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UNCONVENTIONAL MONETARY POLICY AND THE INTEREST RATE CHANNEL: SIGNALLING AND PORTFOLIO REBALANCING

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In response to financial turmoil that began in 2007 and the effective lower bound for short-term interest rates that was reached in late-2008, the Federal Reserve adopted a raft of `unconventional' monetary policies, notably: forward guidance and large-scale asset purchases. These policies transmit to the real economy, inter alia, via an interest rate channel, with two sub-channels: signalling and portfolio rebalancing. I apply the OIS-augmented decomposition of interest rates from Lloyd (2017a) to identify these two sub-channels. I demonstrate that US unconventional monetary policy announcements between November 2008 and April 2013 did exert significant signalling and portfolio balance effects on financial markets, reducing longer-term interest rates. Signalling effects were particularly powerful at horizons in excess of two years. As a result of these declines, unconventional monetary policy aided real economic outcomes. I show that the signalling channel exerted a more powerful influence on US industrial production and consumer prices than portfolio rebalancing. In terms of long-term bond yield and industrial production effects, the signalling channel is associated with around two-thirds to three-quarters of the total effects attributed to the two channels.

Unconventional Monetary Policy and the Interest Rate Channel: Signalling and Portfolio Rebalancing*

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Abstract

In response to financial turmoil that began in 2007 and the effective lower bound for short-term interest rates that was reached in late-2008, the Federal Reserve adopted a raft of 'unconventional' monetary policies, notably: forward guidance and large-scale asset purchases. These policies transmit to the real economy, *inter alia*, via an interest rate channel, with two sub-channels: signalling and portfolio rebalancing. I apply the OIS-augmented decomposition of interest rates from Lloyd (2017a) to identify these two sub-channels. I demonstrate that US unconventional monetary policy announcements between November 2008 and April 2013 did exert significant signalling and portfolio balance effects on financial markets, reducing longer-term interest rates. Signalling effects were particularly powerful at horizons in excess of two years. As a result of these declines, unconventional monetary policy aided real economic outcomes. I show that the signalling channel exerted a more powerful influence on US industrial production and consumer prices than portfolio rebalancing. In terms of long-term bond yield and industrial production effects, the signalling channel is associated with around two-thirds to three-quarters of the total effects attributed to the two channels.

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Key Words: Unconventional Monetary Policy; Large-Scale Asset Purchases; Forward Guidance; Signalling; Portfolio Rebalancing; Interest Rates; Term Structure; Overnight Indexed Swaps.

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1 Introduction

Before the recent crisis, monetary policy was primarily conducted with one instrument: a short-term nominal interest rate. In the wake of financial turmoil and the subsequent reduction of short-term interest rates to their effective lower bound (ELB), central banks increasingly turned to 'unconventional' monetary policy tools, defined here as instruments beyond the 'traditional' policy rate. In this paper, I focus on US unconventional monetary policies announced since November 2008:[1] large-scale asset purchases (LSAPs) and forward guidance. These two policies can transmit to the real economy, *inter alia*, via an interest rate channel with two subcomponents: signalling and portfolio rebalancing. I assess the relative importance of these two channels for US unconventional policy in terms of their effect on the *real economy* — the ultimate goal of the policies. I show that unconventional monetary policies have placed significant downward pressure on long-term interest rates via both the signalling and portfolio balance channels. The primary finding is that reductions in long-term interest rates during the period of unconventional monetary policy easing between November 2008 and April 2013 have exerted a more powerful influence on the real economy through the signalling channel than through portfolio rebalancing. In terms of long-term bond yield and industrial production effects, the signalling channel is associated with around two-thirds to three-quarters of the total effects attributed to the two channels.

Federal Reserve (Fed) LSAPs have involved the direct purchase of longer-term assets from secondary markets. Since December 2008, the Fed has purchased a range of longer-term US Treasuries, agency debt and mortgage-backed securities (MBS), expanding its balance sheet by over 600%.[2] The policy was initiated "to put downward pressure on yields of a wide range of longer-term securities, support mortgage markets and promote a stronger economic recovery".[3] The Fed announced the purchase of MBS and agency-backed bonds from private markets on November 25, 2008. On March 18, 2009 this was extended to include the purchase of $300 billion of longer-term Treasury securities over a six-month period. These combined purchases were dubbed 'QE1' and concluded on March 16, 2010, with the Fed holding $1.25 trillion of MBS and $175 billion of agency-backed debt. The value of the asset stock was held constant until the inception of 'QE2' on November 3, 2010, following strong suggestions of further purchases in Fed Chairman Ben Bernanke's August speech at Jackson Hole[4] and his October speech at the Boston Fed.[5] From the outset of QE2, the Fed stated that it would purchase $600 billion of longer-term US Treasuries over a six-month period, concluding in June 2011. 'QE3' marked the

[1]US large-scale asset purchases were first announced on November 25, 2008, just before the Federal Funds rate was lowered to its ELB on December 16, 2008.

[2]A similar policy was adopted by the Bank of England in March 2009, stimulating a large body of research in itself. The BoE has predominantly purchased longer-term UK gilts. The focus of this paper, and the references within, is on US policy.

[3]www.federalreserve.gov/faqs/what-are-the-federal-reserves-large-scale-asset-purchases.htm.

[4]www.federalreserve.gov/newsevents/speech/bernanke20100827a.htm.

[5]www.federalreserve.gov/newsevents/speech/bernanke20101015a.htm.

most recent expansion of US LSAPs, announced on September 13, 2012.[6] The Fed committed to buying $40 billion of MBS and $45 billion of longer-term US Treasuries per month for an indefinite period. After false expectations of a tapering in the amount of monthly purchases under QE3 in May 2013, the Fed announced seven consecutive reductions in the rate of asset purchases of $10 billion per month between December 18, 2013 and September 17, 2014. When LSAPs were concluded in October 2014, the Fed held $4.5 trillion of securities outright.[7]

The Fed have adopted numerous forms of forward guidance since December 2008 (Geraats, 2014). Initial guidance was qualitative, informing agents that the policy rate would be maintained "for some time" (December 2008) or "for an extended period" (March 2009). Subsequently, quantitative forward guidance was provided, including calendar-based guidance (August 2011) — informing agents that economic conditions were "likely to warrant exceptionally low levels for the federal funds rate" at least until a specified date — and threshold-based guidance (December 2012) — stating that the "exceptionally low range for the federal funds rate will be appropriate at least as long as the unemployment rate remains above 6.5 percent".[8] Moreover, the Fed engaged in forward guidance with respect to QE3, determining the size, pace and composition of future purchases in relation to future economic conditions.

Understanding the relative importance of different transmission channels of unconventional monetary policy is important because it can inform current and future policy. This study is motivated by the differing policy implications of the signalling and portfolio balance channels. Unconventional monetary policy can have *signalling* effects by influencing agents' expectations of the future policy rate path. Forward guidance can do this directly, though LSAPs can have signalling benefits if they are perceived to signal a lower policy rate path for longer, especially when announced in advance of actual purchases. A policy that works through the signalling channel is likely to be most effective when it is clearly communicated, such that private sector expectations react to it. Portfolio rebalancing can occur as a result of LSAPs. By purchasing a longer-term asset from secondary markets, the central bank reduces the supply available to investors, bidding up the price and reducing the yield of the asset. With lower returns on their remaining holdings of the asset, investors can rebalance their portfolio to seek higher returns, demanding other assets. This readjustment will increase the prices and reduce the yields of other assets. The efficacy of the portfolio balance channel relies on the 'large-scale' of LSAPs to generate sufficient portfolio adjustment to reduce long-term rates. Moreover, its benefits are likely to be greatest when markets are not functioning normally (Vayanos and Vila, 2009).

Two key predictions of the interest rate channel have been tested thoroughly: (i) that LSAPs and forward guidance reduced longer-term interest rates on announcement dates; and (ii) that they had expansionary effects on output and inflation. Many authors have shown that LSAPs

[6] Between QE2 and QE3, the Fed also initiated a maturity extension program (MEP), which was announced in September 2011 and was concluded in late 2012. The MEP was designed to extend the average maturity of the Treasuries in the Fed's portfolio, placing downward pressure on longer-term interest rates to support economic conditions. The Fed sold a total of $667 billion shorter-term Treasury securities under the MEP, buying longer-term Treasuries with the proceeds.

[7] Federal Reserve Statistical Release H.4.1, Factors Affecting Reserve Balances.

[8] These quotes are available here: `www.federalreserve.gov/newsevents/press/all/XXXXall.htm`, where `XXXX` denotes the year.

did reduce longer-term interest rates (e.g. Krishnamurthy and Vissing-Jorgensen, 2011; Gagnon, Raskin, Remache, and Sack, 2011; Christensen and Rudebusch, 2012; Wright, 2012; Bauer and Rudebusch, 2014) on a range of assets, not only those purchased (D'Amico and King, 2012; Rogers, Scotti, and Wright, 2014).[9] Studies have shown that LSAPs averted deflation and provided an expansionary impulse for output (e.g. Baumeister and Benati, 2013; Gambacorta, Hofmann, and Peersman, 2012),[10] though only IMF (2013) and Lloyd (2013) have explicitly considered the importance of the signalling and portfolio balance channels for the real economy.

The majority of existing work has assessed the relative importance of the channels against their *financial market effects*. Using decompositions of long-term interest rates, authors have linked the portfolio balance channel to the term premium and the signalling channel to estimated risk-neutral yields. Disagreement in the results from this literature originates from the different yield curve decompositions used. Gagnon et al. (2011) use the survey-augmented affine Gaussian arbitrage-free dynamic term structure model (GADTSM) decomposition of US Treasury yields by Kim and Wright (2005) to show that, in terms of the yield effect, the portfolio balance channel has dominated the signalling benefits of US LSAPs at the 10-year horizon. However, Christensen and Rudebusch (2012) and Bauer and Rudebusch (2014), using alternative decompositions of US Treasury yields, have found the opposite result.

In this paper, I focus on the relative importance of the two channels in terms of their effects on the *real economy*, the ultimate goal of US policy. Using a structural vector autoregression (SVAR) methodology, Lloyd (2013) concludes that the signalling channel was relatively more effective than the portfolio balance channel for US real GDP growth using the Kim and Wright (2005) decomposition of the 10-year Treasury yield. This paper's findings extend and reinforce those in Lloyd (2013). To reach this conclusion, I offer novel solutions to two challenges in existing literature: (i) the yield curve decomposition associated with signalling and portfolio rebalancing; and (ii) the identification of signalling and portfolio balance shocks to the macroeconomy.

In response to the first challenge, I compare three decompositions of the nominal US Treasury yield curve into risk-neutral yields and term premia:[11] (i) a bias-corrected model (Bauer, Rudebusch, and Wu, 2012), used to assess LSAPs by Bauer and Rudebusch (2014); (ii) a survey-augmented model (Kim and Wright, 2005), used to assess LSAPs by Gagnon et al. (2011); and (iii) an overnight indexed swap (OIS) rate-augmented decomposition proposed in Lloyd (2017a). As is widely recognised in the literature, GADTSMs suffer from an identification problem that results in estimates of interest rate expectations that are spuriously stable (e.g. Bauer et al., 2012; Kim and Orphanides, 2012; Guimarães, 2014). In this paper, I provide complementary evidence to Lloyd (2017a) and show that, in comparison to financial market-based and survey expectations of future short-term interest rates, the interest rate expectation estimates from

[9] Joyce, Lasaosa, Stevens, and Tong (2011) reach similar conclusions for the UK.

[10] Kapetanios, Mumtaz, Stevens, and Theodoridis (2012) provide similar results for the UK.

[11] In GADTSMs, the risk-neutral yield corresponds to the average expected future short-term interest rate path, plus a convexity (Jensen's inequality) term. This convexity term is, in practice, small, and so the terms 'risk-neutral yield' and 'average expected future short-term interest rate' are used interchangeably in the literature and this paper.

OIS-augmented models are superior to estimates from the bias-corrected and survey-augmented GADTSMs. Moreover, I document that, despite efforts to improve identification, the survey-augmented Kim and Wright (2005) decomposition does not fully overcome the identification problem and attributes too much variation in interest rates to term premia. Thus, the financial market event study estimates with the Kim and Wright (2005) decomposition represent a lower bound for the relative efficacy of the signalling channel.

Using these yield curve decompositions, I carry out an event study of the financial market effects of signalling and portfolio rebalancing. This is the first paper to apply the OIS-augmented GADTSM to the analysis of macroeconomic policy at the ELB. I find that LSAP and forward guidance announcements had sizeable effects on interest rates and their associated expectations and term premia components. At the 2, 5 and 10-year horizons, the OIS-augmented model attributes 74.19-95.29% of the decline in yields on announcement days to signalling. Interestingly, interest rate expectations were affected well beyond the 2-year horizon traditionally associated with monetary policy's transmission lags. The results from the OIS-augmented decomposition differ starkly from the corresponding results using the survey-augmented Kim and Wright (2005) decomposition, which attributes only 22.85-30.41% of event-day yield declines to signalling at the 2, 5 and 10-year horizons.

To tackle the second challenge and estimate the relative effects of signalling and portfolio rebalancing on real economic outcomes, I set up an SVAR. The baseline VAR includes four monthly variables: industrial production, the consumer price index, and the risk-neutral yield and term premium components of longer-term interest rates derived from each of the three yield curve decompositions in turn. I identify structural shocks using combinations of zero-impact and sign restrictions, with signalling shocks propagating through the risk-neutral yield and portfolio rebalancing shocks through the term premium. To separately identify the signalling and portfolio balance shocks, I assess the robustness of results to two restriction schemes. In the first scheme, I impose that portfolio balance shocks cannot contemporaneously affect the risk-neutral component of long-term rates — this captures a 'pure term premium' shock. In the second, I impose the opposite: signalling shocks cannot immediately effect the term premium — this captures a 'pure expectations' shock.

Under both restriction schemes I find that an expansionary signalling shock has significantly positive lagged effects on US industrial production and consumer prices. In contrast, an expansionary portfolio rebalancing shock has insignificant effects on these two variables, indicating that signalling exerted a more powerful effect on US industrial production and consumer prices than portfolio rebalancing. The signalling shock explains around two-thirds to three-quarters of the total peak industrial production increase due to the long-term interest rate shocks. The results are robust to: (i) the inclusion of bank credit and the real exchange rate as controls; (ii) the interest rate maturity considered — even with longer-maturity yields, which place greater weight on portfolio rebalancing in the event study, the signalling channel is shown to be relatively more important for real outcomes; (iii) the sample length; and (iv) the term structure decomposition used — the result even holds in SVAR specifications using the Kim and Wright

(2005) yield curve decomposition, which places the lowest weight on signalling in the event study. The results are also robust to using the 2-year OIS rate, instead of the 2-year risk-neutral yield, alongside the 2-year term premium in the VAR to account for the possibility that, because both the risk-neutral yield and the term premium are estimated within the same GADSTM, they do not vary independently. My results suggest that current and future unconventional monetary policy action by the Fed may reap greater economic rewards if combined with clear communication about the future short-term interest rate path.

The remainder of this paper is structured as follows. The transmission channels of unconventional monetary policy are defined in section 2. Section 3 presents the yield curve decompositions used in the event study (section 4) and SVARs (section 5). Section 6 concludes.

