Understanding the impact of large scale asset purchases on long-term government bond yields: the quantitative easing paradox

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Abstract

Empirical event studies estimate that Large Scale Asset Purchases (LSAP) push down long-term interest rates through the portfolio balance channel. However, since portfolio reallocation takes time to materialise, a longer horizon may be more appropriate to assess the effects of LSAP. With a longer horizon in mind, a deep look at historical experiences leads to the quantitative easing paradox: LSAP raise long-term government bond yields, while a premature exit lowers long-term government bond yields. To solve this puzzle, this paper argues that LSAP mainly raise the government term premium. In the wake of a severe economic and financial crisis, the period of heightened risk aversion and the safe asset shortage weigh on the government term premium. Through the portfolio balance channel, LSAP increase the supply of safe assets and decrease the demand of money at the same time, thereby lifting the government term premium. Finally, a new econometric method introduced by Brodersen et al. (2014), which infers the causal impact of LSAP on the term premium, confirms that LSAP have a significant positive effect on long-term government bond yields.

JEL classifications: E43, E44, E52, G1

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Introduction

During the worst of the Great Recession, central banks turned to non-traditional monetary policy approaches to support the recovery, such as forward guidance and Large Scale Asset Purchases (LSAP, also often referred to as quantitative easing or "QE"). Unconventional monetary transmission is highly complex and while its broad features are apprehended, there is no consensus on its detailed functioning, as stated by Krishnamurthy and Vissing-Jorgensen (2013) or Bernanke (2012).

Over the last few years, there has been a substantial increase of empirical and theoretical research on LSAP. The common belief is that, through the portfolio balance channel, LSAP drive down long-term government yields below levels that otherwise would have prevailed. This paper differs from other studies that focused on event-study event study methodologies. Since portfolio reallocation is not immediate and takes time to materialise, a longer horizon may be more appropriate to asses the effects of LSAP. For instance, institutional investors, such as pension funds, often have an investment board, who selects strategic and tactical investment targets and then delegates the portfolio construction to in-house or external portfolio managers. Moreover, after many years of a debilitating sequence of crises, firms and households are very hesitant to take on economic risk. With a longer horizon in mind, this paper demonstrates that LSAP raise long-term government rates, which can be seen as the quantitative easing paradox. The aim of this paper is thus to explain how the central bank's increasing demand for long-term government bonds is offset by the fall in demand for long-term government bonds from the private sector and foreign central banks.

The rest of the paper is organized as follows. Section 1 reviews LSAP past experiences to highlight the quantitative easing paradox. Section 2 focus on the effects of unconventional monetary policy on bond yields to point out that LSAP should mainly affect the government bond term premium. Section 3 explains how LSAP raise the government bond term premium by reducing the safe asset shortage and lessening the risk aversion. Distinct econometric analysis confirm the previous results in the last section.

1 The quantitative easing paradox

1.1 The Japanese experience

After a series of fairly ineffectual policy actions, the Bank of Japan undertook its quantitative easing policy from March 19, 2001, to March 9, 2006. The

BoJ announced that it would start to increase the amount of its outright purchases of long-term Japanese government bonds to 400 billion yen per month, which it ultimately enhanced to 1.2 trillion yen per month from November 2002 onwards. In January 2002, the range of bonds to be purchased was broadened from only 10 and 20-year bonds to also include shorter-maturities (2, 4, 5 and 6-year bonds). Under this policy the 10-year Japanese bond yield raised from 1.1% to 1.7%, as shown in the figure 1.

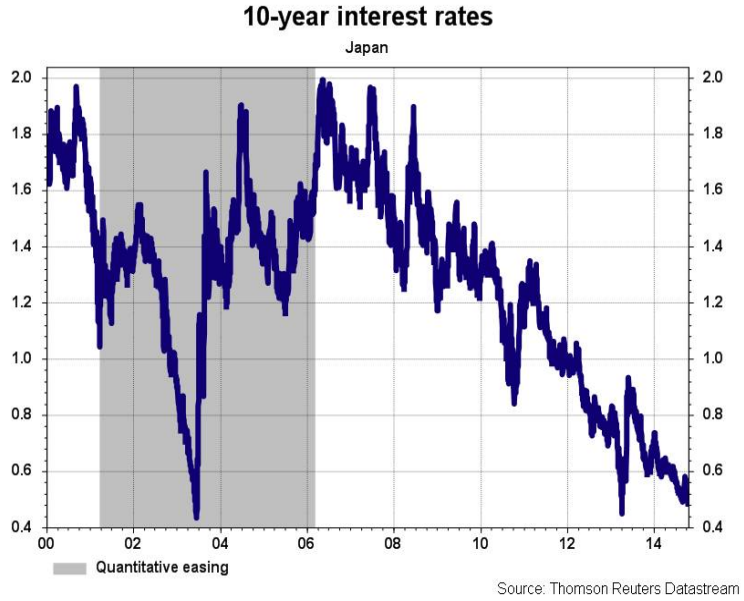

Figure 1: Japanese rates and Japanese QE

Empirical event studies estimate that LSAP push down long-term interest rates (see Spiegel (2006))

1.2 The American experience

After reaching the zero lower bound in December 2008, the Fed launched three different LSAP programs to support the recovery, known as "QE1", "QE2" and "QE3":

-On November 25, 2008, the Fed announced that it would purchase up to $600 billion in agency mortgage-backed securities (MBS) and agency debt. On December 16, the program was formally launched. On March 18, 2009, the FOMC announced that the program would be expanded by an additional $750 billion in purchases of agency MBS and agency debt and $300 billion in purchases of Treasury securities. The Fed completed its previously an-

nounced asset purchases by the end of March 2010.

-On November 3, 2010, the Fed announced that it would purchase $600 billion of longer dated treasuries, at a rate of $75 billion per month. Purchases ended by the end of June 2011.

-On September 13, 2012, the Federal Reserve announced an open-ended commitment to purchase securities per month until the labor market improves "substantially". Purchases were halted on October 29, 2014.

