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Macroeconomic Effects of Large-Scale Asset Purchases: New Evidence

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Abstract

We examine the macroeconomic effect of large-scale asset purchases (LSAPs) and forward guidance (FG) using a proxy structural VAR estimated on data through 2015, where the stance of the LSAP policy is measured using primary dealer expectations of the Federal Reserve's asset holdings. Monetary policy shocks are identified using instruments constructed from event study yield changes, and additional assumptions are employed to separately identify LSAP and FG shocks. We find that unexpected expansions in the Federal Reserves asset holdings during the ZLB period between 2008 and 2015 had significant expansionary effects on the macroeconomy, with real activity and inflation rising and unemployment declining notably following the shock. The policy accommodation appears to be transmitted to the economy both through financial markets–including Treasury yields, credit spreads and equity prices–and through bank lending. The effects on Treasury yields and term premiums appear to be longer-lived than previously documented, while the effects on credit spreads and especially bank lending also appear persistent. These results appear fairly robust to alternative identification and econometric methodologies, alternative policy indicators and instruments, and controlling for any possible Federal Reserve information effect. A counterfactual analysis shows that absent the LSAP3 program implemented between late 2012 and 2014, CPI inflation would have been about 1 percentage point lower, while the unemployment rate would have been about 4 percentage points higher, by the end of 2015.

Keywords: Unconventional monetary policy; forward guidance; quantitative easing; structural VAR; external instruments; identification; primary dealer survey.

JEL classification: E44, E52, E58.

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1 Introduction

What are the effects of large-scale asset purchases (LSAPs) on unemployment and inflation? More than 10 years after the Federal Reserve and the Bank of England initiated large expansions of their balance sheets through the purchase of a range of assets, and more than two decades after the Bank of Japan initiated Quantitative Easing (QE), there remains a great deal of controversy around the effectiveness of this policy tool for helping central banks achieve their macroeconomic objectives. In this paper, we provide new evidence on this issue using a structural VAR (SVAR) approach that relies on the use of new data and identifying assumptions, and we examine the robustness of the results to a range of alternative assumptions. We particularly focus on the important but underappreciated role of the formation of the public's understanding of systematic responses of the Federal Reserve's balance sheet policies to economic conditions.

There are two key challenges in assessing the effects of balance sheet policies. One is the classic problem of distinguishing exogenous innovations to balance sheet policies from endogenous responses. In a broad sense, balance sheet policies were entirely the endogenous response of policymakers to unprecedented economic challenges at a time when policy rates were already at their lower bound. However, some of these policy responses may have come as a surprise to the public. The key identification issue is therefore to properly measure the surprise component of QE actions from private agents' perspective. In this regard we make use of survey-based information about the expected size of the Federal Reserve's balance sheet, and we build on recent studies using proxy SVARs with external instruments, such as Gertler and Karadi (2015) and Caldara and Herbst (2019). In contrast to these studies, we are explicitly focusing on the post-crisis period, during much of which the effective lower bound was binding.

The second challenge is that central banks used QE in conjunction with other tools, notably forward guidance about the future path of policy rates. In fact, on several occasions, the Federal Reserve and other central banks combined announcements about future balance sheet policies with revised forward guidance about the future path of short-term interest rates. This feature makes it difficult to disentangle the effects of these two policies from each other, and we present results based on several different approaches to deal with this issue. In this regard, we are building on studies by Gürkaynak, Sack, and Swanson (2005) and Swanson (2018) by identifying exogenous innovations for multiple policy instruments.

These studies measure an unconventional policy shock by its effects on certain financial variables, such as intra-day responses of yields at various maturities. By contrast, our goal is to directly relate such policy shocks back to the size and maturity composition of an asset purchase program.

The previous literature on the effects of the Federal Reserve's LSAPs, recently reviewed by Kuttner (2018), has mostly focused on the effects of these programs on financial market variables. Much of this literature has relied on event studies. Studies that have tried to assess the effects of LSAPs on the Federal Reserve's goal variables of employment and inflation mostly take a two-step approach, combining the results from event studies with a specific macro model that captures how the changes in financial conditions resulting from an LSAP are being transmitted to real activity and inflation. Unavoidably, these studies take as given the transmission mechanism embedded in that model, which relies on a number of maintained hypotheses. Our study is intended to capture the transmission in a parsimonious and agnostic way, using minimal identifying assumptions in the spirit of the VAR literature pioneered by Sims (1980, 1992).

We find that asset purchase shocks have significant stimulative effects on the macroeconomy that are robust to alternative specifications. In particular, a *surprise* $500 billion asset purchase is estimated to raise the level of industrial production by about 1.5 percent and the level of the CPI by about 0.8 percent, while reducing unemployment by about 0.4 percentage points, at the peak. The shock appears to operate both through asset prices and through the bank lending channel, as Treasury yields and term premiums decline, excess bond premiums and mortgage spreads narrow, equity prices rise, and C&I lending expands following the shock. In contrast to previous studies that considered the effects of asset purchase *programs*, from the perspective of our VAR analysis the bulk of the historical asset purchase programs was the endogenous, systematic policy response to dire macroeconomic conditions, not policy *shocks*. Reflecting the limited persistence of the latter (as opposed to the systematic component of the asset purchases), the decline in Treasury yields and term premiums appear to be short-lived, while the decline in excess bond premiums and the rise in equity prices and bank loans appear more persistent.

2 Related Literature

Our paper contributes to the literature on the efficacy of unconventional monetary policy measures, which central banks around the world employed to provide additional stimulus as the traditional policy tool—the short-term interest rate—fell to its effective lower bound (ELB). As reviewed recently by Kuttner (2018), most studies of central bank asset purchases focus on their effects on financial markets.[1] By contrast, studies of their macroeconomic effects are far fewer and their findings less conclusive. Many of these studies for the U.S. take a two-step approach, where they first obtain estimates of asset price effects from other studies and then assess the macro effects of those asset price changes using either a macroeconomic model or a structural VAR that do not embed any formal role for central bank asset holdings.[2] This two-step approach often fails to control for anticipation of the announcements and the results could be sensitive to event window sizes. A few studies do estimate the financial market effects endogenously. For example, Meinusch and Tillmann (2016) treats QE announcements in the U.S. as a censored measure of a latent variable that represents the Fed's propensity to announce QE, and uses a SVAR to jointly estimate the latent QE propensity and to assess its macro effects. Gambacorta, Hofmann, and Peersman (2014) and Weale and Wieladek (2016) employ SVARs similar to ours, where QE shocks are measured as shocks either to the central bank's realized balance sheet size or to cumulative announced purchases, and identified through a combination of zero and sign restrictions. By relying on the ex-post realizations of the actual balance sheet size or announced purchases, these studies ignore a potential anticipation effect, where market expectations of upcoming asset purchases could already affect asset prices before the purchases begin or are announced. The paper most closely related to ours is Hesse, Hofmann, and Weber (2018), who also examines expectations of future asset purchases from the FRBNY's Primary Dealer Survey as one potential indicator of QE policy, in addition to cumulative announced purchases, although the identification is achieved through a combination of zero and sign restrictions, rather than through external instruments as in this paper. To the best of our knowledge, this is the first

[1] See, for example, Gagnon, Raskin, Remache, and Sack (2011), D'Amico and King (2013) and Li and Wei (2013) for the U.S., Joyce, Lasaosa, Stevens, and Tong (2011) for the U.K., and Andrade, Breckenfelder, De Fiore, Karadi, and Tristani (2016) and Eser, Lemke, Nyholm, Radde, and Vladu (2019) for the Euro Area.

[2] See, for example, Chung, Laforte, Reifschneider, and Williams (2012) and Engen, Laubach, and Reifschneider (2015) for the former, and Baumeister and Benati (2013) and Liu, Theodoridis, Mumtaz, and Zanetti (2019) for the latter.

paper that studies the macroeconomic effects of Federal Reserve's asset purchases using a structural VAR with external instruments.

On the methodological front, our paper is related to the growing literature on identifying structural shocks in a VAR setting using information outside the VAR.[3] Earlier studies, such as Romer and Romer (2004), take a narrative approach in treating certain noisy measures of structural shocks as true shocks and studying their effects using time series regressions. More recently, Mertens and Ravn (2013) and Stock (2008) proposed methods that use those measures as instruments to identify shocks. Gertler and Karadi (2015) and Caldara and Herbst (2019) applied this approach to identify monetary policy shocks, using asset price responses within narrow windows surrounding monetary policy announcements as instruments. We extend those studies to differentiate between shocks to current and expected future policy rate and shocks to expected future central bank asset holdings. Similar to us, Rogers, Scotti, and Wright (2018) also use event study yield changes to construct measures of target, FG and LSAP shocks and use them as instruments to identify monetary policy shocks in a SVAR and study how those shocks transmit across countries. However, they do not include central bank asset purchases or holdings data in the VAR and do not allow more than one monetary policy shock at the same time.

When constructing the external instruments, we draw on studies of high-frequency asset price responses to monetary policy announcements, especially those documenting more than one dimension of intraday yield changes around FOMC communications. For example, Gürkaynak et al. (2005) show that prior to the crisis, there appear to be a target factor, which captures changes to the funds rate target, and a path factor, which captures information from the rest of the statement and has the largest effect on yields at the two-year maturity. More recently, Swanson (2018) shows that an additional factor emerges post crisis that is needed to capture yield changes associated with the Fed's asset purchase announcements. More recent work, such as Nakamura and Steinsson (2018) and Jarociński and Karadi (forthcoming), emphasizes a so-called "Fed information effect," where unanticipated Federal Reserve actions are perceived to convey information not just about the FOMC's policy intentions, but also its perception of the state of the economy. If the FOMC is perceived to have private information or superior information processing abilities than private investors, such perceptions may cause investors to revise their macroeconomic outlook and could cause

[3] Ramey (2016) and Stock and Watson (2016) provide a recent review of the structural VAR literature.

financial markets to move differently than in the case of a traditional monetary policy shock. In addition, Kroencke, Schmeling, and Schrimpf (2019) and Cieslak and Schrimpf (2019) document an additional risk aversion shock associated with central bank announcements when event study changes in yields and stock prices are jointly considered. In our analysis, we follow Swanson (2018) in constructing two factors for the post-crisis period and use them as instruments in identifying LSAP and FG shocks, but do not separately consider Fed information effect or risk aversion shocks.

3 Methodology and Data

3.1 Methodology

Our basic framework is a SVAR model with external instruments, an approach pioneered by Mertens and Ravn (2013) and Stock (2008). This approach, also referred to as a proxy structural VAR (PSVAR), assumes that there exist m instruments that are correlated with k ($\leq m$) shocks but not with other shocks in the VAR.[4] In the case of $k = 1$, one can uniquely identify the shock under consideration up to scaling. Traditional studies of monetary policy shocks in a SVAR setting achieve identification by imposing the recursive assumption that monetary policy either responds to or affects another VAR variable within the same period, but not in both directions. By contrast, identification with external instruments allows for contemporaneous interactions between monetary policy and other variables in the VAR in both ways, which is important when fast-moving financial variables are included in the VAR as in our study.

In much of the paper, we focus on identifying one shock using one instrument, assuming that all other shocks in the VAR are uncorrelated with this instrument. However, in some sections, we attempt to disentangle multiple monetary policy shocks—shocks related to forward guidance and asset purchases—that are likely to be correlated with any event study yield responses to FOMC announcements—the external instruments we use. Therefore, additional assumptions are needed to separately identify those shocks.

Formally, consider a reduced-form VAR with L lags:

$$y_t = B_0 + B_1 y_{t-1} + B_2 y_{t-2} + ... + B_L y_{t-L} + u_t, \quad u_t \sim \mathcal{N}(0, \Sigma) \tag{1}$$

[4] In the remainder, we assume $k = m$. If $k < m$, the instruments' dimension can be reduced, typically by projection as in 2SLS.

where y_t and u_t are n-by-1 column vectors containing the VAR variables and reduced-form residuals, respectively, B_0 is a n-by-1 column vector of constants, $B_1, ..., B_L$ are n-by-n matrices of coefficients, and Σ is a n-by-n variance-covariance matrix.

The reduced-form residuals are related to the structural shocks ϵ_t as follows:

$$u_t = C\epsilon_t, \tag{2}$$

where C is an n-by-n matrix that satisfies $CC' = \Sigma$ and $\epsilon_t \sim \mathcal{N}(0, I)$ is a column vector of length n. The goal is to estimate the columns in C that correspond to the shocks we are trying to identify.

The use of external instruments help put additional restrictions on C. Let z_t be a column vector of m instruments where $m < n$. We assume that z_t is only correlated with the first m structural shocks, $\{\epsilon_{1t}, \ldots, \epsilon_{mt}\}$, but has zero correlation with the remaining structural shocks. In other words we have the following "exclusion" restriction:

$$E\left[z_t \epsilon_{it}\right] = 0, \quad i = m + 1 \ldots n. \tag{3}$$

As shown in Appendix A, a matrix C that satisfies $CC' = \Sigma$ and the exclusion restriction always exists. In addition, such a matrix identifies the two blocks of shocks, the instrumented shocks, $\{\epsilon_{1t}, \ldots, \epsilon_{mt}\}$, and the remaining shocks, $\left\{\epsilon_{(m+1)t}, \ldots, \epsilon_{nt}\right\}$, both uniquely up to a rotation. In other words, if a matrix C_0 satisfies the exclusion restriction, then a different matrix C satisfies the same restriction if and only if:

$$C = C_0 \begin{bmatrix} R_m & 0 \\ 0 & R_{n-m} \end{bmatrix}, \tag{4}$$

where R_m and R_{n-m} are m-by-m and $(n-m)$-by-$(n-m)$ orthonormal matrices, respectively. Additional restrictions are needed to pin down R_m and R_{n-m} to uniquely identify the matrix C.

Following Gertler and Karadi (2015), we use as instruments high-frequency changes in money market futures rates and Treasury yields over short windows around releases of FOMC statements and minutes and other significant FOMC-related events.[5] Those asset price movements over narrow event windows can be used as instruments as they reflect predominantly surprises associated with the corresponding events plus a small amount of noise that

[5] For FOMC statements we use a window from 5 minutes before to 25 minutes after each statement. For other FOMC events we try to use the same window as much as possible, but sometimes deviate due to the nature of the event or because the event occurred outside normal trading hours. See Section 3.3 for more details on the construction of the instruments.

is unlikely to be related to any of the structural shocks. In the following analysis, we will use either one or two instruments to identify the same number of monetary policy shocks. In the case of one instrument and one monetary policy shock, the shock is determined up to a sign and we only need to choose a convention to sign the shock.

In the case of two instruments and two shocks, we obtain identification by imposing one of two restrictions in addition to signing the shocks. Under the first restriction, we impose a zero correlation between one monetary policy shock and one of the instruments, such that one off-diagonal term in $E\left[z_t\left[\epsilon_{1t}, \epsilon_{2t}\right]\right]$ is zero. This is equivalent to first identifying a structural shock using one of the two instruments, and then identifying another structural shock as the only component among the remaining structural shocks that is correlated with the second instrument. Under the second restriction, the two monetary policy shocks are identified recursively, such that one off-diagonal term in the top 2-by-2 block of C is zero. This means that we are identifying two structural shocks that are correlated with the two instruments, such that one of the shocks is not contemporaneously affecting one of the VAR variables.