2 Transmission Channels

Unconventional monetary policy can affect the economy via numerous channels. The interest rate channel is the primary focus of this analysis. By purchasing assets directly from secondary markets, central bank LSAPs can raise asset prices and reduce a range of interest rates that investors face. This can positively impact upon the real economy through, *inter alia*, reduced borrowing costs and positive wealth effects.

A sizeable literature has amassed discussing a number of interest rate mechanisms through which LSAPs affect the real economy (Krishnamurthy and Vissing-Jorgensen, 2011). The focus of my study, in line with work by Gagnon et al. (2011), Bauer and Rudebusch (2014) and others, is on two components of the interest rate channel: signalling and portfolio rebalancing.

Primarily, I consider these channels because of their link to the canonical decomposition of the long-term interest rate into a risk-neutral expected future short-term interest rate and term premium[12] component:

$$y_t^{(L)} = \frac{1}{L}\mathbb{E}_t \sum_{j=0}^{L-1} i_{t+j}^{(1)} + tp_t^{(L)} \tag{1}$$

where $y_t^{(L)}$ is the L-period government bond yield at time t, $i_t^{(1)}$ is the one-period (net) interest rate and $tp_t^{(L)}$ is the L-period term premium. In line with the existing literature, I link signalling to the risk-neutral component and portfolio rebalancing to the term premium.

Additionally, the signalling and portfolio balance channels are of direct relevance to policy. They make up the language of policymakers. Bernanke (2010) emphasised the importance of the portfolio balance channel as a means through which LSAPs can affect the economy:

> "I see the evidence as most favorable to the view that such purchases work primarily through the so-called portfolio balance channel..."

Moreover, the policy implications relevant to each of the two channels differ: the signalling channel implies that policymakers should clearly communicate the future path of short-term

[12] Where the term premium is defined broadly to encompass compensation for interest rate risk, inflation risk, liquidity premia, counterparty risk, etc..

interest rates; the portfolio balance channel relies on the stock of assets purchased being sufficient enough in scale to influence term premia.

2.1 Signalling

The signalling channel refers to any effect that (unconventional) monetary policy announcements have on investors' expectations of future short-term policy rates. Such expectations can be influenced by future macroeconomic outcomes or the expected conduct of monetary policy. If, following forward guidance or LSAP announcements, investors anticipate the central bank to keep interest rates lower for longer, then the announcement will influence long-term interest rates by reducing expected future short-term interest rates. Although this definition subsumes signals about future policy rates from forward guidance or LSAPs, it excludes any LSAP policy anticipation or announcement effects that cause immediate portfolio changes. These will be attributed to the term premium. In addition, although the main purpose of forward guidance is to influence expectations of future policy rates, this could also reduce uncertainty about future interest rates and thereby term premia (Akkaya, 2014).

In 2008, when the Fed initiated LSAPs, many critiques of the policy cited irrelevance and neutrality propositions (e.g. Wallace, 1981). Integral to all of these results are assumptions regarding: timing; household homogeneity; perfect asset substitutability; non-distortionary taxation; and the link between government and central bank balance sheets. The logic behind these results is as follows. The purchase of long-term assets by the central bank can increase households' *pre*-tax state-contingent income. However, the purchase of the asset does not remove risk from the aggregate economy. LSAPs will reduce the returns earned by the central bank portfolio, necessitating an increase in lump-sum taxation by a non-distortionary government to balance the joint government and central bank budget constraint. The *after*-tax state-contingent income of homogeneous households will be unchanged, rendering LSAPs neutral for the economy. Within these models, LSAPs can only circumvent neutrality propositions through signalling; portfolio rebalancing is ineffective. In Eggertsson and Woodford (2003), only when LSAPs are *perceived* to engender a commitment to keep interest rates lower for longer can they stimulate the real economy. Bhattarai, Eggertsson, and Gafarov (2015) show that, following the purchase of longer-term assets and a shortening of the duration of privately held outstanding government debt, it is optimal for the central bank to keep short-term interest rates lower for longer to avoid capital losses on their balance sheet. Therefore, at the ELB, LSAPs can optimally stimulate the real economy by lowering the expected future path of real short-term interest rates.

2.2 Portfolio Rebalancing

The portfolio balance channel is linked to movements in term premia. By purchasing longer-term assets from the private sector, LSAPs concurrently increase the private sectors' holdings of short-term reserves. For investors who view different asset classes and maturities as imperfect substitutes to willingly accept this change, the price of longer-term assets must rise and their yield fall. To the extent that this change occurs independently of the short-term interest rate, it works through the term premium on longer-term assets. With lower long-term asset returns, investors will rebalance their portfolios, searching for higher yields by demanding other longer-term assets. This demand-driven rebalancing will inflate prices and reduce term premia on a range of long-term assets. D'Amico and King (2012) show that, although the term premia reduction was largest for the assets purchased by the Fed, US LSAPs did engineer declines in the term premia on a range of other longer-term assets. Ultimately, the lower term premia and higher asset prices that result from portfolio rebalancing can transmit to the real economy by reducing borrowing costs for the private sector and generating positive wealth effects for private asset holders. The strength of portfolio rebalancing depends on the stock of assets purchased.

Because the term premium is defined to include compensation for interest rate risk, forward guidance may also affect term premia. If, following central bank announcements, investors' uncertainty surrounding the future path of short-term interest rates falls, this will be reflected in lower term premia.[13] Similarly, forward guidance about LSAPs can be expected to influence term premia by instigating portfolio changes on announcement days.

Irrelevance propositions preclude portfolio rebalancing's efficacy in many macroeconomic models. To admit such effects, theorists have incorporated imperfect asset substitutability (Tobin, 1956, 1969) with agent heterogeneity. Harrison (2011, 2012) and Chen, Cúrdia, and Ferrero (2012) show that LSAPs can benefit the real economy via portfolio rebalancing within theoretical models.

2.3 Other Channels

Unconventional policy can transmit to the real economy through other channels. Joyce, Miles, Scott, and Vayanos (2012) discuss a credit channel through which LSAPs can affect output and inflation, independent of long-term interest rates. By purchasing assets from non-bank financial institutions, the deposits these institutions place in banks may rise. If deposits exceed banks' demand for liquidity, banks may be more willing to extend credit in the form of lending or less willing to contract it if they suffer funding losses from other sources. This channel is likely to be most effective when bank funding is disfunctional, as it was after the 2007-2008 financial crisis. It is likely to be relevant for US LSAPs, where the Fed has purchased the majority of its assets from households (including hedge funds), broker dealers and insurance companies (Carpenter, Demiralp, Ihrig, and Klee, 2013).

Unconventional monetary policy may also have international effects, through an exchange rate channel. If forward guidance or LSAP announcements reduce contemporaneous interest rates and expected future rates, they may lead international investors to seek higher returns away from the domestic economy. Theoretically, this should depreciate the domestic currency, *ceteris paribus*, aiding the price competitiveness of exports and, thus, domestic output. Bauer and Neely (2012) argue that since these changes work through long-term interest rates, these international effects are due to signalling and portfolio rebalancing. As a result, I assess the

[13] The term premium may also include liquidity premia. In my study, any liquidity effects due to unconventional monetary policy are attributed to portfolio rebalancing.

relative importance of signalling and portfolio rebalancing both with and without controls for the international transmission of policy in section 5.

3 Decompositions of the Yield Curve

To assess the relative importance of the signalling and portfolio rebalancing channels, I rely on decompositions of the yield curve, informed by (1), into risk-neutral yields (expectations of future short-term interest rates) and term premia. Like other authors (e.g. Gagnon et al., 2011; Bauer and Rudebusch, 2014), I associate the signalling channel with the risk-neutral yields and portfolio rebalancing with the term premium. To decompose yields, I estimate three no-arbitrage Gaussian affine dynamic term structure models (GADTSMs) and compare the results across different models. The differing conclusions in the existing literature are driven by the different GADTSMs used. For instance, Gagnon et al. (2011) use the survey-augmented Kim and Wright (2005) GADTSM and conclude that the effects of portfolio rebalancing dominate those of signalling, while Bauer and Rudebusch (2014) use the bias-corrected Bauer et al. (2012) GADTSM and attribute a larger proportion of influence to signalling.

The differing predictions of GADTSMs in analyses of signalling and portfolio rebalancing arise from an identification problem that results in estimates of interest rate expectations that are spuriously stable (e.g. Kim and Orphanides, 2012; Guimarães, 2014). Central to the identification problem is an informational insufficiency. Unaugmented GADTSMs use bond yield data as their sole input to inform the estimation of two quantities: fitted yields and risk-neutral yields.[14] As a symptom of the identification problem, a 'finite-sample' bias will arise where there is insufficient information and a limited number of interest rate cycles in the observed yield data.[15] Finite-sample bias will result in estimates of expected future short-term interest rate that are spuriously stable and, because bond yields are highly persistent, the bias can be severe. Moreover, the severity of the bias is increasing in the persistence of the yield data. For daily frequency yields, which are necessary for an event study and display greater persistence than lower-frequency data, the bias is particularly pertinent.

In response to this, three solutions have been proposed: bias correction (Bauer et al., 2012); survey-augmentation (Kim and Orphanides, 2012);[16] and OIS-augmentation (Lloyd, 2017a).

The bias-corrected model is directly focused on resolving the finite-sample bias in GADTSMs. Bauer et al. (2012) document that their bias-corrected estimates of future interest rate expectations "are more plausible from a macro-finance perspective" (p. 454) than those from unaugmented GADTSMs. However, the bias correction does not directly tackle the informational insufficiency at the heart of the problem. Actual bond yields remain the only estimation input. Wright (2014) argues that bias-corrected estimates of future interest rate expectations are "far too volatile" (p. 339).

[14]The term premium is the risk-neutral yield minus the corresponding-maturity fitted yield.

[15]Kim and Orphanides (2012, p. 242) state that a sample spanning 5-15 years may contain too few interest rate cycles.

[16]The Kim and Wright (2005) decomposition is estimated using the Kim and Orphanides (2012) algorithm, first circulated in Kim and Orphanides (2005).

Survey-augmentation of GADTSMs aims to directly tackle the identification problem: two inputs are used — actual bond yields and survey expectations of future short-term interest rates — to separately identify two outputs — fitted yields and expected future short-term interest rates, respectively. Kim and Orphanides (2012) document that, between 1990 and 2003, the survey-augmented model does produce sensible estimates of interest rate expectations. However, Lloyd (2017a) shows that estimated interest rate expectations from a survey-augmented model, estimated using the algorithm of Guimarães (2014), perform poorly for the 2002-2016 period relative to the OIS-augmented model, deviating markedly from market implied expectations during the ELB period especially.

OIS-augmentation of GADTSMs is similar in philosophy to survey-augmentation, but offers numerous advantages that result in superior estimates of risk-neutral yields and term premia. Although survey expectations do help to address the informational insufficiency problem, they are ill-equipped for the estimation of daily frequency expectations. Survey expectations of future short-term interest rates are only available at a low frequency: quarterly or monthly, at best. However, OIS rates are available at a daily frequency, so provide information for the separate identification of risk-neutral yields at the same frequency at which they are estimated. Moreover, Lloyd (2017b) documents that 1 to 24-month OIS rates, on average, provide accurate measures of interest rate expectations in the US, UK, Japan, and the Eurozone. Lloyd (2017a) argues that by using OIS rates at these tenors to augment the GADTSM, they provide valid information with which to identify interest rate expectations. Lloyd (2017a) documents that the interest rate expectation estimates from OIS-augmented models are superior to estimates from existing GADTSMs, including the bias-corrected and survey-augmented models. In this paper, I provide additional evidence to support this finding.

In the following sub-sections, I describe the data and algorithms I use to estimate the three GADTSMs in this paper.[17] I compare model-implied risk-neutral yields to comparable-horizon federal funds futures rates and survey expectations, and show that the OIS-augmented model provides superior estimates of interest rate expectations for the period of relevance to this paper.

3.1 Estimation of GADTSMs

To foster the closest possible comparison to the related literature, I compare the OIS-augmented model to the survey-augmented (Kim and Wright, 2005) and bias-corrected (Bauer et al., 2012) GADTSMs.[18] The Kim and Wright (2005) data I use is publicly available and estimated with daily frequency bond yield data from July 18, 1990 to December 31, 2015 with 3 and 6-month T-Bill yields and 1, 2, 4, 7 and 10-year US Treasury zero-coupon bond yields (Gürkaynak, Sack, and Wright, 2007).[19] I estimate the bias-corrected model with the same data, using the algorithm of Bauer et al. (2012, Section 4). Because US OIS rate data is only available

[17]See Lloyd (2017a) for a detailed exposition of GADTSM estimation algorithms.

[18]I use the survey-augmented model estimated by Kim and Wright (2005) estimated using the algorithm of Kim and Orphanides (2012), first circulated in Kim and Orphanides (2005), as opposed to the survey-augmented model estimated using the algorithm of Guimarães (2014), because the former of these is used by Gagnon et al. (2011), perhaps the most widely referenced US LSAP event study to date.

[19]T-Bill rates are converted from their discount basis to the yield basis. Data sources are listed in appendix A.

from late-2001, I estimate the OIS-augmented decomposition using data from January 2, 2002 to December 31, 2015 to isolate the benefits of OIS-augmentation, and using the same bond maturities as in Lloyd (2017a).[20] I use use 3, 6, 12 and 24-month OIS rates, as in the 4-OIS-augmented model in Lloyd (2017a) (hereafter the 'OIS-augmented decomposition'). Lloyd (2017a) documents that this model risk-neutral yields that are superior to those from existing GADTSMs, excluding Kim and Wright (2005), for the 2002-2016 period, exhibiting the lowest root mean square error (RMSE) fit *vis-à-vis* federal funds futures rates and survey expectations. For each model, three pricing factors determine bond prices.[21]

Figure 1 presents the results from the three GADTSMs at the 2-year horizon. Panel A plots the actual time series of the 2-year yield against the fitted values from the three GADTSMs over the 2002-2015 period. The illustration corroborates an important finding in Lloyd (2017a): GADTSM-augmentation does not compromise the overall fit of the model with respect to actual bond yields. The series co-move extremely closely.[22] As stated in Lloyd (2017a), this finding is intuitive. Survey and OIS-augmentation have been proposed to improve the identification of risk-neutral yields. Even in unaugmented GADTSMs, bond yield data is sufficient for the accurate fitting of actual bond yields.

3.2 Interest Rate Expectations

Unlike fitted yields, panels B and C of figure 1 illustrate that the risk-neutral yields and term premia from each of the GADTSMs differ markedly. The differences are a direct consequence of the identification problem. The risk-neutral yields differ starkly from late-2008 onwards, the period most relevant to this analysis. The 2-year risk-neutral yield from the survey-augmented Kim and Wright (2005) decomposition remains persistently above 1% from December 2008 onwards, while the bias-corrected and OIS-augmented models attribute a greater proportion of the fall in yields during 2008 to falling expectations of future short-term interest rates. In fact, the 2-year risk-neutral yield from the bias-corrected model is persistently negative from mid-2009 to late-2011, counter-factually implying that investors' average expectation of future short-term interest rates was negative. In contrast, the 2-year risk-neutral yield from the survey-augmented and OIS-augmented models never fall negative.[23]

In figure 1, as in Lloyd (2017a), the 2-year term premium from the OIS-augmented model is persistently negative from mid-2004 to mid-2008. This is a direct consequence of the accurate fitting of risk-neutral yields. However, this feature is not true for all maturities; estimated term premia at longer horizons are frequently and persistently positive.

