The Large-Scale Asset Purchases Had Large International Effects

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Abstract: This paper evaluates the effect of the Federal Reserve's large scale asset purchases (LSAP) on international long bond yields and exchange rates, then considers whether the observed behavior is consistent with a simple portfolio balance model and standard exchange rate parity conditions. The LSAP announcements substantially reduced international long-term bond yields and the spot value of the dollar. These changes closely followed announcement times and were very unlikely to have occurred by chance. A simple portfolio choice model explains the changes in foreign bond yields but underestimates the U.S. yield changes. Likewise, the LSAP announcements prompt smaller exchange rate responses than parity conditions imply, but the actual responses are qualitatively consistent with those predictions. The LSAP's success in reducing international long-term interest rates and the value of the dollar shows that central banks are not toothless when short rates hit the zero bound.

Keywords: Large scale asset purchase, quantitative easing, event study, announcement,

monetary policy, zero bound.

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Following the extreme credit market disturbances in the fall of 2008, the Federal Reserve announced an unusual program to purchase large quantities of long-term securities to improve credit market conditions, particularly in the housing market. On November 25, 2008, the Federal Reserve announced that it would purchase up to $100 million of government-sponsored enterprise (GSE) debt and up to $500 million in 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) press release announced that the Federal Reserve 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 of GSE debt, MBS, and long-term Treasuries "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, at most, moderately successful, probably because the purchases were insufficiently large and offset by new Treasury issuance (Blinder (2000)).

The recent LSAP are especially informative because the program is an unusually large "natural experiment"—an isolated change in the economic environment—that illuminates market reactions and joint asset price determination. In particular, it establishes the quantitative significance of the portfolio balance channel and the efficacy of this rarely used monetary policy instrument, which might be useful either in normal conditions or at the zero bound.

Several financial crisis policy studies are directly related to the present paper. Aït-Sahalia et al. (2010) take the broadest view of policy interventions by classifying interventions

by type and looking at pooled and unpooled effects across countries. This assumes homogeneous effects of interventions within policy classes that include interest rate cuts, liquidity support, liability guarantees, and recapitalization, from many countries on many financial variables. 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.

Two papers study the LSAP program specifically. Stroebel and Taylor (2009) argue the Federal Reserve's purchases of MBS produce small or statistically insignificant effects on mortgage-Treasury spreads that are adjusted for pre-payment and default risks. Stroebel and Taylor (2009) differs from the current study in looking for effects of transactions on spreads, rather than announcement effects on yields. Although they note that "the MBS purchase program reduced the Treasury-OAS [option adjusted spread] by about 30 bps" (p. 20), they credit this decline to an increased commitment to guarantee GSE liabilities. In contrast to Stroebel and Taylor's (2009) methods and conclusions, Gagnon et al. (2010) cite announcement effects and a statistical model of debt yields to argue that the LSAP did reduce U.S. long-term yields (see also Kohn (2009) and Meyer and Bomfim (2010)).[1] Because Fama's (1970) efficient markets hypothesis states that markets react rapidly to publicly available information, asset prices should react immediately to LSAP news, not to expected transactions.[2] Therefore Gagnon et al.'s (2010) event study methods seem most appropriate to the study of LSAP effects.

Hamilton and Wu (2010) model the term structure of U.S. debt to study the effects of changes in its maturity structure. Their point estimates of the effects of a large swap of short-term for long-term debt are roughly consistent with the predictions of the simple portfolio

[1] Joyce et al (2010) find that the Bank of England's quantitative easing program had quantitatively similar bond yield effects as those Gagnon et al (2010) found for the U.S. program.
[2] Concentrating on the Treasury LSAP, D'Amico and King (2010) find small (3.5 basis point) flow effects of purchase operations.

balance model in this paper.

All of the above studies consider domestic effects of financial crisis programs. In addition to influencing U.S. yields, however, the LSAP will affect international asset prices because risk-arbitrage ties expected international returns closely together in a world of capital mobility.[3] Ceteris paribus, a fall in U.S. bond yields would cause investors to reduce their portfolio weights in U.S. bonds in favor of foreign bonds, pushing up the prices of those foreign bonds and reducing their yields until a new equilibrium was reached. Because expected returns to an international debt investment depend on both expected bond returns and expected exchange rate changes, the LSAP should influence both international interest rates and exchange rates.[4] The contribution of this paper is to evaluate the LSAP's effect on international long bond yields and exchange rates, as well as to consider whether the observed asset price behavior is consistent with a simple portfolio balance model and standard exchange rate parity conditions.

The LSAP program significantly reduced the 10-year yields of Australia, Canada, Germany, Japan, and the United Kingdom and also depreciated the USD versus the currencies of those countries. This paper asks how much of the observed changes in yields and immediate exchange rate movements can be explained by a simple portfolio balance and UIP-PPP model, respectively. The LSAP effects on expected real U.S. bond yields somewhat exceed those implied by portfolio choice model, but the changes in international bond yields are consistent with such a model. Exchange rates changes at the time of the LSAP announcements are smaller than—but in the same direction as—those implied by an "overshooting" effect produced by UIP and long-run purchasing power parity (PPP). Overall, the evidence is consistent with a strong

[3] Kozicki, Santor and Suchanek (2010) use time series regressions to estimate how changes in central bank balance sheets affect international 5- and 10-year forward interest rates over 28-year samples.
[4] There have been studies of the international effect of short-term interest rate changes: Valente (2009) examines how interest rates in Hong Kong and Singapore respond to the unexpected component of U.S. federal funds target announcements.

but plausible portfolio balance effect, coupled with a flight to quality that mitigated the predicted exchange rate effects. These findings reinforce and significantly extend the view of Gagnon et al. (2010) that central banks retain effective tools at the zero bound.

1. The LSAP Events

The LSAP program consisted of suggestions of possible future purchases, firm statements of planned purchases, including time-frames and quantities, and announcements of purchase slowdowns and a cutback. FOMC statements and speeches described the motives for these asset purchases in several ways but repeatedly returned to the themes of directly supporting credit markets—especially for housing—to increase the availability and affordability of credit with the ultimate goal of stimulating the economy. That is, the intermediate goal was to reduce medium- and long-term U.S. interest rates.

To determine the impact of these purchases, we must look at announcement effects because efficient markets should react to news about future asset values, not to expected transactions. Examination of press releases, FOMC member speeches, FOMC statements, and news reports confirms Gagnon et al.'s assessment that 8 events/announcements associated with the LSAP program had potentially important information: 5 of those events discussed purchases or suggested future purchases; 3 discussed slowing and/or limiting purchases. Table 1 describes the time and information content of those 8 events.

The FOMC announced purchases or suggested possible future purchases 5 times: On November 25, 2008, the Federal Reserve announced purchases of up to $100 billion of GSE debt and up to $500 billion in MBS in response to widening GSE debt spreads and housing credit market turmoil. On December 1, 2008, Chairman Bernanke cited the limited ability of conventional monetary policy to further influence financial conditions—the Federal funds target

was one percent—and mentioned possible purchase of "longer-term Treasury or agency securities on the open market in substantial quantities." The December 16, 2008, FOMC press release said that the Federal Reserve was evaluating the possibility of buying long-term Treasury debt. The January 28th FOMC statement reiterated that the Fed stood ready to buy additional agency and Treasury debt if such actions would help credit market conditions.[5] This failure to actually announce purchases disappointed markets, but the FOMC soon announced such specific plans on March 18, 2009: "The Committee decided today to increase the size of the Federal Reserve's balance sheet further by purchasing up to an additional $750 billion of agency mortgage-backed securities, bringing its total purchases of these securities to up to $1.25 trillion this year, and to increase its purchases of agency debt this year by up to $100 billion to a total of up to $200 billion. Moreover, to improve credit market conditions, the Committee decided to purchase up to $300 billion of longer-term Treasury securities over the next six months."

These purchases were of unprecedented size. Gagnon et al. (2010) estimate that the $1.725 trillion dollar total debt purchase is 22 percent of the 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 also excludes U.S. corporate debt, which is appropriate in view of the extreme behavior of corporate-Treasury spreads during this period.

To briefly summarize Gagnon et al. (2010) on the 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 most heavily in 4- to 10-year and "underpriced" issues. The rate of purchase was fairly steady, but increased (decreased) when liquidity was good (poor).

[5] Arguably, the January 28th release should be classified as a sell event because it reduced market expectations of asset purchases. I choose to classify it as a buy event because the actual language discussed additional purchases and I do not wish to classify events based on the ex post price reaction but on the announcement language.

Three announcements caused the public to expect slower or reduced purchases: On August 18, 2009, the FOMC statement announced that the Treasury purchases would be finished by the end of October, rather than September 18, as originally announced. On September 23, 2009, the FOMC statement said that agency debt and MBS purchases would be slowed and finished by the end of 2010Q1, rather than the end of 2009. On November 4, 2009, the FOMC reduced the planned purchase of agency debt from $200 billion to $175 billion.

2. What To Expect?

2.1 A portfolio balance model of real bond returns

Gagnon at al. (2010) strongly argue that the LSAP reduced U.S. yields through a portfolio balance effect: By removing duration and convexity from private portfolios, the LSAP reduced the return required for holding a diminished amount of this risk.[6] One would like to quantify how much of a portfolio balance effect to expect from a given purchase announcement, however. To determine this, we consider how reducing available supply affects the portfolio choice of a mean-variance investor who represents all agents except the Federal Reserve and the U.S. government. The investor chooses an N-by-1 vector of portfolio weights (w) to maximize the following function of asset returns:

$$\max_w w'\mu - 0.5\gamma w'Vw, \tag{1}$$

where μ is the N-by-1 vector of expected net returns on the assets, V is the N-by-N covariance matrix of the asset returns and γ is the investor's coefficient of relative risk aversion. The following expression gives the optimal portfolio weights:

[6] Long-term yields are the sum of average expected future short rates and the risk premium. The term premium, which compensates investors for the risk of rising interest rates, is the major component of the U.S. Treasury risk premium; credit and liquidity premia also contribute to MBS and agency debt risk premia. Convexity denotes the tendency of bonds with prepayment risk, such as MBS, to fall in duration as interest rates rise.

$$w = \frac{1}{\gamma} V^{-1} \mu.^{7} \quad (2)$$

If the Federal Reserve purchases a large portion of some 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 commensurately. Some linear combination of expected returns on the N assets must change to induce the investor to willingly reduce his holdings of the asset, or the quantity demanded would exceed the quantity supplied.[8] After an asset purchase that changes the public's portfolio weights from w_0 to w_1, the change in the expected asset returns, Δμ, would be given by the following:

$$\mu_1 - \mu_0 = \gamma V (w_1 - w_0) = \Delta\mu. \quad (3)$$

Equation (3) assumes that the LSAP program does not change the covariance matrix of returns. This assumption is probably a reasonable approximation.