The 10-year US bond yield increased from 2.5% to 3.8% during QE1, from 2.6% to 3% during QE2 and from 1.7% to 2.3% during QE3. It is important to note that the 10-year US bond yield decreased from 3.8% to 2.6% between QE1 and QE2 and from 2.6% to 1.7% between QE2 and QE3, as emphasized in the figure 2.

As asset prices and yields are not only affected by current securities purchases but also by market expectations concerning future FOMC securities holdings (Krugman (1998)), it is important to look at hints given by the Fed regarding the future of its LASP:

-On February 24, 2010 Bernanke (2010) declared that the Fed anticipates that its balance sheet will shrink toward more historically normal levels, thereby promising that the monetary base will not stay larger.

-On March 7, 2011, Jon Hilsenrath, the Fed's favorite journalist, wrote that it seems increasingly likely that the securities purchase program is likely to end in June as scheduled.

-The Fed began tapering its asset purchases on December 19, 2013[1].

If we consider those dates as the "real" ends of QE, referred to as "refined QE", then the 10-year US bond yield raised from 2.6% to 3.5% during QE2 and from 1.7% to 2.9% during QE3, as highlighted in the figure 3.

[1]"Beginning in January, the Committee will add to its holdings of agency mortgage-backed securities at a pace of $35 billion per month rather than $40 billion per month, and will add to its holdings of longer-term Treasury securities at a pace of $40 billion per month rather than $45 billion per month"

Figure 2: 10-year US bond yield and QE

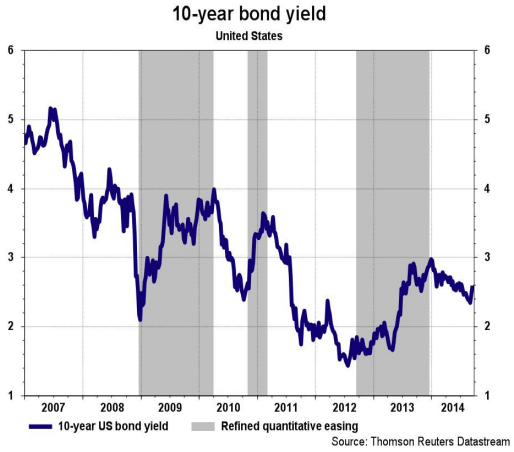

Figure 3: 10-year US bond yield and refined QE

However, empirical event studies estimate that LSAP programs push down long-term interest rates, as summarized by Williams (2014): *"The central tendency of the estimates reported indicates that $600 billion of Federal Reserve's asset purchases lowers the yield on ten-year Treasury notes by around 15 to 25 basis points. To put that in perspective, that is roughly the same size move in longer-term yields one would expect from a cut in the federal funds rate of 3/4 to 1 percentage point"*. Nevertheless, these findings have been challenged by Thornton (2013) on the ground that the necessary requirements for results to hold are not met. Thornton (2013) concludes that event-studies provide modest evidence that QE reduces long-term yields.

The belief that QE dramatically reduces government bond rates is shared by almost all fund managers, including Bill Gross, who used to run the world's biggest bond fund. Nevertheless, an investor betting on a rise of the BofA Merril Lynch 5+ year US Treasury index during LSAP programs would have lost 4.8% during QE1 and 0.9% during QE2. However, this investor would have earned 1.9% between QE1 and QE2 and 14.8% between QE2 and QE3.

2 Unconventional monetary policy and government bond yields

Woodford (2003) emphasizes that central banks influence long-term interest rates: when a central bank changes its short-term interest rate, interest rates at intermediate to medium-term maturities tend to shift in the same direction, if there is a signal that the new level of the short-term interest

rate is likely to persist. Indeed, the expectations theory of the term structure holds that the long-term interest rate is a weighted average of present and expected future short-term interest rates plus a term premium. More generally, for n-period bonds,

$$i_t^n = \frac{1}{n}\sum_{j=0}^{n-1} E_t(i_{t+j}^1) + \xi^n \tag{1}$$

where, $E_t(i_{t+j}^1), j = 0, ..., n-1$ is the expected path of future one period interest rates over the life of the bond and ξ^n is the term premium, that may differ across maturities. The first element is thus the expectations-based component and the term premium captures the compensation that investors require for bearing interest rate and liquidity risk. Monetary policy not only impacts the expected path of short-term interest rates, but also influences the compensation for having the money tied up for a long period.

The rest of this section aims at analysing how unconventional monetary policy affects bond yields, starting with forward guidance, which is an explicit statements by a central bank about the outlook for future policy, in addition to its announcements about the immediate policy actions that it is undertaking (Woodford (2012)).

2.1 Impact of forward guidance on long-term government bond yields

Eggertsson and Woodford (2003) provide strong theoretical justifications for the use of forward guidance. There is no doubt that forward guidance has a strong impact on rates: if monetary policymakers are expected to keep short-term interest rates low, then current longer-term interest rates are likely to be low as well, all else being equal (see Filardo and Hofmann (2014) for a review on forward guidance). For example, forward guidance has proven to be a very useful policy tool to lower interest rates in August 2011 when the Fed stated that it *"anticipates that economic conditions are likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013"*, as shown in the figure 4.