To accurately attribute yield changes to signalling and portfolio rebalancing effects, it is nec-

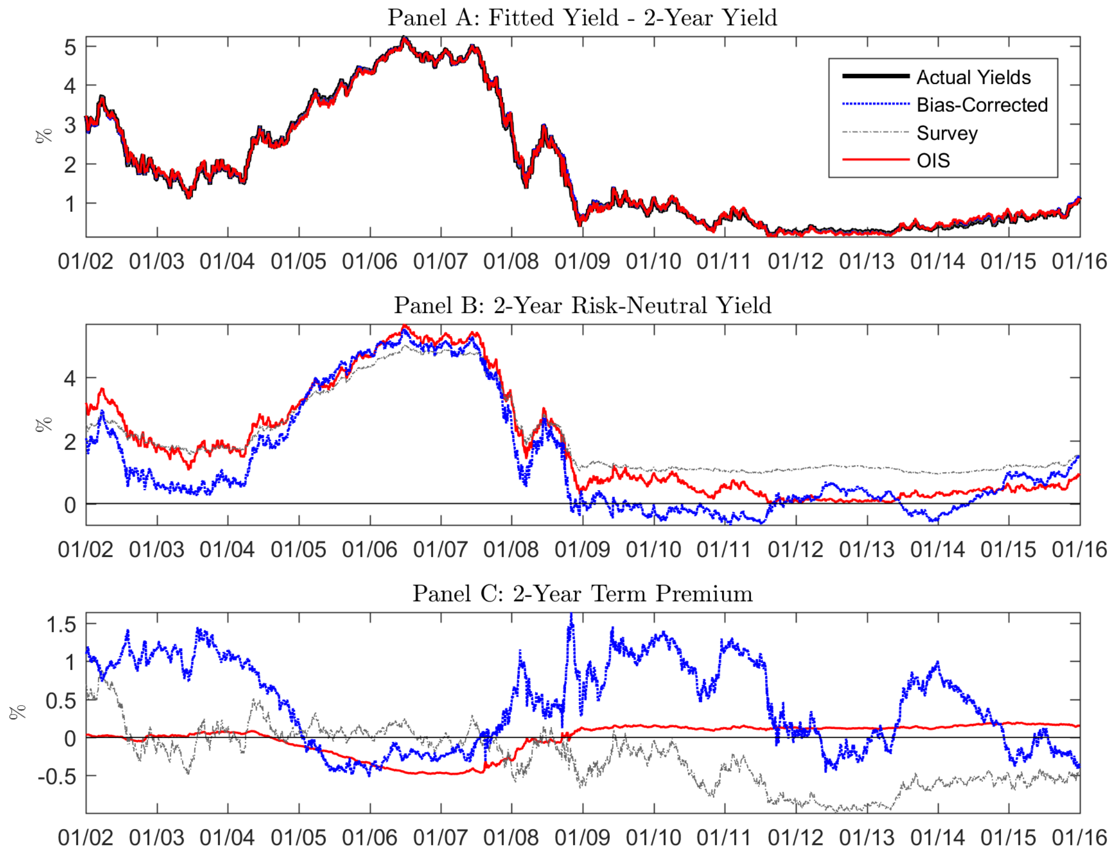
[20] 3 and 6-month T-Bill rates and 12, 18, ..., 60, 84, and 120-month zero-coupon Treasury bond yields.

[21] Kim and Wright (2005) and Bauer et al. (2012) also use three pricing factors. Litterman and Scheinkman (1991) demonstrate that the first three principal components of bond yields explain over 95% of their variation.

[22] The residuals of the fitted yields are extremely similar across models at all maturities.

[23] As in Lloyd (2017a) this is true at all horizons for the OIS-augmented model, despite the fact that additional restrictions are not imposed on the model to prevent interest rate expectations from going negative. This represents an important contribution in light of recent computationally burdensome proposals for term structure modelling at the ELB (see, for example, Christensen and Rudebusch, 2013a,b).

Figure 1: Estimated Yield Curve Decomposition: July 1990-December 2015



Note: In panel A, I plot the actual 2-year bond yield and fitted 2-year bond yields from each of three GADTSMs. In panels B and C, I plot the estimated risk-neutral yields and term premia from the three GADTSMs, respectively. The three models are: (i) the bias-corrected model of Bauer et al. (2012) (Bias-Corrected); (ii) the survey-augmented model of Kim and Wright (2005) (Survey); and (iii) the OIS-augmented model of Lloyd (2017a) (OIS). The bias-corrected and survey-augmented models are estimated using daily data from July 18, 1990 to December 31, 2015. The OIS-augmented model is estimated using daily data from January 2, 2002 to December 31, 2015. All models use three pricing factors. All figures are in annualised percentage points.

essary to attain accurate measures of the risk-neutral yields and term premia used to identify the channels. With this goal in mind, I compare the model-implied interest rate expectations, from the risk-neutral yields, to federal funds futures rates and survey expectations. The preferred GADTSM should accurately reflect the qualitative and quantitative evolution of comparable-horizon survey and market-implied expectations.

3.2.1 Risk-Neutral Yields and Federal Funds Futures Rates

I first compare the GADTSM-implied risk-neutral yields to federal funds futures (FFFs) rates. FFFs rates have long been used as measures of investors' expectations of future short-term interest rates. A FFFs contract pays out at maturity based on the average effective federal funds rate realised for the calendar month specified in the contract. The risk-neutral yields from the preferred GADTSM should closely align with corresponding-maturity federal funds futures rates for the post-2008 period relevant to this analysis. FFFs are available for the first 35 calendar months into the future (including the current month) and are often used to measure interest rate expectations out to the 1-year horizon.

To compare GADTSM-implied interest rate expectations to FFFs rates, I perform the following steps.[24] First, I construct a FFFs-implied expectation of the average short-term interest rate over a 12-month period. To do this, I calculate the arithmetic mean of the 1, 2, ..., 12-month ahead FFFs rates on the final day of each calendar month, generating a monthly frequency series of average market-implied interest rate expectations over the subsequent 12-months.[25] Second, I compare the monthly frequency FFF-implied expectation to the corresponding-horizon 1-year risk-neutral yield from each GADTSM on the final day of each calendar month.

Table 1 reports a root mean square error (RMSE) comparison of the FFF-implied and GADTSM-implied expectations for three sample periods: January 2002 to December 2015; the baseline SVAR sample period from November 2008 to April 2013; and November 2008 to December 2015. On a RMSE basis, the OIS-augmented model unambiguously provides superior estimates of expected future short-term interest rates, as measured by FFFs rates. Between November 2008 and December 2015, the RMSE of the OIS-augmented model approximately half of the RMSE of the survey-augmented model, and almost a third of the RMSE of the bias-corrected model. For all three periods, the bias-corrected model provides the worst fit of FFF-implied market expectations.

[24] Ideally, I would follow the steps in Lloyd (2017a, Section 6.2.1), and compare FFFs rates to model-implied risk-neutral forward yields 1, 2, ..., 11 months ahead. However, because I do not estimate the survey-augmented Kim and Wright (2005) decomposition, and because they do not report 1, 2, ..., 11-month risk-neutral yields, I must alter the analysis from Lloyd (2017a). In Lloyd (2017a), I show that the OIS-augmented model performs unambiguously better than other models at the 1, 2, ..., 11 month horizons.

[25] I only use FFFs rates on the final day of each calendar month due to the maturity structure of FFFs contracts (see Lloyd, 2017b, for more details). An n-month contract traded on day t_i of the calendar month t has the same settlement period as an n-month contract traded on a different day t_j in the same calendar month t. For this reason, the horizon of the FFFs-implied expectation and the 1-year risk-neutral yield only align on the final day of each calendar month. I use the arithmetic mean in accordance with FFFs market convention — see CME Rulebook, Chapter 22, 22101: `www.cmegroup.com/rulebook/CBOT/V/22/22.pdf`.

Table 1: GADTSM-Implied Expectations: Root Mean Square Error (RMSE) of the 1-Year Risk-Neutral Yield *vis-à-vis* the Federal Funds Futures-Implied 1-Year Expectation

RMSE vs. 1-Year FFF-Implied Expectation			
		Sample	
Model	Jan. 2002 to Dec. 2015	Nov. 2008 to Apr. 2013	Nov. 2008 to Dec. 2015
Bias-Corrected	0.5275	0.5386	0.4707
Survey-Augmented	0.3462	0.3521	0.3456
OIS-Augmented	**0.2522**	**0.2138**	**0.1713**

Note: RMSE of the 1-year risk-neutral yields from each of the three GADTSMs in comparison to the federal funds futures-implied expectation. The three models are: (i) the bias-corrected model (Bauer et al., 2012); (ii) the survey-augmented model (Kim and Wright, 2005); and (iii) the OIS-augmented model (Lloyd, 2017a). The bias-corrected and survey-augmented models are estimated using daily data from July 18, 1990 to December 31, 2015. The OIS-augmented model is estimated using daily data from January 2, 2002 to December 31, 2015. All models use three pricing factors. All figures are in annualised percentage points. The lowest RMSE model has been emboldened for ease of reading.

3.2.2 Risk-Neutral Yields and Survey Expectations

I also compare the GADTSM-implied interest rate expectations to survey expectations. Because survey expectations reflect respondents' expectations of future short-term interest rates, the risk-neutral yields from the preferred GADTSM should closely align with corresponding-maturity survey expectations, especially during the post-2008 period of interest.

Formally, I compare the estimated 6-month and 1-year risk-neutral yields to corresponding-horizon average short-term interest rate expectations from surveys.[26] I calculate approximate future short-term interest rate expectations using data from the quarterly *Survey of Professional Forecasters* at the Federal Reserve Bank of Philadelphia. I construct the approximations from a weighted geometric average of the median expectation of the 3-month T-Bill rate for the remainder of the current quarter, and the first, second, third and fourth quarters ahead.[27] To compare the estimated risk-neutral yields to these survey expectations, I calculate the RMSE of the risk-neutral yield *vis-à-vis* the corresponding horizon survey expectation on survey submission deadline dates.

Table 2 presents the numerical results for the comparison of 6 and 12-month expectations. The results indicate that the OIS-augmented GADTSM unambiguously provides the best fit for survey expectations. Of particular note is the performance of the OIS-augmented model over the baseline 2008 Q4 to 2013 Q2 sample most relevant to the subsequent analysis. Here the RMSE fit of the 1-year survey expectation from the OIS-augmented model is almost one-third of the RMSE fit of the survey-augmented model and around a quarter of the RMSE fit of the bias-corrected model.

[26] Estimates of the Kim and Wright (2005) decomposition are only available for 1-year bond maturities, or more, so I am unable to compare this to survey forecasts at the 6-month horizon. Nevertheless, I compare the bias-corrected and OIS-augmented models at the 6-month horizon, to stress the superiority of OIS-augmentation over the bias-corrected model at multiple horizons.

[27] A complete description of how these approximations are calculated is in Lloyd (2017a, Appendix B).

Table 2: GADTSM-Implied Expectations: Root Mean Square Error (RMSE) of the In-Sample Risk-Neutral Yields *vis-à-vis* 6-Month and 1-Year Survey Expectations

Model	Sample 2002 Q1 to 2015 Q4	2008 Q4 to 2013 Q2	2008 Q4 to 2015 Q4
	RMSE vs. 6-Month Survey Expectation		
Bias-Corrected	0.2725	0.2977	0.2606
Survey-Augmented	N/A	N/A	N/A
OIS-Augmented	**0.1505**	**0.1132**	**0.0979**
	RMSE vs. 1-Year Survey Expectation		
Bias-Corrected	0.4555	0.5016	0.4329
Survey-Augmented	0.2992	0.3519	0.3292
OIS-Augmented	**0.1685**	**0.1400**	**0.1306**

Note: RMSE of the risk-neutral yields from each of the three GADTSMs in comparison to approximated survey expectations. The three models are: (i) the bias-corrected model (Bauer et al., 2012); (ii) the survey-augmented model (Kim and Wright, 2005); and (iii) the OIS-augmented model (Lloyd, 2017a). The bias-corrected and survey-augmented models are estimated using daily data from July 18, 1990 to December 31, 2015. The OIS-augmented model is estimated using daily data from January 2, 2002 to December 31, 2015. All models use three pricing factors. All figures are in annualised percentage points. The lowest RMSE model at each maturity, for each sub-sample, has been emboldened for each of reading.

Overall, the OIS-augmented decomposition provides superior estimates of interest rate expectations, in comparison to both FFFs rates and survey expectations. Hereafter, the OIS-augmented model is deemed the preferred model of interest rate expectations.

4 Financial Market Impact of LSAPs and Forward Guidance

Before assessing the effect of shocks to longer-term interest rates on real economic outcomes, I document the impact of LSAP and forward guidance announcements on interest rates by carrying out an event study. To label the shocks identified in section 5 as the 'signalling' and 'portfolio rebalancing' effects of LSAPs and forward guidance, policy announcements must have exerted a significant impact on the risk-neutral yield and term premium components of longer-term bond yields. I verify this here.

Event studies are ubiquitous in the literature assessing the financial market effects of unconventional monetary policy. As is the norm, I evaluate the change in interest rates within a one-day event window on event days where notable announcements pertaining to forward guidance or the *expansion* of LSAPs occurred.

Event studies rely on the lumpy nature of monetary policy announcements. Although US unconventional monetary policy announcements have occurred at different points in time and at irregular intervals, they have been multifaceted and have become increasingly complex.[28] Numerous policies have been announced in a single statement. For instance, on December 16,

[28] Rogers, Scotti, and Wright (2014) note that the average word count for FOMC statements has increased from around 200 words in 2008 to over 600 in 2013.

2008, the Fed announced that the target range for the federal funds rate would be reduced to 0-0.25%, that interest rates would be kept low "for some time", and that LSAPs would be continued. Thus, I study forward guidance and LSAPs jointly, as on some event days the effects of the two are not separately identifiable.

My results extend upon the existing US unconventional monetary policy event study literature in three ways. First, this is the first study to apply the OIS-augmented yield curve decomposition of Lloyd (2017a) to the analysis of macroeconomic policy at the ELB. Second, I consider a longer sample period of events: from November 25, 2008 to April 2013, though the last event date corresponding to expansionary monetary policy is December 12, 2012. Third, the classification of events differs to those of Rogers, Scotti, and Wright (2014) and Gilchrist, López-Salido, and Zakrajsek (2015), who are the only other authors to explicitly consider the simultaneous occurrence of forward guidance and LSAP announcements on event days. These authors classify the events in a binary manner, as either predominantly LSAP-related or forward guidance-related. I add a third classification to account for event dates on which both notable LSAP and forward guidance events took place. Admitting the joint impact of these policies is especially important, as either policy is likely to contaminate event studies into the other. For instance, in an LSAP-only event study, the sizeable reduction in US Treasury yields on March 18, 2009 may be entirely attributed to the announced purchase of longer-term Treasuries as part of QE1. However, on the same day the Fed altered its forward guidance from stating that it would maintain the policy rate at its lower bound "for some time" to "an extended period". By defining this as a combined LSAP and forward guidance event, I explicitly capture the multifaceted nature of unconventional monetary policy. Finally, I consider movements in the risk-neutral yield and term premium at multiple horizons: specifically 2, 5 and 10 years. Although movements in yields of different maturities are highly correlated, there is no *a priori* reason to expect changes in interest rate expectations to be equally important at all time horizons. In fact, as forward guidance is often strongly linked — either explicitly when time-dependent, or implicitly otherwise — to a 1 to 2-year horizon, it seems likely that signalling effects will be most important at these tenors. Additionally, 10-year interest rate movements, which are the sole focus of some existing LSAP event studies, may not be the most relevant for economic activity. By additionally considering 2 and 5-year rates, I am better able to account for heterogeneous effects of signalling and portfolio rebalancing across horizons.