This analysis assumes that agency debt and agency MBS are very close substitutes for the nominally riskless Treasury debt. Although the Federal government did not formally guarantee debt from Fannie Mae and Freddie Mac prior to putting them under conservatorship in September 2008, financial markets have long believed that the U.S. government would not allow these agencies to default on their obligations and consequently lent to those organizations at rates that remained only modestly above Treasury rates. The Treasury explicitly guaranteed agency liabilities in September 2008 and Treasury officials have since reiterated this promise (e.g., Barr (2010)). Therefore Treasuries and agency obligations are extremely close substitutes—essentially the same asset—for international portfolio choice decisions.

While it is most natural to think of a large purchase of those domestic securities affecting

[7] Campbell (1999) discusses this portfolio choice model, concluding that omitting assets and extending the model with intertemporal hedging demand does not affect substitutability of assets.
[8] Doh (2010) describes the evidence on the effect of supply shifts in several contexts.

U.S. Treasury and agency bond prices/yields, equation (3) shows that the prices/returns on all correlated assets—especially those on closely correlated assets such as high-quality, long-term foreign bonds—will generally need to adjust to clear markets. Specifically, if the decrease in available quantity of Treasuries raises their price, then investors will tend to purchase the now relatively cheaper debt of similar quality—i.e., sovereign debt of other developed countries—driving up the price of that debt. Equation (3) shows that the change in the expected returns to country k's bonds is the product of the reduction in the weight of U.S. bonds in the market and the covariance between the real U.S. bond returns of country k and those of the United States.[9] That is, the LSAP programs should not only raise prices/reduce expected returns on MBS, agency debt, and Treasuries, but should also reduce expected real U.S. returns on foreign bonds with positively correlated returns.

Is foreign long-term sovereign debt a close substitute for U.S. debt of similar maturity? Comovement of yields and returns suggests that it is. Figure 1 illustrates U.S., Australian, Canadian, German, Japanese, and U.K. 10-year bond yields from January 1, 2005, through April 26, 2010. Using data from January 1985 through May 2010, correlations in monthly 7- to 10-year real, U.S. bond returns for the U.S., Canada, Germany, and U.K. vary from 0.35 for the U.S.-U.K. bond return to 0.69 for the German-U.K. bond return.[10] Because international bond returns are imperfectly correlated, the announcements of purchases of U.S. bonds reduced U.S. bond yields more than foreign bond yields.

Of course, the LSAP program increased bank reserves commensurately with the decrease

[9] Note that the change-in-weights vector, $(w_1\text{-}w_0)$ in (3), consists of zeros, except for the element reflecting U.S. weights, which is equal to -0.22 times the original weight on U.S. bonds. Although the change-in-return calculation in (3) would appear to depend on γ, it does not. The original portfolio weights are calculated from equation (2): $w_0 = \frac{1}{\gamma} V^{-1} \mu$ and the new portfolio weight vector, w_1, equals w_0, except for a 22 percent reduction on the U.S. bond share in w_0. Therefore the risk-aversion parameter does not affect the change-in-return calculation in equation (3) because its value in the numerator of (3) is cancelled by its effect on the denominators of the formulas for w_0 and w_1.

[10] Warnock and Warnock (2009) find international capital flows substantially affect long-term U.S. interest rates.

in public bond holdings. The increase in bank reserves reflects a strong desire for safe, liquid assets that the simple portfolio balance model is ill-equipped to model with its focus on the means and covariances of asset returns. Therefore the benchmark portfolio balance model does not directly model the market for bank reserves.

The simple portfolio balance model in equation (3) implies expected real return changes that the LSAP program might produce by reducing the non-U.S.-government portfolio weight on U.S. debt by 22 percent. Using 303 real monthly returns in USD, 1985:02 to 2010:04, on the S&P 500, and U.S., Canadian, British, Japanese, and German 10-year bond indices to estimate μ and V, equation (3) implies that a 22 percent reduction in the quantity of long-term U.S. debt would reduce the expected U.S. bond real return by 88 basis points and the foreign expected real returns (in terms of U.S. goods) by 57 to 76 basis points, depending on the country. For simplicity, these calculations assume that V is homoskedastic.

To measure the effect of sampling variation on the estimates of μ, V and expected returns, I drew 1000 samples of 303 observations from the six return series, maintaining the whole sample contemporaneous covariance but sampling independently over time, and used those to construct 1000 estimates of μ, V and the estimated change in expected returns. These calculations produced a 90 percent confidence interval of 29 to 150 basis points for the expected real return to U.S. debt and approximately 20 to 134 basis points—varying with the country—for the expected real returns in U.S. goods to the Canadian, British, Japanese, and German 10-year bond indices. [11]

[11] To test the robustness of the results to possible time variation in the data generating process, I repeated the exercise with a subsample consisting of the return observations from 2000:01 to 2010:4. The sampling distributions for μ, V and the estimated change in expected returns had significant overlap with those from the full sample and were consistent with those results. The more recent data predicted somewhat smaller expected asset return changes than the full sample: a 40 point fall in U.S. 10-year bond real returns and 20-to-40 b.p. declines in the real returns to the 10-year bonds of the other countries. In addition, the portfolio balance model predictions were also robust to excluding Japan.

One observes announcement effects on bond prices/yields; one does not observe the expected holding period returns from the portfolio balance model. A fully specified term structure model could relate expected holding period returns to changes in yields but that would be of questionable value in a time of such unusual bond market behavior. If the market believed that the changes in expected returns applied throughout the N-year life of the securities, however, then the change in expected returns would translate directly into changes in yields, as the yield is just the average annual return over the life of the security. On the other hand, if markets expect the LSAP purchases to be actively reversed over the maturity of the security, the announcement-effect changes in expected returns would overstate the changes in expected yields. The latter assumption seems to be reasonable. The changes in expected returns probably overstate the magnitude of changes in yields but it is difficult to say by how much.

2.2 Bond yields and the time path of exchange rates

The portfolio choice model implies that a purchase of U.S. debt would tend to reduce expected U.S. returns at least as much as expected returns on foreign debt. This difference in expected returns will very likely translate into differences in relative yields that should affect expected exchange rate changes. If U.S. yields decline more than foreign yields, for example, UIP would predict that the USD must be expected to appreciate over the relevant horizon, compared to its previous sample path. This subsection describes what sort of exchange rate changes that UIP-PPP parity conditions imply, conditional on the LSAP bond yield changes.

But why consider UIP effects, given UIP's empirical failure when applied to floating exchange rates? [12] UIP remains a benchmark for foreign exchange behavior for several reasons. First, UIP's failure has three important exceptions. Flood and Rose (1996) have shown that UIP

[12] Hodrick (1987) documents UIP's failure and Engel (1996) reviews the early literature on the topic.

performs much better for target zone exchange rates where expectations are tied down; Chaboud and Wright (2005) have shown that UIP holds over very short horizons; and—most relevant for the present study—Chinn and Meredith (2004) and Chinn (2006) have shown that UIP holds over very long horizons. Second, UIP remains intuitively attractive and a workhorse of economic modeling, despite the complications that poorly understood risk premia and/or volatile expectations probably produce.

UIP implies that the expected change in the exchange rate over a horizon of N years should be a function of interest differentials at that horizon. This should be true both before and after the announcement.[13] That is,

$$E_{t^-}(s_{t+N}) \approx s_{t^-} + N\left(i^{foreign}_{t^-,N} - i^{US}_{t^-,N}\right) \qquad \forall N \in \mathbb{R} \tag{4}$$

and

$$E_t(s_{t+N}) \approx s_t + N\left(i^{foreign}_{t,N} - i^{US}_{t,N}\right) \qquad \forall N \in \mathbb{R} \tag{5}$$

where the expectations operators E_{t^-} (E_t) denote expectations taken prior to (after) the announcement at time t, s_{t+N} is the log of the foreign-currency-per-dollar in period t+N, s_{t^-} (s_t) is the log exchange rate just before (after) the announcement and,$i^{foreign}_{t^-,N}$ and $i^{US}_{t^-,N}$ ($i^{foreign}_{t,N}$ and $i^{US}_{t,N}$) are the logs of the gross yields of foreign and U.S. zero-coupon debt over N years before (after) the announcement.

The announcement effect on the expected exchange rate in N years is (5) less (4).

$$E_t(s_{t+N}) - E_{t^-}(s_{t+N}) \approx s_t - s_{t^-} + N\left(i^{foreign}_{t,N} - i^{US}_{t,N}\right) - N\left(i^{foreign}_{t^-,N} - i^{US}_{t^-,N}\right) \ \forall N \in \mathbb{R} \tag{6}$$

Are the UIP-implied "jumps" in the exchange rate at the time of the announcement, $(s_t - s_{t^-})$ in (6), consistent with the actual, measured jumps in exchange rates? Two reasonable assumptions about long-run exchange rate expectations enable one to calculate the UIP-implied jump.

[13] Equations (4) and (5) are log approximations of the UIP relation $E[S(t+N)] = S(t)*(1+ i^{for}(t,N))^N/ (1+ i^{US}(t,N))^N$.

- Assumption 1: PPP holds in the long run; the real exchange rate is stationary. Therefore the long-run expectation of the real exchange rate, q_t, is always approximately the unconditional mean of the real exchange rate, $\bar{q}$.

$$E_{t^-}\left(s_{t+N} - p_{t+N}^{foreign} + p_{t+N}^{US}\right) = E_t\left(s_{t+N} - p_{t+N}^{foreign} + p_{t+N}^{US}\right) \approx \bar{q} \qquad \text{for large N} \tag{7}$$

Assumption 1 implies that the expected long-run nominal rate after the announcement is the expected long-run nominal rate prior to the announcement plus the announcement effect on expected long-run relative price levels (i.e., $\Delta E_{t^-,t}\left(p_{t+N}^{foreign} - p_{t+N}^{US}\right)$):

$$E_t(s_{t+N}) - E_{t^-}(s_{t+N}) \approx E_t\left(p_{t+N}^{foreign} - p_{t+N}^{US}\right) - E_{t^-}\left(p_{t+N}^{foreign} - p_{t+N}^{US}\right), \qquad \text{for large N}$$

$$E_t(s_{t+N}\ ) - E_{t^-}(s_{t+N}) \approx \Delta_{t^-,t}E_t\left(p_{t+N}^{foreign} - p_{t+N}^{US}\right), \qquad \text{for large N.} \tag{8}$$

where $\Delta_{t^-,t}$ denotes the change in a variable at the time of the announcement at time t.