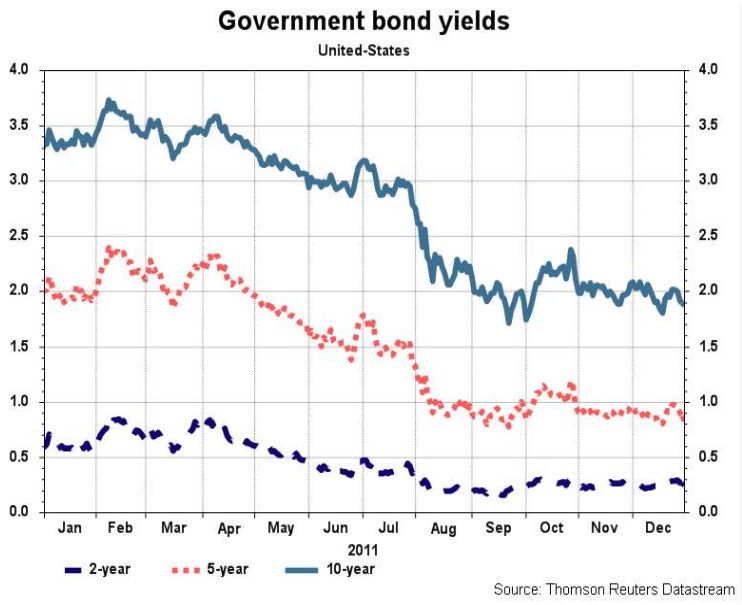

Figure 4: Forward guidance reduces rates

As the central bank explicitly promises not to hike rates before long, the expected path of short-term interest rates volatility should be lowered, thereby reducing the term premium. Based on Eurodollar futures contracts, which are the most liquid approximation of Fed funds futures, the study of market-based federal funds rate expectations volatility seems conclusive. For instance, the new forward guidance in August 2011 seems to have lower market's expectations volatility, as shown the figure 5. The volatility on Fed Fund rates expectations went from 0.14% before the announcement of forward guidance policy to 0.02% in December 2011. This drop in volatility could have very well reduce the term premium.

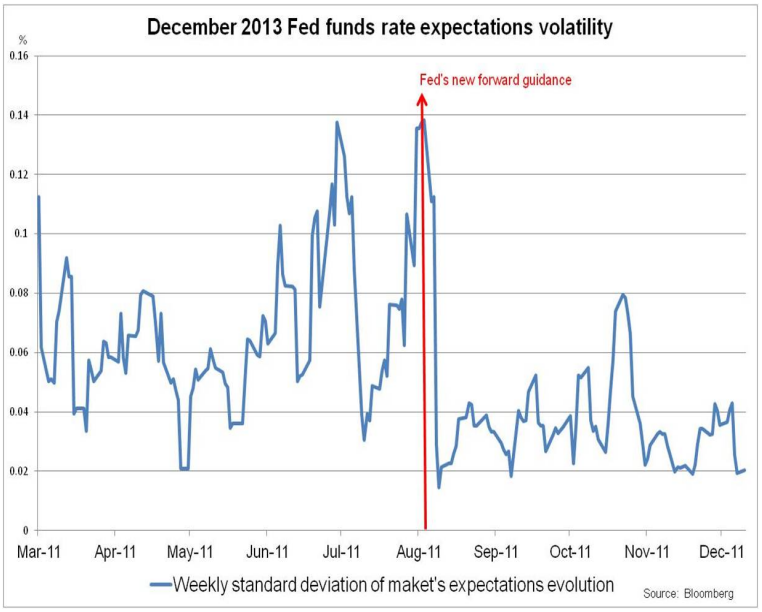

Figure 5: Forward guidance and volatility of market-based federal funds rate expectations

2.2 Impact of LSAP on long-term government bond yields

Many academic studies underline that quantitative easing is effective because it provides a signal to the private sector that the central bank will keep the short-term real interest rates low even when the zero lower bound is no longer a constraint in future (see Bhattarai et al. (2014) and Bauer and Rudebusch (2014)). But Woodford (2012) is uncertain that LSAP could send a very effective signal: *"If a central bank's intention in announcing such purchases is to send such a signal, the signal would seem more likely to have the desired effect if accompanied by explicit forward guidance, rather than regarded as a substitute for it. A more logical policy would rely on a combination of commitment to a clear target criterion to guide future decisions about interest-rate policy with immediate policy actions that should stimulate spending immediately without relying too much on expectational channels".*

A close look at market expectations seems to corroborate Michael Woodford's view. Figures 6 and 7 reveal that the impact of LSAP on the expected path of short-term interest rates is not straightforward. In fact, LSAP do not seem to consistently lower the expected path of short-term interest rates and LSAP might even increase short-term rates anticipations, especially it the timeline of the "refined QE" is taken into consideration. For instance, when

QE2 was launched on November 2010, the federal funds rate was expected to rise by 70 basis points before December 2012. Market's expectations climbed to 167 basis points on March 2011, just before Hilsenrath's article, and then decreased to 82 basis points as purchases ended. Markets expectations for December 2013 behave in a similar way.