3.2 Sample choice, VAR Variables and LSAP Measures

We use January 1990 to December 2015 as our baseline sample. By comparison, Gertler and Karadi (2015) and many others use a longer sample starting in July 1979. We choose a later starting point due to concerns that the economy likely experienced structural changes over the long span since 1979. For example, there is evidence that the slope of the Phillips curve flattened significantly from the mid-1970s to the early 1990s (see Blanchard, Cerutti, and Summers (2015) among others). Including the early years in the sample may therefore bias our estimates of the effect of monetary policy on inflation. For comparison, we also report in the robustness section results from using the longer sample starting in July 1979, as well as a shorter post-crisis-only sample starting in December 2008.

Our baseline VAR has six monthly variables, including three monetary policy indicators—the federal funds rate, the 10-year Treasury yield, and a balance-sheet-based LSAP measure to be described below—and three other variables used in Gertler and Karadi (2015)—the logarithm of the consumer price index (CPI), the logarithm of industrial production (IP), and the Gilchrist and Zakrajšek (2012) excess bond premium (EBP). Our baseline LSAP measure is the one-year-ahead expected size of the Federal Reserve's balance sheet constructed from the Federal Reserve Bank of New York (FRBNY)'s Survey of Primary Dealers, conducted 8 times a year about a week before each FOMC meeting. More specifically, we calculate median expectations across dealers of the total par value of security holdings in the Federal Reserve's System Open Market Account (SOMA) one year from the survey dates. All securities that the Federal Reserve bought through the various asset purchase programs between 2008 and 2014 were managed on this account. It is important that the LSAP measure captures the degree of accommodation provided by the Federal Reserve via its asset purchase programs. The accommodation arguably did not depend only on assets that had already been purchased, but also on assets that the Federal Reserve was expected to purchase in the future, as those expectations can have important contemporaneous effects on forward-looking asset prices and the behavior of various financial institutions.

As an alternative we also construct a purchase-based LSAP measure, calculated as the median cumulative asset purchases, beginning in December 2008, by the Federal Reserve expected one year from the survey dates. Compared to the balance-sheet based measure, the purchase-based measure does not take into account previous or expected future redemptions of the assets. As the Federal Reserve redeemed only a tiny fraction of assets between 2008 and 2015, the difference between these two measures is small and, as shown in Section 5, using either measure does not change our empirical results in any meaningful way. Figure 1 shows both LSAP measures along with the actual path of SOMA.

A few considerations go into constructing these LSAP measures. First, the questions in the surveys change over time and do not always directly speak to the measures we are trying to construct. For example, no survey questions were asked about the Federal Reserve's balance sheet before 2009 or between December 2009 and August 2010. For these periods we assume that investors did not expect additional purchases and SOMA was expected to remain at its present levels, an assumption that is consistent with market narratives at the time. The survey questions also changed over time, asking about cumulative purchases over the next 5 to 8 quarters from April 2009 to November 2009, about the total size of LSAP2 from September 2010 to April 2011, and about SOMA size at various horizons over the next five years from January 2011 to December 2014. We interpolate the median responses to those questions to obtain constant-horizon 12-month-ahead forecasts. Second, we date the survey responses to the due dates of the surveys, typically the Monday or Tuesday of the week before the FOMC meeting. Finally, we convert the survey forecasts, which are

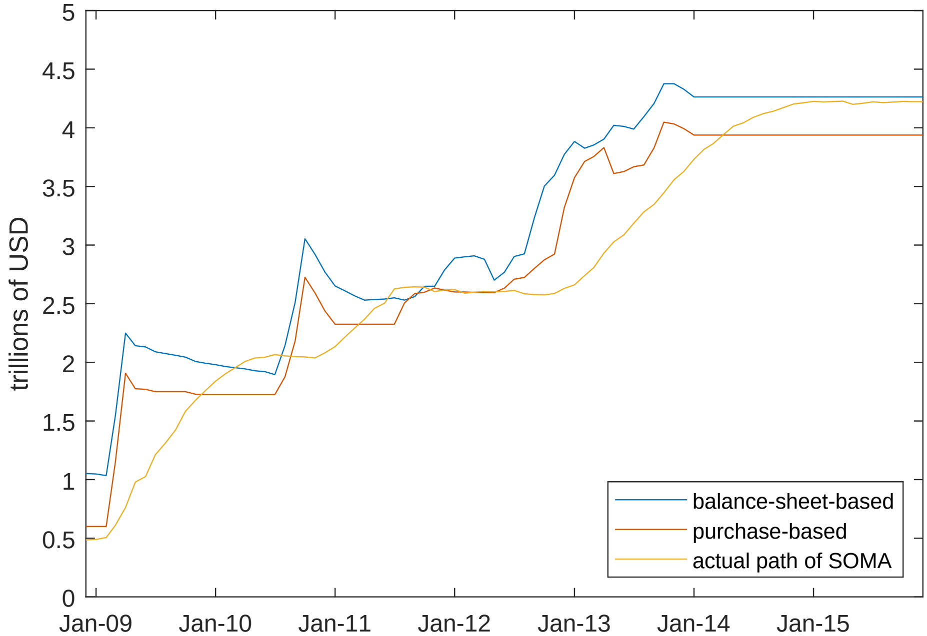

Figure 1: Path of LSAP measures and the actual size of SOMA.

The blue line shows the expected size of SOMA, one year into the future. The yellow line shows the actual path of SOMA, which roughly aligns with the blue line shifted by one year to the right. The red line shows the expected cumulative asset purchases by one year from the current date, since the beginning of the LSAP in late 2008. The initial difference between the expected SOMA size and the expected cumulative purchase reflects the size of SOMA at the beginning of the first series of purchases.

available at the FOMC frequency, to monthly measures by linearly interpolating. Appendix B describes the data and the construction of the LSAP measures in more detail.

Prior to 2008 there were no expectations that the FOMC would use LSAPs as an active policy tool. We capture this fact by restricting the VAR model so that expected SOMA holdings are an exogenous constant prior to December 2008. Similarly, we assume that the federal funds rate is constant from December 2008 onward, as the federal funds rate was held near the zero lower bound and no longer responded to economic conditions. As a result, the federal funds rate equation is estimated using data prior to December 2008 and the LSAP equation is estimated using data after December 2008, while all other equations are estimated over the full sample. We identify two monetary policy shocks, LSAP and forward guidance, using VAR residuals and instruments for December 2008 and later. Appendix C provides more detail on the estimation process.

3.3 Instruments for Monetary Policy Surprises

We construct our instruments using interest rate changes around FOMC events in three steps. First, building on Gürkaynak et al. (2005) we compile a list of important Fed events, including statements, minutes, the Chair's press conferences since 2011, as well as a few economic data releases and Federal Reserve speeches. We use changes in twelve money market futures rates and Treasury yields: the current-month and one- and two-month-ahead federal funds futures rates, the first three quarterly Eurodollar futures rates, and yields on three- and six-month Treasury bills, and two-, five-, ten- and thirty-year on-the-run Treasury notes and bonds.[6] This data set spans the period from July 1991 to December 2015.

All three monetary policy shocks—target, FG, and LSAP—could in principle affect the entire term structure, albeit in different ways. For example, Gürkaynak et al. (2005) show that the target shock has the largest effect at the very front end, with the effect diminishing as the maturity lengthens, while the "path" shock, a shock associated with forward looking statements by the FOMC, has a hump-shaped effect on the yield curve with peak effects at 2- to 5-year maturities. By contrast, event studies of LSAP announcements, such as Gagnon et al. (2011), show that the yield effects of LSAP announcements peak at maturities around 10 years. Utilizing those diverging patterns, we first extract three orthogonal factors that

[6] Following Gertler and Karadi (2015), we modify the current-month federal funds futures rates to better capture the expected federal funds rates after the upcoming FOMC meetings, taking into account the fact that the federal funds futures contracts settle on the average funds rate over the entire month.

correspond to the different types of shocks from the cross section of intraday yield changes on event days, and then apply those orthogonalized factors as instruments to identify the shocks in the structural VAR. The orthogonalization of the factors serves two purposes: first, it reduces the dimensionality of instruments to match the number of shocks as required; and second, it increases the correlation between the instruments and the shocks they instrument for and therefore helps sharpen the identification.

We construct a monthly series of orthogonalized instruments in two steps. First, we follow the procedures outlined in Swanson (2018) to construct orthogonalized target, FG, and LSAP factors on event days from intraday interest rate changes. More specifically, we compute the first three principal components from intraday interest rate changes over the full sample between July 1991 and December 2015, and rotate them into target, FG, and LSAP factors by imposing that both the FG and LSAP factors have zero effect on the current-month federal funds futures and that the magnitude of the LSAP factor over the pre-crisis period (up to December 2008) is minimized. We normalize the factors to have unit variances and positive loadings on the front-month futures and 2- and 10-year yields, respectively.[7] These restrictions uniquely determine the three factors.[8] In the second step, we convert the orthogonalized factors on event days into monthly series following the procedure in Gertler and Karadi (2015), by accumulating event-day factors over time and looking at monthly averages. This procedure gives more weight to events that occur early in the month and allows an event that occurs later in the month to affect the values both in the current month and in the following month.[9]

Table 1 shows the percentages of variation across event study yield changes explained by the three factors over three samples: July 1991 to December 2015 ("full sample"), July 1991 to November 2008 ("pre-crisis"), and December 2008 to December 2015 ("post-crisis"). For the full sample, the target shock is the dominant monetary policy shock and accounts

[7] This is approximately true because we do not subtract the mean. We do not subtract the mean because we take zero movement in yield as uninformative, rather than the mean movement. Technically, for each factor the mean of squares is one, and the mean of the two factors' products is zero.

[8] For comparison purposes, we also construct an alternative set of factors following the split-sample approach proposed by Swanson (2018). This approach extracts two principal components from the pre- and post-crisis samples respectively, and rotates them into two orthogonalized factors that correspond to the target and FG factors in the pre-crisis sample and the FG and LSAP factors in the post-crisis sample. This rotation is achieved by imposing that the FG shock has no contemporaneous effect on the front-month federal funds futures rate pre-crisis, and that the effects of the FG shock on the cross section of yields are as close as possible pre- and post-crisis. Results using instruments constructed this way are similar.

[9] Reversing these two steps to first construct monthly event study surprises and then rotate into monthly factors gives nearly identical results.

Table 1: Percentage of variation explained by factors

	Factors			
	Target	FG	LSAP	Total
Full sample	52.3	32.1	7.8	93.2
Pre-crisis	60.1	30.5	2.8	93.5
Post-crisis	13.0	41.8	36.8	91.5

This table shows the percentages of variances of event study yield changes explained by the three factors over three samples: July 1991 to December 2015 ("full sample"), July 1991 to November 2008 ("pre-crisis"), and December 2008 to December 2015 ("post-crisis"). For subsamples, the percentage is calculated by dividing the sum of covariances between yield changes and each factor by the sum of variances of yield changes.

for slightly more than half of the variation in yields within the event study window, while FG news explains four times as much variation in yields as LSAP shocks. Together the three factors explain more than 90 percent of event study changes in yields. The target and FG factors alone explain a similar proportion of yield changes during the pre-crisis sample, while FG and LSAP factors capture close to 80 percent of the interest rate changes over the post-crisis period. By construction, the LSAP factor explains hardly any variation in the pre-crisis period, while the importance of target shocks is greatly diminished post crisis. Figure 2 shows the effects of the three factors on interest rates at different maturities. The target factor has the largest effect on the front-month federal futures rate and the 3-month Treasury bill yield, the FG factor has a hump-shaped effect peaking around 2 years, while the effect of the LSAP factor rises monotonically up to the 10-year maturity. This is consistent with previous evidence in the literature and with the intuition that forward guidance operates at the intermediate horizon while LSAPs operate at much long maturities.

Table 2 reports results from tests that examine the strength of the instruments by regressing first-stage VAR residuals for the two monetary policy indicators on the FG and LSAP instruments. The first two columns treat each pair of indicator and instrument separately and regress each residual on the corresponding instrument only. In this case, Stock, Wright, and Yogo (2002) recommended a threshold of 10 for the F test. The last two columns regress the residuals on both instruments jointly. In this case, we use the minimal eigenvalue of the concentration matrix to quantify the strength of the instruments, which can be viewed as a

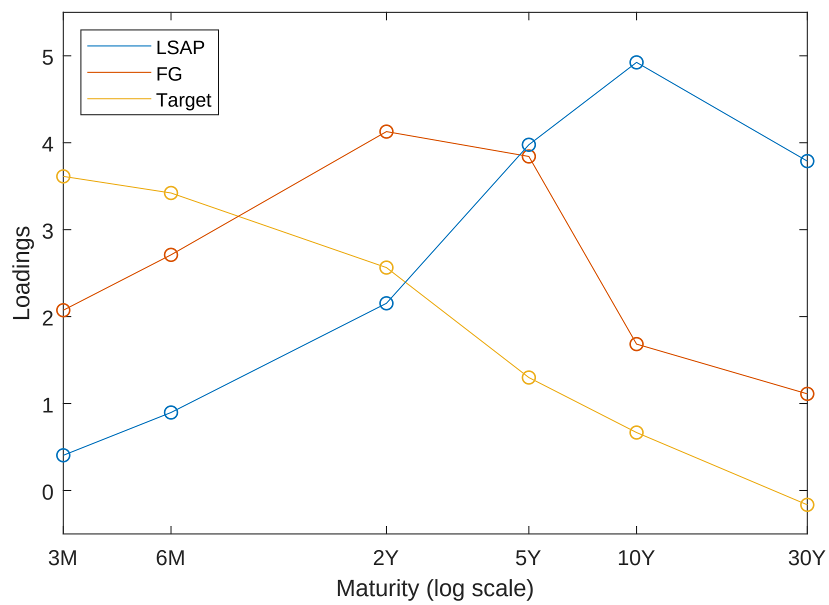

Figure 2: Yield Loadings on Target, FG, and LSAP Factors

Each plot line shows how much change in Treasury yield is implied by each factor, across six different maturities, ranging from 3-month to 30-year. The LSAP factor is heavily loaded on the 10-year maturity, comparable to the maturity of Treasury securities purchased through QE programs. The FG factor is heavily loaded on the 2-year, a reasonable horizon for forward guidance.

matrix analog of the F test, following Cragg and Donald (1993) and Stock and Yogo (2005). The F-statistics from the univariate regressions suggest that the LSAP factor appears to be a strong instrument for the LSAP indicator, while the strength of the FG factor for the 10-year yield is weaker. When both instruments are considered jointly, the strength of the LSAP factor appears slightly weakened.