- Assumption 2: The long run is 10 years, which is the longest maturity of consistent BIS zero-coupon data.

Equating the right-hand sides of (6) and (8) and rearranging provides an expression for the announcement jump size in terms of changes in observable interest and price level differentials.

$$s_t - s_{t^-} \approx -N\left(\Delta_{t^-,t}i_{t,10}^{foreign} - \Delta_{t^-,t}i_{t,10}^{US}\right) + \Delta_{t^-,t}E_t\left(p_{t+N}^{foreign} - p_{t+N}^{US}\right)$$

$$\approx \left(N\Delta_{t^-,t}i_{t,10}^{US} - \Delta_{t^-,t}E_t p_{t+N}^{US}\right) - \left(N\Delta_{t^-,t}i_{t,10}^{foreign} - \Delta_{t^-,t}E_t p_{t+N}^{foreign}\right). \tag{9}$$

That is, the jump size equals the change in the relative expected long run real interest rate.

Intuitively, UIP requires expected dollar appreciation over the long run, compared with its previous expected path, because the LSAP "buy" events reduced U.S. real yields relative to foreign real yields. But if the long-run real exchange rate is unchanged, then the dollar must jump depreciate at the time of the announcement, as in the Dornbush (1976) "overshooting"

model.[14] One can compare the implied exchange rate jump in (9) with the observed change in the exchange rate during the announcement windows to test the UIP-PPP model.

2.3 What do changes in real U.S. returns imply for yields on foreign bonds?

Are observed changes in foreign bond yields (in the foreign currency) consistent with the portfolio balance model's predictions about expected real returns in U.S. goods? The nominal return in the foreign currency is the real return to the foreign bond in terms of U.S. goods ($r_t^{for,US\ goods}$) plus the appreciation of the dollar, plus U.S. inflation.

$$r_t^{for,FX} = r_t^{for,US\ goods} + \Delta S_t + \pi_t^{USD} \tag{10}$$

where $r_t^{for,FX}$ is the nominal return to the foreign bond in a foreign currency, ΔS_t is the change in foreign currency units per USD, and π_t^{USD} is the U.S. inflation rate. Applying the expectations and difference operators to (10), the expected change in the foreign nominal return is as follows:

$$\Delta_{t^-,t} E r_{t+1}^{for,FX} = \Delta_{t^-,t} E r_{t+1}^{for,US\ goods} + \Delta_{t^-,t} E \Delta S_{t+1} + \Delta_{t^-,t} E \pi_{t+1}^{USD} \tag{11}$$

where $\Delta_{t^-,t} E r_t^{for,US\ goods}$ is the change in the expected return on foreign bonds in U.S. goods during the LSAP window(s). The change in the foreign bond's expected nominal return at an LSAP announcement is the sum of the changes in the foreign bond's expected real return in U.S. goods, the expected appreciation of the USD, and the expected U.S. inflation rate.

To determine if the observed changes in foreign nominal bond yields are consistent with the portfolio balance model's predictions about expected real returns in U.S. goods, we can compare the observed changes in yields with the sum on the right hand side of (11), where the change in the expected real U.S. return on foreign bonds comes from the portfolio balance model, relative 10-year BIS zero-coupon bond yields measure expected USD appreciation and

[14] This jump depreciation is consistent with efficient markets because it occurs immediately and is unanticipated. The jump depreciation permits both UIP to hold continuously and PPP to hold in the long run. That is, the overshooting model assumes that financial markets adjust continuously but that goods prices may be sticky.

observed Treasury inflation-protected securities (TIPS) spreads measure changes in expected U.S. inflation. All changes are calculated during the LSAP buy announcement windows.

In summary, the portfolio balance and UIP-PPP models make three testable predictions about asset prices during LSAP windows: 1) U.S. long-bond expected real returns—or their equivalent in real yields—fall 29 to 150 basis points; 2) the USD jump depreciates according to equation (9); 3) foreign 10-year, expected real returns in U.S. goods fall 20 to 134 basis points.

3. Methods

Because asset prices react relatively rapidly to "news" that shapes market participants' views of fundamentals, an event study of the LSAP announcement effects is most appropriate. Event studies assume that causality runs one way from the announcements to the asset returns.[15] That is, policymakers determine the announcement prior to observing asset price movements within the announcement window; so, the latter changes have no effect on the announcement.

Event studies have often used very high frequency data to precisely measure the rapid asset price changes usually seen after macro announcements. LSAP announcements might produce protracted adjustment periods, however. In fact, the announcement literature has shown that unexpected news or heterogeneous interpretations of news will extend adjustment periods (e.g., Almeida, Goodhart, and Payne (1998), Love and Payne (2008) and Gagnon et al. (2010)). For example, Evans (2010) interprets evidence in Carlson and Lo (2006) to indicate that the market took hours to fully adjust to a surprise Bundesbank interest rate hike. Therefore, this study will initially consider a relatively long, 2-day window around the announcements before

[15] Rigobon and Sack (2004) point out that one way to think about the econometrics of an event study is that, in a sufficiently short interval around the announcement, the variance of the announcement shock is arbitrarily large compared with the variance of the shock to the asset price, meaning that the effect of the announcement on the asset price is identified. Rigobon and Sack (2004) alternatively suggest identifying the responses of asset prices to interest rate shocks with a heteroskedasticity dependent method. 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.

turning to intraday data for high frequency analysis.[16]

Typical studies of macro announcement effects pool estimates of reactions across many events, assuming a constant relation between the unexpected portion of the announcement and the asset price movement.[17] Unfortunately, it is difficult to separately quantify the effect on expectations of each of the 8 LSAP announcements because one cannot easily measure LSAP expectations. Some announcements might have been partially expected, and so the surprise component was small; other events might have induced large expectations of purchases although no actual purchases were announced. One might think, however, that the combined set of LSAP announcements correctly informed market expectations about the eventual size of the program. Therefore this paper considers separate effects for each of the 8 LSAP announcements, as well as the sum of the "buy" and "sell" effects.

To illustrate the size of the LSAP announcement effects compared with ordinary news, I compare the LSAP reactions to the historical distributions of 2-day asset price changes. In addition, I follow Gagnon et al. (2010) in comparing the LSAP effects with those of FOMC announcements that contain no information about the LSAP. These results—omitted for brevity — confirm that the LSAP announcements affected yields much more than other FOMC news.

If all changes in LSAP expectations occur within the event windows and the LSAP drives all changes in expectations during event windows, then the sum of the event window yield changes exactly measures the impact of the LSAP. The changes in LSAP expectations outside the event windows or a non-zero net effect of non-LSAP news within the event window—e.g.,

[16] The overall results with 1-day and 2-day windows produced qualitatively comparable inference. The 2-day changes in yields/prices tended to be of the same sign and larger than the 1-day changes, however, suggesting a protracted market adjustment to these unusual LSAP announcements. The U.S. Baa and 30-year mortgage yields and expected U.S. inflation exhibited the largest discrepancies between the 1- and 2-day windows. The U.S. Baa and 30-year mortgage yields cumulatively fell 26 and 27 more basis points, respectively, during the 2-day windows than during the 1-day windows. 10-year expected U.S. inflation was particularly volatile, being cumulatively about 45 basis points higher over the 2-day windows than over the 1-day windows.

[17] Neely and Dey (2010) survey the literature on foreign exchange return reactions to macro announcements.

macro announcements—could bias the event window sum. For example, if markets anticipated the LSAP prior to the November 25, 2008, window, then yields would have fallen prior to that date and the LSAP event sum would underestimate the true fall. Conversely, if markets falsely expected significant extensions of the LSAP at the final buy announcement, then the LSAP event sum would overstate the true LSAP effect.

How important are these biases? First, the initial LSAP release seems to have been largely unexpected; the bond market reaction was sizeable and news reports did not mention that it was anticipated. Second, it is difficult to find clear evidence of falling LSAP expectations after the final buy announcement on March 18. Third, analysis of high frequency data shows that the LSAP events dominated systematic asset price movements during the event windows, despite the presence of news events during the LSAP windows. The event window sum is an imperfect measure of the LSAP's effects—and one can argue about what events to include or how big to make the windows—but it is a reasonable measure.

4. The Data

The Bank for International Settlements (BIS) provided daily data on U.S. and foreign 10-year zero-coupon interest rates and short-term rates. Haver Analytics provided further daily bond yields, U.S. TIPS-implied inflation expectations, daily exchange rates, and equity prices. The long-term interest rates were the U.S. 10-year Treasury, constant-maturity yield, Moody's Baa yield, the *Wall Street Journal*'s 30-year fixed mortgage rate, and the Australian, Canadian, German, Japanese and U.K. 10-year government bond yields. The daily exchange rate data on the AUD/USD, CAD/USD, EUR/USD, JPY/USD, and GBP/USD were from the H.10 release, recorded at the New York close. The daily equity index data were from the U.S. S&P 500, the Australian All Ordinaries index, the Canadian S&P/TSX Composite index, the German Xetra

Dax index, the Japanese Nikkei 225, and the U.K. *Financial Times* All Share index. Bloomberg was the source for inflation swaps data for the United Kingdom and the euro area. Tickwrite provided futures prices on Canadian, German, British, Japanese, and U.S. bonds and the S&P 500. Disktrading provided intraday spot exchange rate data on the AUD/USD, CAD/USD, EUR/USD, JPY/USD, and the GBP/USD.

5. The Effect of LSAP on International Asset Prices

5.1 Daily results

Table 2 shows the bond yield changes around 5 LSAP buy and 3 LSAP sell events for U.S., Australian, Canadian, German, Japanese, and U.K. long-term bonds. Confirming Gagnon et al. (2010), buy events are usually associated with large reductions in long-term U.S. interest rates in the 2-day windows. Specifically, the U.S. 10-year constant Treasury yield fell by a cumulative total of 107 basis points around the 5 buy events while the Baa 10-year rate and the WSJ 30-year mortgage rate fell by 78 and 38 basis points, respectively.[18] To provide some perspective on how likely such changes were, Table 2 shows the percentage of 2-day bond yield changes for each series that exceeded the observed reaction in absolute value. The numbers in parentheses beneath the "event sum" row show the probability (p-values) that the sum of 5 randomly chosen 2-day price changes would exceed those of the 5 buy day event windows. The responses on LSAP announcement days are usually very large compared with the distribution of all 2-day changes in yields and the sum of the changes over the 5 buy events is always exceedingly unlikely to be observed if there was nothing special about the LSAP events. That is, the p-values for the "event sums" are essentially zero.

