treasury Market recap was especially useful in determining factors that influenced bond markets.

At first glance, there appear to be several bits of non-policy news that might significantly influence bond and/or foreign exchange prices during the event windows. There were, for example, at least two U.S. macro announcements during most event windows and the CPI release on December 16 was a fairly large negative surprise. There were several Fed news events that were not directly related to the policies considered here: The Term Asset-Backed Securities Loan Facility (TALF) was announced coincidentally with the first asset purchase announcement on November 25, the FOMC announced that it would implement TALF on January 28, 2009 and the FOMC reduced the funds target from 100 bp to a 0-25 bp range on December 16, 2008.

Despite the existence of non-policy news events, examination of previous event studies, news reports, and high-frequency price responses suggest that none of the non-policy events had particularly large effects on bond or foreign exchange markets. For example, Faust et al. (2007) find that CPI surprises do not influence exchange rates in an economically or statistically significant sense. Similarly, the FOMC fed funds reduction on December 16 was largely expected, with a surprise component of only 12.5 bp, and so probably produced very small effects. Faust et al.'s (2007) point estimates imply that this fed funds shock would produce a trivial 1.25 bp change in nominal 10-year Treasury yields.

There were also several potentially important non-U.S. news reports during the event windows. For example, the Bank of Japan increased its own bond-buying program on March 18, 2009 and there was a big negative surprise in the Australia CPI on January 28, 2009. Closer examination of these events suggests that they do not unduly bias estimates. The Bank of Japan's purchase announcement was very small, just $4 billion a month, and partially expected. Examination of high frequency Australian data—omitted for brevity—suggests almost no effect of the CPI announcement on Australian rates.

Finally, the Dow Jones Treasury Market recaps generally led with policy news after buy announcements. I conclude that neither U.S. nor foreign -policy announcements significantly biased the estimates of the effects of unconventional U.S. policy.

Table A1: Non-policy news during the policy buy announcement windows

Date	Announcement/News	Time (ET)	Reported	Market Expectation	Forecast Error	Std Dev of Forecast Errors	Unit
11/23/2008	Citigroup Capital Injection						
11/25/2008	TALF Announcement	8:15 AM					
	Chain Deflator (Preliminary)	8:30 AM	4.20%	4.20%	0.00%		level
	GDP (Preliminary)	8:30 AM	-0.50%	-0.50%	0.00%	0.39%	Q/Q %Chg
	Consumer Confidence	10:00 AM	44.9	38.3	6.60	5.13	
	Minutes of October discount rate meetings released	2:00 PM					
12/1/2008	Construction Spending	10:00 AM	-1.20%	-1%	-0.20%	1%	M/M %Chg
	ISM Index	10:00 AM	36.2	37	-0.80	2.07	Index, 50+ = Increasing
	NBER officially declares a recession.	10:36 AM					
12/16/2008	Building Permits	8:30 AM	620	700	-80	60	level, thousands
	Housing Starts	8:30 AM	625	350	275	97	level, thousands
	Core CPI	8:30 AM	0%	0.10%	-0.10%	0.11%	M/M %Chg
	CPI	8:30 AM	-1.70%	-1.30%	-0.40%	0.15%	M/M %Chg
	FOMC Rate Decision	2:15 PM	0-0.25%	0.250%	0.125%		
	Cuts in Fed Discount Rates	2:15 PM					
	FOMC statement forecast "...exceptionally low levels of the federal funds rate for some time."	2:15 PM					
1/28/2009	Crude Inventories	10:30 AM	1,762,000				barrels
	FOMC Rate Decision	2:15 PM	0-0.25%	0.125%	0.00%		
	TALF to be implented	2:15 PM					
3/18/2009	Core CPI	8:30 AM	0.20%	0.10%	0.10%	0.11%	M/M %Chg
	CPI	8:30 AM	0.40%	0.30%	0.10%	0.15%	M/M %Chg
	Current Account Balance	8:30 AM	-132.8	-137	4.2	6.64	billions of dollars
	Crude Inventories	10:30 AM	1,784,000				barrels
	FOMC Rate Decision	2:15 PM	0-0.25%	0.125%	0.00%		
	TALF Collateral Expansion	2:15 PM					
	FOMC statement forecast "… exceptionally low levels of the federal funds rate for an extended period."	2:15 PM					
	UK announcement on QE purchase facility details (3/19/2009)						

Appendix B: Intraday analysis and robustness to the length of the selection window

B.1 Intraday analysis

Intraday data illustrate that the declines in bond yields and the value of the dollar closely followed the policy announcements. Figures B1 through B5 show the intraday time paths of the long bond futures prices (top panels), foreign exchange rates (center panels), and S&P 500 and oil futures prices (bottom panel) around the 5 LSAP buy announcements: 11/25/2008, 12/01/2008, 12/16/2008, 01/28/2009, and 03/18/2009. All series are normalized to show percentage deviations from the asset's nominal value at the time of the announcement.

Figure B1 shows that the 8:15 AM announcement of the Fed's agency debt and MBS purchase program had a slowly developing, but eventually substantial, effect on U.S. bond futures and—to a lesser extent—Canadian, German, Japanese, and U.K. bond futures (top panel). The reaction in the foreign exchange market (center panel) was faster, with the dollar falling by 2 to 3.5 percentage points within 2 or 3 hours, except against the JPY, where the reaction was muted and delayed. The very low levels of nominal Japanese bond yields shown in Figure 1 probably help explain the very modest Japanese bond futures and foreign exchange reactions in Figure B1. The transient rises in oil prices and the S&P 500 futures suggest that the initial LSAP announcement may have briefly increased expected growth (bottom panel of Figure B2).