Table 3 presents the list of 16 announcement dates that I consider. All announcements are based on a set of official communications by the Fed and speeches by senior Fed officials, which contained new information on unconventional policy. To select the events, I independently scoured all Fed press releases.[29] To be included in the event set, the news had to mark a notable, broadly unanticipated change in LSAP or forward guidance policy. Many of the events in the first half of the study corroborate with those in other event studies (Gagnon et al., 2011; Christensen and Rudebusch, 2012; Filardo and Hofmann, 2014).

[29]These press releases are available here: `www.federalreserve.gov/newsevents/press/all/XXXXall.htm`, where `XXXX` should be replaced by the year of interest.

Table 3: Event Set and Descriptions

#	Date	Description
I	25/11/2008	**Initial LSAP announcement**: *LSAPs* - Fed to purchase MBS and agency bonds.[GRRS,CR,W]
II	01/12/2008	**Bernanke speech**: *LSAPs* - US Treasuries *may* be purchased.[GRRS,CR,W,a]
III	16/12/2008	**FOMC statement**: *FG* - "... weak economic conditions are likely to warrant exceptionally low levels of the federal funds rate for some time"; *LSAPs* - Further mention of possible Treasury purchases.[GRRS,CR,W,FH]
IV	28/01/2009	**FOMC statement**: *LSAPs* - "The Federal Reserve continues to purchase large quantities of agency debt and mortgage-backed securities to provide support to the mortgage and housing markets, and it stands ready to expand the quantity of such purchases and the duration of the purchase program as conditions warrant".[GRRS,CR,W]
V	18/03/2009	**FOMC statement**: *FG* - "... economic conditions are likely to warrant exceptionally low levels of the federal funds rate for an extended period"; *LSAPs* - Purchase of long-term Treasuries announced.[GRRS,CR,W,FH]
VI	10/08/2010	**FOMC statement**: *LSAPs* - Fed to reinvest holdings of assets purchased under 'QE1' to keep overall value of asset stock constant.[W]
VII	27/08/2010	**Bernanke speech at Jackson Hole**: *LSAPs* - "additional purchases ... would be effective".[W,b]
VIII	21/09/2010	**FOMC statement**: *LSAPs* - Fed to reinvest holdings of assets purchased.[W]
IX	15/10/2010	**Bernanke speech at Boston Fed**: *FG & LSAPs* - "the FOMC is prepared to provide additional accommodation if needed to support the economic recovery and to return inflation over time to levels consistent with our mandate".[W,c]
X	03/11/2010	**FOMC statement**: *LSAPs* - 'QE2' announced; $600bn purchase of long-term Treasuries over six months.
XI	09/08/2011	**FOMC statement**: *FG* - "... economic conditions ... are likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013"; *LSAPs* - Fed to reinvest holdings of assets purchased under 'QE1' and 'QE2' to keep overall value of asset stock constant.[W,FH]
XII	26/08/2011	**Bernanke speech at Jackson Hole**: *FG & LSAPs* - "[T]he [Fed] has a range of tools. ... We will continue to consider those".[W,d]
XIII	25/01/2012	**FOMC statement**: *FG* - "... economic conditions ... are likely to warrant exceptionally low levels for the federal funds rate at least through late 2014".[FH]
XIV	31/08/2012	**Bernanke speech at Jackson Hole**: *FG & LSAPs* - "nontraditional policy tools ... can continue to be effective".[e]
XV	13/09/2012	**FOMC statement**: *FG* - "... low levels for the federal funds rate are likely to be warranted at least through mid-2015"; *LSAPs* - 'QE3' announced.[FH]
XVI	12/12/2012	**FOMC statement**: *FG* - "... exceptionally low range for the federal funds rate will be appropriate at least as long as the unemployment rate remains above 6.5 percent, inflation between one and two years ahead is projected to be no more than half a percentage point above the Committee's 2 percent longer-run goal, and longer-term inflation expectations continue to be well anchored".[FH]

Abbreviations: LSAPs = Event date with LSAP news; FG = Event date with forward guidance announcement. [GRRS]: In the baseline event set of Gagnon et al. (2011); [CR]: Included in the event set of Christensen and Rudebusch (2012); [W]: Included in the important event set of Wright (2012); [FH]: Included in event set of Filardo and Hofmann (2014).

For speeches, the source is `www.federalreserve.gov/newsevents/speech/XX` where `XX` is `bernanke20081201a.htm` for [a]; `bernanke20100827a.htm` for [b]; `bernanke20101015a.htm` for [c]; `bernanke20110826a.htm` for [d]; and `bernanke20120831a.htm` for [e].

News source sampled from all Fed press releases 2008-2013: `www.federalreserve.gov/newsevents/pressreleases.htm`.

4.1 Model-Free Evidence

I first consider the behaviour of Treasury yields and OIS rates on event days without a model for investors' interest rate expectations. This 'model-free' evidence is a useful benchmark for comparing the results attained using formal yield curve decompositions.

OIS rates are particularly relevant for studies of the signalling channel of unconventional monetary policy, as they are associated with investors' expectations of the future short-term interest rate path. Lloyd (2017b) explains how OIS rates theoretically reflect interest rate expectations and demonstrates that, for the 2002-2016 period, US OIS contracts out to the 2-year horizon provide accurate information about investors' expectations of future short-term interest rates. Longer-maturity OIS rates include term premia that are increasing in contract maturity, which mean this model-free evidence can only provide illustrative evidence on the importance of signalling for the propagation of unconventional monetary policy.

I compare the changes in actual Treasury yields to comparable-horizon OIS rates on event days. For the 2-year OIS rate, quantitative similarities in the daily changes of OIS and Treasury rates indicate the existence of a common factor explaining the co-movement. Expectations of future short-term interest rates, which are reflected in both OIS and Treasury rates, are a prime candidate for this factor. However, because term premia are likely to contaminate daily changes in 5 and 10-year OIS rates, a close co-movement between OIS and Treasury rates at these horizons is less likely to be explained by a single common expectations factor.

Table 4 presents the results of the model-free event study, using US Treasury zero-coupon yields from Gürkaynak et al. (2007) and OIS rates from *Bloomberg*. US unconventional monetary policy announcements did have a significant impact on financial markets at a range of horizons.[30] Treasury yields and OIS rates fell significantly on many of the event days. On the whole, the results depict a hump-shaped response of the Treasury yield curve in reaction to news: the largest cumulative fall in Treasury yields over the 16 announcement dates was at the 5-year maturity. The cumulative responses of OIS rates do not exhibit such a defined hump-shaped pattern across maturities. On LSAP-only and forward guidance-only event days, the cumulative fall in OIS rates is increasing in contract maturity. Though, on all event days, the 5-year OIS rate exhibits the largest cumulative fall, exceeding the 10-year figure by 0.75 basis points. The differing response of the OIS maturity structure to news, *vis-à-vis* Treasury yields, provides illustrative evidence of the term premia that exist in longer maturity OIS contracts.

The primary finding from table 4 is that the spread between 2-year Treasury and OIS rates moved very little on most event days. Changes in interest rate expectations are likely to have acted as a common factor driving this co-movement, indicating an important role for signalling effects in the transmission of US unconventional monetary policy to financial markets. Most strikingly, the total change in 2-year OIS rates on LSAP event days is 75.81% (-58.60 basis

[30]To assess the significance of these daily changes, I control for other macroeconomic data releases. Formally, the tests assess whether the change on an event date is significantly different to the average change on a non-event day, controlling for macroeconomic data releases. See appendix B.2 for more details. Similar results are attained when the Citigroup Economic Surprise Index, a summary measure of differences between economic data releases (excluding monetary policy) and pre-announcement expectations, is used as a control variable.

Table 4: One-Day Change in Actual US Treasury Yields and OIS Rates on Event Dates

#	Event Date & Description		Maturity - All Figures in Basis Points					
			2-Year		5-Year		10-Year	
			(1)	(2)	(3)	(4)	(5)	(6)
			$\Delta\ yld_2$	$\Delta\ i_2^{ois}$	$\Delta\ yld_5$	$\Delta\ i_5^{ois}$	$\Delta\ yld_{10}$	$\Delta\ i_{10}^{ois}$
I	25/11/2008	L	-14.35***	-13.80***	-22.50***	-24.80***	-21.38***	-28.10***
II	01/12/2008	L	-11.86***	-12.80***	-21.42***	-20.70***	-21.55***	-19.10***
III	16/12/2008	F,L	-10.72***	-15.25***	-16.26***	-28.55***	-17.48***	-31.75***
IV	28/01/2009	L	+4.57***	+5.60***	+10.11***	+10.70***	+12.04***	+13.65***
V	18/03/2009	F,L	-26.41***	-12.00***	-47.08***	-26.70***	-51.88***	-37.70***
VI	10/08/2010	L	-2.69**	-1.20	-7.09***	-5.30***	-6.87***	-4.40***
VII	27/08/2010	L	+5.40***	+5.10***	+12.30***	+13.00***	+16.64***	+18.30***
VIII	21/09/2010	L	-3.71***	-4.05***	-9.57***	-10.30***	-10.73***	-12.40***
IX	15/10/2010	F,L	-1.21**	-0.50***	+2.61***	+1.80***	+8.62***	+4.30***
X	03/11/2010	L	-1.52***	-0.70***	-4.04***	-3.10***	+4.07***	-1.70***
XI	09/08/2011	F,L	-8.56***	-5.95***	-19.09***	-10.35***	-20.50***	-8.60***
XII	26/08/2011	F,L	-1.70	-0.75	-4.21	-4.65***	-3.50	-6.00
XIII	25/01/2012	F	-3.77***	-1.40***	-9.39***	-10.45***	-8.03***	-5.70***
XIV	31/08/2012	F,L	-3.67***	-1.10***	-6.43***	-7.00***	-7.02***	-7.10***
XV	13/09/2012	F,L	-0.86	-1.20	-3.70***	-4.80***	-2.93***	-5.60***
XVI	12/12/2012	F	+0.03	+0.25**	+2.25***	+2.65***	+5.71***	+4.10***
Total Change on Event Days								
LSAP Events			-77.30	-58.60	-136.37	-120.75	-122.47	-126.20
($\Delta\ i^{ois} \div \Delta\ yld$)				*(75.81%)*		*(88.55%)*		*(103.05%)*
FG Events			-56.89	-37.90	-101.30	-88.05	-97.02	-94.05
($\Delta\ i^{ois} \div \Delta\ yld$)				*(66.62%)*		*(86.92%)*		*(96.94%)*
All Events			-81.05	-59.75	-143.51	-128.55	-124.79	-127.80
($\Delta\ i^{ois} \div \Delta\ yld$)				*(73.72%)*		*(89.58%)*		*(102.41%)*

Notes: L = Event date with LSAP news; F = Event date with forward guidance announcement; Δyld_n = Change in actual n-year zero-coupon bond yield on event days; Δi_n^{ois}: Change in actual n-year OIS rate on event days. Tests to determine the significance of daily changes are described in appendix B.2; t-statistics are calculated using Newey and West (1987) standard errors. Daily changes that are significant at the 1%, 5% and 10% levels are denoted with asterisks ***, ** and * respectively. *Data Sources*: Appendix A.

points) of the cumulative change in the 2-year Treasury yield (−77.30 basis points) on the same event days. The corresponding percentages for the forward guidance-only events and all events are 66.62% and 73.72% at the 2-year horizon. At the 5 and 10-year horizons the ratios of the cumulative falls in OIS rates to Treasury yields are higher than for the 2-year tenor. However, these figures are likely to reflect significant term premia within OIS contracts in addition to a common expectations factor, motivating the subsequent GADTSM-based study.

Treasury yields and OIS rates fell significantly on most event days.[31] However, on some event days, Treasury and OIS rates increased (e.g. IV, VII, IX, and XVI),[32] and their moves were statistically insignificant on other days (e.g. XII). Nevertheless, the conclusions are robust

[31] Although yields fell by more on event XII than on other days (e.g. X), the statistical insignificance of the changes occurs because a preliminary US GDP release occurred on the same date. Preliminary US GDP releases also occurred on days I and VII, but the yield moves on these days were larger and, thus, statistically significant.

[32] Appendix B.1 explains why Treasury yields increased on these event days with reference to news reports.

to the removal of these dates from the event set. When event days IV, VII, IX, XII and XVI are not included, the cumulative fall in the 2-year Treasury yield is 88.12 basis points, while the 2-year OIS rate cumulatively falls by 69.45 basis points. The 5 and 10-year Treasury yields fell by 166.57 and 164.30 basis points, respectively, on the remaining 11 event days, while the 5 and 10-year OIS rates declined by 152.05 and 162.15 basis points in turn.

Tables 4 also provides some indication of the changing efficacy of unconventional monetary policy announcements over time. In particular, actual Treasury yields fell most in response to earlier policy announcements, linked with QE1. The largest fall in Treasury yields came on event day V, when the Fed announced the extension of QE1 to include the purchase of long-term Treasuries, and altered their forward guidance from stating that the federal funds rate would remain low, from "for some time" to "an extended period." The introduction of calendar-based forward guidance on event day XI was the only to depress bond yields by a similar order of magnitude to the early announcements.