[18] The 30-year mortgage rate, which is a retail rate, responds sluggishly to LSAP news. Wider windows show larger responses for the 30-year mortgage rate and the Baa rate.

The increase in Treasury and Baa yields on January 28, 2009, deserves some 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 probably significantly increased long yields by reducing market expectations for Treasury purchases.

The lower panel of Table 2 shows that the three sell events—in which previously announced purchases were marginally delayed or scaled back—did not strongly or consistently affects U.S. bond yields, presumably because they changed expectations very little in comparison with several of the LSAP buy announcements. That is, the first two sell announcements merely delayed the pace of purchases somewhat and the third sell announcement merely scaled back one component of the purchase by $25 billion, only 1.45 percent of the total announced LSAP purchase of $1.725 trillion.

The right-hand side of Table 2 shows that the LSAP buy announcements were also—if more remarkably—associated with large changes in foreign bond yields: Australian, Canadian, German, Japanese, and British long bond yields cumulatively fell by 78, 54, 50, 19, and 65 basis points during the same 5 buy event windows.[19] Japanese long yields were already much lower than those of other countries (see Figure 1), which probably accounts for their relatively small reaction. P-values in parentheses show that the individual yield changes during buy event windows were often very large compared with typical 2-day changes during the 2005-2010 sample. Similarly, the p-values for the "event sum" rows show that there is essentially no chance that one would randomly obtain foreign yield drops as large as those observed during the LSAP buy announcement days. 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.

[19] A study with BIS 10-year zero coupon yields instead of the Haver bond yields produced very similar results.

One might think that any FOMC announcement strongly affected U.S. and/or foreign bond yields in this period. To investigate this possibility, I calculated the effect of 13 "non-LSAP" FOMC announcements—days in which there were no significant news about the LSAP program—during the December 2008 to February 2010 sample. Although I omit the full results for brevity, the non-LSAP changes are much smaller and tend to be slightly positive, at least for the government bond yields. The very modest rise in government bond yields on these days probably reflects the reversal of the September 2008 flight-to-quality and the removal of market expectations of LSAP expansion. That is, every Fed announcement that did not expand the LSAP marginally increased yields as buy expectations were extinguished. The contrast in yield changes between LSAP buy days and other types of FOMC news indicates that the LSAP announcements really did reduce yields.

Did the LSAP announcements of long-term debt purchases also influence short-term yields? Table 3 documents little strong or consistent movement of international short-term rates during the LSAP buy and sell windows. U.S. short-term rates fell modestly on some announcements, mostly before the federal funds target hit zero on December 16, 2008, but the LSAP announcements had very little effect on foreign short-term interest rates. This lack of response from short-term interest rates is consistent with the argument of Gagnon et al. (2010) that the LSAP did not affect expected short rates significantly but rather lowered bond risk premia by reducing the required return for holding duration and convexity.

Table 4 shows the LSAP announcement effects on the foreign exchange value of the USD during the same event windows. The USD cumulatively declined by 3.6 to almost 10.8 percent—depending on the currency—over the 5 buy days, and these declines were very large

compared with the typical movements in the value of the dollar.[20] The chance that the USD would depreciate so strongly if the LSAP buy events contained no unusual information is no greater than 10 percent for all the exchange rates. In contrast, the LSAP sell events had no large or consistent effect on the value of the dollar. Although I omit the full results for brevity, there was only a modest tendency for the dollar to depreciate on the 13 "non-LSAP" FOMC announcement windows. The movements on the "non-LSAP" days were not nearly as large, on average, as on LSAP buy days and were not consistent across exchange rates. The USD appreciated, for example, against the JPY during the 13 "non-LSAP" control days.

5.2 Intraday analysis

The daily event studies strongly suggest that the LSAP announcements significantly reduced U.S. and foreign bond yields, as well as the foreign exchange value of the dollar. Intraday bond futures and exchange rate data confirm that the LSAP announcements were almost certainly responsible for those asset price changes. Figures 2 through 6 show the intraday time paths of the long bond futures prices (top panels), foreign exchange rates (center panels), and S&P 500 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 value at the time of the announcement.

Figure 2 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, and Japanese bond futures (top panel). The

[20] 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.

reaction in the foreign exchange market (center panel) was somewhat 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 Japanese bond yields shown in Figure 1 probably help explain the very modest Japanese bond futures and foreign exchange reactions in Figure 2. The bottom panel of Figure 2 shows that the U.S. equity futures market—the S&P 500—rose immediately after it opened at 9:30 AM.

On December 1, 2008, Chairman Bernanke gave a speech that suggested that the Federal Reserve could buy Treasuries if the situation warranted. Figure 3 illustrates that this idea elicited a strong and more immediate bond market response than the November 25 release: U.S. and foreign bond futures prices climbed immediately. Foreign exchange markets did not react strongly or consistently to the speech, however.

The December 16 FOMC release that mentioned possible purchases of Treasuries also produced sizeable increases in U.S., British, German, and Canadian bond futures prices, as well as a 1 to 3 percent depreciation of the dollar, which Figure 4 displays. Equity markets also appeared to react positive to the press release, which also reduced the federal funds target from 1 percent to a range of 0 to 25 basis points.

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 at the time of the FOMC statement's release at 2:15 PM (see Figure 5). The combination of bond price declines and dollar appreciation is consistent with reduced expectations of bond purchases.

Finally, Figure 6 shows that the March 28 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. Prices appear to move faster on March 28 than after previous announcements, suggesting that views were becoming less heterogeneous.

In summary, almost all of the substantial foreign bond market and exchange rate reactions were at or very soon after the estimated times of the announcements, confirming that the LSAP announcements produced substantial price changes in U.S. and foreign assets. The markets often took hours to fully price the announcements, however. The reaction pattern was fairly consistent: 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.

6. Discussion

Section 2 made three testable predictions from the portfolio balance model and UIP-PPP parity conditions about asset prices during LSAP windows: 1) U.S. long-bond expected real returns—or their equivalent in real yields—fall 29 to 150 basis points; 2) the USD jump depreciates according to equation (9); 3) the foreign long-bond nominal yields fall in line with the predictions of the portfolio choice model for real returns in U.S. goods and equation (11). This section evaluates the extent to which the data bears these predictions out.

6.1 Portfolio balance effects and expected real U.S. bond returns

Section 2.1's simple portfolio model predicted changes in real holding period returns on U.S. bonds, but the observed changes are in nominal yields. Although a full term structure model would be necessary to formally compare returns and yields, one can compare expected real returns to nominal yields with some reasonable assumptions and a measure of expected inflation. If the LSAP purchases had permanent effects on yields—over the life of the security—then the changes in expected U.S. real returns should be similar to the changes in expected real yields, as a bond yield is the average annual holding period return. On the other hand, if markets

expected the LSAP program to be at least partly reversed, then future expected returns would be higher than current expected returns and the actual drop in real yields at the time of the announcement should be smaller in absolute value than the predicted changes in current expected real returns.

Recall that 1) the simple model predicted that a 22 percent reduction in the quantity of U.S. debt outstanding would decrease expected real U.S. bond returns by 88 basis points and 2) a bootstrapping exercise provided a 90 percent confidence interval of 29 to 150 basis points for the expected real return to U.S. debt. Table 2 showed that nominal 10-year U.S. Treasury yields fell by 107 basis points over the 5 buy announcement windows. In addition, TIPS spreads indicate that 10-year inflation expectations rose by 80 basis points per year. This implies that real Treasury yields fell by 187 basis points, above the upper bound of the 90 percent confidence interval for real U.S. returns.

The troubled state of global credit markets in the autumn of 2008 meant that long-term high-quality asset prices were already very high, by historical standards, when the LSAP was announced. This makes the size of the falls in real U.S. Treasury yields even more surprising. It is very possible that the LSAP buy announcements were interpreted as "bad news" about the global economy and thus provoked a flight to safe U.S. assets. Such a flight would reduce required real returns to U.S. assets, both domestically and in foreign currencies.

6.2 Relative yield changes and exchange rate overshooting

Were the observed USD declines roughly consistent with Section 2's UIP-PPP model predictions, given the changes in relative yields around the LSAP buy events? Equation (9) expressed the exchange rate jump size in terms of changes in relative nominal bond yields and relative expected price levels.

$$s_t - s_{t^-} \approx -N\left(\Delta_{t^-,t} i_{t,10}^{foreign} - \Delta_{t^-,t} i_{t,10}^{US}\right) + \Delta_{t^-,t} E_t\left(p_{t+N}^{foreign} - p_{t+N}^{US}\right)$$

$$\approx \left(N\Delta_{t^-,t} i_{t,10}^{US} - \Delta_{t^-,t} E_t p_{t+N}^{US}\right) - \left(N\Delta_{t^-,t} i_{t,10}^{foreign} - \Delta_{t^-,t} E_t p_{t+N}^{foreign}\right). \quad (9)$$

Although expected inflation figures are not available for all countries, TIPS and inflation swaps data imply event window changes in relative 10-year inflation expectations for the United States and the United Kingdom and the Euro area, respectively; the BIS provides 10-year zero-coupon bond yields. These data can be used in (9) to calculate implied exchange rate jumps. The right-hand panel of Table 4 shows that the implied GBP/USD and EUR/USD jumps are negative on all the buy days, except for January 28, and typically over twice as large as the actual USD jump in the 2-day windows. Some of the discrepancy in actual and predicted jump values can be attributed to December 1, 2008, which was a day of much-better-than-predicted USD performance as bad news provoked a flight-to-safety that will be discussed in section 6.4.

Despite the discrepancy in the magnitude of event sum changes, the predictions and the observed changes in the exchange rate correspond in telling ways: The largest predicted USD depreciations—March 18, 2009, November 25, 2008, and December 16, 2008—corresponded to the dates of the three largest depreciations of the dollar against the euro and pound, respectively. And the largest predicted appreciation of the USD against the euro, January 28, 2009, was also the date of the largest actual appreciation against the euro.