On December 1, 2008, Chairman Bernanke gave a speech that suggested that the Federal Reserve could buy Treasury notes and bonds if the situation warranted. Figure B2 illustrates that U.S. and foreign bond futures prices climbed more immediately than they had after the November 25 release. Other markets did not appear to react to the speech, however.

The December 16 FOMC release reduced the federal funds target from 1 percent to a range of 0 to 25 bp, mentioned possible purchases of Treasuries and stated that the FOMC expects "exceptionally low levels of the federal funds rate for some time." Figure B3 shows that U.S. and foreign bond futures prices immediately rose substantially, the dollar depreciated by 1 to 3 percent and S&P 500 futures gained modestly.

In its January 28th statement, the FOMC failed to announce purchases that were probably partially priced-in, which produced modest bond futures price declines (i.e., higher bond yields) and a 0 to 2 percent appreciation of the dollar (see Figure B4). The combination of bond price declines and dollar appreciation is consistent with reduced expectations of bond purchases.

Finally, Figure B5 shows that the March 18 announcement of additional large MBS, agency debt, and new Treasury purchases raised bond futures prices by 1 to 3.5 percent and reduced the value of the dollar by 2 to 3 percent. Equity and oil prices rose by more than 2 percent in the hour following the announcement, which is consistent with the interpretation that the announcement increased expected growth. Prices moved faster on March 18 than after previous announcements, suggesting that views were becoming less heterogeneous.

In summary, unconventional policy announcements that raised (reduced) U.S. bond futures prices tended to raise (reduce) foreign bond futures prices and reduce (raise) the value of the USD. Reactions typically started quickly but markets appear to have often taken hours to fully price the events, which is consistent with other reactions to complex or unexpected information.

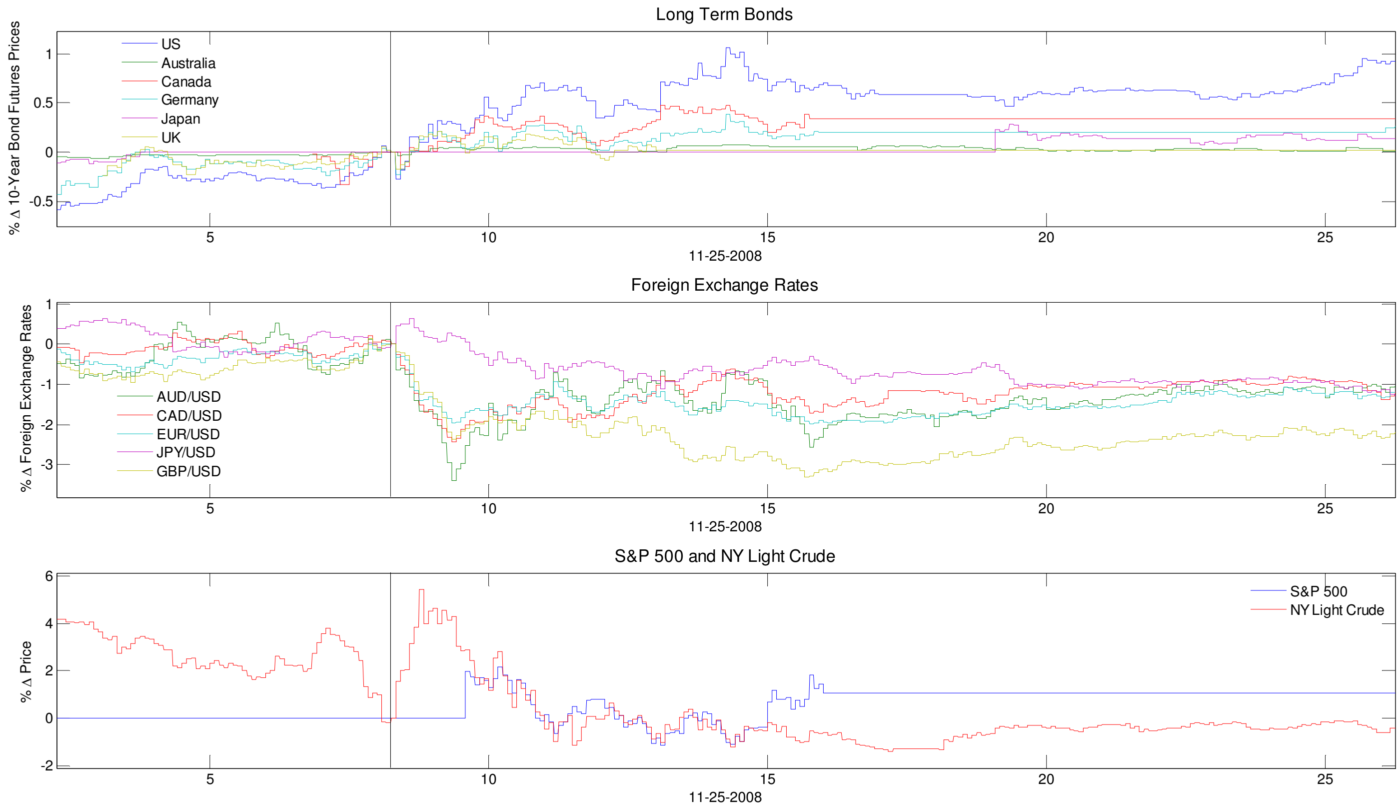
B.2 Robustness of results to the length of the selection window

How sensitive are the results in Tables 2 and 3 to the length of the event windows? Table D1 compares nominal asset price changes for 2.5 hour, 1-day, and 2-day windows for sums of buy, sell, control, and all FOMC events. The intraday changes are in percentage changes in futures prices while the 1-day and 2-day bond data are in changes in nominal (local currency) yields in bp. To compare these data, note that an X percent rise in the local currency futures price of an n-year zero coupon bond implies an $X(100/n)$ bp reduction in nominal yield. The futures prices typically pertain to bonds of somewhat shorter maturities than 10-years.[21]

Table B1 shows that buy events usually elicit slightly larger 2-day responses than 1-day responses. For example, the last column of Table B1 shows that 2.5 hour, 1-day and 2-day average exchange rate responses are –4.8, –5.2 and –6.6 percent, respectively. Aside from that pattern of increasing response, the reactions are fairly consistent across the lengths of event windows. Most notably, the high frequency responses in the control days are almost uniformly very small compared to the 1- or 2-day responses on the same days. This suggests that the movements on control days are not systematically related to the policy announcements and that the inclusion of the control days simply increases the noise in the estimates of the policy announcement effects.