4.2 Event Study Results

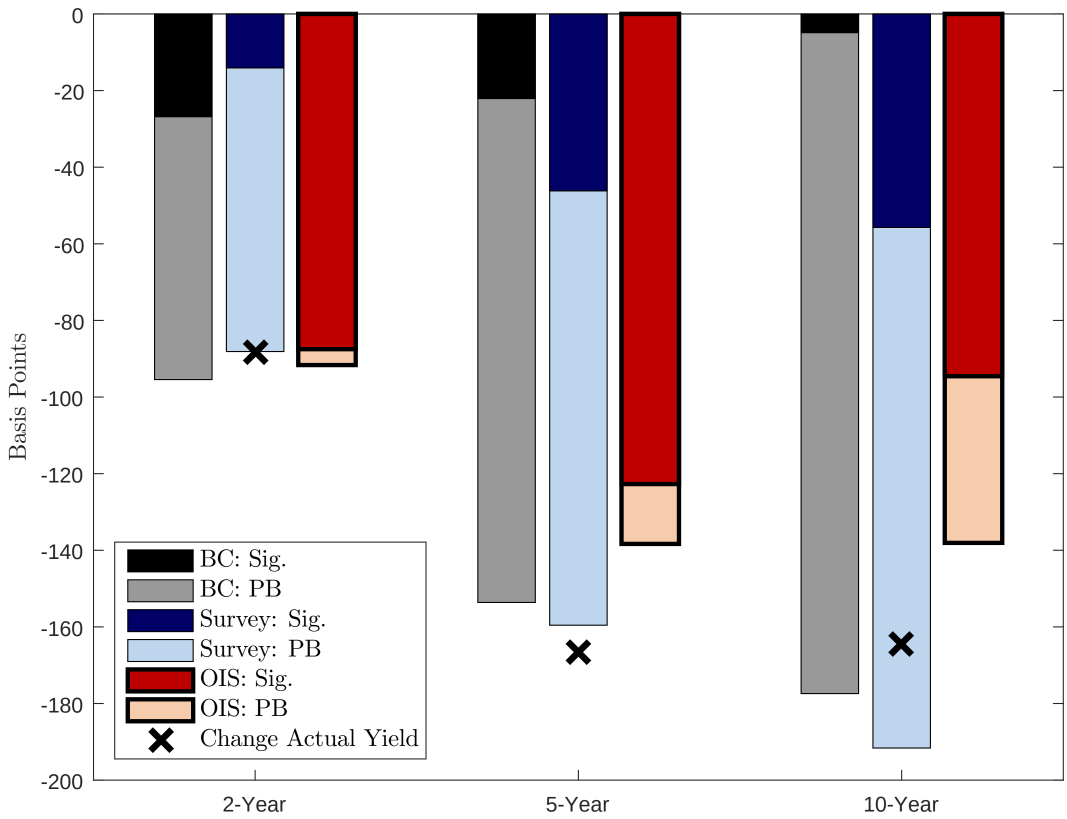
To explicitly consider the reaction of interest rate expectations and term premia to policy announcements, I perform an event study using the three GADTSM decompositions described in section 3. As in the existing literature, the risk-neutral yields are associated with the signalling channel and term premia with portfolio rebalancing. The results are reported in tables 5, 6 and 7 for the 2, 5 and 10-year yields respectively. To assess the statistical significance of daily changes, I control for major US macroeconomic data release dates.[33] All three tables indicate that changes in fitted yields and their sub-components on event days were sizeable, and statistically significant on many event dates. Notably, both the signalling and portfolio balance channels are shown to be operative, albeit to differing degrees at different horizons and with different yield curve decompositions.

Figure 2 graphically depicts the headline results. It plots the cumulative fall in actual 2, 5 and 10-year yields (denoted by a cross) along with the cumulative fall in fitted yields, risk-neutral yields and term premia from the three term structure models on the 11 event days when bond yields fell significantly. These 11 dates exclude events IV, VII, IX, XII and XVI, when fitted yields either increased or fell insignificantly. The graph demonstrates that the survey-augmented decomposition attributes a greater proportion of variation in fitted yields to the term premium, and thus portfolio rebalancing. It attributes 84.01% of the cumulative fall in the 2-year fitted yield on the 11 event days to the term premium, the highest proportion of the three models at this maturity. The corresponding figures for the 5 and 10-year horizons are 71.05% and 70.91% respectively. However, for the reasons outlined in section 3, the results from the survey-augmented decomposition over-attribute variation in fitted yields to the term premium, falsely overstating the efficacy of the portfolio balance channel relative to signalling.

Although the bias-corrected decomposition attributes a lesser percentage of fitted yield variation to term premia at all three horizons than the survey-augmented decomposition on all 16

[33] See appendix B.2 for further details.

Figure 2: Cumulative Fall in Yields on 11 Event Days with Statistically Significant Falls in Fitted Yields



Note: Plot of the cumulative fall in actual yields, fitted yields, risk-neutral yields and term premia on 11 event days with statistically significant falls in fitted yields. The 11 dates exclude events IV, VII, IX, XII and XVI. The remaining 11 event days are listed in table 3. The cumulative fall in actual 2, 5 and 10-year yields is denoted by a black cross. The cumulative fall in fitted 2, 5 and 10-year yields from the bias-corrected ('BC') (Bauer et al., 2012), survey-augmented ('Survey') (Kim and Wright, 2005) and OIS-augmented ('OIS') (Lloyd, 2017a) GADTSMs are depicted in the bars. The upper, dark, segment of each bar depicts the cumulative fall in risk-neutral yields — the signalling channel ('Sig.'). The lower, light, segment of each bar depicts the cumulative fall in term premia — the portfolio balance channel ('PB').

event dates, it attributes the greatest proportion of variation in fitted yields to the term premium at the 5 and 10-year horizons on the 11 dates when fitted yields fell significantly. At the 2, 5 and 10-year horizons the bias-corrected decomposition respectively attributes 71.89%, 85.63% and 97.24% of the cumulative fall in fitted yields term premia, and thus portfolio rebalancing, on these 11 days.

The preferred OIS-augmented decomposition highlights a powerful role for signalling at all horizons. Of the cumulative fall in fitted yields at the 2, 5 and 10-year horizons on the 11 event days with significant falls in fitted yields, the OIS-augmented decomposition respectively attributes 95.49%, 88.71% and 68.49% to falls in risk-neutral yields and thus signalling. The corresponding figures for the complete set of 16 event dates are 95.29%, 90.61% and 74.19%. The OIS-augmented model attributes the greatest proportion of variation to signalling at the 2-year horizon. But in terms of absolute size, the reaction of risk-neutral yields is hump-shaped with respect to bond maturity. The 2-year risk-neutral yield fell by a total of 87.51 basis points on the 11 event days, while the 5 and 10-year figures were 122.72 and 94.57 basis points respectively, indicating that interest rate expectations were affected well beyond the 2-year horizon. The relative and absolute size of term premium changes are increasing in maturity, reflecting greater importance of risk at longer horizons.

Tables 5-7 provide a more detailed breakdown of the event study, allowing a comparison of LSAP and forward guidance event days. For all three maturities, falls in risk-neutral yields from the OIS-augmented decomposition explain a marginally larger proportion of falls in fitted yields on forward guidance event days than LSAP event days. For instance, falls in risk-neutral yields explain 91.31% of the reduction in the 5-year fitted yield on forward guidance days, and 89.96% on LSAP days. However, this comparison is blurred because most forward guidance events also included some information about LSAPs. Nevertheless, it is particularly striking that proportional expectations effects were strong on LSAP-only event days (events I, II, VI, VIII and X especially). For instance, on event date VIII, when the Fed announced it would reinvest maturing assets to maintain the stock of asset purchases, over 60% of the fall in the 10-year fitted yield is attributed to a reduction in the risk-neutral yield.

Tables 5-7 indicate some interesting differences between each of the three yield curve decompositions on specific event days too. For example, on event day II (December 1, 2008), Fed Chairman Ben Bernanke stated that "US Treasuries may be purchased" as part of the LSAP program. The survey-augmented decomposition attributes just 15% of the fall in the 2-year fitted yield on that day to the risk-neutral yield, whereas the OIS-augmented model attributes around 94% to the fall in the risk-neutral yield. According to this latter decomposition, the signalling effect of this announcement was more pronounced. Similar differences exist on event day V (March 18, 2009), when the Fed stated that low interest rates would likely be warranted for "an extended period" and announced the purchase of longer-term Treasuries as part of the LSAP program. On this day, the bias-corrected and survey-augmented models respectively attribute 19% and 16% of the fall in the 2-year fitted yield to the risk-neutral yield. In contrast, the corresponding figure for the OIS-augmented decomposition is 96%.

In sum, the event study evidence indicates that different yield curve decompositions provide differing conclusions about the relative efficacy of signalling and portfolio rebalancing. Using the preferred OIS-augmented model, I find that unconventional monetary policy announcements had particularly powerful signalling effects on financial markets, explaining between 68.49% and 95.49% of the cumulative decline in bond yields on announcement days.

5 Signalling, Portfolio Rebalancing and the Real Economy

To assess the relative importance of signalling and portfolio rebalancing effects of unconventional monetary policy for the real economy, I identify the shocks with a combination of zero-impact

Table 5: 2-Year US Treasury Yield and its Components: Changes on Event Dates for Three Decompositions of US Zero-Coupon Treasury Yields (All Figures in Basis Points to 2 Decimal Places)

#	Event Date & Type		GADTSM Decomposition: Bias-Corrected			Survey-Augmented			OIS-Augmented		
			(1) $\Delta\widehat{yld}_2$	(2) $\Delta\widehat{exp}_2$	(3) $\Delta\widehat{tp}_2$	(4) $\Delta\widehat{yld}_2$	(5) $\Delta\widehat{exp}_2$	(6) $\Delta\widehat{tp}_2$	(7) $\Delta\widehat{yld}_2$	(8) $\Delta\widehat{exp}_2$	(9) $\Delta\widehat{tp}_2$
I	25/11/2008	L	-14.63***	-7.79***	-6.84***	-14.35***	-4.11***	-10.24***	-12.23***	-11.88***	-0.35***
II	01/12/2008	L	-12.98***	-7.05***	-5.93***	-11.86***	-1.78***	-10.08***	-12.81***	-12.00***	-0.81***
III	16/12/2008	F,L	-11.55***	-6.35***	-5.19***	-10.72***	-4.17***	-6.55***	-11.15***	-11.04***	-0.11***
IV	28/01/2009	L	3.68***	-6.12***	9.79***	4.57***	0.17**	4.40***	5.31***	5.19***	0.12***
V	18/03/2009	F,L	-28.08***	-5.34**	-22.74***	-26.41***	-4.29**	-22.12***	-26.30***	-25.35***	-0.95***
VI	10/08/2010	L	-3.09**	0.95	-4.05***	-2.68*	0.00	-2.68***	-2.86**	-2.71**	-0.15***
VII	28/08/2010	L	5.72***	-3.82	9.54***	5.39***	-0.65	6.04***	6.35***	5.97***	0.37***
VIII	21/09/2010	L	-4.03***	2.59***	-6.62***	-3.71***	0.43***	-4.14***	-4.67***	-4.33***	-0.34***
IX	15/10/2010	F,L	-1.05*	-9.89***	8.84***	-1.21**	-2.59***	1.38***	-0.01	0.12	-0.12***
X	03/11/2010	L	-2.58***	-6.89***	4.31***	-1.51***	-0.97***	-0.54***	-1.93***	-1.63***	-0.29***
XI	09/08/2011	F,L	-9.26***	2.46*	-11.72***	-8.56***	0.09	-8.65***	-9.32***	-8.92***	-0.40***
XII	26/08/2011	F,L	-1.64	0.60**	-2.24**	-1.70	0.22**	-1.92	-2.65	-2.42	-0.23***
XIII	25/01/2012	F	-4.18***	0.26	-4.45***	-3.78***	0.24***	-4.02***	-4.74***	-4.34***	-0.40***
XIV	31/08/2012	F,L	-3.70***	-0.45***	-3.25***	-3.67***	-0.50***	-3.17***	-3.72***	-3.58***	-0.14***
XV	13/09/2012	F,L	-1.35*	0.78	-2.13***	-0.87	0.97***	-1.84***	-1.93***	-1.73***	-0.20***
XVI	12/12/2012	F	-0.15	-4.75***	4.60***	0.03	-1.58***	1.61***	0.23*	0.12	0.11***
Total Change on Event Days											
LSAP Events			-84.55	-46.32	-38.24	-77.29	-17.18	-60.11	-77.91	-74.32	-3.60
				(54.78%)	*(45.22%)*		*(22.23%)*	*(77.78%)*		*(95.39%)*	*(4.61%)*
FG Events			-60.96	-22.68	-38.28	-56.89	-11.61	-45.28	-59.59	-57.16	-2.43
				(37.21%)	*(62.79%)*		*(20.41%)*	*(79.59%)*		*(95.91%)*	*(4.09%)*
All Events			-88.89	-50.80	-38.08	-81.04	-18.52	-62.52	-82.43	-78.54	-3.88
				(57.16%)	*(42.84%)*		*(22.85%)*	*(77.15%)*		*(95.29%)*	*(4.71%)*

Proportion of total change in fitted yield $\Delta\widehat{yld}_2$ explained by $\Delta\widehat{exp}_2$ and $\Delta\widehat{tp}_2$ shown in brackets beneath.

Abbreviations: L = Event date with LSAP news; F = Event date with forward guidance announcements.

$\Delta\widehat{yld}_2$: Change in 2-year fitted yield on event dates from the bias-corrected Bauer et al. (2012), survey-augmented Kim and Wright (2005), and OIS-augmented Lloyd (2017a) decompositions. $\Delta\widehat{exp}_2$ ($\Delta\widehat{tp}_2$): Change in 2-year risk-neutral yield (term premium) on event days. Tests to determine the significance of daily changes are described in appendix B.2; t-statistics are calculated using Newey and West (1987) standard errors. Daily changes that are significant at the 1%, 5% and 10% levels are denoted with asterisks ***, ** and * respectively.

Table 6: 5-Year US Treasury Yield and its Components: Changes on Event Dates for Three Decompositions of US Zero-Coupon Treasury Yields (All Figures in Basis Points to 2 Decimal Places)

#	Event Date & Type		GADTSM Decomposition								
			Bias-Corrected			Survey-Augmented			OIS-Augmented		
			(1) $\Delta\widehat{yld}_5$	(2) $\Delta\widehat{exp}_5$	(3) $\Delta\widehat{tp}_5$	(4) $\Delta\widehat{yld}_5$	(5) $\Delta\widehat{exp}_5$	(6) $\Delta\widehat{tp}_5$	(7) $\Delta\widehat{yld}_5$	(8) $\Delta\widehat{exp}_5$	(9) $\Delta\widehat{tp}_5$
I	25/11/2008	L	-21.33***	-8.03***	-13.30***	-21.57***	-6.77***	-14.80***	-17.66***	-15.90***	-1.76***
II	01/12/2008	L	-21.14***	-8.31***	-12.83***	-20.53***	-5.57***	-14.96***	-19.07***	-17.20***	-1.87***
III	16/12/2008	F,L	-16.42***	-6.47***	-9.95***	-16.16***	-6.15***	-10.01***	-15.06***	-13.91***	-1.15***
IV	28/01/2009	L	8.00***	-9.16***	17.16***	9.43***	2.51***	6.92***	7.57***	6.84***	0.74***
V	18/03/2009	F,L	-45.23***	-2.61	-42.62***	-47.07***	-13.48***	-33.59***	-39.03***	-34.77***	-4.26***
VI	10/08/2010	L	-5.98***	1.63	-7.61***	-6.52***	-1.94***	-4.58***	-5.44***	-4.32***	-1.12***
VII	28/08/2010	L	11.98***	-5.75	17.73***	12.63***	2.99***	9.64***	10.11***	8.78***	1.33***
VIII	21/09/2010	L	-8.39***	3.92***	-12.31***	-9.12***	-2.31***	-6.81***	-8.00***	-6.74***	-1.26***
IX	15/10/2010	F,L	2.58***	-13.03***	15.62***	3.68***	0.38	3.30***	2.42***	0.93	1.49***
X	03/11/2010	L	-1.67***	-8.93***	7.25***	-1.92***	-1.04***	-0.88***	-2.43***	-2.52***	0.09***
XI	09/08/2011	F,L	-16.91***	4.71***	-21.63***	-18.43***	-4.73***	-13.70***	-16.50***	-13.50***	-3.01***
XII	26/08/2011	F,L	-3.19	1.00**	-4.19**	-3.50	-0.66	-2.84	-3.62	-3.46	-0.16
XIII	25/01/2012	F	-7.69***	0.81**	-8.50***	-8.42***	-2.06***	-6.36***	-7.23***	-6.51***	-0.72***
XIV	31/08/2012	F,L	-6.07***	0.00	-6.07***	-6.36***	-1.68***	-4.68***	-5.71***	-5.00***	-0.71***
XV	13/09/2012	F,L	-2.80***	1.19	-3.98***	-3.46***	-0.46	-3.00***	-2.21***	-2.36***	0.15
XVI	12/12/2012	F	2.56***	-6.00***	8.56***	2.89***	0.09*	2.80***	2.12***	1.13***	0.99***
Total Change on Event Days											
LSAP Events			-126.56	-49.84	-76.72	-128.90	-38.91	-89.99	-114.63	-103.12	-11.51
				(39.38%)	*(60.62%)*		*(30.19%)*	*(69.81%)*		*(89.96%)*	*(10.04%)*
FG Events			-93.17	-20.41	-72.77	-96.83	-28.75	-68.08	-84.83	-77.45	-7.38
				(21.90%)	*(78.10%)*		*(29.69%)*	*(70.31%)*		*(91.31%)*	*(8.69%)*
All Events			-131.69	-55.03	-76.66	-134.43	-40.88	-93.55	-119.74	-108.50	-11.24
				(41.79%)	*(58.21%)*		*(30.41%)*	*(69.59%)*		*(90.61%)*	*(9.39%)*

Proportion of total change in fitted yield $\Delta\widehat{yld}_5$ explained by $\Delta\widehat{exp}_5$ and $\Delta\widehat{tp}_5$ shown in brackets beneath.