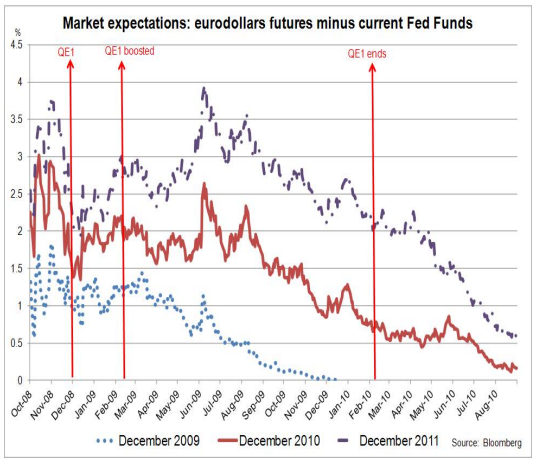

Figure 6: Market's expectations of future short rates and QE1

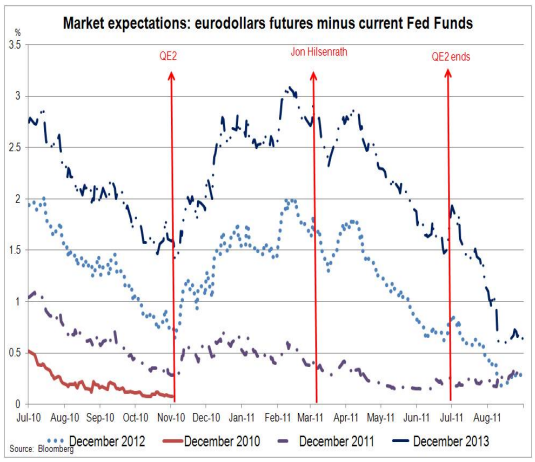

Figure 7: Market's expectations of future short rates and QE2

Moreover, Bernanke (2013) and Gagnon et al. (2011) estimate that forward rate guidance affects longer-term interest rates primarily by influencing investors' expectations of future short-term interest rates and that the primary channel through which LSAP appear to work is by affecting the risk premium on the asset being purchased. Even if the term premium estimation is not an easy task (see Kim and Orphanides (2007) or Bauer et al. (2014) for a review on this subject), the Fed provides its own estimation of the term premium, based on Kim and Wright (2005). Figure 8 speaks for itself: LSAP increase the term premium, as measured by Kim and Wright. The Fed of New-York provides another estimation of the term premium, based on Adrian et al. (2013). The results lead to the same conclusion, as highlighted in figure 9.

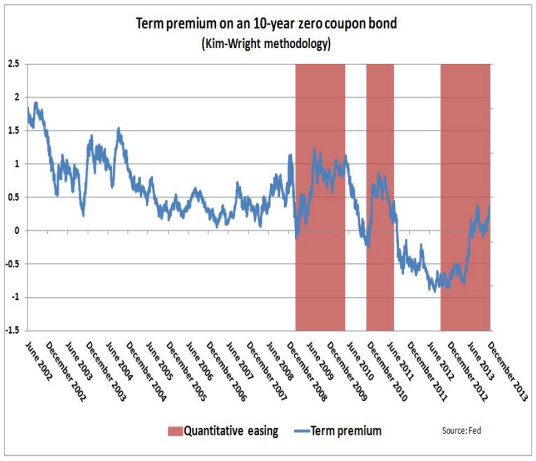

Figure 8: Fed's estimation of the term premium

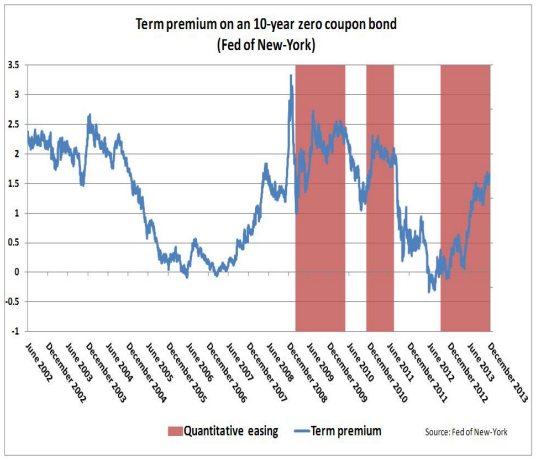

Figure 9: NY Fed's estimation of the term premium

In both cases, LSAP increase the term premium[2]. It should be noted that end of 2012 was dominated by the "fiscal cliff" issue, thereby limiting the effect of QE3 at first. It seems hazardous to precisely quantify the exact effects of LSAP on government term premium, As the term premium estimation is quite hard, but the sign of the impact seems clear.

To sum up, forward guidance reduces long-term rates by lowering expectations of future short-term interest rates. The impact on the term premium is difficult to assess but data on expectation volatility show that it probably reduces the term premium. LSAP, in contrast, raise long-term rates by boosting the term premium. Effects on the expected path of interest rates are uncertain, but it seems that LSAP might even increase short-term rates anticipations.

3 The hidden links between LSAP and the term premium: supply and demand of safe assets

3.1 The safe asset shortage

The U.S. Securities and Exchange Commission defines a safe asset as any debt asset that promises a fixed amount of money in the future with virtually no

[2]To my knowledge, there is no available estimation of the Japanese government bond term premium.

default risk. Safe assets are generally considered to be information insensitive: investors' concerns about asymmetric information or adverse selection are improved when trading because the asset's creditworthiness is known with near certainty, reducing the need for investors to collect information. The safety of a given asset does not depend on the creditworthiness of the issuer alone but also is determined by the liquidity of the market in which the asset trades and by guarantees. Any asset can be rendered safe by an implicit or explicit promise from a central bank or credit-worthy institution to buy it if its price falls below a certain level.

Investors rely on safe assets to provide a reliable store of value, collateral in repurchase and derivatives markets, instruments to fulfil prudential requirements, and pricing benchmarks. It is important to note that the supply of U.S. private safe assets has been significantly larger than the stock of U.S. government safe assets, according to Gorton et al. (2012), as highlighted in figure 10.

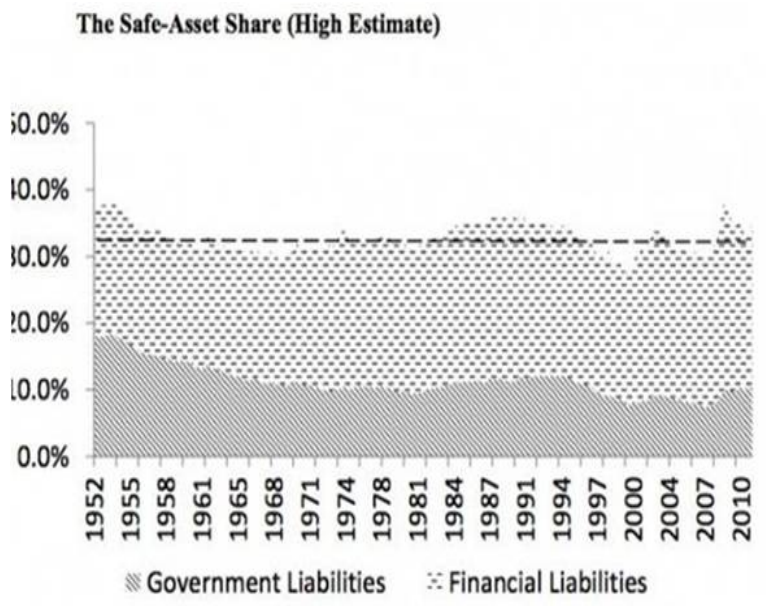

Figure 10: Stock of safe assets (fraction of total "safe" liabilities to total assets in the economy), according to Gorton et al. (2012)

During the financial crisis of 2007-2008, some purportedly safe private-label assets lost their information insensitive status when valuations fell and ratings were downgraded. Between the end of 2007 and the end 2012, the outstanding value of US private debt securities fell by $1.8 trillion. The IMF (2012) estimates that the supply of private sector securitization issuance

declined from more than $3 trillion in the United States and Europe in 2007 to less than $750 billion in 2010.