6.3 Portfolio balance effects and expected foreign bond returns

The bootstrapping exercise based on the portfolio balance model produced a 90 percent confidence interval of approximately 20 to 134 basis points—depending on the bond—for the change in the expected real (in U.S. goods) returns to the Canadian, British, Japanese, and German 10-year bond indices. To determine if the changes in nominal foreign bond yields are

consistent with this prediction about expected real returns in U.S. goods, we can compare the observed changes in foreign yields with the sum of three terms on the right-hand side of (11):

$$\Delta_{t^-,t} E r_{t+1}^{for,FX} = \Delta_{t^-,t} E r_{t+1}^{for,US\ goods} + \Delta_{t^-,t} E \Delta S_{t+1} + \Delta_{t^-,t} E \pi_{t+1}^{USD}. \quad (11)$$

The portfolio balance model implies the change in the expected real U.S. return on foreign bonds, relative 10-year BIS zero-coupon bond yields measure expected annual USD appreciation and TIPS spreads measure changes in expected U.S. inflation. All changes are calculated during the LSAP buy announcement windows.

Table 5 compares the observed changes in foreign bond yields for buy events with the corresponding distribution of changes in bond returns implied by the portfolio balance model, expressed in equation (11). The 4 observed buy-event-sum changes in the 10-year bond yields ($\Delta_{t^-,t} y_{10\ year,t}^{for,FX}$) are well inside the 90 percent confidence intervals for the foreign returns ($\Delta_{t^-,t} E r_{t+1}^{for,FX}$). The observed changes in foreign long yields are consistent with the portfolio balance model.

6.4 Another explanation: Markets interpreted the LSAP as signaling weak growth

The portfolio balance model implies that the LSAP purchases affected yields directly through the term premium by reducing the supply of duration risk and convexity in private portfolios. An alternative explanation for the LSAP effects is that markets interpreted the announcements as signals that the global economic outlook was much worse than anticipated. This story would interpret the declines in bond yields as reflecting expectations of much weaker growth over a period of many years.

Do the data support this "forecast of weak growth" hypothesis? Table 6 shows equity percentage returns in the 5 buy announcement windows for 6 major international equity indices: the U.S. S&P 500, the Australian All Ordinaries index, the Canadian S&P/TSX Composite

index, the German Xetra Dax index, the Japanese Nikkei 225, and the U.K. *Financial Times* All Share index. For 4 of the 5 buy event windows, equity prices were either clearly up over the window or mixed. The exception, a window of large negative returns, was November 31 to December 2, 2008. The bottom panel of Figure 3 clearly shows that the large drop in S&P 500 prices was associated with the opening return, with some further fall at the close.

There were a number of negative news reports on December 1 that might explain this bearish action. First, the U.K. Chancellor of the Exchequer promised to back retail deposits at London Scottish Bank, which market analysts interpreted as effectively backing all retail bank deposits in the U.K. This weakened the GBP and might have created further doubts about global financial stability. Second, U.S. construction spending and the ISM index both came in weaker than expected at 10 AM Eastern Time. Third, at 10:36 AM the NBER dating committee declared that the U.S. was officially in a recession.[21] All of these events could have contributed to the morning equity declines. In addition, the latter two could have weakened the dollar.

The Chairman's speech at 1:40 PM on December 1 produced significant rises in bond futures prices but essentially no movement in foreign exchange or equity markets. That is, the data are not consistent with the idea that the December 1 bond market reaction to the Chairman's speech was purely or mostly due to lower expectations of real activity. Indeed Figures 2 through 6 confirm that the LSAP buy announcements were usually associated with either significant gains in equity prices or with very little reaction at all. The lack of consistent, large drops in equity prices during the LSAP buy windows is not consistent with the hypothesis that bond markets simply interpreted the LSAP announcements as a signal of very weak future growth.

[21] I thank Jean Roth of the NBER for personal communication on the time of the NBER's December 1, 2008 release.

6.5 Did the LSAP effects last?

Shortly after the final buy announcement on March 18, 2009, long-term Treasury yields rose fairly steadily, gaining almost 150 basis points by mid-June. Long-term sovereign debt yields from Canada, Germany, and the U.K. similarly rose during the March-to-June period (Figure 1). These changes led many observers to conclude that the LSAP failed because long yields did not remain low. Why did U.S. and foreign yields increase and does this imply that the LSAP effects did not last?

Meyer and Bomfim (2009) argue that higher expected growth, new Treasury issuance, and the return of investors' risk appetite drove the increase in Treasury yields from late March through mid-June 2009. To the extent that the LSAP increased confidence and risk appetites, it sowed the seeds of its own partial reversal; but higher confidence signals success rather than failure. A parallel rise in equity prices over the same March-to-June period tends to corroborate the explanation that higher expected growth and a rise in risk appetites raised long rates.

Does the increase imply that the LSAP's effects on yields were ephemeral? Given that uncertainty about asset prices usually rises with the forecast horizon, no one can know the LSAP's long-term effects; but the market's best guess must have been that the LSAP effects would persist because expectations of a temporary impact would have created a risk-arbitrage opportunity for investors willing to bet on the reversal of the LSAP effects. The efficient markets hypothesis implies that the immediate reaction—a significant fall in real yields—is the market's best guess of the appropriate pricing of the LSAP's effects.

7. Conclusion

This paper has illustrated that LSAP buy announcements reduced long-term U.S. bond real yields, long-term foreign bond yields, and the spot value of the dollar. The asset price

changes associated with the LSAP buy announcements were much too large to have been generated by chance and these price changes closely followed LSAP announcements.

In contrast to the strong effects associated with the creation or expansion of these asset purchase programs, the announcements of minor delays in LSAP purchases or marginal reductions in purchases had small effects. Neither did the LSAP programs influence international short-term interest rates. Likewise, FOMC announcements that were not associated with LSAP news produced relatively small and inconsistent effects on asset prices. The January 28, 2009, FOMC statement produced unusual effects. Although it mentioned the possibility of additional asset purchases, it increased U.S. and foreign bond yields and appreciated the dollar, probably because markets had priced-in a probability of expanded LSAP purchases and the lack of such news reduced purchase expectations.

U.S. real 10-year Treasury yields fell by a total of 187 basis points during the 5 LSAP buy windows. This decline is somewhat larger than those predicted by a simple portfolio choice model that was estimated using monthly data from 1985 to 2010, even accounting for sampling variability associated with the model's estimated parameters. The USD exchange rate jumps during the LSAP announcements windows are smaller than, but consistent in direction with those implied by a UIP-PPP model. In contrast, the declines in real (in U.S. goods) foreign bond yields are consistent with the changes in real returns implied by the portfolio choice model.

One plausible explanation for both the unusually large fall in real U.S. bond yields and the relatively small decline in the dollar during LSAP buy windows is that markets interpreted the LSAP buy announcements as bad news for the world economy, provoking flights to safety that further depressed U.S. yields compared with international substitutes and reduced the required return to dollar assets, which reduced the required jump depreciations at LSAP buy

announcement times. In summary, the evidence suggests that the LSAP buy announcements had strong portfolio balance effects on bond yields, but also might have increased the demand for safe assets, which magnified the LSAP effect on U.S. bond yields but mitigated the predicted exchange rate effects.

U.S., Canadian, German, and U.K. long-term sovereign debt yields all began climbing shortly after the final LSAP buy announcement in March 2009, eventually rising substantially by June 2009. Some observers have interpreted this ascent as indicating that the LSAP's effects were short-lived and therefore not useful. In fact, the parallel rise in equity prices over the same March-to-June period suggests that the LSAP successfully increased confidence and risk appetites and the efficient markets hypothesis implies that the initial impact is the best estimate of the LSAP's long-run effect.

The success of the LSAP 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. Contrary to long- and widely held conventional wisdom, large asset purchases can affect both domestic and international long rates. And monetary policy effects at the zero bound include international channels. The reduction in foreign bond yields and the value of the USD is likely to have stimulated the U.S. economy through export channels, for example. From an international perspective, these findings imply that central banks should coordinate their asset purchase policies to avoid contradictory or overly stimulative effects.