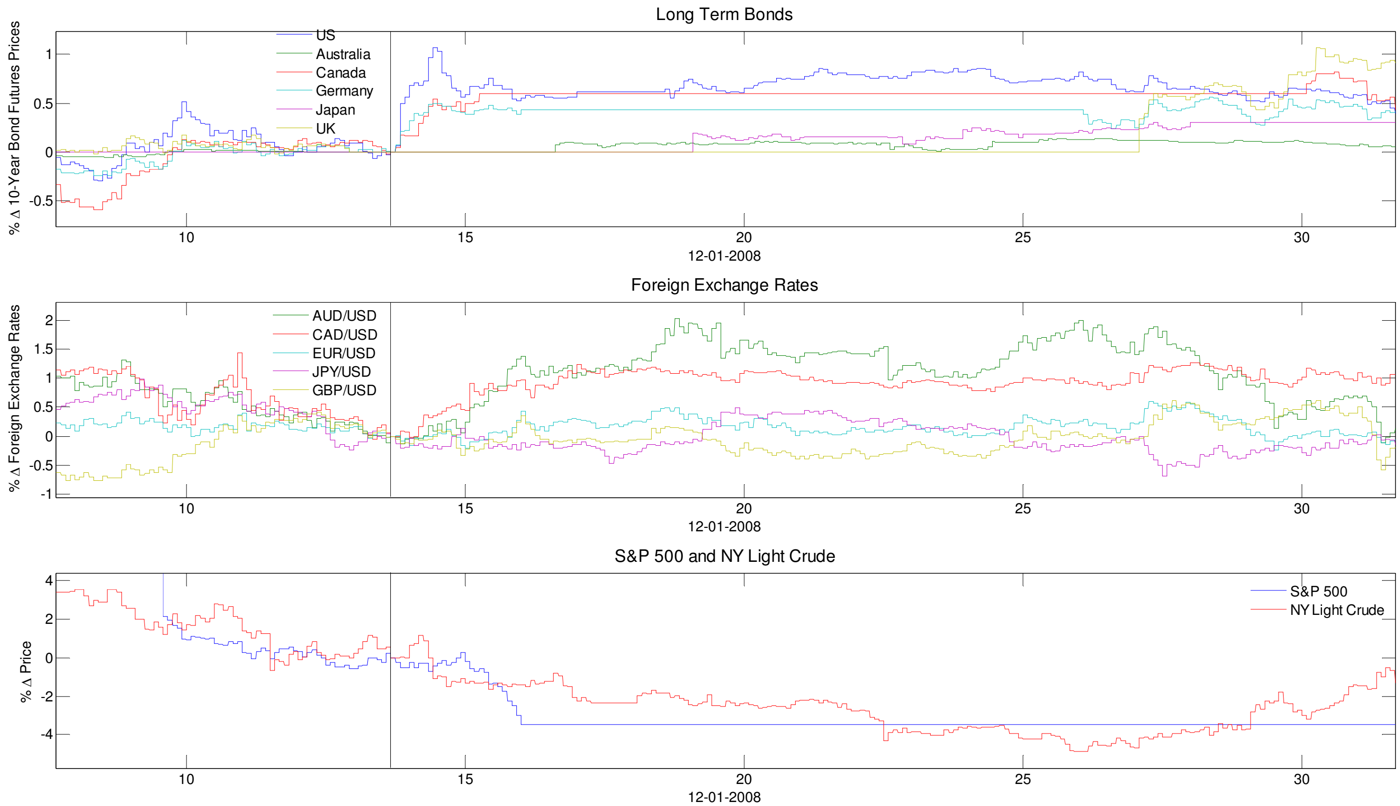
[21] The deliverable maturity range for the CME contract on the U.S. 10-year note is between 6.5 years and 10 years. The daily returns on international bond futures were highly correlated (> 85%) with implied returns from zero coupon yields on bonds with maturities of 7 to 10 years, depending on the country.