Moreover, a flight to quality[3] and a flight to liquidity[4] took place, especially after the bankruptcy of Lehman Brothers. Safety and liquidity were costless: US government bonds were bought at any price, thereby reducing the term premium.

All in all, the demand for safe asset climbed when the supply melted, thereby increasing the price of safe assets. De facto, a financial crisis almost always causes a safe asset shortage (see Gourinchas and Jeanne (2012) or Gorton et al. (2012)). Indeed, safe asset supply is not sufficient enough to respond to the global demand for store of value and collateral by households, corporations, governments, insurance companies, and financial intermediaries more broadly. The value of the existing assets must rise (Caballero (2006)).

To sum up, the shortage of safe assets slows down the economic activity, because this excess money demand is keeping aggregate nominal expenditure growth below where it should be. This heightened demand for government bonds lowers long-term interest rates, mainly by weighing on the term premium.

3.2 LSAP raise the supply of safe assets and lessen the demand of safe assets by private investors

LSAP help to restore hope, since concerns about "tail" risks such as deflation diminish (Bernanke (2012)). As confidence slowly comes back, the demand for safe asset should gradually fall, . Indeed, when investors regain confidence, they are more willing to take more risks. They rebalance their portfolios by replacing Treasuries deliberately sold to the Fed with assets with higher relative returns: the domestic demand for safe assets is reduced through portfolio rebalancing[5]. Finally, as LSAP do not seem influence for-

[3] A flight to quality refers to a sudden shift in investment behaviours in a period of financial turmoil whereby investors seek to sell assets perceived as risky and instead purchase safe assets.

[4] A flight to liquidity refers to an abrupt shift in large capital flows towards more liquid assets.

[5] *"One mechanism through which such purchases are believed to affect the economy is the so-called portfolio balance channel, which is based on the ideas of a number of well-known monetary economists, including James Tobin, Milton Friedman, Franco Modigliani, Karl Brunner, and Allan Meltzer. The key premise underlying this channel is that, for a variety of reasons, different classes of financial assets are not perfect substitutes in investors' portfolios"*(Bernanke (2012)). Indeed, if assets are not perfect substitutes, then a change in the quantity of a specific asset will lead, *ceteris paribus*, to a change in its relative expected rate of return.

eign official institutions purchases of treasuries (see the figure 11), the total demand for treasuries is reduced.

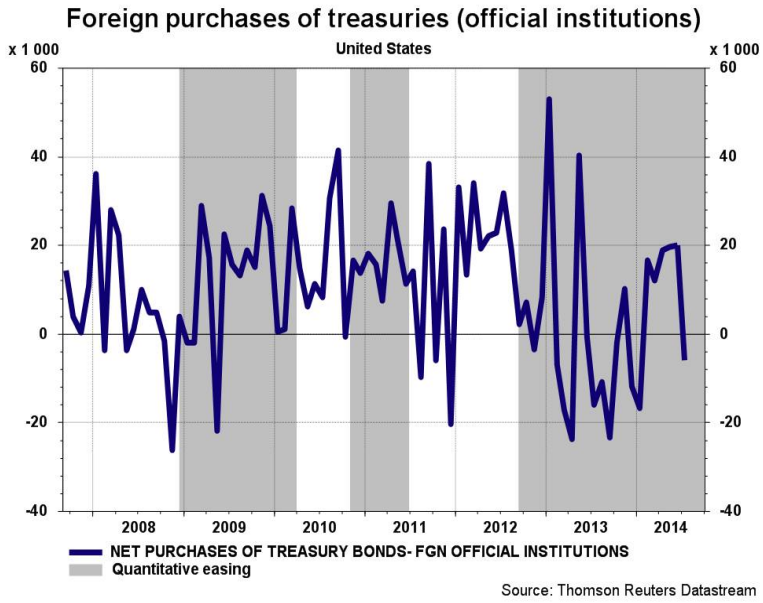

Figure 11: Foreign purchases of US government bonds

An additional consequence of this rebalancing of portfolios is an increase in stocks prices and a decline in corporate spreads, as highlighted in the figure 12. A virtuous circle of confidence and risky asset prices is imitated. It is important to note that the portfolio reallocation process takes time, as many investors, insurances for example, are often less reactive and more risk averse than some hedge funds. A quite long horizon should thus be considered to assess the effectiveness of LSAP.