Table 2: First-Stage Instrument Strength Test: Post-crisis Sample

	Monetary policy indicators			
	Univariate		Bivariate	
Instruments	10-year yield	expected SOMA size	10-year yield	expected SOMA size
FG factor	0.12***		0.10**	0.01
	(0.04)		(0.04)	(0.02)
LSAP factor		-0.04***	0.04**	-0.04***
		(0.01)	(0.02)	(0.01)
No. Obs.	85	85	85	85
Adjusted R^2	0.09	0.13	0.13	0.12
F-statistic	7.80***	12.89***	6.83***	6.45***
min. eigenvalue			2.23	

This table shows the first-stage instrument strength tests of the baseline model. The first two columns report results from univariate regressions where the VAR residual for the policy indicator is regressed on the corresponding instrument alone. The last two columns report results from bivariate regressions where the residuals are regressed on both instruments. The symbols ***, ** and * denote significance at the 1, 5 and 10 percent levels, respectively.

4 Baseline Model

In this section we describe the results from the baseline model. We first discuss the results where we only use the LSAP instrument to identify one monetary policy shock, implicitly imposing the assumption that all other shocks are uncorrelated with the LSAP instrument. Next, we use both the FG and LSAP instruments to identify both types of monetary policy shocks.

4.1 Single Instrument: Impulse Responses

We first estimate the baseline model using a single instrument—the LSAP factor. In doing so, we implicitly impose that the monetary policy shock is the only structural shock that is correlated with the LSAP instrument. We use two lags, which maximizes conventional information criteria for post-crisis observations.[10] The impulse responses estimated with a single lag are similar in signs and magnitudes.[11]

Figure 3 plots the impulse responses to the only monetary policy shock thus identified. The shock is scaled such that the expected SOMA measure rises by $500 billion on impact in response to the shock. The shock dissipates rapidly over the first year, but remains significantly above the pre-shock level four years out.[12] The transitory nature of the shock reflects the historical feature of the LSAPs: As shown in Figure 1, the Federal Reserve consistently expanded its asset holdings between 2009 and 2015, and the model sees the LSAP measure as quickly converging to its overall expanding path following any unexpected shocks. Both industrial production and the price level rise following the surprise increase in the LSAP measure. The effect on IP peaks around 30 months after the shock at 180 basis points, and remains significant out to 4 years. The effect on the CPI is more subdued and less significant statistically. The excess bond premium declines in response to the shock and stays significantly lower for about two years. The ten-year Treasury yield falls about 40 basis points on impact, and remains on average 15 bps lower over the first year.

Table 3 compares the baseline estimates with previous estimates of the peak macro effects of QE shocks and traditional policy rate shocks.[13] Our shock of $500 billion purchase is roughly equal to 2.5% of nominal GDP. When adjusted for the unit of the shock, the peak output effect is close to those from Weale and Wieladek (2016) and Gertler and Karadi (2013) but much larger than those from Hesse et al. (2018) and Chen, Cúrdia, and Ferrero (2011). Our estimate of the peak price level response, on the other hand, is comparable to that from Hesse et al. (2018) but much smaller than that from Weale and Wieladek (2016).

[10] The Aikake Information Criterion (AIC) is maximized when using two lags, whether calculated using only post-crisis residuals from the baseline VAR or using residuals from the VAR estimated using post-crisis observations only ('post-crisis' sample as in section 5.3). In either case the difference in AIC between one and two lags is small.

[11] We construct the 90 percent confidence intervals using the recursive wild bootstrap method based on 10000 simulations as in Mertens and Ravn (2013) and Gertler and Karadi (2015).

[12] Gambacorta et al. (2014) find an even faster decay in LSAP shocks based on the central bank's actual balance sheet size, with the shock fading out after 3 months.

[13] The output and price effects are from the baseline model reported above. The unemployment rate response is from a VAR with the unemployment rate added to the baseline VAR.

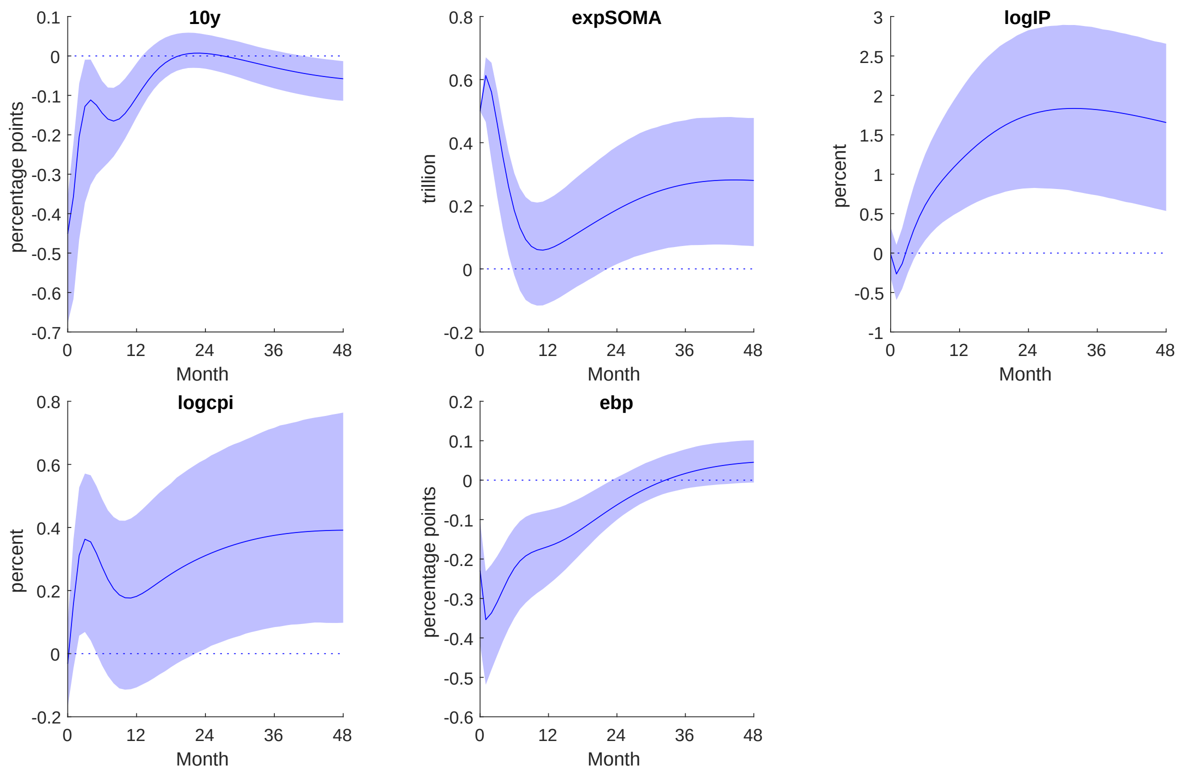

Figure 3: Impulse Responses to a LSAP Shock

The solid lines plot the impulse responses to a $500 billion shock to 1-year ahead expected SOMA holdings. The shaded areas represent 90 percent confidence intervals estimated using bootstrap methods.

The relative peak response of output to that of the price level, reported in column (7), is estimated to be around 4.5 in our baseline model, slightly above the upper range found in the literature for both conventional policy rate shocks and QE shocks.

We now take a closer look at the estimated shocks. The estimated monetary policy structural shock has a correlation of about -37% with the LSAP factor, which, together with the evidence shown in Table 2, suggests that the LSAP factor is a reasonable instrument for monetary policy shocks between 2008 and 2015. Figure 4 plots the estimated monetary policy structural shock as well as the LSAP factor, with vertical lines corresponding to the eight major announcements listed in Table 4. A couple of things are worth noting. First, some announcements—March 2009 and September 2013, for example—are estimated to be associated with large accommodative monetary policy shocks, while for others—November 2011 and December 2012, for example—the estimated shocks are close to zero or even con-

Table 3: Selected Estimates of Peak Macro Effects of Monetary Policy Shocks

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Model	Sample period	Experiment	output	price	(5)/(6)	inflation	unemp
Baseline estimates	SVAR[2]	1990M1-2015M12	$500b (2.5% GDP) expected purchase	1.8%	0.4%	4.5		-0.60%
QE shocks: Two-Step Estimates								
Chung et al. (2012)	FRB/US	n/a	QE1-2 (-65 bps to 10y tp)	3%	1%	3.0		-0.75%
Engen et al. (2015)	FRB/US	n/a	QE1-3 and MEP (-120 bps to 10y tp)		0.5%			-1.2%
Baumeister and Benati (2013)	SVAR[1]	1965Q4-2011Q4	QE1 (-60 bps to 10-year minus ffr)	0.9%			1%	-0.75%
Liu et al. (2019)	SVAR[1]	1965M4-2011M3	1 sd (-10 bps) shock to 10y-ffr spread				0.2%	0.06%
QE shocks: One-Step Estimates								
Gertler and Karadi (2013)	DSGE	n/a (calibrated)	QE1 (6% GDP purchase)	2.2%			3%	
			QE2 (2.5% GDP purchase)	1%			1.4%	
Chen et al. (2011)	DSGE	1959Q3-2009Q3	QE2 ($600b purchase)	0.1%			0.03%	
Gambacorta et al. (2014)	SVAR[1]	2008M1-2011M6	1 sd (3%) shock to CB balance sheet	0.07%	0.02%	3.5		
Weale and Wieladek (2016)	SVAR[1]	2009M3-2014M5	1% GDP purchase	0.58%	0.62%	0.9		
Hesse et al. (2018)	SVAR[1]	2008M11-2014M10	1% GDP purchase	0.2%	0.2%	1.0		
Conventional policy rate shocks								
Christiano, Eichenbaum, and Evans (1999)	SVAR[1]	1965Q3-1995Q2	1 sd (71 bps) shock to ffr	0.5%	0.4%	1.3		
Gertler and Karadi (2015)	SVAR[2]	1979M7-2012M6	25 bps shock to 1-year yield	0.4%	0.1%	4.0		
Caldara and Herbst (2019)	SVAR[2]	1994M1-2007M6	25 bps shock to ffr	0.4%	0.2%	2.0		0.05%

This table reports selected estimates of macro effects of QE and conventional monetary policy shocks in the literature.
1 - identified with zero and sign restrictions; 2 - identified with external instruments

No.	Date	Announcement content
1	3/18/2009	$1.15 trillion Treasury and Mortgage-backed securities (MBS) purchases.
2	8/10/2010	Reinvesting all maturing securities.
3	11/3/2010	$600 billion Treasury purchase.
4	9/21/2011	Maturity extension purchases of Treasury securities.
5	6/20/2012	Continuing maturity extension.
6	9/13/2012	$40 billion MBS purchase per month.
7	12/12/2012	$45 billion purchases of Treasury securities per month.
8	9/18/2013	No immediate tapering of ongoing asset purchase.

Table 4: Major LSAP Announcements.

tractionary. This heterogeneity could reflect the fact that announcements were to varying degrees anticipated by investors. Second, the estimated monetary policy shock and the LSAP factor sometimes disagree on the magnitude of the surprise following the announcements. For example, the announcements in March 2009 and September 2013 are viewed as strong expansionary surprise by both measures, while those in August 2008 and September 2012 are only noticeable in the estimated monetary policy shocks.

To illustrate the importance of endogenous LSAP responses from the perspective of the VAR, the blue line in Figure 5 plots the counterfactual path of SOMA holdings assuming zero LSAP *shocks*. This path rises over time, reflecting the endogenous response of SOMA holdings to changing economic conditions, including shocks unrelated to monetary policy, over this period. The difference between this path and the actual path, plotted by the dotted black line, reflects changes in SOMA holdings due to LSAP shocks.

To see the impact of major expansionary LSAP shocks during this period, we construct a second counterfactual path, the red line, that incorporates LSAP shocks associated with the four most pronounced LSAP events over this period, Those four events are the releases of FOMC statements on March 2009, August 2010, September 2012 and September 2013, corresponding to events 1, 2, 6 and 8 in Table 4. Since all these FOMC events occur in mid-month, we apply shocks about evenly to the announcement months and the following months. The shocks from these four announcements alone would have pushed the expected SOMA holdings measure above the zero-LSAP-shock path throughout this period. Consistent with the impulse responses on Figure 3, these positive shocks also raise the paths of log CPI and log IP significantly, as shown in Figure 6.

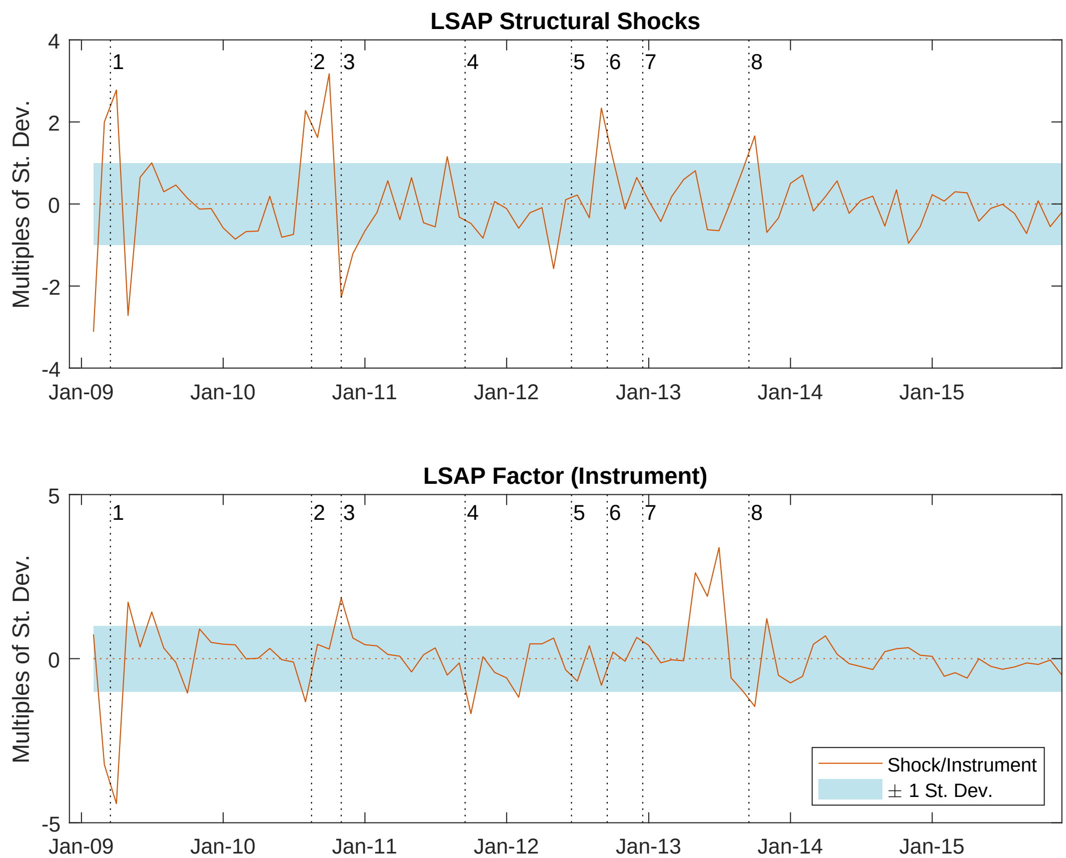

Figure 4: Monetary Policy Shocks and the LSAP Factor.