Abbreviations: L = Event date with LSAP news; F = Event date with forward guidance announcements.

$\Delta\widehat{yld}_5$: Change in 5-year fitted yield on event dates from the bias-corrected Bauer et al. (2012), survey-augmented Kim and Wright (2005), and OIS-augmented Lloyd (2017a) decompositions. $\Delta\widehat{exp}_5$ ($\Delta\widehat{tp}_5$): Change in 5-year risk-neutral yield (term premium) on event days. Tests to determine the significance of daily changes are described in appendix B.2; t-statistics are calculated using Newey and West (1987) standard errors. Daily changes that are significant at the 1%, 5% and 10% levels are denoted with asterisks ***, ** and * respectively.

Table 7: 10-Year US Treasury Yield and its Components: Changes on Event Dates for Three Decompositions of US Zero-Coupon Treasury Yields (All Figures in Basis Points to 2 Decimal Places)

#	Event Date &	Type	GADTSM Decomposition								
			Bias-Corrected			Survey-Augmented			OIS-Augmented		
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
			$\Delta\widehat{yld}_{10}$	$\Delta\widehat{exp}_{10}$	$\Delta\widehat{tp}_{10}$	$\Delta\widehat{yld}_{10}$	$\Delta\widehat{exp}_{10}$	$\Delta\widehat{tp}_{10}$	$\Delta\widehat{yld}_{10}$	$\Delta\widehat{exp}_{10}$	$\Delta\widehat{tp}_{10}$
I	25/11/2008	L	-22.62***	-6.56	-16.06***	-23.91***	-7.17***	-16.74***	-17.43***	-12.14***	-5.29***
II	01/12/2008	L	-21.79***	-7.22***	-14.57***	-24.01***	-6.58***	-17.43***	-17.64***	-13.30***	-4.34***
III	16/12/2008	F,L	-17.36***	-5.35***	-12.00***	-18.44***	-6.54***	-11.90***	-14.32***	-10.48***	-3.84***
IV	28/01/2009	L	13.89***	-12.26***	26.15***	11.82***	3.30***	8.52***	7.50***	5.20***	2.30***
V	18/03/2009	F,L	-54.14***	3.37	-57.51***	-56.06***	-16.11***	-39.95***	-39.06***	-26.68***	-12.38***
VI	10/08/2010	L	-7.93***	2.77	-10.70***	-8.70***	-2.68***	-6.02***	-6.89***	-3.41***	-3.48***
VII	28/08/2010	L	16.97***	-8.53***	25.50***	16.30***	4.29***	12.01***	10.43***	6.83***	3.60***
VIII	21/09/2010	L	-11.84***	5.85***	-17.69***	-12.03***	-3.35***	-8.68***	-8.74***	-5.30***	-3.44***
IX	15/10/2010	F,L	8.73***	-16.00***	24.73***	7.09***	1.80***	5.29***	6.32***	0.85	5.47***
X	03/11/2010	L	1.85***	-10.51***	12.36***	-2.11***	-1.01***	-1.10***	-0.84***	-1.97***	1.12***
XI	09/08/2011	F,L	-22.65***	8.06***	-30.71***	-23.34***	-6.41***	-16.93***	-19.92***	-10.56***	-9.36***
XII	26/08/2011	F,L	-4.30	1.63**	-5.93***	-4.25	-0.93	-3.32*	-2.62	-2.68	0.06
XIII	25/01/2012	F	-9.63***	2.01***	-11.65***	-10.74***	-2.87***	-7.87***	-6.48***	-5.08***	-1.41***
XIV	31/08/2012	F,L	-7.42***	0.87*	-8.29***	-7.42***	-1.98***	-5.44***	-5.98***	-3.85***	-2.13***
XV	13/09/2012	F,L	-3.89***	1.81	-5.69***	-4.86***	-1.03***	-3.83***	-0.76*	-1.80***	1.04**
XVI	12/12/2012	F	5.54***	-7.47***	13.01***	4.57***	0.82***	3.75***	4.11***	1.02***	3.08***
Total Change on Event Days											
LSAP Events			-132.48	-42.06	-90.42	-149.92	-44.40	-105.52	-109.95	-79.28	-30.67
				(*31.75%*)	(*68.25%*)		(*29.62%*)	(*70.38%*)		(*72.11%*)	(*27.89%*)
FG Events			-105.10	-11.06	-94.05	-113.45	-33.25	-80.20	-78.71	-59.26	-19.45
				(*10.52%*)	(*89.48%*)		(*29.31%*)	(*70.69%*)		(*75.28%*)	(*24.72%*)
All Events			-136.57	-47.51	-89.07	-156.09	-46.45	-109.64	-112.33	-83.34	-28.99
				(*34.79%*)	(*65.21%*)		(*29.76%*)	(*70.24%*)		(*74.19%*)	(*25.81%*)

Proportion of total change in fitted yield $\Delta\widehat{yld}_{10}$ explained by $\Delta\widehat{exp}_{10}$ and $\Delta\widehat{tp}_{10}$ shown in brackets beneath.

Abbreviations: L = Event date with LSAP news; F = Event date with forward guidance announcements.

$\Delta\widehat{yld}_{10}$: Change in 10-year fitted yield on event dates from the bias-corrected Bauer et al. (2012), survey-augmented Kim and Wright (2005), and OIS-augmented Lloyd (2017a) decompositions. $\Delta\widehat{exp}_{10}$ ($\Delta\widehat{tp}_{10}$): Change in 10-year risk-neutral yield (term premium) on event days. Tests to determine the significance of daily changes are described in appendix B.2; t-statistics are calculated using Newey and West (1987) standard errors. Daily changes that are significant at the 1%, 5% and 10% levels are denoted with asterisks ***, ** and * respectively.

and sign restrictions within a structural vector autoregression (SVAR).[34]

5.1 SVAR Methodology

The baseline reduced-form VAR, labelled **model 1**, consists of four monthly time series:

$$\mathbf{Y}_t = \left[ip_t, p_t, exp_t^{(j)}, tp_t^{(j)}\right]' \tag{2}$$

where ip_t is the logarithm of industrial production and p_t is the logarithm of the consumer price index (CPI).[35] Because the federal funds futures rate reached its ELB in December 2008, I do not include this in the set of variables. Instead, I use the components of longer-term interest rates to indicate the stance of monetary policy over the sample period. $exp_t^{(j)}$ represents the monthly average of the j-year risk-neutral yield estimated from one of the three GADTSMs described in section 3, while $tp_t^{(j)}$ denotes the monthly average of the j-year term premium from the same GADTSM. In accordance with the existing unconventional monetary policy VAR literature (e.g. Baumeister and Benati, 2013; IMF, 2013; Lloyd, 2013), I use the 10-year US Treasury yield in my baseline analysis. To assess the robustness of my results, I also run the SVAR with decompositions of different horizon yields.

I estimate the VAR using data from November 2008 to April 2013, the period in which LSAP and forward guidance announcements occurred and policy rates were at the ELB.[36] In line with the Schwarz-Bayes information criterion, the lag order of the VAR is two.

To further assess the robustness of my results, I account for additional channels through which LSAPs and forward guidance may transmit to the real economy. I control for each additional channel in turn.

I account for the credit channel by extending the baseline VAR (2) to form a five-variable system, labelled **model 2**:

$$\mathbf{Y}_t = \left[ip_t, p_t, exp_t^{(j)}, tp_t^{(j)}, cred_t\right]' \tag{3}$$

where $cred_t$ is the logarithm of US bank credit, a measure of bank lending.

Model 3 accounts for international effects. Bauer and Neely (2012) argue that the exchange rate channel of unconventional monetary policy works through international interest rate differentials, so is a component of signalling and portfolio balance channels. For this reason, I omit real exchange rate from models 1 and 2. However, in model 3, I assess the robustness of my findings to the inclusion of international factors:

$$\mathbf{Y}_t = \left[ip_t, p_t, exp_t^{(j)}, tp_t^{(j)}, rer_t\right]' \tag{4}$$

[34] To impose these restrictions, I use the algorithm of Binning (2013). Arias, Rubio-Ramírez, and Waggoner (2014) state that this algorithm for zero-impact and sign restrictions does not impose extra hidden sign restrictions on the model, unlike other existing approaches.

[35] Data sources are provided in appendix A. Variables are included in (log) levels, consistent with Sims, Stock, and Watson (1990) who show that parameter estimates from a VAR with potentially non-stationary log-level variables (e.g. ip_t and p_t) are consistent.

[36] The November 2008 sample start date is defined by the first LSAP announcement in table 3. The April 2013 sample end date is chosen because of the May 2013 'taper tantrum'. Nevertheless, the results are robust when December 2015 is chosen as the end date.

where rer_t represents the logarithm of the effective exchange rate series for the US against 60 other countries.[37]

5.2 Sign Restrictions

For the baseline specification (2), I identify four structural shocks: aggregate demand; aggregate supply; signalling; and portfolio rebalancing. It is important that these structural shocks are separately identified, posing a challenge for the identification of signalling and portfolio balance shocks. Given this, I assess the robustness of my results to two identification schemes, summarised in table 8.

Table 8: Sign Restriction Schemes 1 & 2 for the Four Variable VAR (2) - Model 1

	Variables					
	Schemes 1 & 2		Scheme 1		Scheme 2	
Shock	ip	p	$exp^{(j)}$	$tp^{(j)}$	$exp^{(j)}$	$tp^{(j)}$
Demand	>0	>0	>0	·	>0	·
Supply	>0	<0	·	·	·	·
Signalling	0	0	>0	·	>0	**0**
Portfolio Balance	0	0	**0**	>0	·	>0

· denotes an unrestricted response. 0 denotes a response that is restricted to zero in the month of the shock. $<$ ($>$) denotes a response that is strictly negative (positive) in the month of the shock.

To identify the first two structural shocks, to aggregate demand and supply, I appeal to a standard set of sign restrictions used in a number of studies of conventional and unconventional monetary policy (e.g. Baumeister and Benati, 2013). For these shocks, I use the same identification restrictions in schemes 1 and 2. A positive demand shock must increase industrial production and the price level. Moreover, since the shock should tighten future monetary policy (conventional or unconventional), I impose that the expected future path of short-term interest rates $exp^{(j)}$ must also increase. A supply shock must have opposing effects on industrial production and the price level, while the response of all other variables is left unrestricted.

Signalling and portfolio balance shocks emanate from changes in the expected future short-term interest rate component $exp^{(j)}$ and the term premium $tp^{(j)}$ respectively. Section 4.2 showed that unconventional monetary policy announcements did significantly reduce both components of longer-term yields, ratifying the assumption that shocks to these components in the VAR can be associated with policy. The effects of these two shocks on industrial production and the price level are the same for identification schemes 1 and 2. Contractionary signalling or portfolio balance shocks are constrained to have no effect on industrial production or the price level on impact to ensure that the time path of their reaction to shocks is realistic. Thereafter, the sign of the shock is unconstrained. This is a useful feature, because the sign and size of

[37] An increase in rer_t corresponds to an appreciation of the US real exchange rate.

the responses of industrial production and the price level to signalling and portfolio rebalancing shocks will be used as metrics to gauge the relative efficacy of the two sub-channels.

To separately identify the signalling and portfolio balance shocks, the $exp^{(j)}$ and $tp^{(j)}$ columns of table 8 must differ. In identification scheme 1, I impose that the portfolio balance shock has no instantaneous impact on the expected future path of short-term interest rates. This is labelled a 'pure term premium shock', such that shocks to the term premia on a j-period bond do not alter investors' expectations of future short-term interest rates over the same horizon with a given month. To assess the sensitivity of my results to this restriction, I impose its converse in scheme 2: signalling shocks cannot exert a contemporaneous impact on the term premium. This is labelled a 'pure expectations shock'. Of the two schemes, scheme 1 is most plausible. The term premium includes interest rate risk, which is likely to be immediately influenced by the signalling shock. However, to the extent that both expectations and term premia significantly responded to unconventional monetary policy announcements, scheme 1 may provide a more realistic quantitative assessment of signalling shocks, while scheme 2 may be better suited to capturing portfolio rebalancing shocks.

When controlling for bank credit and the real exchange rate in models 2 and 3, I do not identify additional shocks. In model 2, I restrict the impact response of bank credit to signalling and portfolio rebalancing shocks to zero, motivated by evidence that bank lending reacts to monetary policy with a lag (Bernanke and Blinder, 1992). The response of bank credit in subsequent periods is unrestricted in size and sign. For model 3, I impose that the real exchange rate must depreciate on impact in response to expansionary signalling and portfolio rebalancing shocks, but leave the response thereafter unrestricted. This is motivated by evidence that nominal exchange rates depreciated in response to US LSAP surprises (Glick and Leduc, 2012), implying real exchange rate depreciation in the presence of price stickiness.