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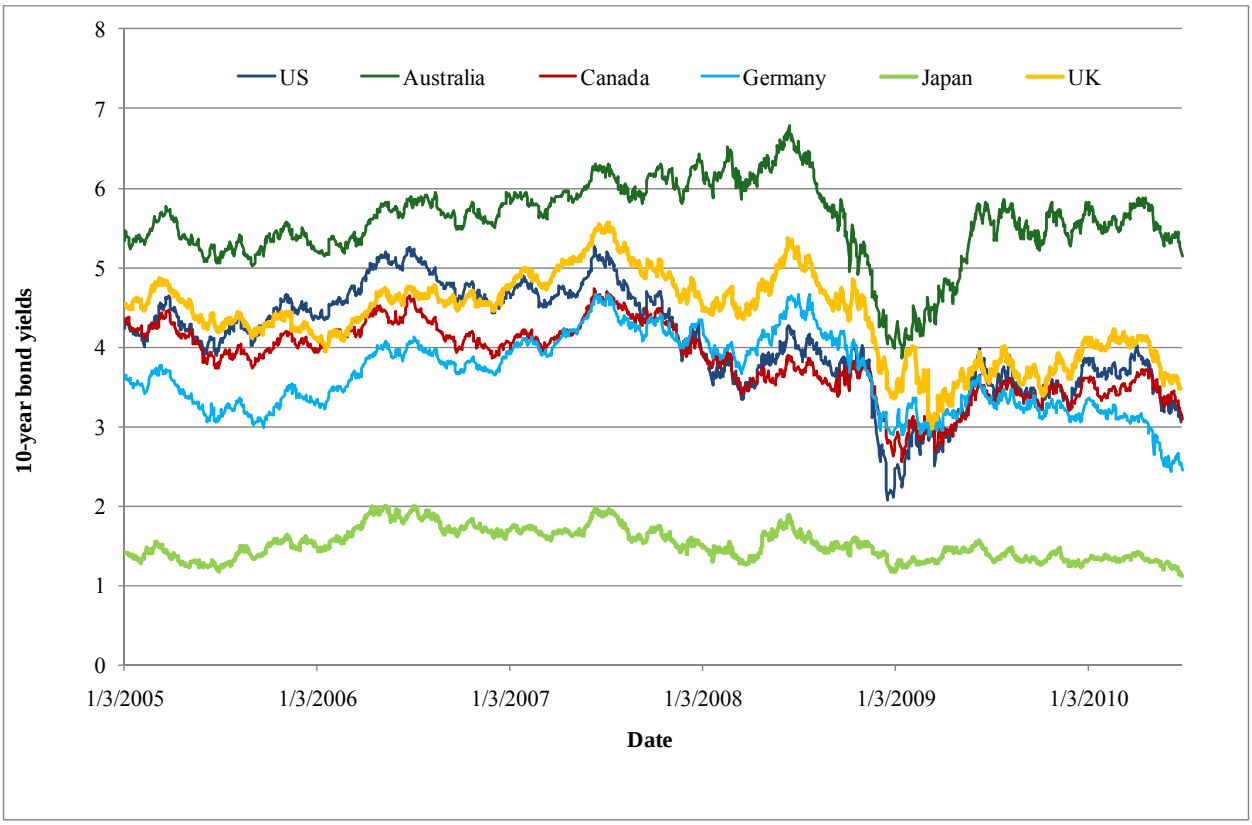
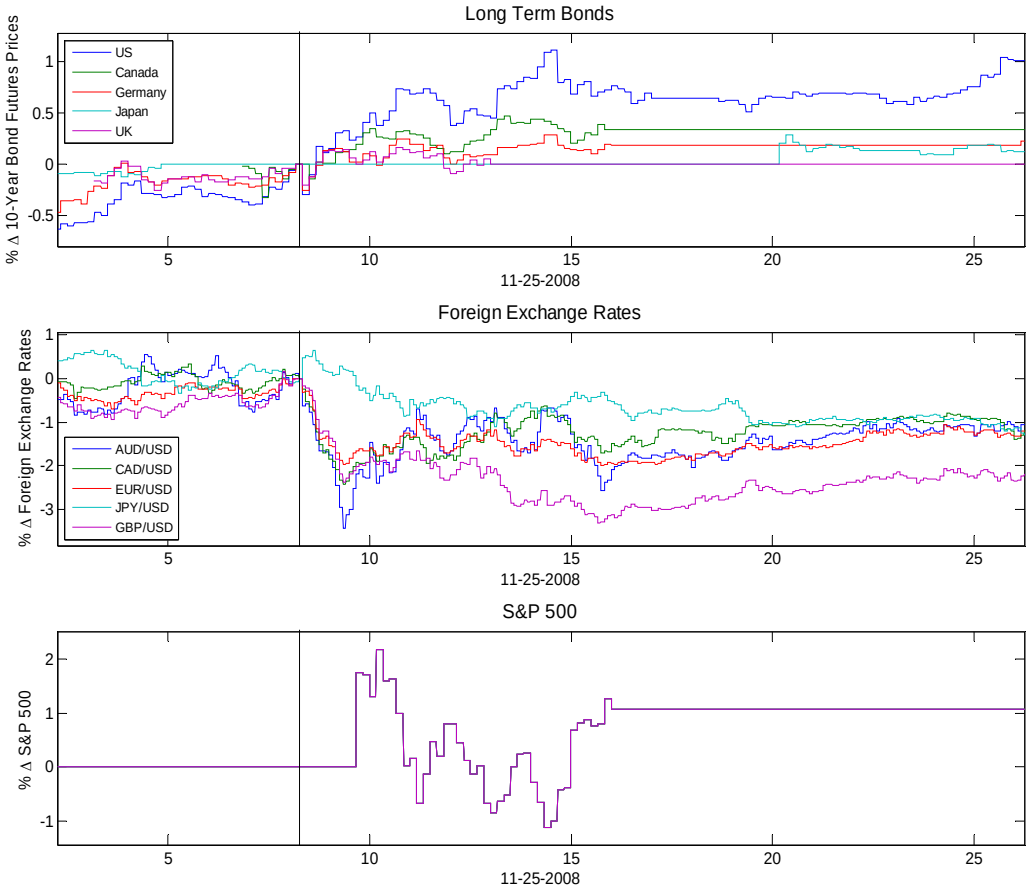
Figure 1: Yields on 10-year government bonds



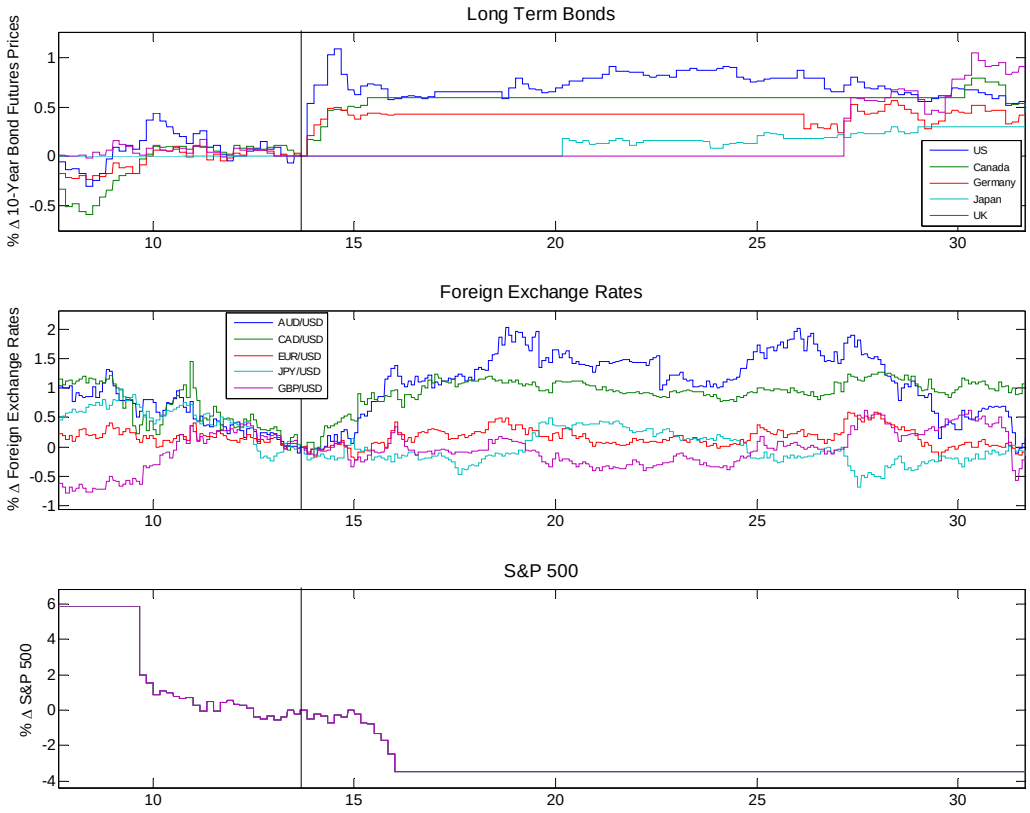
Notes: The figure depicts yields on 10-year sovereign debt for the U.S., Australia, Canada, Germany, Japan, and the U.K. The source is Haver Analytics.

Figure 2: High-frequency bond yield and exchange rate movements on November 25, 2008



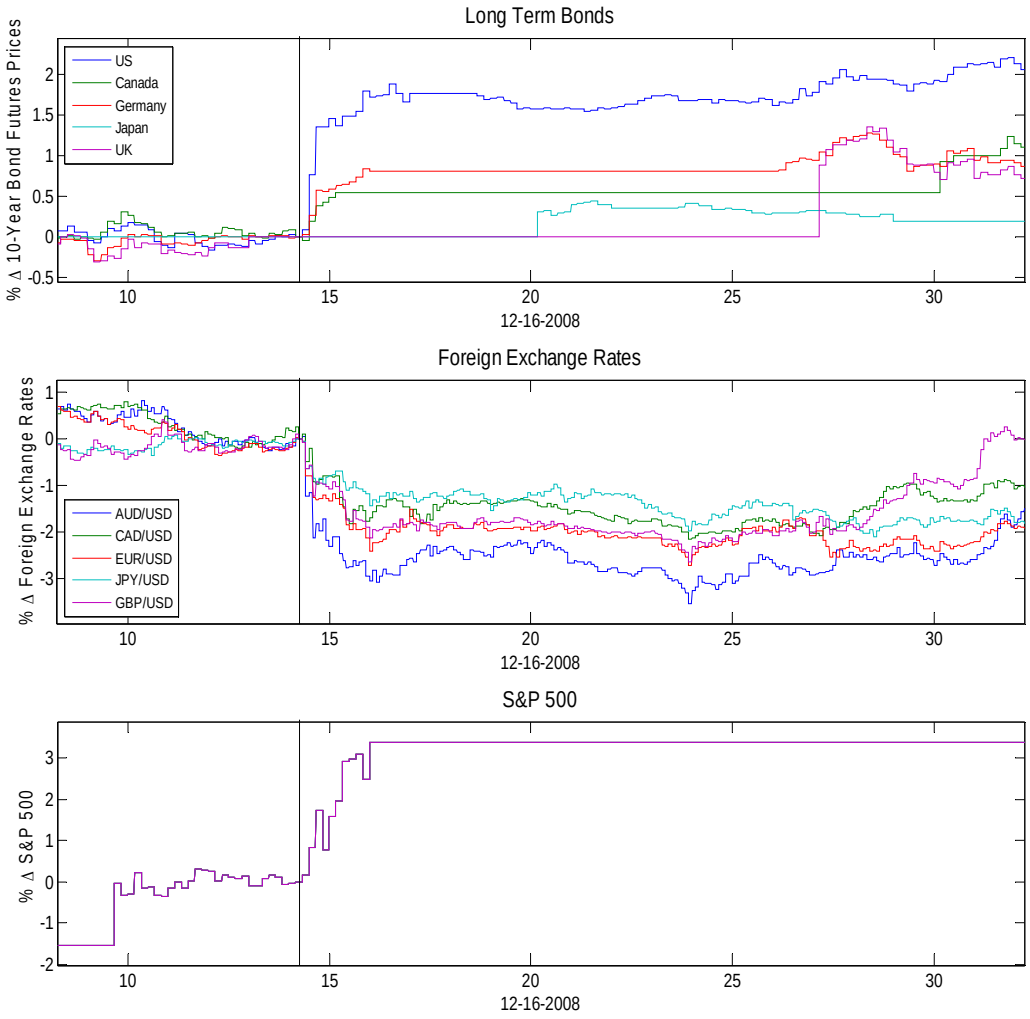
Notes: The figure shows the high-frequency movements of international bond futures prices (top panel), spot exchange rates (center panel), and S&P 500 futures (bottom) in the hours around the initial LSAP press release (vertical line) on November 25, 2008. The x-axis values denote hours from midnight,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

Figure 3: High-frequency international bond yield and exchange rate movements on December 1, 2008