The top panel shows the estimated monthly series of the LSAP structural shock from the VAR. The bottom panel shows the LSAP instrument for each month, extracted from yield curve movements around FOMC announcements and other monetary policy events. Note that in the top panel positive values represent expansionary shocks, while in the bottom panel positive values represent positive changes in yields, which would normally represent contractionary shocks. Numbered vertical lines indicate the dates for important LSAP-related announcements, as described in Table 4.

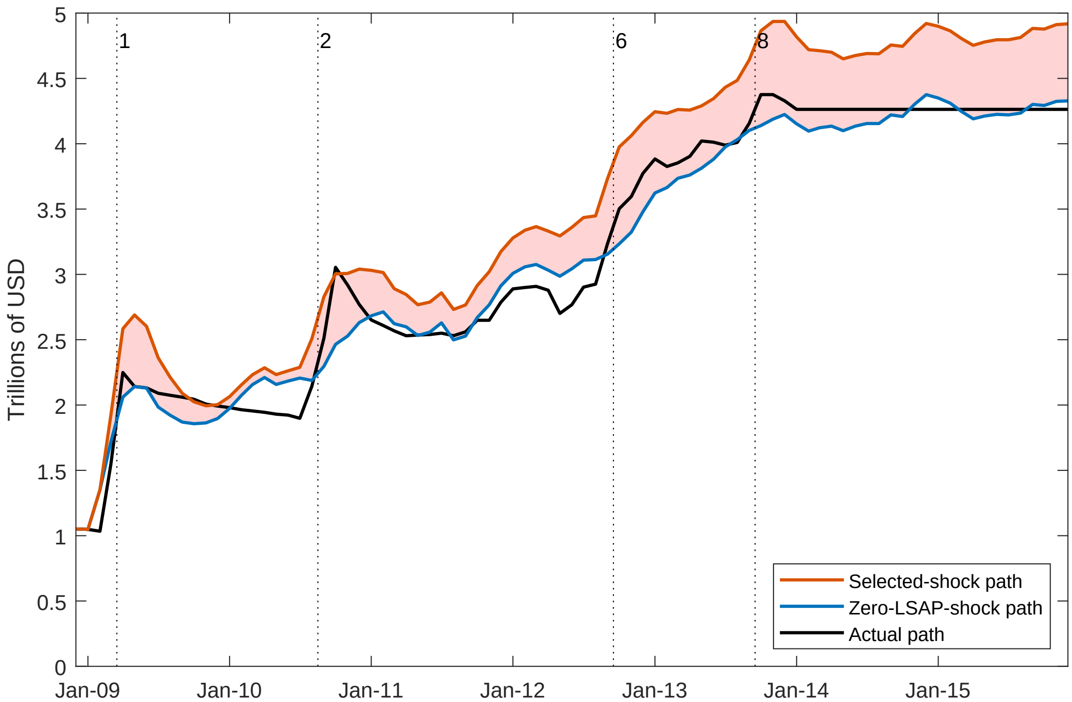

Figure 5: Impact of Selected Events on the LSAP Measure.

The lines show the evolution of the LSAP measure over the sample period. The black line shows the actual path. The blue line shows the path generated from the starting conditions, estimated model coefficients and estimated shocks, with the LSAP shock assumed to be zero in every period. The red line shows the path generated with the LSAP shock assumed to be zero in every period except for those affected by the four major LSAP-related announcements—events 1, 2, 6 and 8 in Table 4. For those time periods, we apply the estimated LSAP structural shocks.

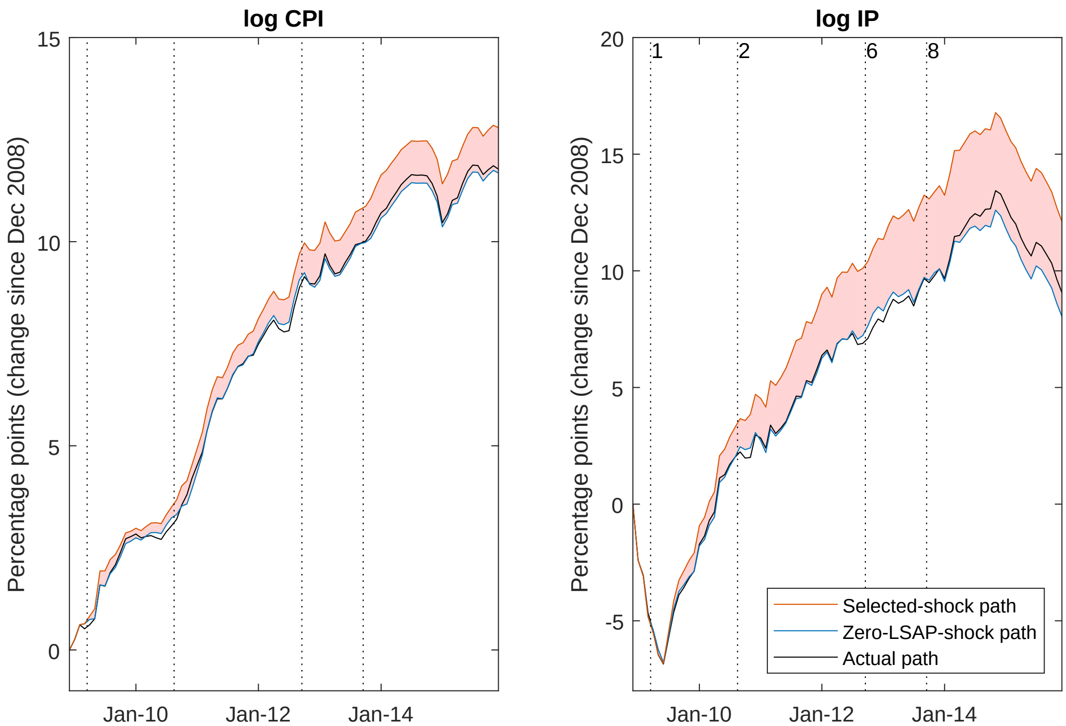

Figure 6: Impact of Selected Events on Price and Production.

The lines show the evolution of the two macroeconomic variables—log CPI and log IP—over the sample period. As in Figure 5, the black line shows the actual path, the blue line shows the path generated from the starting conditions and zero LSAP shocks, and the red line shows the path generated from the starting conditions and zero LSAP shocks except for the estimated LSAP structural shocks corresponding to events 1, 2, 6 and 8 in Table 4.

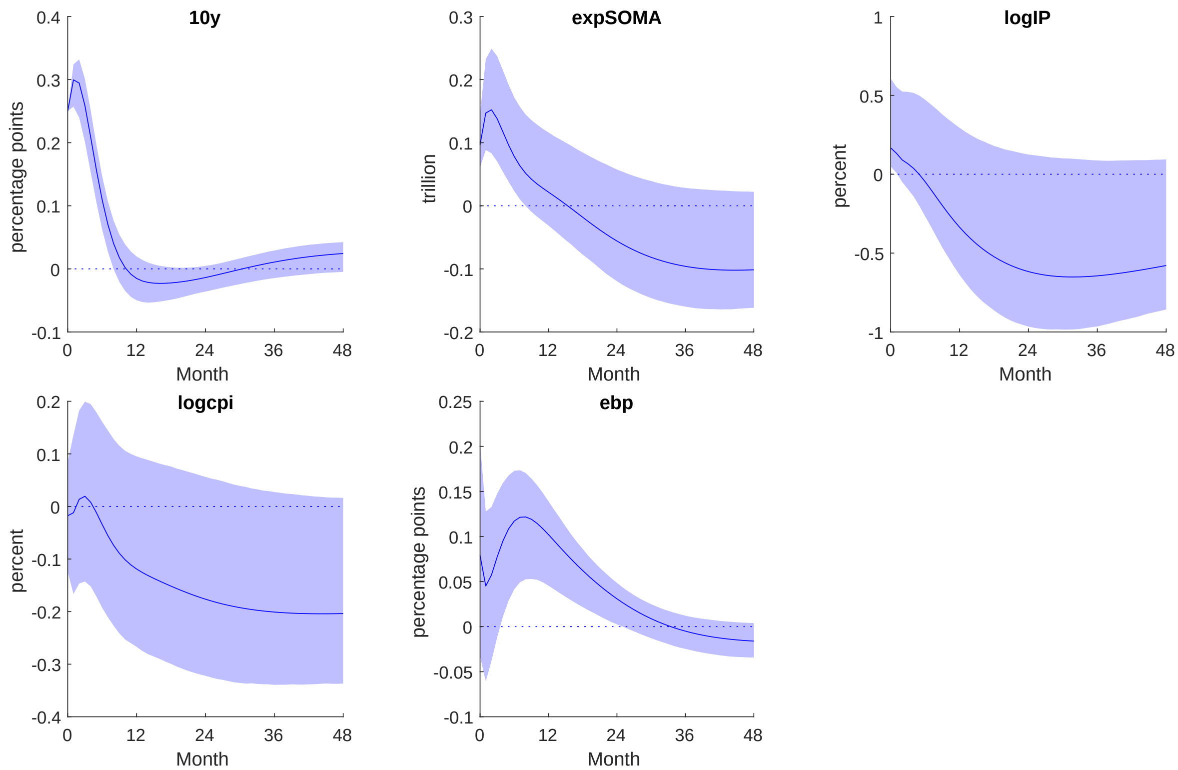

Figure 7: Impulse Responses to FG Shocks

The solid lines plot the impulse responses to a rate path shock that raises the ten-year yield by 25 basis points on impact. The shaded areas represent 90 percent confidence intervals estimated using bootstrap methods.

4.2 Two Instruments: Impulse Responses

We estimate the baseline model again trying to identify two monetary policy shocks using both the LSAP and the FG factors as instruments. As discussed earlier we need an additional restriction to separately identify the two shocks, in addition to signing the shocks. We examine two such restrictions. Under the first restriction, we assume that the FG structural shock has zero correlation with the LSAP factor. Under this restriction, the LSAP shock is identified exactly the same way as the previous case with one instrument, as the LSAP structural shock remains the only shock correlated with the LSAP factor. Accordingly, the impulse responses to this shock are identical to those shown in Figure 3. The FG shock is then identified as the only remaining shock with a nonzero correlation with the FG factor.

Figure 7 plots the impulse responses to a FG shock scaled to raise the 10-year yield by

25 basis points on impact. Both log CPI and log IP decline while the EBP rises after the shock, as can be expected following a surprise monetary policy tightening. The expected level of SOMA holdings increases on impact but only slightly. Indeed, when we impose the alternative identification restrictions that the FG shock has no contemporaneous effect on expected SOMA holdings, the results look nearly identical and are therefore not reported.

5 Robustness

5.1 Alternative Ways of Calculating Impulse Responses

Jordà (2005) advocates calculating impulse responses using local projections, which consist of a set of predictive regressions of future target variables on measures of structural shocks one horizon at a time, while controlling for other lagged explanatory variables. IRFs calculated from these regressions do not rely on the structural parameters of the VAR model, and hence are less susceptible to model misspecifications which could get compounded as the horizon lengthens. Specifically, we estimate the following regressions for each horizon h:

$$y_{t+h} = A_0^h + A_1^h y_{t-1} + A_2^h y_{t-2} + A_e^h e_t + \eta_{t+h}, \tag{5}$$

where y_t is the vector of VAR variables, e_t is a vector of measured structural shocks, and $A_i^h, i \in \{0, 1, 2, e\}$ are coefficient vector or matrices. The matrices $\{A_e^h\}$ over different horizons h determine the impulse response to the shock.

Figure 8 plots the IRFs to an LSAP shock calculated from the proxy SVAR on the left and those using local projections on the right. The IRFs using the local projection methods are more jagged than those from the SVAR, but follow broadly similar patterns.

5.2 Alternative Policy Indicators and Instruments

In this section we consider alternative indicators of monetary policy, including 1-, 2- and 5-year yields and survey expectations of the federal funds rate 12 months or 18 months ahead. The Survey of Primary Dealers, which is used to construct our LSAP policy indicator, also contains questions on dealers' expectations about the federal funds rate at various horizons. We construct 12- and 18-month-ahead median expectations of the funds rate from the surveys, and convert them into monthly measures following the same methodology as

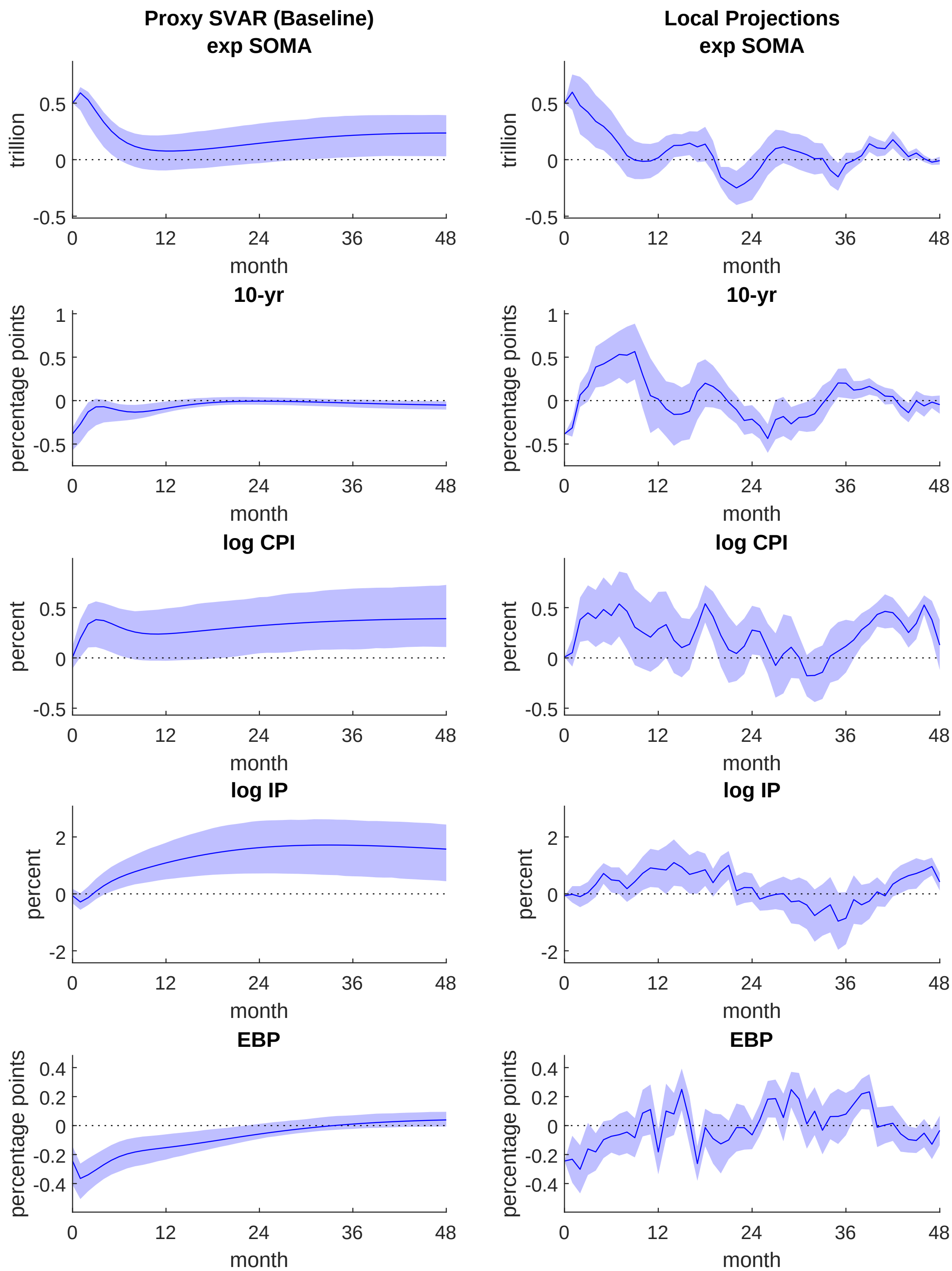

Figure 8: Impulse Responses to LSAP Shocks: Alternative IRF Calculation

The solid lines plot impulse responses of variables in the baseline VAR to a LSAP shock that raises the expected SOMA holdings by $500 billion on impact, with impulse responses calculated either within the VAR (left panel) or using local projections treating the instruments as the true shocks (right panel). The shaded areas represent 90 percent confidence intervals constructed either using bootstrap methods for the VAR-implied IRFs or using OLS standard errors for the local projections method.