5.3 SVAR Results

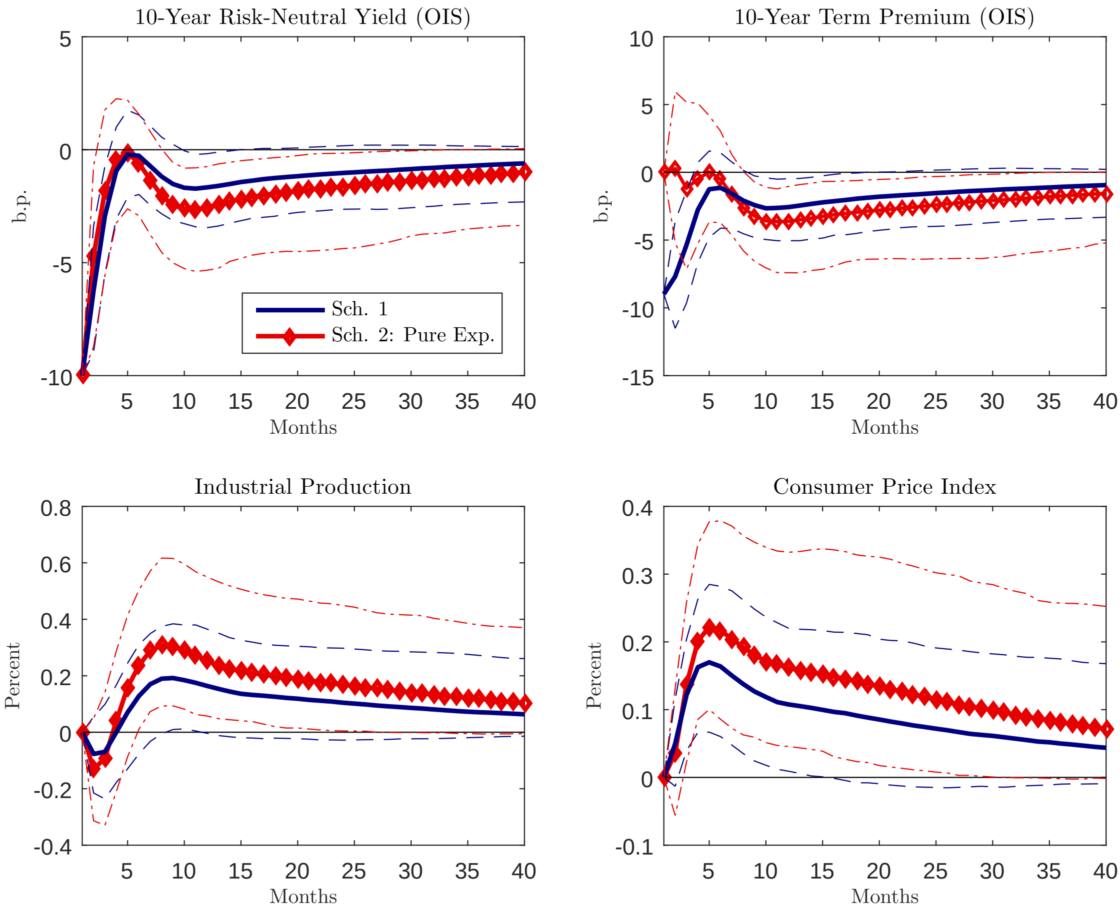
The sign-restricted SVAR results show that, contrary to the prior beliefs of policymakers (Bernanke, 2010), reductions in longer-term interest rates between November 2008 and April 2013 have exerted a more powerful effect on US industrial production via the signalling channel.

5.3.1 Model 1: 4 Variable SVAR

Figures 3 and 4 present the median impulse response functions, together with the 5% and 95% confidence intervals, for the signalling and portfolio rebalancing shocks from model 1, estimated using the preferred OIS-augmented 10-year yield decomposition. To foster comparison, the median shocks are normalised to represent a 10 basis point fall in the corresponding yield component.[38] Within the VAR, the average proportion of historical variation in industrial

[38] The median response of the expectations (term premium) component for a signalling (portfolio rebalancing) shock is similar in quantity. The two responses have been equalised to enable discussion of the effects of equal-sized shocks. I use a residual-based block bootstrap with 1000 replications and 100 rotations per bootstrap, which Brüggemann, Jentsch, and Trenkler (2016) demonstrate leads to asymptotically valid inference on structural impulse response functions in the presence of conditional heteroskedasticity, unlike a wild or pairwise bootstrap.

Figure 3: Impulse Response Functions to a Signalling Shock for Model 1 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield



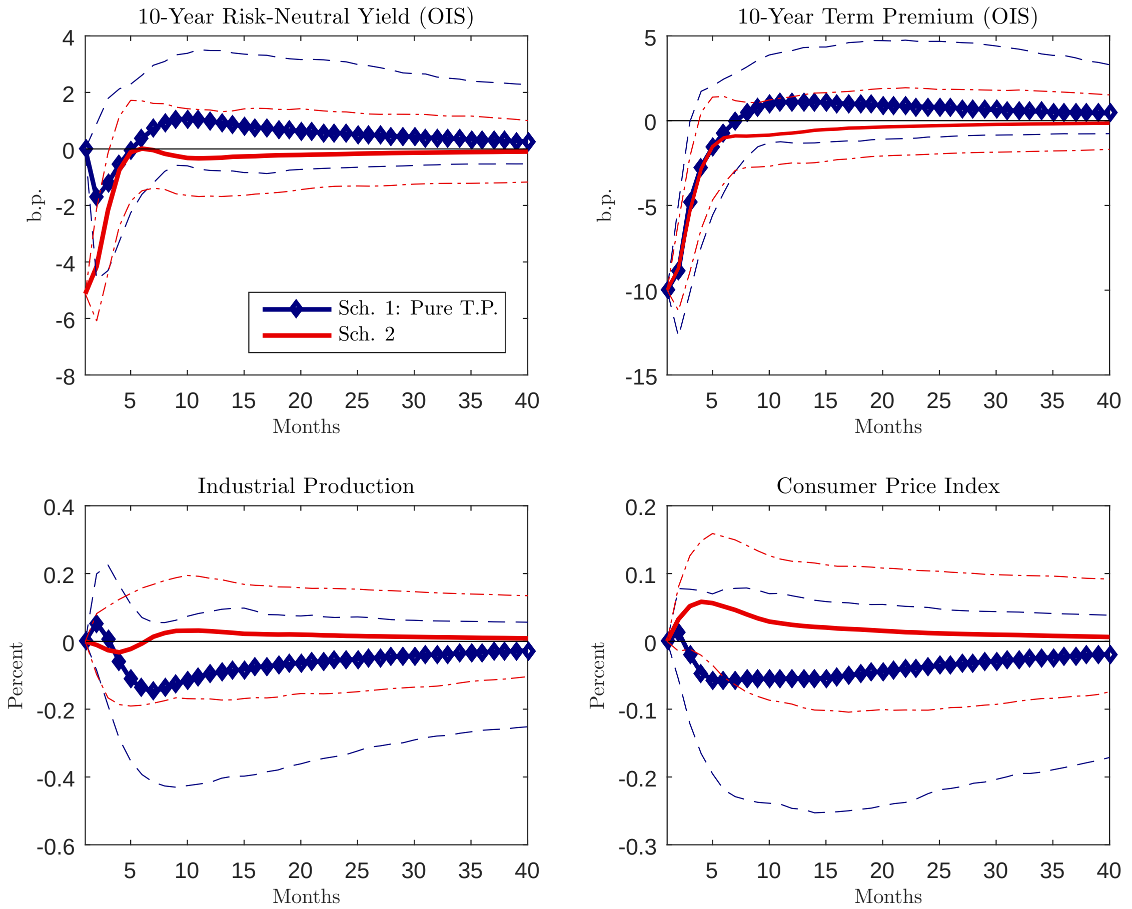
Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 10-year risk-neutral yield, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

production attributed to the two long-term interest rate shocks is 29.5% and 5.4% under schemes 1 and 2 respectively.

Figure 3 documents that the signalling shock has a significant lagged positive effect on industrial production and CPI using both identification schemes. With scheme 1, the response of industrial production is significantly positive 9 to 11 months after the shock, peaking at 0.19% after 9 months. The peak response of industrial production under scheme 2, the pure expectations shock, is larger at 0.30% after 8 months, and the impulse response is significantly positive 6 to 27 months after the shock. The CPI also significantly increases 3 to 15 months after the shock under scheme 1, and 3 to 31 months under scheme 2. Its peak responses, 5 months after the shock, are 0.17% and 0.23% under schemes 1 and 2 respectively.

In contrast to the signalling shock, the responses of industrial production and CPI to an expansionary portfolio rebalancing shock in figure 4 are statistically insignificant at all horizons.

Figure 4: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 1 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield



Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 10-year term premium, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

Moreover, their peak responses are considerably smaller than their responses to the signalling shock. Under scheme 1, the pure term premium shock, the peak responses of industrial production and CPI are 0.09% and 0.01% respectively. The corresponding figures for scheme 2 are 0.03% and 0.06%. All are insignificantly different from zero. Comparing the peak responses of industrial production to the two shocks indicates that the signalling shock explains 68% to 91% of the total peak industrial production effect due to the long-term interest rate shocks.

The signalling shock also accounts for a greater proportion of industrial production forecast error variation than the portfolio rebalancing shock in the year following a shock under both identification schemes. With scheme 1, the signalling shock explains 77.8% of industrial production forecast error variation attributed to the two long-term interest rate shocks after 3 months. Although the peak figure under scheme 2 is smaller, the signalling shock, on average, explains

58.4% of industrial production forecast error variation due to the long-term interest rate shocks in the 12-month period after the perturbation. Thus, the signalling channel is associated with around two-thirds to three-quarters of the total effects of long-term interest rate shocks on US industrial production between November 2008 and April 2013.

In summary, when model 1 is estimated using the OIS-augmented decomposition of the 10-year Treasury yield, the signalling channel is associated with the majority of total industrial production effects attributed to shocks to longer-term interest rates. Appendix C.1 presents robustness exercises. It illustrates that the results strengthen when a longer sample period (November 2008 to December 2015) is used. Extending the sample period makes the effects of the signalling shock on industrial production and CPI stronger and significant for a longer horizon. The results are also robust to the use of different maturity yields and different yield curve decompositions. Even for the 2-year survey-augmented model, which attributes a smaller fraction of variation in interest rates to signalling in the event study, the signalling shock has stronger effects on industrial production and CPI than the portfolio rebalancing shock. The results are also robust to using the 2-year OIS rate, instead of the 2-year risk-neutral yield, alongside the 2-year term premium in the VAR. This robustness check accounts for the possibility that, because both the risk-neutral yield and the term premium are estimated within the same GADSTM, they do not vary independently.

5.4 Models 2 and 3: Adding Controls

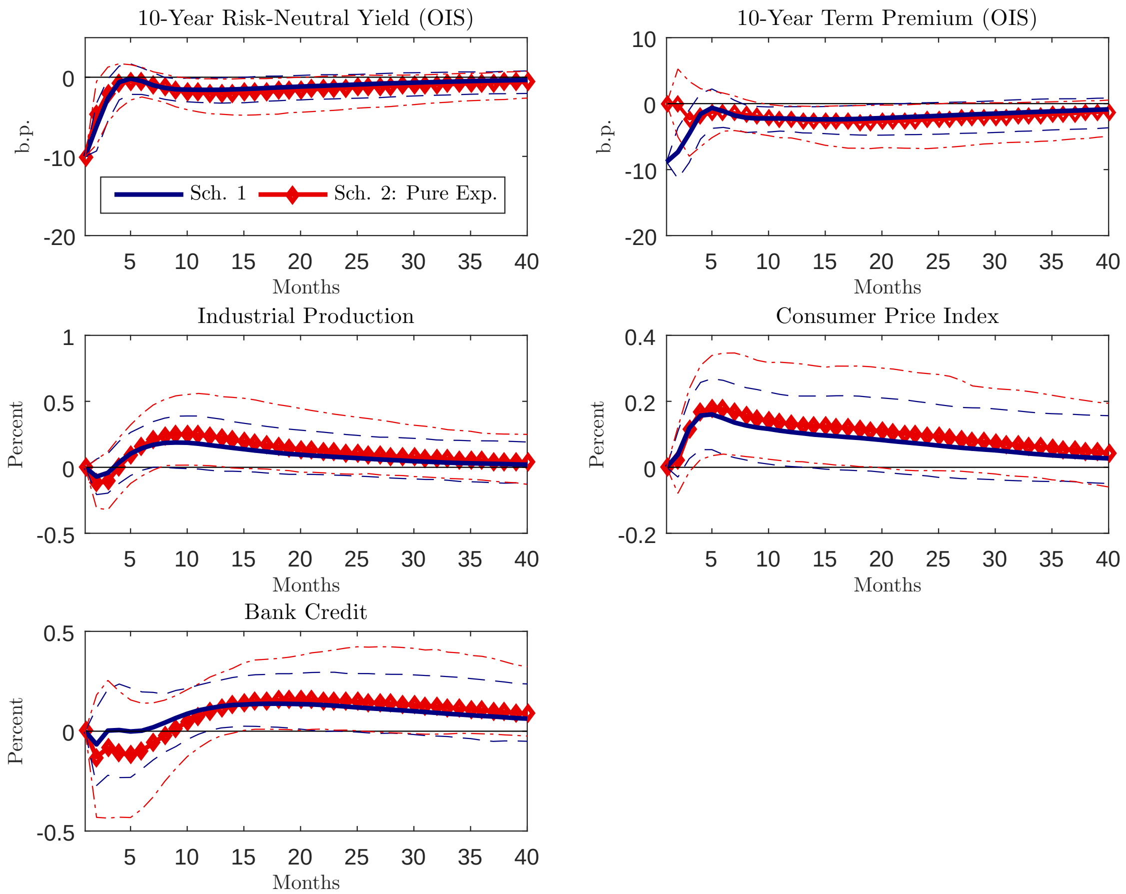
Here, I present the results from models 2 and 3, which control for bank credit and real exchange rates respectively, using the OIS-augmented decomposition of the 10-year yield. As for model 1, these results also strengthen when a longer sample period (November 2008 to December 2015) is used, and are also robust to the use of different maturity yields and different yield curve decompositions. These robustness exercises are presented in appendix C.2.

Figures 5 and 6 present the impulse response functions for model 2, which controls for bank credit, estimated with the OIS-augmented decomposition of the 10-year Treasury yield. The results lend further support to those from model 1. The signalling shock has significantly positive expansionary effects on industrial production and CPI. With scheme 1, the response of industrial production is significantly positive 7 to 9 months after the shock, peaking at 0.19% after 9 months. Similarly, under scheme 2, the pure expectations shock, industrial production's response is significantly positive 8 to 13 months after the shock, peaking at 0.25% after 10 months. The impulse response of CPI is also significantly positive 3 to 13 months after the shock under scheme 1, and 4 to 19 months after the shock under scheme 2. The peak responses are 0.16% after 5 months with scheme 1, and 0.18% after 5 months with scheme 2.

Bank credit significantly increases with a lag in response to the expansionary signalling shock. Its impulse response is significantly positive 12 to 21 months after the shock with scheme 1, and 15 to 25 months after the shock under scheme 2. The peak bank credit response is 0.14% after 18 months, and 0.16% after 20 months under schemes 1 and 2 respectively.