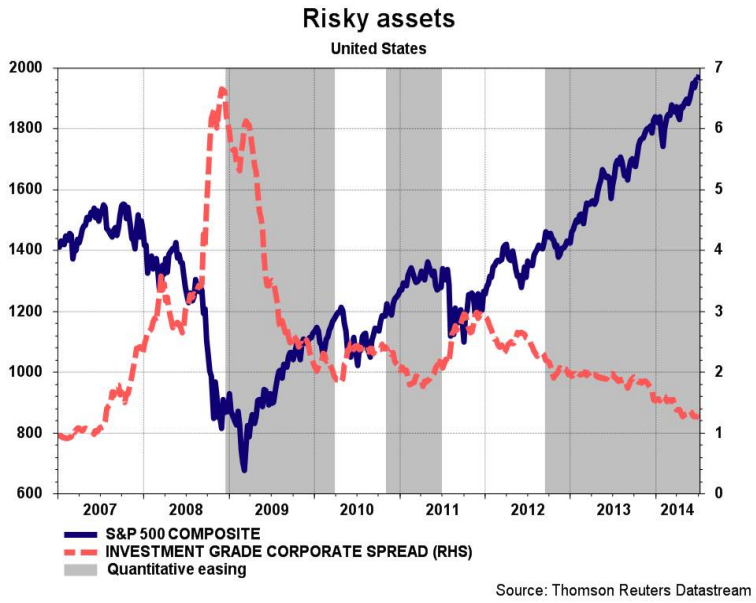

Figure 12: Risky assets and LSAP

Moreover, increasing equities and declining corporate spreads ease the safe asset shortage, as some private-label assets regain their information insensitive status. It is important to keep in mind that the supply of U.S. private safe assets has been significantly larger than the stock of U.S. government safe assets (see 10). Furthermore, citetduca argue that LSAP programs had a large impact on corporate bond issuance, thereby creating possible safe assets. At last, the figure 13 underlines that the Fed's share of treasuries over the past years has been below its long-term average. LSAP only normalize the situation and do not lower the supply of safe assets.

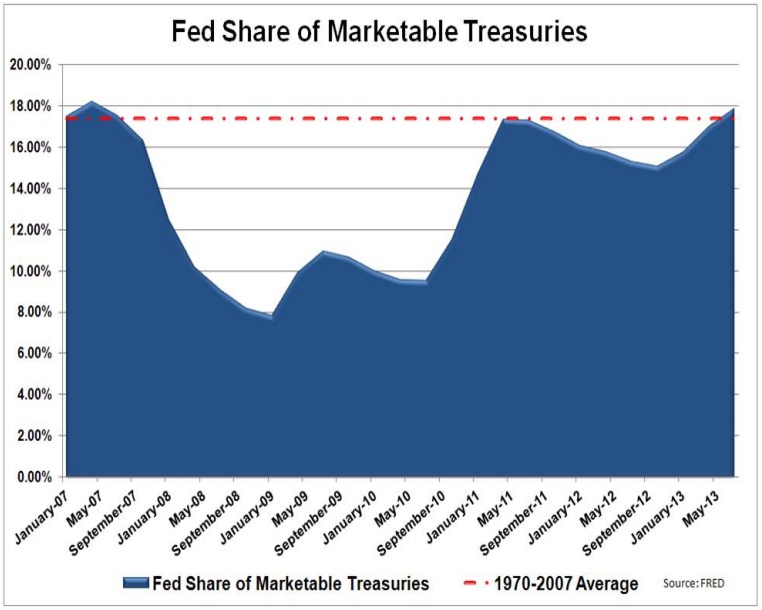

Figure 13: Fed's share of treasuries

However, if investors believe that the recovery is not yet sustainable, risk aversion radically increases as soon as the central bank hints it could end asset purchases, as highlighted in figure 14. As a consequence, investors switch from risky assets to government bonds, thereby reviving the demand for safe assets. For instance, figure 15 emphasizes the asymmetrical behaviour of investors: it can take some time to reinvest in risky assets after a crisis, but the decision to cut positions and take profits is not long in coming.

Figure 14: Cleveland financial stress index

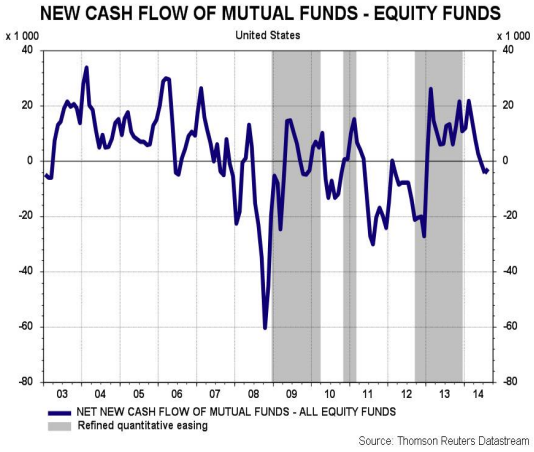

Figure 15: New cash flows of mutual funds into equity funds

Figure 16 highlights that corporate spreads heighten as soon as investors believe LSAP will end.

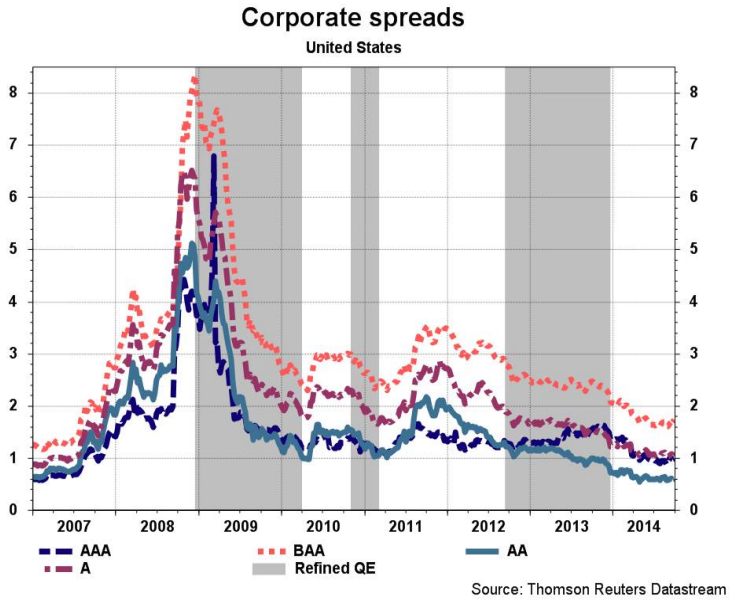

Figure 16: Investment grade corporate spreads and LSAP

It should be noted, that corporate spreads do not seem to react to the end of QE3. It possibly signals that the economic activity is strong enough to support a monetary policy tightening. It could mean that a central bank should

only exit LSAP when long-term government rates and corporate spreads do not react to the announcement of the end of QE.