for the LSAP measures; see Appendix B for more details.[14]

Table 5: Robustness to alternative FG indicators

	10-year yield		1-year yield		2-year yield	
	uni.	bi.	uni.	bi.	uni.	bi.
FG instrument	0.12***	0.10**	0.03	0.03	0.03	0.03
	(0.04)	(0.04)	(0.02)	(0.02)	(0.03)	(0.03)
No. Obs.	85	85	85	85	85	85
Adjusted R^2	0.09	0.13	0.02	0.01	0.01	0.01
F-statistic	7.80***	6.83***	1.96	1.08	0.94	0.89
min. eigenvalue		2.23		0.86		0.47
	5-year yield		12m ahead svy exp ffr‡		18m ahead svy exp ffr‡	
	uni.	bi.	uni.	bi.	uni.	bi.
FG instrument	0.08*	0.07	-0.02	-0.02	0.03	0.03
	(0.04)	(0.04)	(0.01)	(0.01)	(0.02)	(0.02)
No. Obs.	85	85	83	83	83	83
Adjusted R^2	0.04	0.04	0.03	0.02	0.02	0.01
F-statistic	3.37	2.39	2.32	1.15	1.90	0.94
min. eigenvalue		1.33		1.11		0.90

This table repeats the first-stage instrument strength tests in Table 2 for various FG indicators, including the 10-year yield in the baseline model, as well as 1-, 2- and 5-year yields and survey-based measures of expected federal funds rate 12 and 18 months ahead. The two columns under each indicator reports results for univariate or bivariate regressions respectively. The symbols ***, ** and * denote significance at the 1, 5 and 10 percent levels, respectively.
‡: Survey expectations of future federal funds rates are not available before the crisis. Results for those indicators are based on VARs estimated over the post-crisis period.

Table 5 reports the first-stage instrument strength test for the various FG indicators. The 10-year yield is the only indicator that generates a significant F-statistic.

Table 6 reports the first-stage instrument strength test for the various LSAP indicators. The LSAP instrument explains a larger portion of variations in survey-based measures than

[14] Survey expectations of future federal funds rates are not available before the crisis, and results for those indicators are based on VARs estimated over the post-crisis period.

those in the actual SOMA holdings, and the associated F statistics appear much larger, both in univariate or bivariate regressions.

Figure 9 and 10 shows the impulse responses to FG and LSAP shocks, respectively, using the 18-month ahead expected federal funds rate and expected SOMA-to-GDP ratio, both from surveys, as the corresponding policy indicators. The results are qualitatively similar to what is seen from Figures 7 and 3 under the baseline model, although the responses of the log IP and the log CPI appear more transitory.

Table 6: Robustness to alternative LSAP indicators

	expected SOMA		expected SOMA/GDP		expected purchases	
	uni.	bi.	uni.	bi.	uni.	bi.
LSAP instrument	-0.04***	-0.04***	-0.22***	-0.23***	-0.03***	-0.03***
	(0.01)	(0.01)	(0.06)	(0.06)	(0.01)	(0.01)
No. Obs.	85	85	85	85	85	85
Adjusted R^2	0.13	0.12	0.13	0.13	0.11	0.10
F-statistic	12.89***	6.45***	12.01***	6.54***	10.75***	5.37***
min. eigenvalue		2.23		2.69		1.89

	expected purchases/GDP		Actual SOMA	
	uni.	bi.	uni.	bi.
LSAP instrument	-0.18***	-0.19***	0.00	0.00
	(0.06)	(0.06)	(0.00)	(0.00)
No. Obs.	85	85	85	85
Adjusted R^2	0.09	0.09	0.00	0.01
F-statistic	8.60***	4.65**	0.01	0.91
min. eigenvalue		2.17		0.34

This table repeats the first-stage instrument strength tests in Table 2 for various LSAP indicators, including the expected SOMA holdings in the baseline model, as well as expected SOMA-to-GDP ratio, expected asset purchases, expected asset purchases-to-GDP ratio, the ten-year yield, and the actual SOMA holdings. The two columns under each indicator reports results for univariate or bivariate regressions respectively. The symbols ***, ** and * denote significance at the 1, 5 and 10 percent levels, respectively.

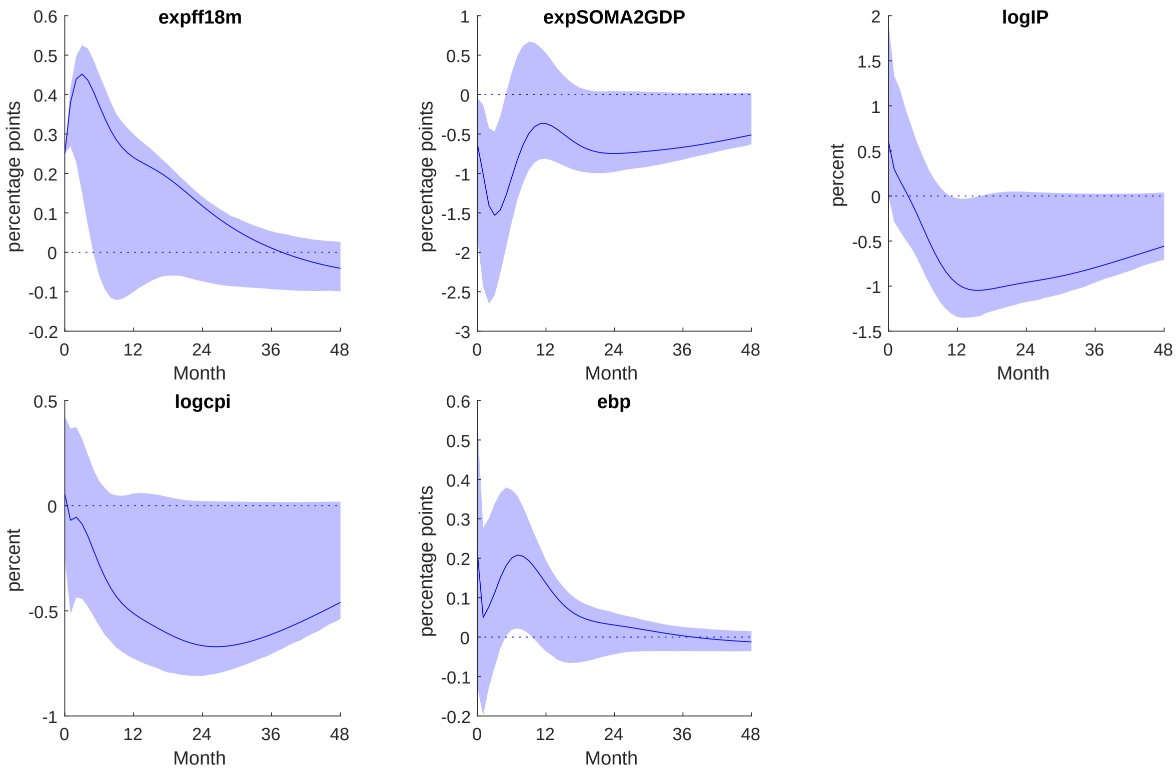

Figure 9: Impulse Responses to FG Shocks (Alternative Indicators)

The solid lines plot the impulse responses to a 25 basis point shock to 18-month ahead expected federal funds rate. The shaded areas represent 90 percent confidence intervals estimated using bootstrap methods.

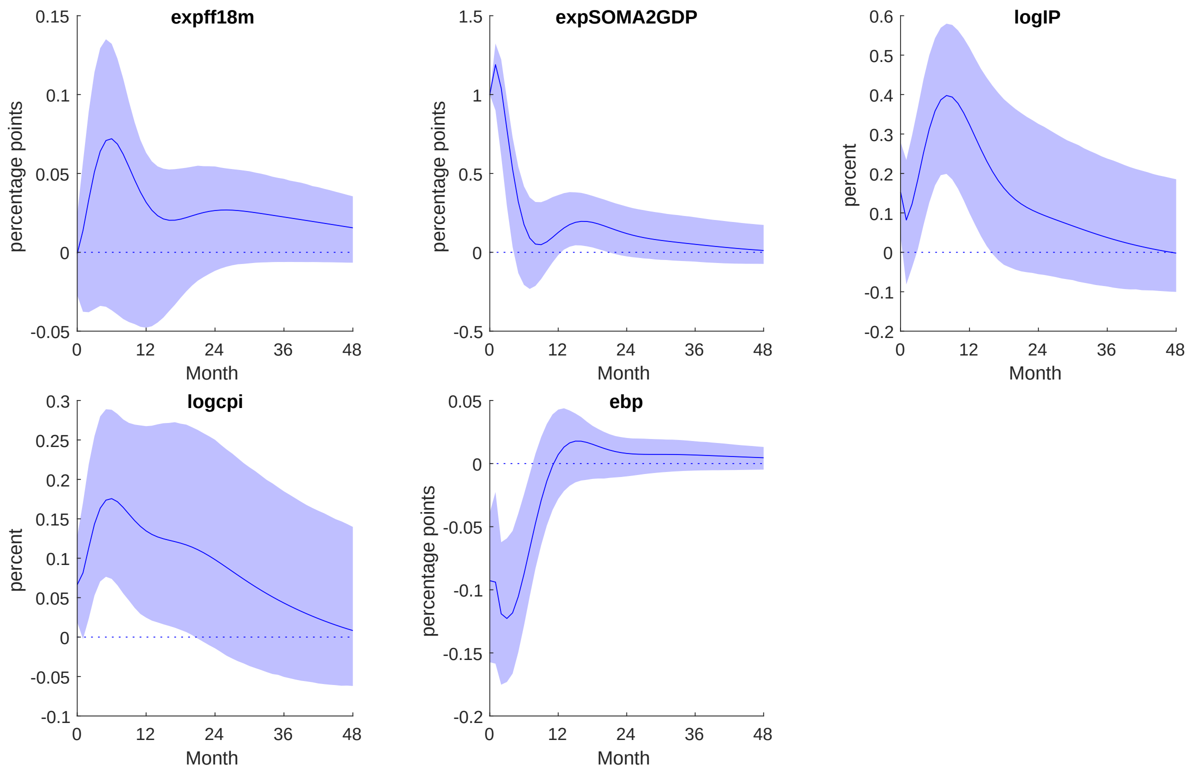

Figure 10: Impulse Responses to LSAP Shocks (Alternative Indicators)

The solid lines plot the impulse responses to a one-percentage-point positive shock to 1-year ahead expected SOMA holdings divided by GDP. The shaded areas represent 90 percent confidence intervals estimated using bootstrap methods.

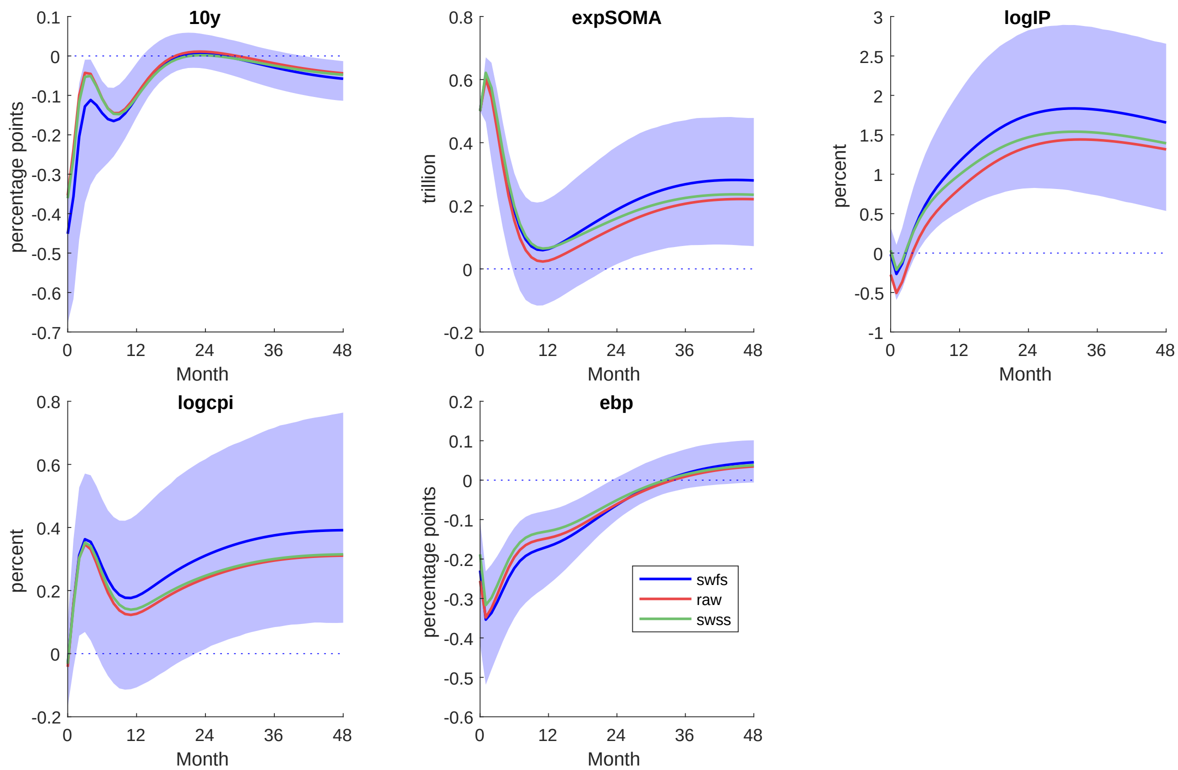

Figure 11: Impulse Responses to LSAP Shocks (Alternative Instruments)

This figure plots impulse responses of variables in the baseline VAR to a LSAP shock that raises the expected SOMA holdings by $500 billion on impact using different instruments, including the Swanson (2018) full-sample factors ('swfs'), monthly series constructed from event study changes in ff4 and the 10-year yield ('raw'), and the Swanson (2018) split-sample factors ('swss'). The shaded areas represent 90 percent confidence intervals estimated using bootstrap methods under the baseline model.