Figure B1: High-frequency nominal futures price movements on November 25, 2008



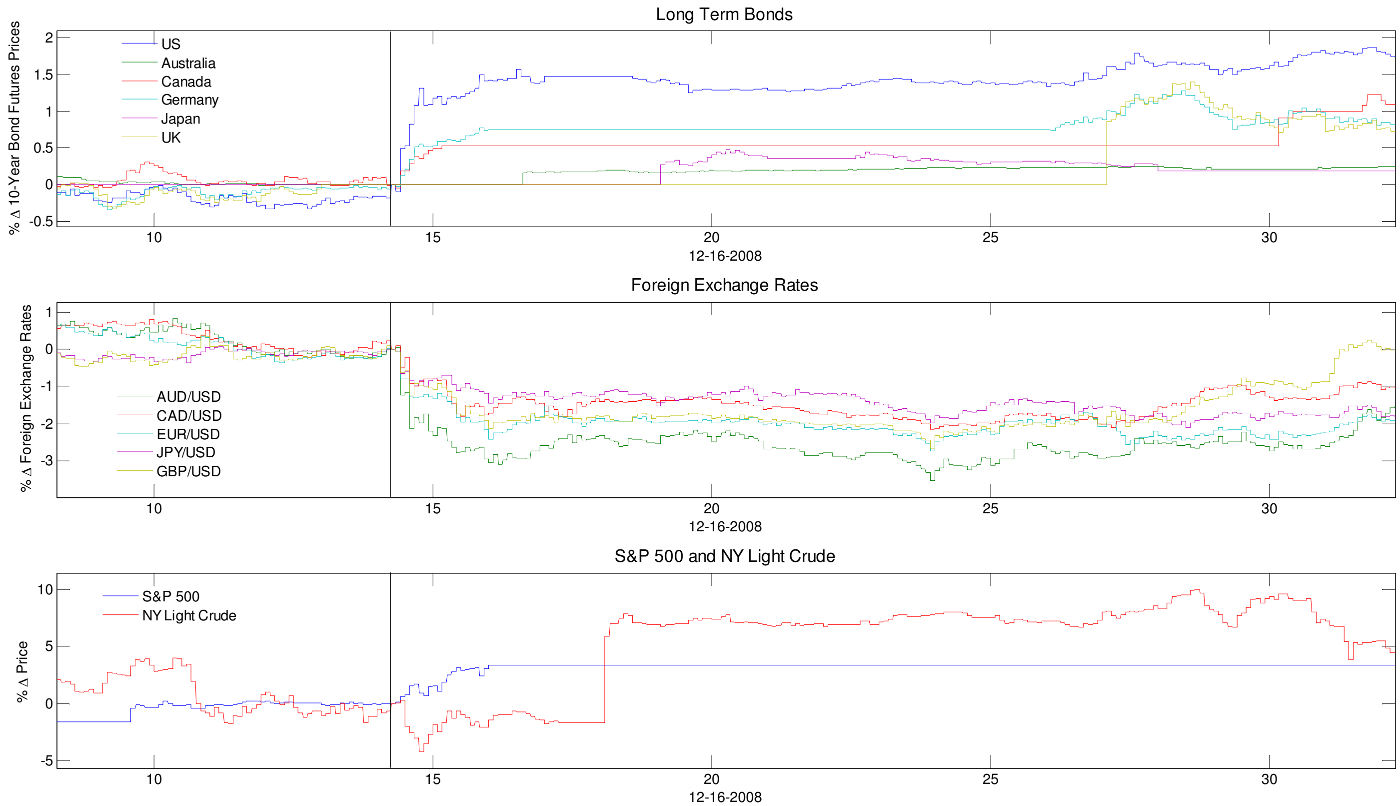
Notes: The figure shows the high-frequency movements of local currency international bond futures prices (top panel), spot exchange rates (center panel), and S&P 500 and NY light crude futures (bottom panel) in the hours around the initial LSAP press release (vertical line) on November 25, 2008. The x-axis values denote hours from midnight, U.S. Eastern time, of the day of the announcement, and the vertical line denotes the time of the announcement.

Figure B2: High-frequency nominal futures price movements on December 1, 2008



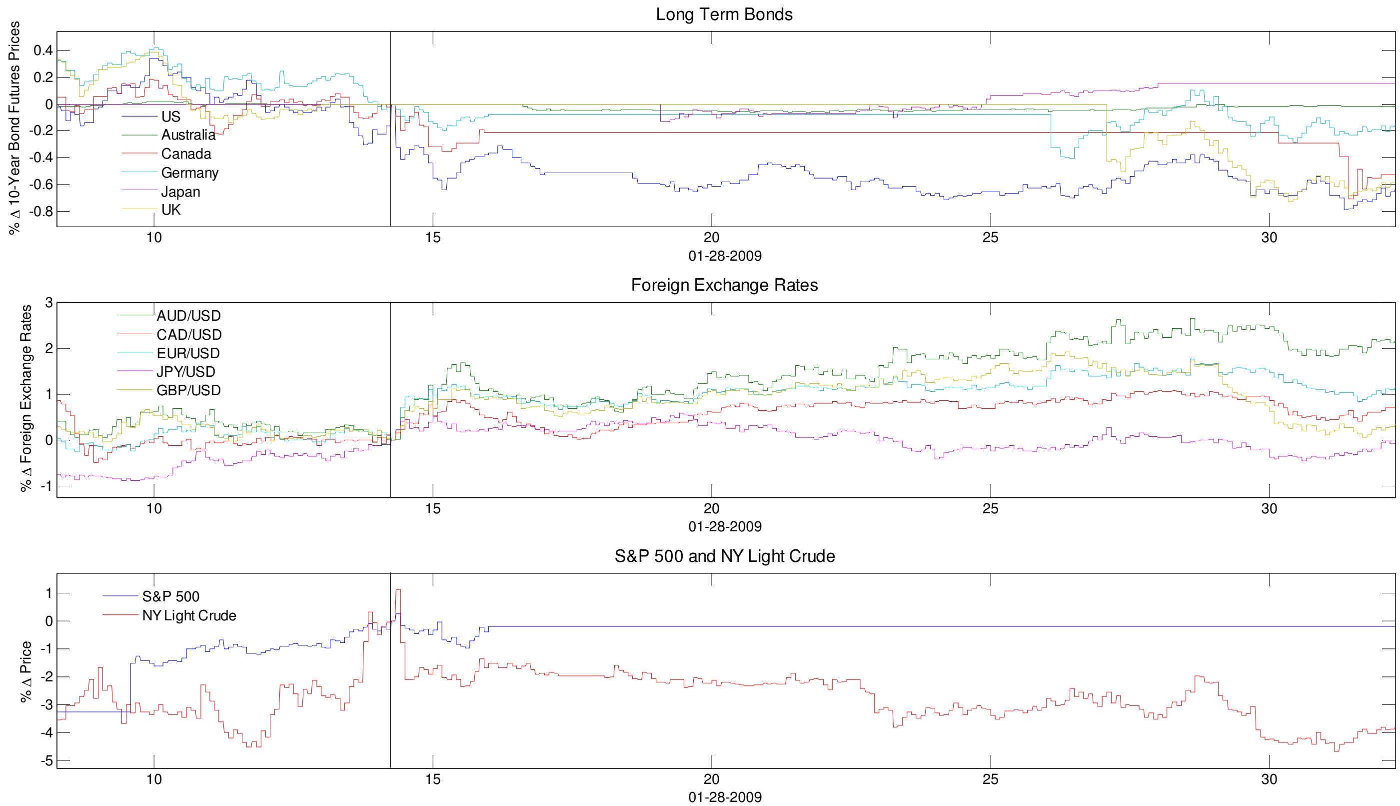
Notes: The figure shows the high-frequency movements of local currency international bond futures prices (top panel), spot exchange rates (center panel) and S&P 500 and NY light crude futures (bottom panel) in the hours around Chairman Bernanke's speech (vertical line) on December 1, 2008. The x-axis values denote hours from midnight, U.S. Eastern time, of the day of the announcement, and the vertical line denotes the time of the announcement.