To sum up, as the private sector decides to sell treasuries to buy risky assets, the safe assets supply rises to more normal levels and the demand for US government bonds falls. In other words, the supply of money increases and the demand for money diminishes. The term premium should thus increase, thereby raising government yields. Finally, this section empirically confirms the findings of Araújo et al. (2013): asset purchases policies are particularly effective when there are collateral constraints and are not equivalent to traditional interest-rate policy.

4 Causal impact

Brodersen et al. (2014) recently introduces a new method to infer the causal impact that a designed market intervention has exerted on an outcome metric over time. The causal effect of interest is the difference between the observed series and the series that would have been observed had the intervention not taken place.

They propose to infer causal impact on the basis of a diffusion-regression state-space model that predicts the counterfactual market response that would have occurred had no intervention taken place. Subtracting the predicted from the observed response during the post-intervention period gives a semiparametric Bayesian posterior distribution for the causal effect.

In this paper, the causal impacts of LSAP on the term premium and on the expected path of short-term rates are computed. The estimation sample uses daily data from July 7, 2007 to December 31, 2014. The study is carried out on the term premium based on Kim and Wright (2005) $(tpkw_t, t = 1, ..., n)$. Figure 8 clearly illustrates that the term premium is a non-stationary time series. The first difference of the term premium series is thus used:

$$\Delta tpkw_t = tpkw_t - tpkw_{t-1}$$

In the interest of brevity, only two tests are computed (see Appendix A for detailed results). With a p-value of 0.046, the first one highlights that the end of QE1 has a significant downside effect on the term premium (see figure 17 for an illustration). With a p-value of 0.002, the second test emphasizes that the term premium increases during the refined QE2 (figure 18 illustrates the results of this test).

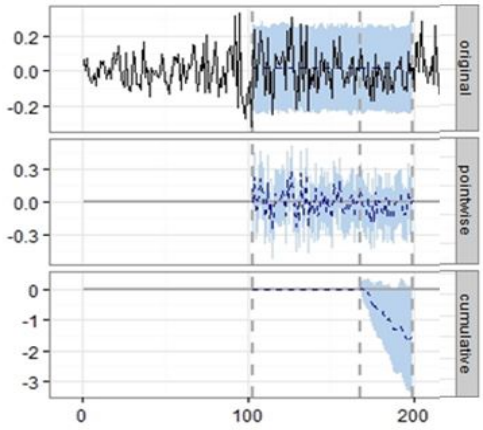

Figure 17: Causal impact of the end of QE1 on the term premium

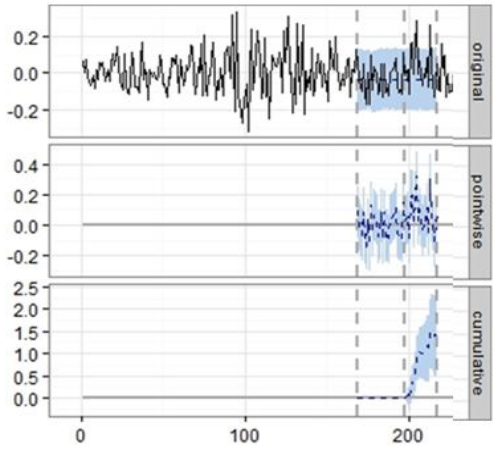

Figure 18: Causal impact of the refined QE2 on the term premium

The same methodology is be used to outline that the impact of LSAP on the expected path of short-term rates is inconclusive (see Appendix A for detailed results). With a p-value of 0.294, the end of QE1 has no significant effect on the expected path of short-term rates. With a p-value of 0.115, the refined QE2 has no significant effect on the expected path of short-term rates.

This analysis confirms the findings of the previous sections: LSAP have a significant positive impact on the government term-premium and the effect on the expected path of short-term rates is unclear (Appendix B highlights that more traditional econometric methods reach the same conclusions).

It should be added that the total amount of purchases needed is hard to assess given nonlinearities in the economy. Central banks should focus on the impact of their actions on risky assets and government rates to monitor their purchases: if government rates do not raise, the Central Bank is not doing enough.

Conclusion

Event studies estimate that LSAP programs push down long-term interest rates through the portfolio balance channel. Since portfolio reallocation is not immediate and takes time to materialise, a longer horizon may be more appropriate to assess the effects of LSAP. With a longer horizon in mind, a look at historical experiences leads to the quantitative easing paradox: LSAP raise long-term government bond yields, while a premature exit low-

ers long-term government bond yields. The expectations theory of the term structure helps to solve this puzzle: the long-term interest rate is a weighted average of present and expected future short-term interest rates plus a term premium, the latter captures the compensation that investors require for bearing interest rate and liquidity risk. Forward rate guidance is explicitly intended to influence market expectations concerning the future trajectory of shorter-term interest rates. LSAP, in contrast, most directly affect the term premium. During financial stress episode, the risk aversion and the safe asset shortage heightened the demand for treasuries, thereby reducing the government term premium. LSAP increase the government term premium through the portfolio balance channel: investors slowly rebalance their portfolios by replacing the assets sold to the central bank with assets with higher relative returns. Increasing risky assets prices not only ease the safe asset shortage, but also have a positive impact on the economic activity. In other words, LSAP increase the supply of money and decrease the demand for money at the same time. Finally, an econometric analysis, which infers the causal impact of LSAP on long-term government bond yields, emphasizes that LSAP have a significant positive effect on the term premium evolution. This paper empirically confirms the findings of Araújo et al. (2013): asset purchases policies are particularly effective when there are collateral constraints and are not equivalent to traditional interest-rate policy. The QE paradox implies that a central bank should only exit LSAP when long-term government rates do not drastically decrease just after the announcement of the future end of asset purchases.

Appendix A: Causal impact

Appendix A.1: Causal impact of the end of QE1

Appendix A.1.1: On the term premium

Summing up the individual data points during the post-intervention period (which can only sometimes be meaningfully interpreted), the response variable had an overall value of -1. Had the intervention not taken place, we would have expected a sum of 0. The 95% interval of this prediction is [-1, 2].