Finally, we also examine the robustness to using different instruments—either raw yield changes around event study windows or instruments constructed using the Swanson (2018) split-sample method. For raw yields, we use event study changes in the fourth federal funds futures rates and the 10-year yields, converted to monthly in the same way as the orthogonalized instruments. The results are reported in Figure 11 and are similar to those from the baseline model.

5.3 Alternative Sample Periods

In this section, we examine how robust the results are to two alternative samples. In the first alternative sample ('start 1979'), we extend the pre-crisis period back to July 1979, a sample used by Gertler and Karadi (2015) and many others. The second alternative sample ('post-crisis') focuses on the post-crisis period from December 2008 to December 2015, a period during which LSAPs and forward guidance were the principal policy tools used by the Federal Reserve, while the federal funds rate was effectively at the zero lower bound, averaging below 0.25 percent in each month. With the sample 'start 1979', we follow the baseline estimation process: The federal funds rate is effectively dropped from the VAR in the post-crisis period, and the LSAP equation is estimated using the post-crisis observations only. The only difference from the baseline is the sample period over which the other equations are estimated. For the 'post-crisis' sample, we estimate a standard VAR with five variables only, excluding the federal funds rate.

Figure 12 shows the impulse responses to the LSAP shock, estimated using the baseline as well as the two alternative samples. Using a longer sample starting in 1979 leaves the results qualitatively similar to the baseline model. The biggest difference is that the log IP response is estimated to be much smaller, while the estimated log CPI response is much larger. This is consistent with the evidence that the Phillips curve was much steeper in the 1980s than in recent years. By contrast, when only post-crisis data are used in the estimation, the 10-year response quickly reverses sign, while log IP and log CPI show stronger positive near-term responses that, however, quickly dissipate. The quick reversal of the 10-year yield is surprising, as LSAPs are typically viewed as exerting persistent downward pressure on the 10-year yield. This pattern appears to be driven by the short-sample behavior of the 10-year yield, as estimating the 10-year yield equation using post-crisis data only while keeping all else unchanged from the baseline model generates a similarly quick reversal in the 10-year yield (not shown).

5.4 Correcting for Having Expansionary Shocks Only

One may argue that the sample period for our study is characterized mostly by large expansionary monetary shocks and a lack of comparable contractionary shocks. This may lead the model to interpret "quiet" time periods with zero monetary shocks as periods of mild contractionary shocks, as the mean monetary shock over the sample period has to be zero on average.

We try to address this problem by allowing the VAR residuals in the LSAP equation to have a non-zero mean. In particular, we assume a zero mean of the LSAP equation residuals

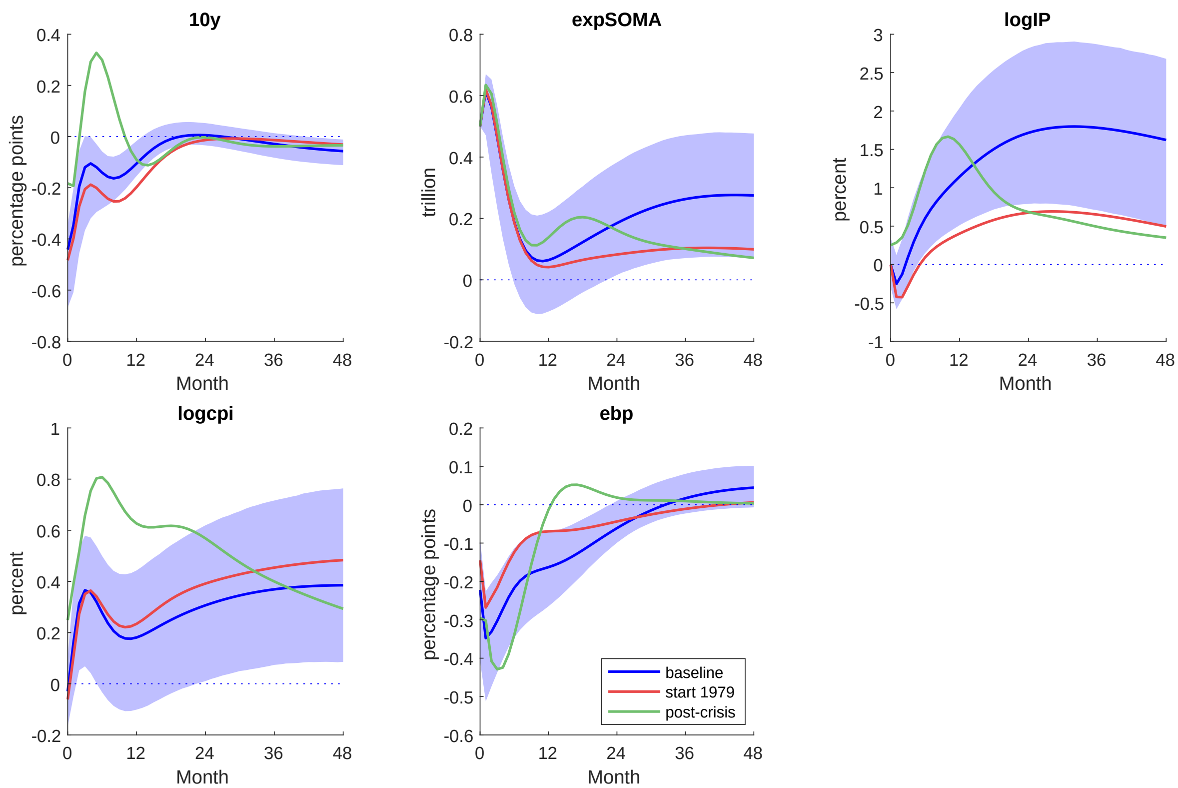

Figure 12: Impulse Responses to LSAP Shocks (Alternative Samples)

Blue lines and bands are baseline (1990-2015) impulse responses and confidence bands to an LSAP shock that increases expected SOMA size by $500 billion on impact. Red lines are impulse responses estimated with a longer sample, starting from July 1979 ('start 1979'). Green lines are impulse responses estimated with a post-crisis sample ('post-crisis').

during a “quiet” period, defined as dates falling into the bottom tercile in terms of the magnitude of the LSAP instrument. We find that this alternative specification changes the results only negligibly.

5.5 Central Bank Information Effect

Echoing earlier work by Romer and Romer (2000, 2004), a recent literature shows that high-frequency changes of asset prices around monetary policy announcements—like the ones we used to construct monetary policy instruments—reflect market responses not only to exogenous shocks to monetary policy but also to new information revealed through the announcement about central banks’ private forecasts about the macroeconomy. In particular, various authors document that monetary policy shocks measured from high frequency changes in money market futures rates are frequently accompanied by changes in equity prices (Jarociński and Karadi (forthcoming)) and in private survey forecasts of the unemployment rate, inflation and the short rate (Campbell, Evans, Fisher, and Justiniano (2012), Nakamura and Steinsson (2018)) that are in the wrong directions for the given shocks. In addition, those shocks appear predictable by past macro variables and lagged central bank macroeconomic forecasts (Miranda-Agrippino and Ricco (2018)). Two approaches have been proposed in the literature to control for this central bank information effect, either by imposing sign restrictions on responses of a range of assets (Jarociński and Karadi (forthcoming) and Cieslak and Schrimpf (2019)) or using central banks’ internal forecasts to remove the effect of central banks’ private information (Miranda-Agrippino and Ricco (2018)).

An examination of the responses of Blue Chip survey forecasts of real output growth, inflation, the unemployment rate, and the short rate suggests that the LSAP shock we identify does not appear to be noticeably affected by the bias from the fed information effect. As can be seen from Figure 13, in response to an easing LSAP shock, survey forecasts of real GDP growth, inflation and the 3-month short rate rise while those of employment rates decline, as what one would expect following unexpected monetary policy easing. We also experimented with dropping the event days when the 2-year yield and the S&P 500 move in the same direction and the moves exceed their respective 1 daily standard deviation, and the results are little changed.

Nonetheless, it is possible that the results we document may still be attenuated by the information effect. We therefore follow Miranda-Agrippino and Ricco (2018) and regress all

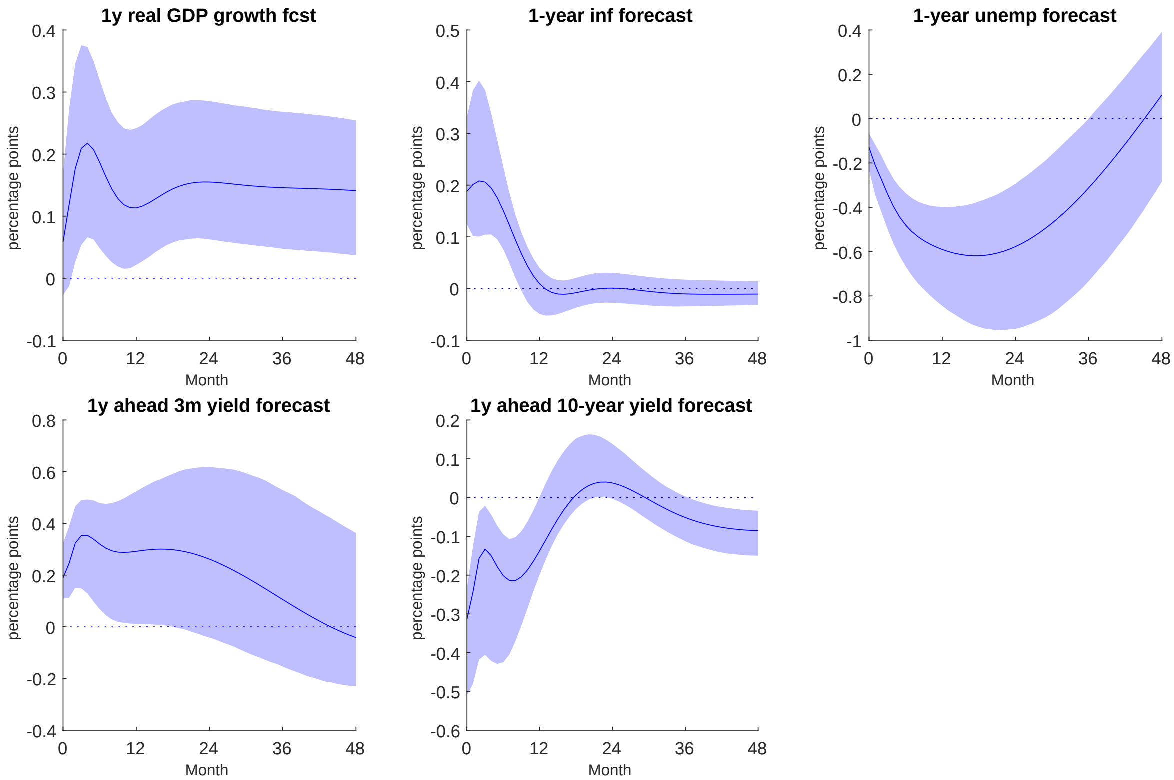

Figure 13: Impulse Responses of Survey Forecasts to LSAP Shocks

The solid lines plot the impulse responses to a $500 billion shock to 1-year ahead expected SOMA holdings, when instruments are purged of the fed information effect. The shaded areas represent 90 percent confidence intervals estimated using bootstrap methods.

event study changes on past Greenbook/Tealbook forecasts to remove possible responses to signals about the Fed's private information:

$$y_m^i = \alpha_0^i + \sum_{j=-1}^{3} \theta_j^i F_m^{cb} x_{q(m)+j} + \sum_{j=-1}^{2} \upsilon_j^i \left[F_m^{cb} x_{q(m)+j} - F_{m-1}^{cb} x_{q(m)+j} \right] + \widetilde{y}_m^i$$

where y_m^i represents the i-th event study response to the announcement from FOMC meeting m, $q(m)$ is the quarter when meeting m is held, $F_m^{cb} x_{q(m)+j}$ denote Greenbook/Tealbook forecasts for a vector x of macroeconomic variables j quarters ahead that are produced just before meeting m, and $F_m^{cb} x_{q(m)+j} - F_{m-1}^{cb} x_{q(m)+j}$ represent the revisions in those forecasts since the previous meeting. We take the residuals, $\tilde{y}_m^i$, as the event study surprises that are purged of the information effect and use them to construct the monthly factors as before. Finally, as in Miranda-Agrippino and Ricco (2018), we estimate an AR(12) model with the monthly factors and remove all autoregressive components to control for slow absorption of information by market participants. The original and the cleaned monthly LSAP factors are plotted in Figure 14. The biggest change in the LSAP instrument is in April 2009 following the LSAP1 Treasury purchase announcement. The methodology attributes part of the market response to perceptions of a more negative economic outlook as signaled by the unprecedented policy action.

The red dashed line in Figure 15 shows the impulse responses to an LSAP shock using the instruments with the information effect removed. Compared with the baseline model, reproduced as the blue line with the shaded 90% confidence bands, the effects on log IP and the EBP become stronger, while responses of the other variables remain largely unchanged.

6 Discussions

6.1 Transmission Channels

To explore how the LSAP shocks gets transmitted through the economy, Figure 16 plots the impulse responses to a \$500 billion LSAP shock of various financial and macro variables, when they are added to the baseline VAR one at a time. The 5-year yield declines by about 30 basis points on impact, about 10 basis points less than the 10-year yield, but quickly reverts back to the pre-shock level. Lower term premiums account for almost all of the decline in yields at the 10-year maturity, but only about half at the 5-year maturity. The effects on yields and term premiums documented here are more persistent than what's found by Wright

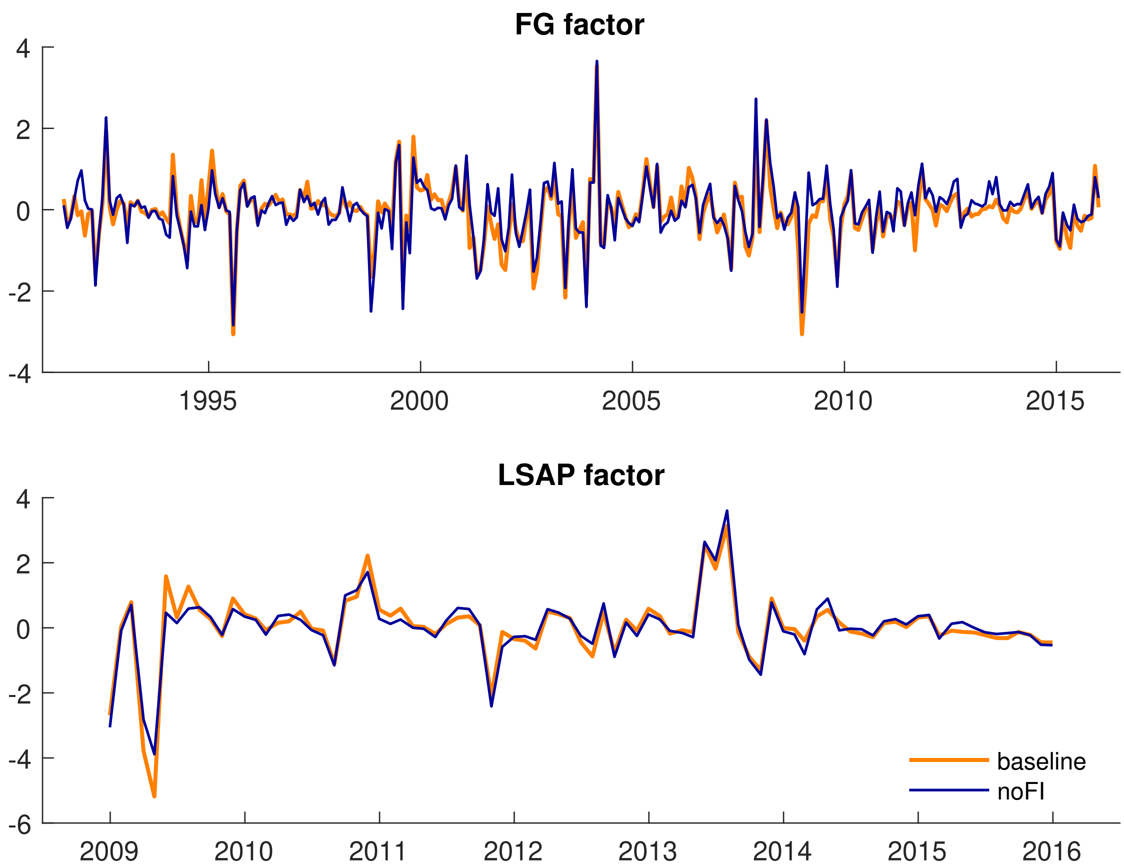

Figure 14: LSAP factor: Removing Fed information effect

The orange lines are our baseline FG and LSAP instruments used in the main analysis. The blue lines remove the Fed information effect following the methodology outlined in Miranda-Agrippino and Ricco (2018).