Figure B3: High-frequency nominal futures price movements on December 16, 2008



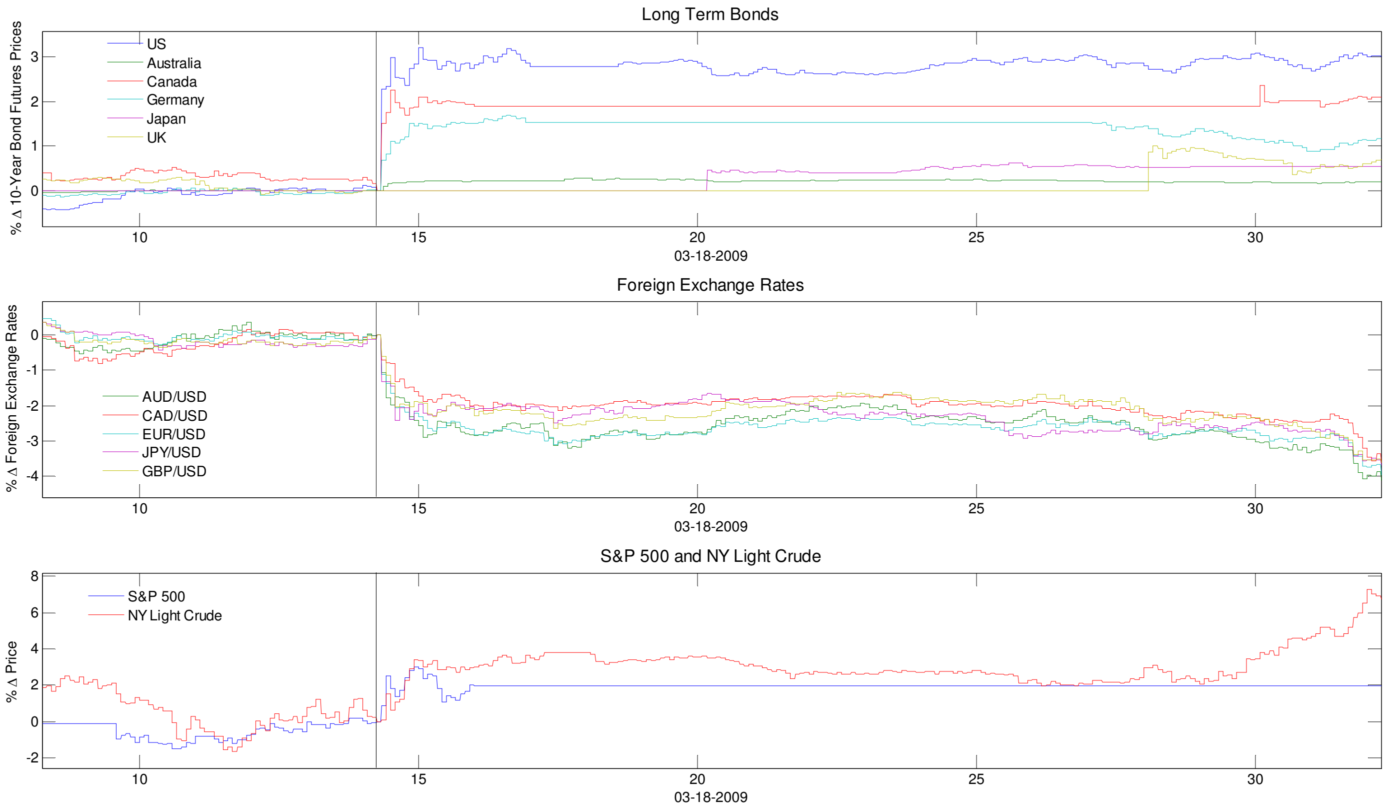
Notes: The figure shows the high-frequency movements of local currency international bond futures prices (top panel), spot exchange rates (center panel) and S&P 500 and NY light crude futures (bottom panel) in the hours around the FOMC release (vertical line) on December 16, 2008. The x-axis values denote hours from midnight, U.S. Eastern time, of the day of the announcement, and the vertical line denotes the time of the announcement.