The above results are given in terms of absolute numbers. In relative terms, the response variable showed a decrease of-334%. The 95% interval of this percentage is [-713%, +36%].

This means that, although it may look as though the intervention has exerted a negative effect on the response variable when considering the intervention period as a whole, this effect is not statistically significant, and so cannot be meaningfully interpreted. The apparent effect could be the result of random fluctuations that are unrelated to the intervention. This is often the case when the intervention period is very long and includes much of the time when the effect has already worn off. It can also be the case when the intervention period is too short to distinguish the signal from the noise. Finally, failing to find a significant effect can happen when there are not enough control variables or when these variables do not correlate well with the response variable during the learning period.

The probability of obtaining this effect by chance is very small (Bayesian tail-area probability p = 0.046). This means the causal effect can be considered statistically significant.

Appendix A.1.2: On the expected path of short-term interest rates

Summing up the individual data points during the post-intervention period (which can only sometimes be meaningfully interpreted), the response variable had an overall value of 0. Had the intervention not taken place, we would have expected a sum of 0. The 95% interval of this prediction is [-1, 1].

The above results are given in terms of absolute numbers. In relative terms, the response variable showed a decrease of-222%. The 95% interval of this percentage is [-980%, +492%].

This means that, although it may look as though the intervention has exerted a negative effect on the response variable when considering the intervention period as a whole, this effect is not statistically significant, and

so cannot be meaningfully interpreted. The apparent effect could be the result of random fluctuations that are unrelated to the intervention. This is often the case when the intervention period is very long and includes much of the time when the effect has already worn off. It can also be the case when the intervention period is too short to distinguish the signal from the noise. Finally, failing to find a significant effect can happen when there are not enough control variables or when these variables do not correlate well with the response variable during the learning period.

The probability of obtaining this effect by chance is p = 0.294. This means the effect may be spurious and would generally not be considered statistically significant.

Appendix A.2: Causal impact of refined QE2

Appendix A.2.1: On the term premium

Summing up the individual data points during the post-intervention period (which can only sometimes be meaningfully interpreted), the response variable had an overall value of 1. By contrast, had the intervention not taken place, we would have expected a sum of -1. The 95% interval of this prediction is [-2, 0].

The above results are given in terms of absolute numbers. In relative terms, the response variable showed a decrease of-225%. The 95% interval of this percentage is [-89%, -362%].

This means that the negative effect observed during the intervention period is statistically significant. If the experimenter had expected a positive effect, it is recommended to double-check whether anomalies in the control variables may have caused an overly optimistic expectation of what should have happened in the response variable in the absence of the intervention.

The probability of obtaining this effect by chance is very small (Bayesian tail-area probability p = 0.002). This means the causal effect can be considered statistically significant.

Appendix A.2.2: On the expected path of short-term interest rates

Summing up the individual data points during the post-intervention period (which can only sometimes be meaningfully interpreted), the response variable had an overall value of 0. By contrast, had the intervention not taken place, we would have expected a sum of 0. The 95% interval of this prediction is [0, 0].

The above results are given in terms of absolute numbers. In relative

terms, the response variable showed a decrease of-255%. The 95% interval of this percentage is [+168%, -661%].

This means that the negative effect observed during the intervention period is statistically significant. If the experimenter had expected a positive effect, it is recommended to double-check whether anomalies in the control variables may have caused an overly optimistic expectation of what should have happened in the response variable in the absence of the intervention.

The probability of obtaining this effect by chance is p = 0.115. This means the effect may be spurious and would generally not be considered statistically significant.

Appendix B: Classical econometric

A standard regression emphasizes that LSAP have a significant positive impact on the government term-premium (t-statistics in parentheses):

$$\Delta tpkw_t = -0.05_{(-1.98)} + 0.012_{(2.97)} I_t^{refinedQE} \quad R^2_{adj} = 0.07$$

where $I_t^{refinedQE}$ is a dummy variable constructed on the basis of refined QE chronology to split the sample:

$$I_t^{refinedQE} = \begin{cases} 1, & \text{if there are purchases at date t} \\ 0, & \text{otherwise} \end{cases}$$

Moreover, to get a better understanding of the determination of the term premium, a Generalized Autoregressive Conditional Heteroskedasticity specification is used (see Bollerslev (1986)). To capture variations in the underlying macroeconomic and financial fundamentals, the following variables are included: the daily $S\&P500$ returns ($spid$), the daily spreads evolutions ($aaad$, aad, ad, $baad$), the daily 10-year and 5-year inflation swaps evolutions ($swap5d$, $swap10d$), the daily Citigroup economic surprise evolution ($surpd$)[6]. To take into account some nonlinearities, polynomial transformations of the variables were performed, but only one has been found significant: $aad^2 = aad * aad$. By minimising information criteria (Akaike, Bayes, Shibata and Hannan-Quinn), the selected model is an ARMAX(2,2)-GARCH(1,1) (t-statistics in parentheses):

[6]To take into account macroeconomic uncertainties, volatilities of inflation swaps and of the economic surprise were tested but were never found significant

$$\begin{aligned}\Delta tpkw_t = {} & 0.25_{64.7}\Delta tpkw_{t-1} + 0.75_{188}\Delta tpkw_{t-2} \\ & + 1.36_{15.8} spid_t - 0.22_{-5.2} aad_t - 0.05_{-0.99} baad_t \\ & - 0.06_{-3.9} aaad_t + 0.05_{0.97} ad_t + 0.08_{4.2} swap5d_t \\ & + 0.09_{5.3} swap10d_t + 0.37_{7.2} aad_t^2 + 0.0008_{5.4} surpd_t\end{aligned}$$

The signs of the coefficients indicate that an improvement of risky assets ($S\&P500$ and corporate spreads) increases the term premium. As LSAP aims at boosting risky assets prices and raising inflation expectations, this model confirms that LSAP should increase the term premium and thus government bond rates.

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