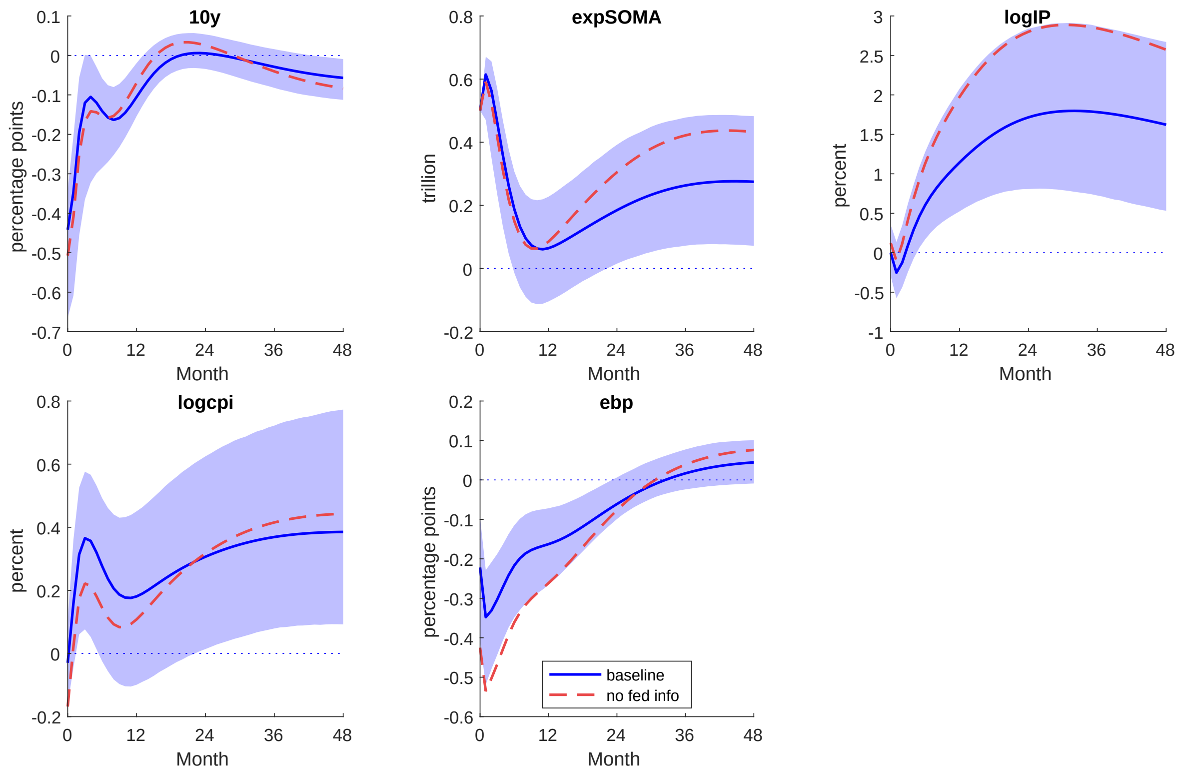

Figure 15: Impulse Responses to LSAP Shocks (Removing Fed Information Effect)

The solid blue lines plot the impulse responses to a $500 billion shock to 1-year ahead expected SOMA holdings from the baseline model. The blue dash line plots the same impulse responses using instruments that are purged of the fed information effect. The shaded areas represent 90 percent confidence intervals estimated using bootstrap methods from the baseline model.

(2012) using a daily structural VAR and by Greenlaw, Hamilton, Harris, and West (2018) using an expanded event study dataset. The LSAP shock also has persistent effects on credit spreads, such as the EBP in the baseline model and the mortgage and corporate bond spreads over Treasury yields shown here, and on equity prices. The LSAP shock boosts C&I lending and real GDP, while reducing unemployment out to 3 years after the shock. Consistent with the response of log IP within the baseline VAR, a broader measure of economic activity constructed by the Chicago Fed—the Chicago Fed National Activity Index (CFNAI)—rises in response to the shock. As noted earlier, the LSAP shock also raises 1 year ahead survey expectations of real GDP growth, inflation, and the short rate, and reduces expected future unemployment rate.

6.2 Effects of LSAP3: a Counterfactual

To illustrate the estimated impact of monetary policy surprises, we construct a counterfactual scenario in which the combined purchases of about $1.6 trillion of MBS and Treasury securities under LSAP 3 did not occur between late 2012 and 2014. To generate the lower counterfactual path of the LSAP measure, we assume counterfactual LSAP shocks that were persistently contractionary after 2012. The first two panels in Figure 17 show the paths of the LSAP measure and monetary policy structural shocks under the actual and counterfactual, respectively.

This analysis implicitly assumes that the market holds it beliefs about the systematic component of balance sheet policy unchanged. It is therefore subject to the Lucas (1976) critique because the market would likely have adjusted its belief about the Fed's reaction function had it observed consistently less accommodative monetary policy than it had expected. However, this exercise may still be relevant, for example, if we are interested in measuring the impact of prolonged legal, political, or market-frictional obstacles to asset purchase programs, as long as such obstacles are not perceived as permanent.

The rest of Figure 17 shows the path of the other variables in the VAR under the counterfactual. At the peak, the 10-year yield would be about 70 basis points higher due to the lack of asset purchase programs. At the end of 2015, the counterfactual levels of IP and CPI would be about 10 and 1.25 percentage points lower than their actual levels, respectively. The annual rate of inflation would be about 65 basis points lower on average over the three years between late 2012 and late 2015. Figure 18 plots the actual and counterfactual paths

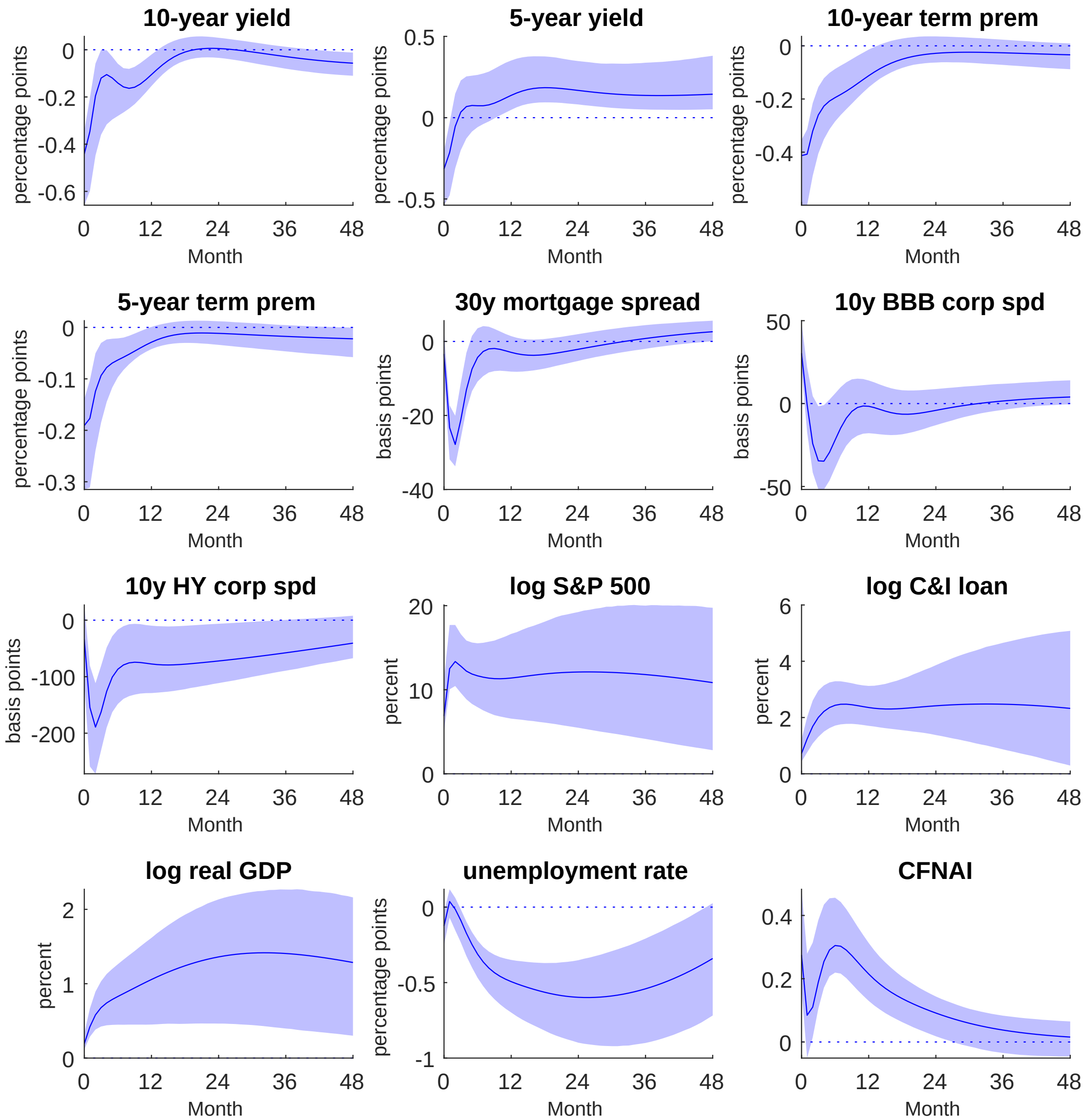

Figure 16: Transmission of LSAP Shocks

The solid lines plot the IRFs to a $500 billion shock to 1-year ahead expected SOMA holdings of various financial and macro variables, when they are added to the baseline VAR one at a time. The variables include the 5- and 10-year Treasury yields, the 5- and 10-year Kim and Wright (2005) term premium estimates, the 30-year mortgage spread, the 10-year BBB-rated and high yield corporate bond spreads, the log S&P 500 index, log C&I loans, log real GDP, the civilian unemployment rate, and the Chicago Fed National Activity Index ('CFNAI'). The shaded areas represent 90 percent confidence intervals estimated using bootstrap methods.

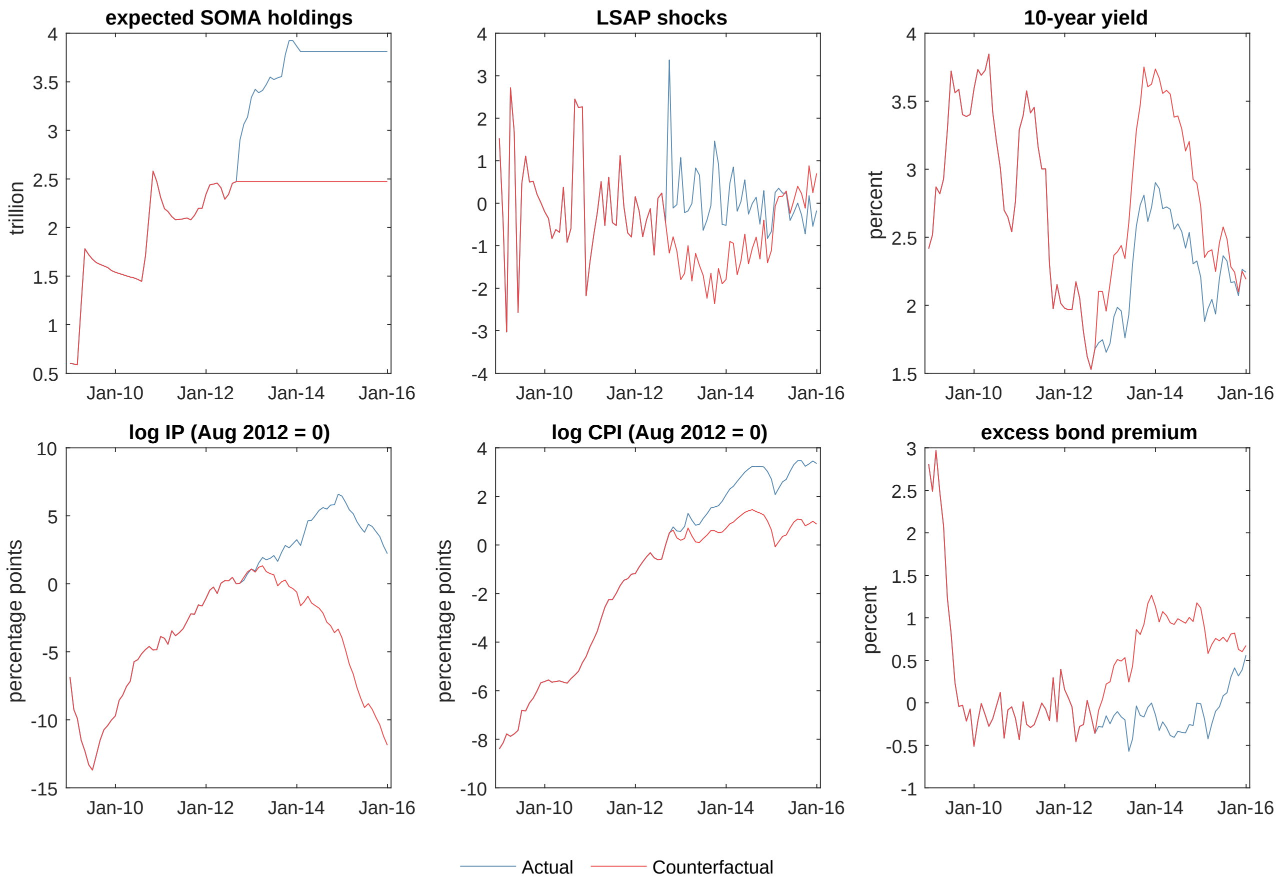

Figure 17: Effects of LSAP3: Shocks and VAR Variables

The top left panel shows the actual LSAP measure (blue) and the LSAP measure in the counterfactual scenario (red). The top middle panel shows the estimated LSAP structural shocks (blue line) and the hypothetical LSAP shocks (red line) that are needed to generate the counterfactual path of the LSAP measure in the top left panel. The other panels show the counterfactual (red) and actual (blue) paths for the other VAR variables. Prior to September 2012, the two paths are identical in all panels.

for the same set of additional variables as shown in Figure 16.