Figure B4: High-frequency nominal futures price movements on January 28, 2009



Notes: The figure shows the high-frequency movements of local currency international bond futures prices (top panel), spot exchange rates (center panel) and S&P 500 and NY light crude futures (bottom panel) in the hours around the FOMC release (vertical line) on January 28, 2009. The x-axis values denote hours from midnight, U.S. Eastern time, of the day of the announcement, and the vertical line denotes the time of the announcement.

Figure B5: High-frequency nominal futures price movements on March 18, 2009



Notes: The figure shows the high-frequency movements of local currency international bond futures prices (top panel), spot exchange rates (center panel) and S&P 500 and NY light crude futures (bottom panel) in the hours around the FOMC release (vertical line) on March 18, 2009. The x-axis values denote hours from midnight, U.S. Eastern time, of the day of the announcement, and the vertical line denotes the time of the announcement.

Table B1: Robustness of results to length of event window

		Long Bonds								USD Exchange Rates					
		U.S.	Australia	Canada	Germany	Japan	U.K.	Foreign Average		Australia	Canada	Germany	Japan	U.K.	Average
Buys	2-Day	-107.0	-78.0	-54.0	-50.0	-19.0	-65.0	-53.2		-5.7	-4.6	-8.1	-10.8	-3.6	-6.6
		(0.00)	(0.00)	(0.00)	(0.00)	(0.04)	(0.01)	(0.00)		(0.14)	(0.09)	(0.00)	(0.00)	(0.17)	(0.00)
	1-Day	-100.0	-65.0	-56.0	-38.0	-18.0	-43.0	-44.0		-4.7	-5.1	-6.7	-7.2	-2.5	-5.2
		(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)		(0.10)	(0.01)	(0.00)	(0.00)	(0.15)	(0.00)
	2.5 Hours	5.1	0.5	3.3	2.6	1.0	1.8	1.8		-5.6	-4.2	-5.8	-3.2	-5.0	-4.8
		(0.00)	(0.00)	(0.00)	(0.00)	(0.03)	(0.01)	(0.00)		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Sells	2-Day	-11.0	6.0	8.0	1.0	-1.0	3.0	3.4		-1.5	0.5	-1.1	-0.1	0.2	-0.4
		(0.55)	(0.75)	(0.55)	(0.96)	(0.92)	(0.84)	(0.75)		(0.57)	(0.79)	(0.52)	(0.97)	(0.89)	(0.79)
	1-Day	6.0	2.0	6.0	-1.0	0.0	0.0	1.4		-1.0	-1.1	-1.1	0.5	-1.0	-0.7
		(0.66)	(0.91)	(0.51)	(0.94)	(1.00)	(0.99)	(0.84)		(0.59)	(0.46)	(0.36)	(0.69)	(0.43)	(0.46)
	2.5 Hours	0.5	0.1	0.2	0.1	0.0	0.2	0.1		0.3	0.4	0.1	-0.5	0.4	0.1
		(0.15)	(0.26)	(0.32)	(0.57)	(0.95)	(0.48)	(0.49)		(0.60)	(0.35)	(0.76)	(0.23)	(0.22)	(0.58)
Control	2-Day	43.0	76.0	22.0	41.0	5.0	49.0	38.6		-8.5	-6.2	-2.7	4.2	-8.3	-4.3
		(0.28)	(0.05)	(0.43)	(0.14)	(0.74)	(0.15)	(0.08)		(0.19)	(0.17)	(0.47)	(0.32)	(0.07)	(0.17)
	1-Day	34.0	37.0	3.0	34.0	9.0	22.0	21.0		-7.4	-6.8	-2.0	1.5	-6.1	-4.2
		(0.23)	(0.20)	(0.89)	(0.08)	(0.42)	(0.33)	(0.14)		(0.13)	(0.03)	(0.45)	(0.62)	(0.04)	(0.06)
	2.5 Hours	-0.2	0.0	0.4	-0.7	-0.5	-1.2	-0.4		0.7	-0.2	0.9	0.1	-0.3	0.2
		(0.80)	(0.99)	(0.51)	(0.10)	(0.49)	(0.16)	(0.26)		(0.68)	(0.82)	(0.26)	(0.96)	(0.69)	(0.56)
All Events	2-Day	-75.0	4.0	-24.0	-8.0	-15.0	-13.0	-11.2		-15.7	-10.3	-11.9	-6.7	-11.7	-11.2
		(0.14)	(0.94)	(0.49)	(0.83)	(0.43)	(0.76)	(0.70)		(0.06)	(0.07)	(0.02)	(0.22)	(0.04)	(0.01)
	1-Day	-60.0	-26.0	-47.0	-5.0	-9.0	-21.0	-21.6		-13.1	-13.0	-9.7	-5.2	-9.7	-10.1
		(0.09)	(0.47)	(0.06)	(0.84)	(0.54)	(0.46)	(0.22)		(0.03)	(0.00)	(0.00)	(0.18)	(0.01)	(0.00)
	2.5 Hours	5.4	0.5	3.9	2.1	0.5	0.8	1.6		-4.7	-4.1	-4.7	-3.7	-4.9	-4.4
		(0.00)	(0.62)	(0.00)	(0.07)	(0.63)	(0.48)	(0.15)		(0.04)	(0.07)	(0.04)	(0.10)	(0.04)	(0.06)

Notes: The left-hand portion of the table shows changes in nominal bond yields in bp for 2- and 1-day windows and in percentage changes in bond futures prices for 2.5 hour windows. The percentage change in an n-year, zero-coupon bond price should be equal to $-(n/100)$ times the change in the bond's yield, measured in bp. The right-hand panel shows percentage changes in the value of the dollar over various event windows. The "p-values" in parentheses below the changes show the proportions of n-day changes from July 2007 through January 2010 that were larger in absolute value than the actual change in the appropriately sized periods around the events.