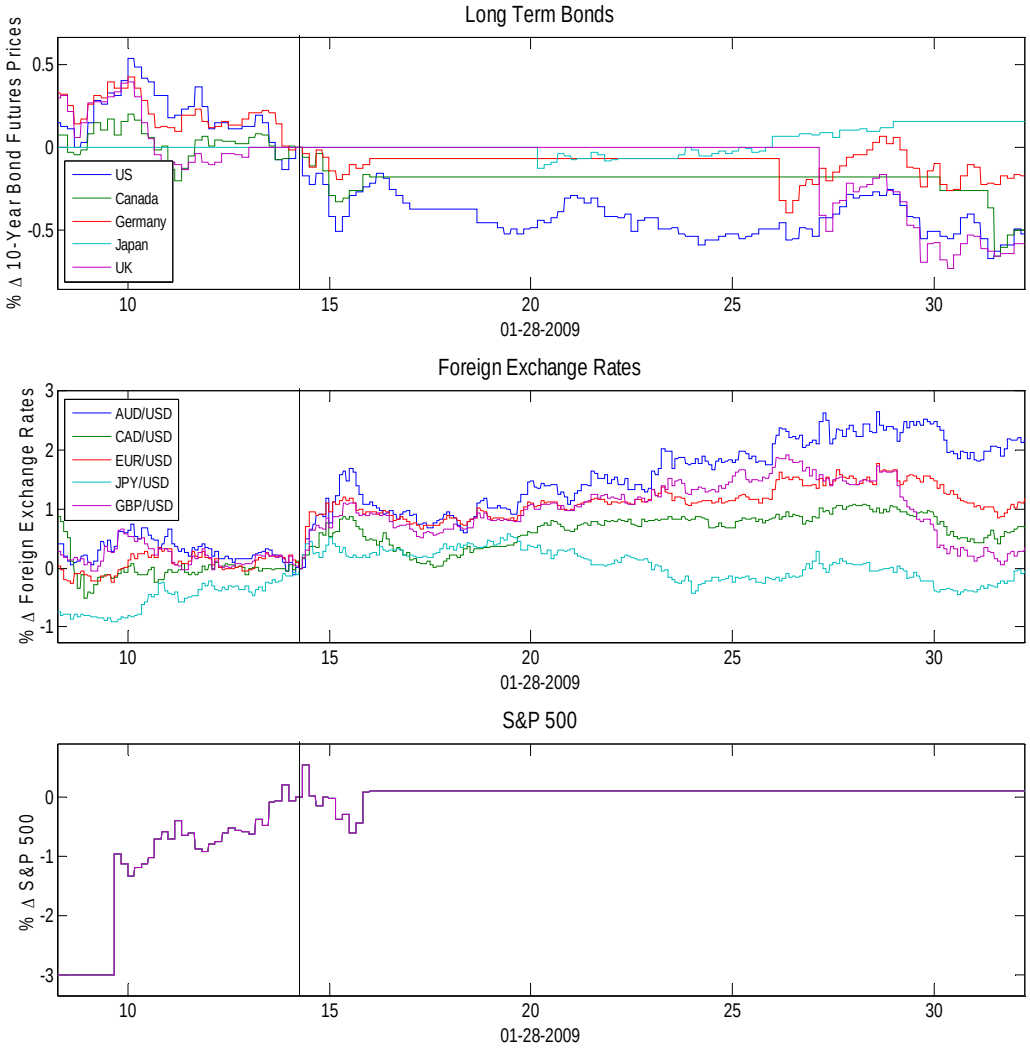
Notes: The figure shows the high-frequency movements of international bond futures prices (top panel), spot exchange rates (center panel) and S&P 500 futures (bottom) in the hours around Chairman Bernanke's speech (vertical line) on December 1, 2008. The x-axis values denote hours from midnight, U.S.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

Figure 4: High-frequency international bond yield and exchange rate movements on December 16, 2008



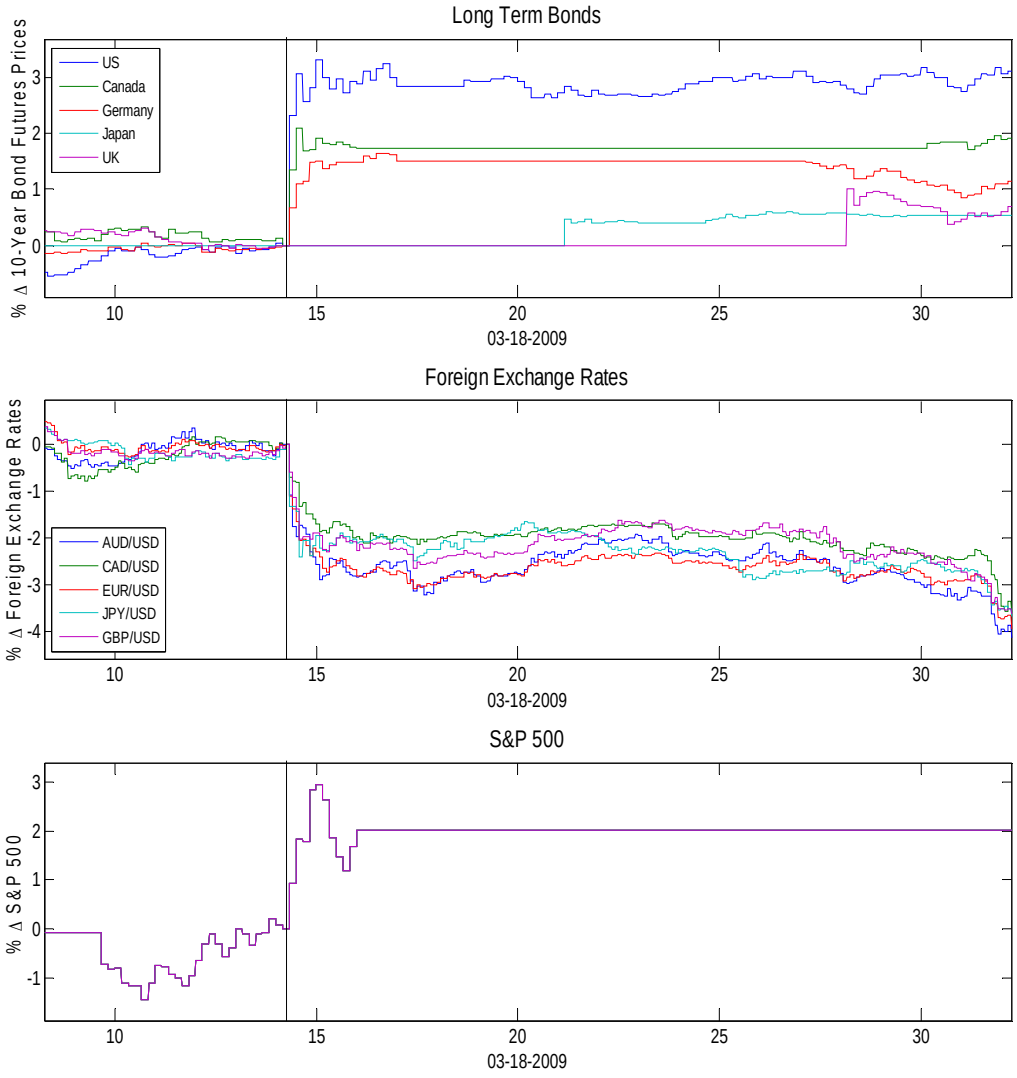
Notes: The figure shows the high-frequency movements of international bond futures prices (top panel), spot exchange rates (center panel) and S&P 500 futures (bottom) in the hours around the FOMC release (vertical line) on December 16, 2008. The x-axis values denote hours from midnight, U.S. Eastern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

Figure 5: High-frequency international bond yield and exchange rate movements on January 28, 2009



Notes: The figure shows the high-frequency movements of international bond futures prices (top panel), spot exchange rates (center panel) and S&P 500 futures (bottom) 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 6: High-frequency international bond yield and exchange rate movements on March 18, 2009



Notes: The figure shows the high-frequency movements of international bond futures prices (top panel), spot exchange rates (center panel) and S&P 500 futures (bottom) 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 1: Announcements associated with the LSAP programs

Date	Event	Time	Bloomberg time	Event	Other significant news in the event window
Announcements or suggestions of future purchases.					
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.	Alistair Darling, Chancellor of the Exchequer, promises backing to retail deposits at London Scottish Bank, effectively backing 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	FOMC statement first mentions possible purchase of long-term Treasuries.	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	13:17	FOMC will purchase an additional $750 billion in agency MBS, to increase its purchases of agency debt by $100 billion, and $300 billion in long-term Treasuries.	
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 purchase 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 raised its policy rate by 25 basis points on November 4, 2009.

Notes: The table describes the 8 events associated with LSAP announcements. The columns denote the date of the announcement, the venue, 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

Date	US 10YR	Moody's Baa	30YR Fixed Mortgage	US Average		Australia 10YR	Canada 10YR	Germany 9-10YR	Japan 10YR	UK 10YR	Foreign Average
Buy Events											
11/25/2008	-36	-18	-21	-25		-7	-14	-5	-2	-14	-8
	(0.00)	(0.04)	(0.02)			(0.35)	(0.04)	(0.38)	(0.66)	(0.06)	
12/1/2008	-25	-24	-3	-17		-18	-16	-12	-5	-24	-15
	(0.02)	(0.02)	(0.53)			(0.06)	(0.03)	(0.07)	(0.21)	(0.01)	
12/16/2008	-33	-41	-7	-27		-26	-19	-20	-9	-24	-20
	(0.01)	(0.00)	(0.22)			(0.01)	(0.01)	(0.01)	(0.03)	(0.01)	
1/28/2009	28	22	-6	15		-1	18	-5	1	1	3
	(0.01)	(0.02)	(0.29)			(0.93)	(0.01)	(0.43)	(0.86)	(0.93)	
3/18/2009	-41	-17	-1	-20		-26	-23	-8	-4	-4	-13
	(0.00)	(0.06)	(0.92)			(0.01)	(0.00)	(0.19)	(0.31)	(0.57)	
Event Sum	-107	-78	-38	-74		-78	-54	-50	-19	-65	-53
	(0.00)	(0.00)	(0.02)			(0.00)	(0.00)	(0.00)	(0.03)	(0.00)	
Sell Events											
8/12/2009	-12	-1	-6	-6		-4	0	-2	-5	-2	-3
	(0.16)	(0.92)	(0.29)			(0.62)	(1.00)	(0.77)	(0.20)	(0.75)	
9/23/2009	-6	-4	3	-2		0	-2	-9	-1	-7	-4
	(0.44)	(0.55)	(0.57)			(1.00)	(0.75)	(0.13)	(0.86)	(0.29)	
11/4/2009	7	6	-8	2		10	10	12	5	12	10
	(0.39)	(0.42)	(0.18)			(0.22)	(0.12)	(0.08)	(0.20)	(0.09)	
Event Sum	-11	1	-11	-7		6	8	1	-1	3	3
	(0.45)	(0.96)	(0.31)			(0.69)	(0.47)	(0.96)	(0.92)	(0.79)	

Notes: The table shows the U.S. and foreign long-term interest rate yield changes in basis points around 8 news events associated with the LSAP program. The "p-values" in parentheses below the yield changes show the proportions of 2-day yield changes from January 2005 through June 2010 that were larger in absolute value than the actual change in the 2-day period around the event.