7 Conclusions

This paper provides new evidence on the effect of Federal Reserve's Large Scale Asset Purchases programs on both financial markets and the macroeconomy, using information from primary dealers' forecasts of the Federal Reserve's asset holdings, among other variables, provided to the FOMC before each meeting. The evidence suggests that unexpected expansions in the Federal Reserve's asset holdings during the ZLB period between 2008 and 2015 had significant expansionary effects on the macroeconomy, with real activity and inflation rising and unemployment declining notably following the shock. The policy accommodation appears to be transmitted to the economy both through financial markets—including Treasury yields, credit spreads and equity prices—and through bank lending. We find the effects on Treasury yields and term premiums to be longer-lived than previously documented, while the effects on credit spreads and especially and bank lending also appear persistent. These results appear fairly robust to alternative identification and econometric methodologies, policy indicators and instruments. One shortcoming of this study is that the survey measures do not capture the expected changes in the maturity of Federal Reserve holdings, such as those associated with the Fed's Maturity Expansion Program. We leave that extension to future studies.

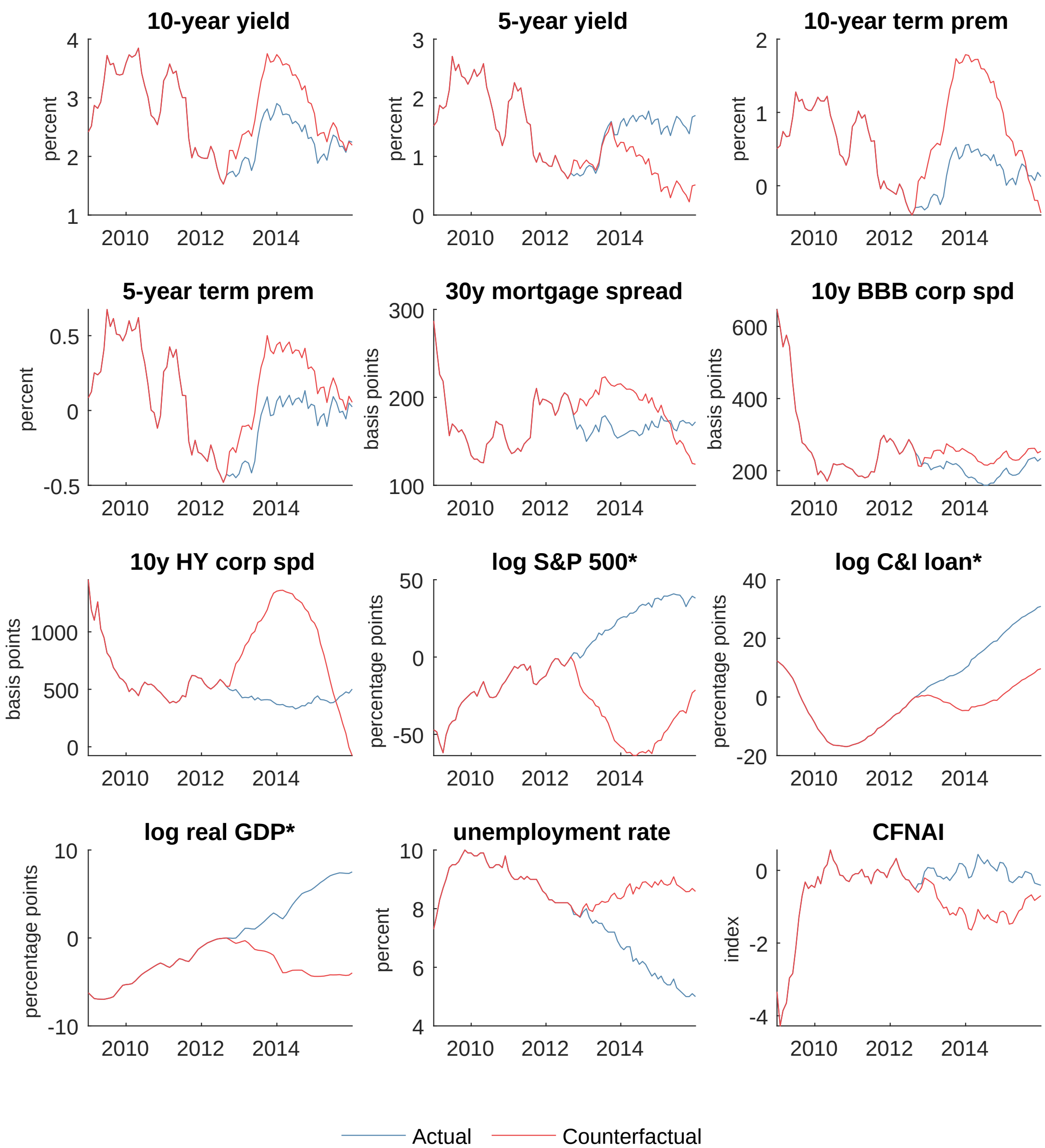

Figure 18: Effects of LSAP3: Additional Financial and Macro Variables

* Aug 2012 levels indexed to zero.

The panels show various macroeconomic and financial variables under the counterfactual (red) in comparison to actual (blue). As in Figure 17, the counterfactual path is generated by keeping the LSAP measure at the August 2012 level by adding a series of negative LSAP structural shocks. CFNAI stands for the Chicago Fed National Activity Index.

Appendix

A Proofs

We show that the exclusion restriction from section 3.1 determines the matrix C uniquely up to a restricted rotation, largely following Kim (2017).

There exists C_1 such that $C_1 C_1' = \Sigma$. Define e_t by $u_t = C_1 e_t$. Then, $E[z_t e_t'] = E[z_t u_t'](C_1^{-1})'$. Since the rank of $E[z_t e_t']$ is m, there exists an orthonormal matrix R such that the last $n-m$ columns of $E[z_t e_t']R = E[z_t u_t']((C_1 R)^{-1})'$ are zero. Define $C = C_1 R$, and it satisfies the exclusion restriction.

To prove uniqueness (up to a restricted rotation), let S be an n-by-n orthonormal matrix such that only its top-left m-by-m submatrix (denoted S_1) and bottom-right $(n-m)$-by-$(n-m)$ submatrix (denoted S_2) are nonzero. Let $C_{eq} = CS$. Then the last $n-m$ columns of $E[z_t u_t'](C_{eq}^{-1})'$ are simply the last $n-m$ columns of $E[z_t u_t'](C^{-1})'$ multiplied from the right by S_2, which are all zero.

Conversely, suppose that C_{eq} is a matrix that satisfies $C_{eq} C_{eq}' = \Sigma$ and the exclusion restriction. Then there exists R such that $C_{eq} = CR$. The last $n-m$ columns of $E[z_t u_t'](C_{eq}^{-1})'$ are zero by the exclusion restriction. Also, the columns are equal to $E[z_t u_t'](C^{-1})'$ multiplied from the right by the last $n-m$ columns of R. Since the first m columns of $E[z_t u_t'](C^{-1})'$ are nonsingular, the top-right m-by-$n-m$ submatrix of R is zero. Since $C = C_{eq} R'$, similarly the top-right m-by-$n-m$ submatrix of R'—the bottom-left $n-m$-by-m submatrix of R—is zero. Therefore R has the block form described in section 3.1.

B Data Sources

Most of the data series we use are from the FRED database. For CPI, we use monthly consumer price index for all urban consumers and for all items, seasonally adjusted (series name in FRED: CPIAUCSL). For IP, we use monthly industrial production index, seasonally adjusted (series name: INDPRO). For the 2-year Treasury yield, we use monthly 2-year constant-maturity Treasury rate (series name: GS2).

Excess bond premium is downloaded from the Federal Reserve Board website.

To create the balance-sheet-based LSAP measure, we used responses to the following questions from the Survey of the Primary Dealers conducted by FRBNY, along with other data:

- October 2008 - March 2009: No response informative about future expected balance sheet size in the survey. Construct expected balance sheet size using FRBNY's SOMA portfolio data (public) and announced asset purchase size and pace from October 2008 FOMC statement. Adjust negatively for asset roll-offs. No Treasury security in SOMA will mature within a year. For agency securities, we know exactly how much will roll off the balance sheet within one year. For mortgage-backed securities (MBS), roll-off rate, determined by principal and interest (P&I), is uncertain. We assume a constant monthly rate (about 1.5 percent) consistent with the observed roll-off of Federal Reserve's MBS holdings between January 2009 and March 2010.

- April 2009 - March 2010: Use current balance sheet size and the size and pace of purchase announced in March 2009 FOMC meeting. Adjust positively by median expectation of purchases in excess of announced amount (the survey asks about cumulative purchases by the end of the next several quarters). Adjust negatively by expected roll-off within a year.

- April 2010 - August 2010: Purchases end in March 2010. Use current balance sheet size, adjust negatively by expected roll-off of agency securities and MBS. In all the surveys, dealers expect no redemption of Treasury securities, but in August 2010 survey (prior to the FOMC meeting), dealers expect continuing MBS redemption. At the August FOMC meeting, reinvestment plan is announced: All maturing securities will be reinvested into Treasury securities. Thus no roll-off adjustment is applied after August 2010 survey.

- September 2010: Use the median of (expected policy action size times expected action probability by the end of 2010), plus a baseline size of 2,054 billion USD. Note that this number comes from a technical report released at the August 2010 FOMC meeting, and is very close to the actual size of SOMA at the meeting.

- November and December 2010: Use the median of expected policy action size over 'intermediate horizon' plus the baseline size of 2,054 billion USD. Note that the 600 billion USD purchase announced at the November meeting is smaller than that expected prior to the meeting, and the expectation in the December survey decreases accordingly.

- January 2011 - September 2012: Use the expected size of SOMA at the end of the current year and the next year, and linearly interpolate to calculate the expected size in one year, and calculate the median of interpolated value across dealers. There were four surveys in which this question did not appear. For them use the last available survey but apply different interpolation weights.

- October 2012 - January 2013: Surveys ask expected change in SOMA by the end of the next few half-years. As previously, interpolate to calculate the expected change in one year and add to the current size of SOMA.

- March and May 2013: Surveys only ask about expected changes in SOMA by the end of Q2 2013. We assume full continuation of ongoing purchase programs (45 billion USD of Treasury securities per month, announced at the December 2012 FOMC meeting, and 40 billion USD of MBS per month, announced at the September 2012 meeting). Other parts of the surveys are broadly consistent with full continuation. First dealers show very little expectation of any change in pace announced at the next three meetings. Second median expected end dates of current purchase programs are at least one year away from the current dates.

- June 2013 - June 2014: Surveys ask about expected pace of purchases following the next 8 FOMC meetings, which give us the median expected purchase path for a whole year. Add the implied balance sheet expansion to the current size of SOMA.

- July 2014 - January 2015: Surveys ask about expected balance sheet changes. As before interpolate between two relevant time points to calculate expected change in a year and add to the current size of SOMA. The question was not asked in the December 2014 survey, so we use November 2014 answers but change weights. In December 2014, dealers expressed very little expectation of rate liftoff within a year, so the continuation of reinvestment, which is implied by the November 2014 survey responses, was expected in December 2014 survey as well. Note that since November 2014, there was no ongoing purchases and all maturing securities were fully reinvested.

- March 2015 - December 2015: No direct question about expected balance sheet size. However in all surveys dealers' median expected end of reinvestment were about a year away, so we simply use the current size of SOMA.

- Note on the terminal value of SOMA size (January 2014 - December 2015): Since January 2014, the expectation on the size of the SOMA is constant, characterized by a gradual tapering of purchase at a constant rate and continuing reinvestment, except for a very small dip for January 2015. However the SOMA balance sheet size has tiny (negligible for the purpose of estimating VAR impulse responses) fluctuations due to technical factors. We simply use a constant value for convenience over this period, except for January 2015 survey.

We also construct 12- and 18-month-ahead rate expectation measures using the Survey of the Primary Dealers. Over the sample period, the survey consistently includes questions about rate expectation, so the construction of rate expectation is relatively straightforward. Generally, the survey asks about the expected rate at the end of individual quarters (sometimes half-years or years, which change over time, but quarters are the most common), and we linearly interpolate the median of the modal rate to calculate the expected rate in 12 and 18 months. Sometimes the responses are in terms of 25-basis-point ranges, in which case we use the midpoint of the range.

C Estimation

In the baseline sample, we have six variables, labeled $i = 1, 2, ..., 6$ in the following order: the federal funds rate, an LSAP measure, the 10-year yield, log CPI, log IP, and the EBP. Recall that we have the following reduced-form VAR:

$$y_t = B_0 + B_1 y_{t-1} + B_2 y_{t-2} + u_t. \tag{6}$$

We treat the federal funds rate and the LSAP measure to ensure continuity, as follows. First, after December 2008, the federal funds rate is fixed at its level in December 2008.[15] Second, we fix the LSAP measure at zero before December 2008, and after December 2008 (including December 2008), we subtract a constant from the LSAP measure, which represents the size of SOMA right before the beginning of the first LSAP program. This makes sure that the increase in the LSAP measure around December 2008 captures only expected increase in the size of SOMA due to LSAP programs.

[15] This lets us ignore any impact that the level of the federal funds rate might have had on the path of LSAP programs in our sample period, which was plausibly zero. Letting the federal funds rate take their actual observed values hardly changes any results.

The coefficients on the equations that determine the last four variables (the bottom four rows of B_0, B_1 and B_2) are calculated using linear regressions over the whole sample, because those equations are not directly affected by the restrictions on the federal funds rate and the LSAP measure; we may lose efficiency but we do not explore it in our exercise. Since the federal funds rate is fixed by assumption after December 2008, the equation on the federal funds rate (the first row of B_0, B_1 and B_2) is estimated using observations up to December 2008; since the LSAP measure is always zero before December 2008, we simply omit the LSAP measure in the regression.

Similarly we only use observations for or after December 2008 in estimating the equation that determines the LSAP measure (the second row of B_0, B_1 and B_2). However, note that we cannot omit the federal funds rate from the equation, because it decreased much over the relevant periods due to lagged observations, for October and November 2008. Since the federal funds rate is fixed for and after December 2008, including the federal funds rate is equivalent to simply ignoring the first two observations, for December 2008 and January 2009, in determining the coefficients on the variables other than the federal funds rate. It also implies that the residuals for the first two months are zero.

Once the coefficients are estimated, we can calculate residuals for all time periods. We only use the post-December-2008 residuals (excluding the first two) in estimating the variance-covariance matrix Σ. We cannot blindly use all the residuals because of the restrictions on our model. For example, there is no residual in the LSAP measure before December 2008 because it is fixed at zero by assumption. We apply post-December-2008 instruments to post-December-2008 residuals to identify shocks of interest.

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