Appendix C: Portfolio Balance Model Predictions

The expected excess returns for a constrained, mean-variance optimizer must satisfy the following:

$$F'Er_{t,t+1/12} = E\tilde{r}^{b}_{t,t+1/12} - E\tilde{r}^{s}_{t,t+1/12} - Er^{f}_{t,t+1/12} = \gamma(F'VF)\Delta\widetilde{w}_t = \gamma\tilde{V}\Delta\widetilde{w}_t \qquad \text{(C.1)}$$

where $Er_{t,t+1/12}$ is the N-by-1 vector of expected monthly real returns in U.S. goods to international bond investors, $E\tilde{r}^{b}_{t,t+1/12}$ and $E\tilde{r}^{s}_{t,t+1/12}$ denote the $N-1$-by-1 vectors of expected nominal returns and exchange rate returns (foreign currency units per dollar) of non-liquidity assets 2 to N, $Er^{f}_{t,t+1/12}$ and $E\pi^{US}_{t,t+1/12}$ are scalars. V is the N-by-N covariance matrix of those real returns, $F'Er_{t,t+1/12}$ and $\tilde{V} = F'VF$ are the $N-1$-by-1 expected excess returns over the first asset and covariance matrix of those excess returns, respectively. $\widetilde{w}_t$ is the $N-1$-by-1 vector of weights on asset 2 to N and the matrices z and F impose the constraint that the full weight vector, w_t, sums to 1, ($z + F\widetilde{w} = w,\ \mathbf{1}'w = 1$). For$N = 3$, for example, $z'$and F' would be $z' = [1 \quad 0 \quad 0]$ and $F' = \begin{bmatrix} -1 & 1 & 0 \\ -1 & 0 & 1 \end{bmatrix}$.

(C.1) implies that a change in $N-1$ non-liquidity weights at time t—$\Delta_t\widetilde{w}_t$— produces the following change in annualized expected returns:

$$\Delta_t E\tilde{r}^{b}_{t,t+1} - \Delta_t E\tilde{r}^{s}_{t,t+1} - \Delta_t Er^{f}_{t,t+1} = 12 \cdot \gamma\tilde{V}\Delta_t\widetilde{w}_t \qquad \text{(C.2)}$$

where the Δ_t operator denotes the change in the variable at time t, $\tilde{r}^{b}_{t,t+1}$ and $\tilde{r}^{s}_{t,t+1}$ denote the $N-1$-by-1 vectors of asset and exchange rate returns from asset 2 to N, $\tilde{V} = F'VF$ is the covariance matrix of excess asset (bond) returns and the right-hand side of (A.2) is multiplied by 12 to account for the annualized returns on the right-hand side. (Returns in (C.1) were monthly.)

If the only change in the expected portfolio weight vector on the days of the policy announcements was a 22 percent reduction in U.S. securities outstanding, then (C.2) implies the following for the first row of (A.2), for the 10-year expected excess return to U.S. bonds:

$$\frac{1}{10}\left(\Delta_t E r_{t,t+10}^{b,US} - \Delta_t E r_{t,t+10}^{f}\right) = -12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{11} \qquad \text{(C.3)}$$

where $w_{t,2}$ is the weight of U.S. long-term securities in the public's portfolio at time t, $\tilde{V}_{11}$ is the (1,1) element of $\tilde{V}$, the covariance matrix of U.S. monthly excess long bond returns. The left-hand side of (C.3) is the annualized expected excess return—10-year returns multiplied by 1/10— and the 12 appears in the right-hand side to adjust the monthly covariance matrix to match the annual terms on the left. (C.3) uses the fact that the expected exchange rate return is always zero for U.S. assets from the standpoint of a U.S. investor. For a 10-year return to a foreign bond, *j*, (C.2) becomes

$$\frac{1}{10}\left(\Delta_t E r_{t,t+10}^{b,j} - \Delta_t E r_{t,t+10}^{s,j} - \Delta_t E r_{t,t+10}^{f}\right) = -12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{1j}. \qquad \text{(C.4)}$$

This excess return to the foreign bond depends on the expected rate of appreciation of the USD. One can subtract (C.4) from (C.3) to get an expression for the change in expected USD appreciation against currency *j*, $\Delta_t E r_{t,t+10}^{s,j}$:

$$\Delta_t E r_{t,t+10}^{s,j} = \Delta_t E r_{t,t+10}^{b,j} - \Delta_t E r_{t,t+10}^{b,US} + 10 \cdot 12 \cdot \gamma \cdot 0.22 w_{t,2}\left(\tilde{V}_{1j} - \tilde{V}_{11}\right). \qquad \text{(A.5)}$$

Note that if investors were risk-neutral ($\gamma = 0$), this expression would collapse to the usual expression for expected exchange rate changes under uncovered interest parity.

Although the expected long-run rate of nominal appreciation is unobserved, one can determine it using observable variables under the assumption that goods market equilibrium determines the real exchange rate over the long run (purchasing power parity) and that policy announcements do not change the long-run expected real exchange rate. The latter assumption can be written as follows:

$$\Delta_t E s^j_{t+10} + \Delta_t E p^{US}_{t,t+10} - \Delta_t E p^j_{t,t+10} = 0\ , \tag{C.6}$$

for a long run of 10 years. Applying the Δ_t operator to the identity $E\pi^{US}_{t,t+10} \equiv Ep^{US}_{t,t+10} - p^{US}_t$ and assuming that aggregate price levels did not jump at the time of the LSAP announcements, then the change in the expected future price level is the change in the 10-year expected inflation rate $\Delta_t E\pi^{US}_{t,t+10} = \Delta_t Ep^{US}_{t,t+10}$. This can be substituted into (C.6) to obtain

$$\Delta_t E s^j_{t+10} = \Delta_t E\pi^j_{t,t+10} - \Delta_t E\pi^{US}_{t,t+10}. \tag{C.7}$$