Table 3: Effect of the LSAP on U.S. and foreign short-term yields

Date	US	Australia	Canada	Germany	Japan	UK	Average
Buy Events							
11/25/2008	-9	0	-0.34	5	-0.1	12	1.3
	(0.19)	(1.00)	(0.56)	(0.27)	(0.70)	(0.20)	
12/1/2008	-5	0	0.08	-5	-3.9	0	-2.3
	(0.32)	(1.00)	(0.87)	(0.29)	(0.07)	(1.00)	
12/16/2008	-6	0	0.09	-8	0.4	0	-2.3
	(0.29)	(1.00)	(0.85)	(0.20)	(0.47)	(1.00)	
1/28/2009	5	0	0	5	0.2	7	2.9
	(0.33)	(1.00)	(1.00)	(0.28)	(0.62)	(0.28)	
3/18/2009	-3	0	0.09	0	0.4	-3	-0.9
	(0.50)	(1.00)	(0.85)	(1.00)	(0.48)	(0.42)	
Event Sum	-18	0	-0.08	-3	-3	16	-1.3
	(0.38)	(1.00)	(0.97)	(0.85)	(0.38)	(0.47)	
Sell Events							
8/12/2009	-1	0	-0.04	-12	0.1	0	-2.2
	(0.74)	(1.00)	(0.92)	(0.14)	(0.70)	(1.00)	
9/23/2009	-1	0	0.34	0	1.2	0	0.1
	(0.79)	(1.00)	(0.56)	(1.00)	(0.23)	(1.00)	
11/4/2009	1	25	-0.23	-1	-0.4	0	4.1
	(0.74)	(0.03)	(0.68)	(0.59)	(0.47)	(1.00)	
Event Sum	-1	25	0.07	-13	0.9	0	2.0
	(0.93)	(0.08)	(0.96)	(0.34)	(0.61)	(1.00)	

Notes: The table shows the U.S. and foreign short-term interest rate yield changes in basis points from t-1 to t+1around 8 news events associated with the LSAP program. The "p-values" in parentheses below the yield changes show the proportions of 2-day yield changes from January 2005 through April 2010 that were larger in absolute value than the actual change in the 2-day period around the event. The Reserve Bank of Australia raised its policy rate by 25 basis points on November 4, 2009 (http://www.rba.gov.au/statistics/cash-rate.html).

Table 4: Effect of the LSAP on the foreign exchange value of the USD

	AUS/USD	CAD/USD	EUR/USD	JPY/USD	GBP/USD	Average Δ in FX rate		Implied Δ in EUR/USD		Implied Δ in GBP/USD
Buy Dates										
11/25/2008	-0.53	-0.22	-0.04	-1.42	-1.25	-0.69		-5.12		-2.96
	(0.58)	(0.77)	(0.96)	(0.13)	(0.15)					
12/1/2008	1.77	1.23	-0.03	-2.41	3.36	0.79		-1.53		-0.82
	(0.12)	(0.17)	(0.98)	(0.03)	(0.01)					
12/16/2008	-4.93	-2.94	-4.86	-3.75	-1.29	-3.55		-4.53		-1.96
	(0.02)	(0.02)	(0.00)	(0.00)	(0.13)					
1/28/2009	1.64	-0.21	1.73	0.97	-1.03	0.62		1.06		2.97
	(0.14)	(0.78)	(0.06)	(0.26)	(0.22)					
3/18/2009	-3.61	-2.50	-4.93	-4.17	-3.37	-3.71		-6.16		-6.25
	(0.03)	(0.03)	(0.00)	(0.00)	(0.01)					
Event Sum	-5.65	-4.64	-8.13	-10.78	-3.57	-6.56		-16.28		-9.04
	(0.07)	(0.04)	(0.00)	(0.00)	(0.10)					
Sell Dates										
8/12/2009	-1.50	-1.15	-0.95	-0.58	-0.60	-0.95		0.68		0.04
	(0.17)	(0.19)	(0.23)	(0.47)	(0.45)					
9/23/2009	0.90	1.85	0.97	0.02	1.90	1.13		0.60		0.45
	(0.37)	(0.06)	(0.22)	(0.98)	(0.06)					
40121.00	-0.91	-0.17	-1.11	0.47	-1.06	-0.55		-1.36		-1.46
	(0.37)	(0.82)	(0.18)	(0.55)	(0.20)					
Event Sum	-1.51	0.53	-1.09	-0.08	0.25	-0.38		-0.09		-0.98
	(0.45)	(0.73)	(0.47)	(0.96)	(0.88)					

Notes: The table shows exchange rate (FX per USD) changes in percentage points from t-1 to t+1 around 8 news events associated with the LSAP program. The "p-values" in parentheses below the yield changes show the proportions of 2-day changes from January 2005 through June 2010 that were larger in absolute value than the actual change in the 2-day period around the event. The implied exchange rate change is the implied jump from the UIP-PPP model, expressed as % change in foreign currency/USD, $s_t - s_{t^-} \approx -N\left(\Delta_{t^-,t} i_{t,10}^{foreign} - \Delta_{t^-,t} i_{t,10}^{US}\right) + \Delta_{t^-,t} E_t\left(p_{t+10}^{foreign} - p_{t+10}^{US}\right)$. See equation (9).

Table 5: Predicted foreign bond returns and observed foreign yield changes

		Canada	Euro	Germany	United Kingdom
	bootstrap 5th percentile	-0.204	-0.254	-0.254	-0.181
$\Delta_{t^-,t} Er_t^{for,US\ goods}$	mean estimate	-0.625	-0.755	-0.755	-0.570
	bootstrap 95th percentile	-1.081	-1.343	-1.343	-1.017
$\Delta_{t^-,t} E\Delta S_t$: 10 year		-0.655	-0.543	-0.652	-0.543
$\Delta_{t^-,t} E\pi_t^{USD}$: 10 year		0.800	0.800	0.800	0.800
	bootstrap 5th percentile	-0.059	0.003	-0.106	0.076
Implied 10 year $\Delta_{t^-,t} Er_t^{for,FX}$	mean estimate	-0.480	-0.498	-0.607	-0.313
	bootstrap 95th percentile	-0.936	-1.086	-1.195	-0.760
$\Delta_{t^-,t} y_{10\ year,t}^{for,FX}$		-0.539	-0.650	-0.541	-0.650

Notes: Rows 1-3 of the table show the portfolio balance model implied changes in expected real returns in USD to foreign bonds along with the bootstrapped 10th and 90th percentiles of the return distribution (i.e., $\Delta_{t^-,t} Er_{t+1}^{for,US\ goods}$). Rows 4-5 show the changes in the implied 10-year rate of USD appreciation from BIS zero-coupon bonds and the change in 10-year US inflation expectations during the LSAP buy windows. Rows 6-8 show statistics on the distribution of implied changes in expected foreign bond returns constructed from the right-hand side of equation (11): $\Delta_{t^-,t} Er_{t+1}^{for,FX} = \Delta_{t^-,t} Er_{t+1}^{for,US\ goods} + \Delta_{t^-,t} E\Delta S_{t+1} + \Delta_{t^-,t} E\pi_{t+1}^{USD}$. Row 9 shows the observed sum of changes in 10-year BIS zero-coupon bond yields during the event windows.

Table 6: Effect of the LSAP on equity values

Date	S&P 500	All Ordinaries	S&P/TSX Composite	Xetra Dax	Nikkei225	FT All Shares	Average η
Buy Events							
11/25/2008	4.12	2.64	2.37	0.14	3.75	0.03	2.18
	(0.05)	(0.11)	(0.14)	(0.93)	(0.08)	(0.98)	
12/1/2008	-5.44	-5.58	-10.72	-2.99	-7.93	-3.88	-6.09
	(0.02)	(0.01)	(0.00)	(0.11)	(0.01)	(0.04)	
12/16/2008	4.04	-0.59	3.05	1.14	-0.60	1.11	1.36
	(0.05)	(0.63)	(0.07)	(0.46)	(0.72)	(0.39)	
1/28/2009	-0.07	2.50	0.04	2.39	2.33	-0.06	1.19
	(0.95)	(0.13)	(0.98)	(0.17)	(0.21)	(0.95)	
3/18/2009	0.76	0.69	1.52	1.39	-0.04	-0.81	0.58
	(0.54)	(0.58)	(0.30)	(0.37)	(0.98)	(0.51)	
Event Sum	3.42	-0.34	-3.75	2.07	-2.49	-3.61	-0.78
	(0.37)	(0.92)	(0.34)	(0.62)	(0.60)	(0.32)	
Sell Events							
8/12/2009	1.83	2.33	1.83	2.16	-0.65	1.81	1.55
	(0.22)	(0.15)	(0.22)	(0.20)	(0.70)	(0.23)	
9/23/2009	-1.97	0.79	-2.62	-1.84	1.66	-1.28	-0.88
	(0.20)	(0.52)	(0.12)	(0.26)	(0.35)	(0.34)	
11/4/2009	2.01	-0.46	1.39	2.36	-0.88	1.87	1.05
	(0.19)	(0.70)	(0.34)	(0.17)	(0.61)	(0.22)	
Event Sum	1.87	2.66	0.60	2.67	0.14	2.40	1.72
	(0.50)	(0.33)	(0.83)	(0.39)	(0.96)	(0.38)	

Notes: The table shows the % change in equity indices in 2-day windows around 5 buy announcements in the LSAP program for 6 major international equity indices: S&P 500, the Australian All-Ordinaries index, the Canadian S&P/TSX composite index, the German Xetra Dax index, the *Financial Times* All Share index, and the Nikkei 225. The "p-values" in parentheses below the yield changes show the proportions of 2-day changes from January 2005 through June 2010 that were larger in absolute value than the actual change in the 2-day period around the event.