Applying the Δ_t operator to an identity for expected USD appreciation over 10 years ($Er^{s,j}_{t,t+10} = Es^j_{t+10} - s^j_t$), gives

$$\Delta_t E r^{s,j}_{t,t+10} = \Delta_t E s^j_{t+10} - \Delta_t s^j_t \tag{C.8}$$

where $\Delta_t s^j_t$ is the "jump" in the nominal exchange rate at the time of the announcement. Using the expression (C.7) for $\Delta_t E s^j_{t+10}$ in (C.8), one gets an expression for the change in the expected rate of appreciation of the dollar in terms of the difference in changes in expected inflation and the exchange rate jump at the time of the announcement:

$$\Delta_t E r^{s,j}_{t,t+10} = \Delta_t E\pi^j_{t,t+10} - \Delta_t E\pi^{US}_{t,t+10} - \Delta_t s^j_t. \tag{C.9}$$

Substituting the right-hand side of (C.9) into (C.5) and solving for $\Delta_t s_t$ implies an expression for the exchange rate jump at the time of the LSAP announcements in terms of changes in relative

10-year real interest rates and the mean-variance risk premium:

$$\Delta_t s_t^j = \left(\Delta_t E r_{t,t+10}^{b,j} - \Delta_t E \pi_{t,t+10}^{j}\right) - \left(\Delta_t E r_{t,t+10}^{b,US} - \Delta_t E \pi_{t,t+10}^{US}\right) - 10 \cdot 12 \cdot \gamma \cdot 0.22 w_{t,2} \left(\tilde{V}_{1j} - \tilde{V}_{11}\right). \qquad \text{(C.10)}$$

Alternatively, one could take the expression for $\Delta_t E r_{t,t+n}^{s,j}$ on the right-hand side of (C.9) and substitute it back into (C.4) to equate the annualized change in the expected foreign excess yield in dollars (left-hand side) with the PB risk premium (right-hand side):

$$\frac{1}{10}\left(\Delta_t E r_{t,t+10}^{b,j} - \Delta_t E r_{t,t+10}^{f} + \Delta_t E \pi_{t,t+10}^{US} - \Delta_t E \pi_{t,t+10}^{j} + \Delta_t s_t^j\right) = -12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{1j}. \qquad \text{(C.11)}$$

Assuming that one can compare changes in yields—which are average returns over the life of the security—to changes in expected returns, (C.3), (C.10), and (C.11) provide testable predictions about changes in asset prices during windows around the LSAP announcements. Specifically, in (C.3) we can compute the right hand side ($-12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{11}$) from historical data and compare the distribution of that statistic to the observed annual change in local currency, nominal yields less expected break-even inflation from TIPS or inflation swaps:

$$\frac{1}{10}\left(\Delta_t E r_{t,t+10}^{b,US} - \Delta_t E r_{t,t+10}^{liquidity}\right) = -12 \cdot \gamma \cdot 0.22 w_{t,2} \tilde{V}_{11}. \qquad \text{(C.3)}$$

In (C.11), we can similarly compare annualized changes in the expected foreign excess yield in dollars (left-hand side) with the PB risk premium (right-hand side). Finally, in (C.10), we can compute a distribution for $\left[-10 \cdot 12 \cdot \gamma \cdot 0.22 w_{t,2} \left(\tilde{V}_{1j} - \tilde{V}_{11}\right)\right]$ from historical data, observe changes in the expected real returns to U.S. and foreign bonds during the announcement windows, and compare that sum to the actual exchange rate changes ($\Delta_t s_t^j$) observed during the announcement windows.

There is a redundancy in these three equations. (C.10) is (C.3) less (C.11). Results from all three are presented for completeness.

Appendix D: Estimating the Portfolio Balance Model

The annualized percentage values of $\widehat{Er}$ for 1-month Treasury bills, the U.S., Canadian, U.K., Japanese, and German 10-year bonds, and the S&P 500 are 1.6, 5.8, 7.6, 7.5, 7.0, 7.4 and 7.0, respectively. The lower triangular of the $\hat{V}$ matrix of the monthly returns (*10,000) is as follows:

	T-Bill	U.S.	Canada	U.K.	Japan	Germany	SP500
T-Bill	0.03						
U.S.	0.04	3.73					
Canada	0.01	2.65	7.83				
U.K.	0.03	2.41	3.65	12.79			
Japan	-0.02	2.38	1.65	6.33	15.75		
Germany	0.00	3.20	3.54	8.86	7.96	12.87	
S&P 500	0.05	0.40	4.82	0.73	-0.90	-0.31	20.97

Note that the above $\hat{V}$ matrix is equal to 1/12 times the usual covariance matrix of annual returns. The estimated annual standard deviation of S&P 500 excess returns could be obtained by multiplying the S&P excess return variance ($\hat{V}_{77}$) by 12 and taking the square root: $\sqrt{12 \times 20.97} = 15.86$. The initial weighting vector is calculated with monthly returns and variances for the seven assets using equation (3). Its elements are -1.55, 1.21, 0.52, 0.28, 0.26, -0.03, and 0.30. The PB model presumably puts negative weight on the liquidity asset and German long bonds because it does not account for the utility of highly liquid transactions balances and low default risk that make those assets attractive with relatively low returns.

This paper reports PB predictions for a CRRA value of 5, although other reasonable values of γ—i.e., 2 and 10— produce very similar distributions for the changes in returns. Although γ influences the change in returns in (7) and (10), it affects the initial weight on Treasury bonds in equation (3) in the opposite way. Thus the changes in returns are relatively insensitive to γ.