Figure 6 demonstrates that the impulse responses of industrial production and CPI to the

Figure 5: Impulse Response Functions to a Signalling Shock for Model 2 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield

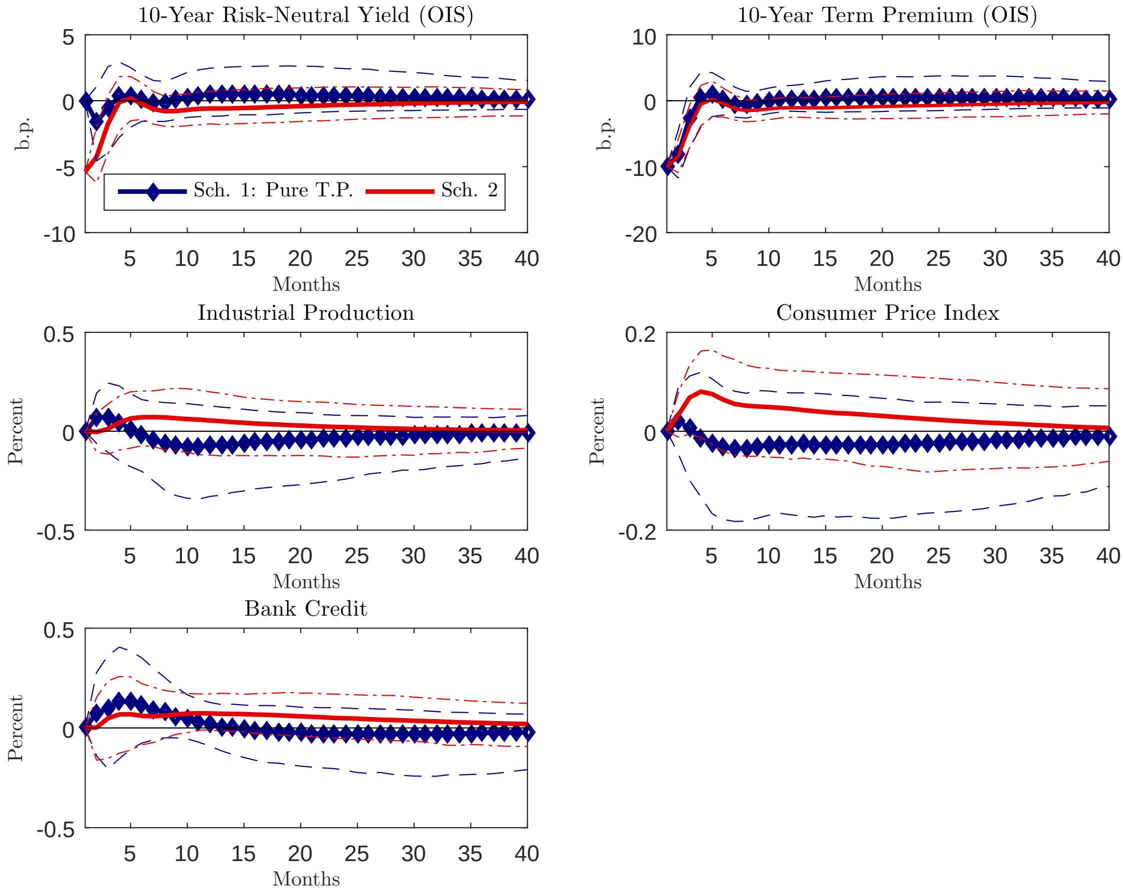


Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 10-year risk-neutral yield, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

portfolio rebalancing shock remain insignificantly different from zero when the VAR is extended to include bank credit as a control variable. As well as being statistically insignificant, the peak responses of industrial production are smaller than their counterparts from figure 5. The peak industrial production responses to the portfolio rebalancing shock are 0.07% after 3 and 7 months under schemes 1 and 2 respectively, less than half of the peak responses to signalling shocks. Comparing these figures to the peak responses of industrial production to the signalling shock indicates that the signalling shock explains around three-quarters of the total peak industrial production effect due to the long-term interest rate shocks.

The VAR results also indicate that portfolio rebalancing shocks had smaller expansionary effects on bank credit than signalling shocks. The peak bank credit increase is 0.13% after 5 months and 0.07% after 11 months under schemes 1 and 2 respectively. Under both schemes, the response of bank credit is insignificantly different from zero at all horizons.

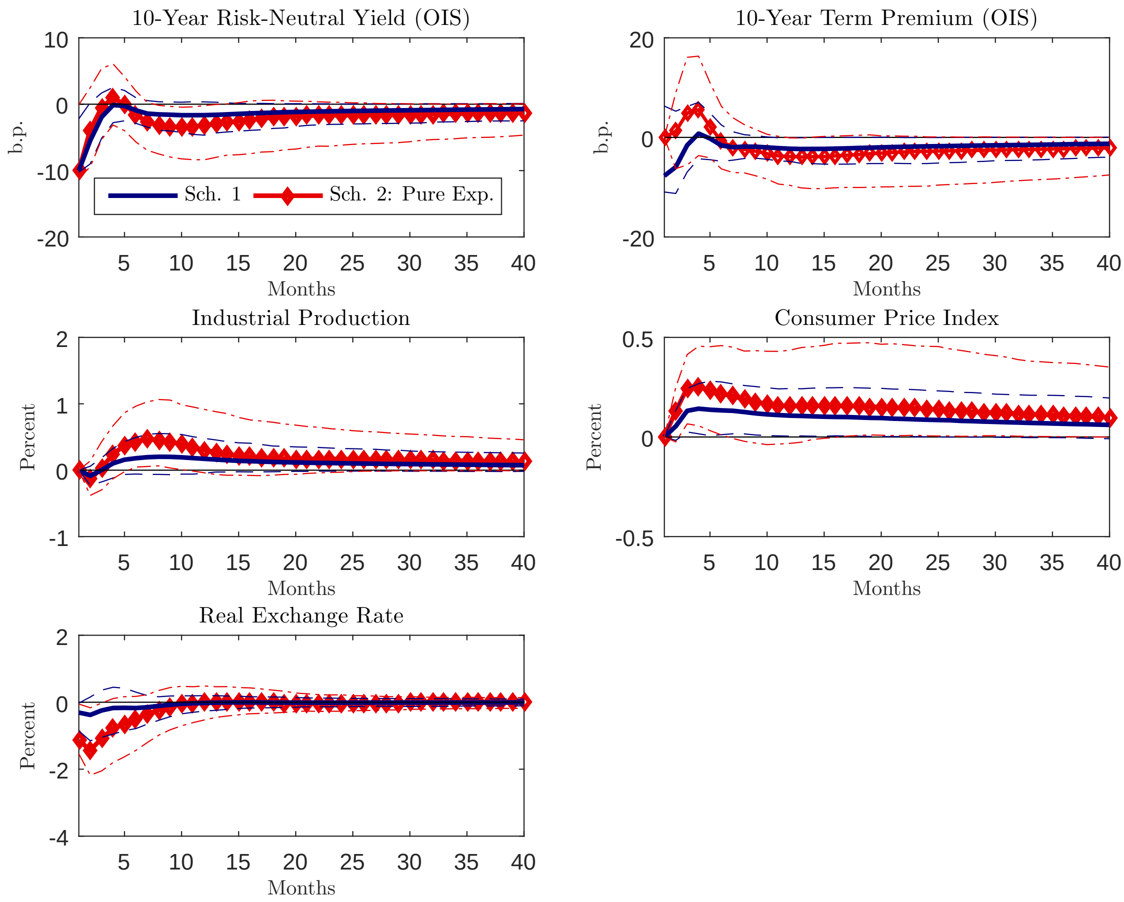
Figure 6: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 2 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield



Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 10-year term premium, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

The impulse response functions for model 3, which includes the real exchange rate, are presented in figures 7 and 8. Figure 7 demonstrates that the signalling shock has a significantly positive and lagged effect on industrial production and CPI under scheme 2. This pure expectations shock generates a significantly positive increase in industrial production 6 to 10 months after the shock, peaking at 0.47% after 7 months. Following the same shock, the peak CPI response is 0.25% after 4 months, and the responses are significantly positive from 3 to 6 and 13 to 39 months after the shock. As in models 1 and 2, the peak industrial production response following a signalling shock is smaller under scheme 1 than scheme 2. In model 3 with scheme 1, the peak is 0.20% after 8 months, although this is statistically insignificant using 5% and 95% confidence intervals. Nevertheless, the response of CPI to a signalling shock under scheme 1 is significantly positive 3 to 25 months after the shock, peaking at 0.14% after 4 months.

Figure 7: Impulse Response Functions to a Signalling Shock for Model 3 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield

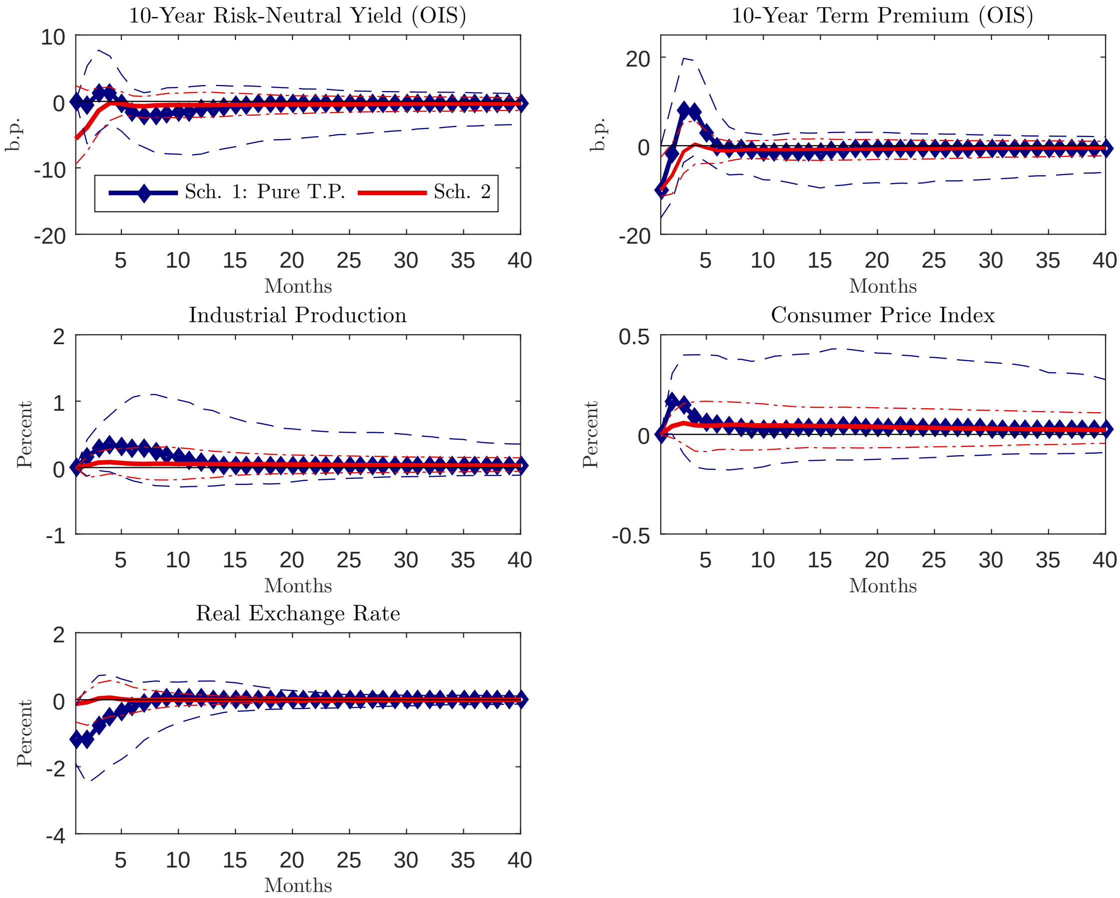


Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 10-year risk-neutral yield, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

Under scheme 2, the peak response of industrial production to a signalling shock is the highest of all three models at 0.47%. This is likely to be explained by the response of the real exchange rate, which depreciates significantly on impact, and for the subsequent two months. This depreciation could stimulate industrial production through a trade balance channel. Interestingly, under scheme 1 which allows the term premium to respond to the signalling shock contemporaneously, the depreciation of the real exchange rate is not significant at any horizon, except on impact, and the response of industrial production is quantitatively smaller. This indicates that the responsiveness of the term premium to unconventional monetary policy announcements may have different implications for exchange rate movements than changes in expected future interest rates.

Figure 8 demonstrates that the impulse responses of industrial production and CPI to a portfolio rebalancing shock are not significantly positive at any horizon when the VAR is extended

Figure 8: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 3 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield



Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 10-year term premium, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

to include the real exchange rate as a control variable. In response to the portfolio rebalancing shock under both restriction schemes, the real exchange rate depreciates significantly on impact as the identification restrictions impose, but its response thereafter is insignificantly different from zero.

The robustness exercises here, together with those in appendix C.1 and C.2, strongly indicate that shocks to expected future short-term interest rates have larger and more significant effects on industrial production and CPI than shocks to term premia. Thus, the signalling channel is associated with the majority of total industrial production and CPI effects attributed to shocks to longer-term interest rates over the November 2008 to April 2013 sample period. Across the three models the signalling channel is associated with around two-thirds to three-quarters of the industrial production effects attributed to the two channels.

6 Conclusion

In response to financial turmoil and the ELB for the short-term nominal policy rate, the Fed enacted a number of 'unconventional' monetary policies, notably LSAPs and forward guidance. Both can transmit to the real economy via longer-term interest rates through two sub-channels: signalling and portfolio rebalancing. In this paper, I ask: through which of these channels — signalling or portfolio rebalancing — did US unconventional monetary policy have the most expansionary effects on output? I conclude that signalling shocks exerted a more powerful influence on US industrial production and consumer prices than portfolio rebalancing effects.

The findings are important because the two channels offer differing implications for monetary policy. Signalling implies that policy is most effective when investors anticipate that the central bank will keep short-term interest rates lower for longer. Portfolio rebalancing requires the large scale of LSAPs in order to generate sufficient portfolio substitution to reduce yields and influence activity in the real economy during periods of sizeable financial turmoil.

In reaching my conclusion, I offer solutions to two challenges: the yield curve decomposition associated with signalling and portfolio rebalancing, and the identification of signalling and portfolio balance shocks.

In response to the first challenge, I use the OIS-augmented decomposition proposed by Lloyd (2017a). This is the first paper to use this decomposition to assess the effects of macroeconomic policy at the ELB. I provide further evidence in support of the conclusions in Lloyd (2017a): the OIS-augmented GADTSM provides risk-neutral yields that closely align with the interest rate expectations implied by FFFs and surveys. Using these daily frequency decompositions of the yield curve, I find that the signalling effects of unconventional monetary policy were particularly powerful at horizons in excess of 2 years. Monetary policy can have powerful effects on longer-term interest rate expectations. Signalling effects explain around two-thirds to three-quarters of the falls in 10-year bond yields on unconventional monetary policy announcement days. The result highlights the economic importance of the signalling effects of unconventional monetary policy announcements, implying that clear communication is likely to be an important determinant of the macroeconomic impact of central bank balance sheet normalisation.

In response to the second challenge, I identify shocks using two combinations of sign and zero-impact restrictions within an SVAR. I find that the signalling channel is associated with around two-thirds to three-quarters of the total peak effects of long-term interest rate shocks on US industrial production between November 2008 and April 2013.

The main conclusion of this paper is that, as a result of reductions in longer-term interest rates between November 2008 and April 2013, the greatest benefits for industrial production and consumer prices were attributable to signalling. Thus, my findings suggest that current and future unconventional monetary policy action by the Fed may reap greater real economic benefits if combined with clear communication about the future short-term interest rate path.

Appendix

A Data Sources

Event Study and GADTSM Decomposition Data Sources	
Data Series	**Description and Source**
US Treasury Yields	US Treasury bill yields of 3 and 6 month maturities, from the Federal Reserve statistical release H.15: `http://www.federalreserve.gov/releases/h15/data.htm`. US Treasury zero-coupon bond yields from Gürkaynak, Sack, and Wright (2007) of the following maturities: 1, 2, 4, 7 and 10 years. Available here: `http://www.federalreserve.gov/econresdata/researchdata/feds200628.xls`.
US OIS Rates	I use US OIS rates of 1, 2, 5 and 10 year maturities for the event study in table 4. The OIS-augmented GADTSM decomposition includes OIS rate data of maturity: 3 and 6 months; 1 and 2 years. The data is from *Bloomberg* with the codes: 3-month *USSOC*; 6-month *USSOF*; 1-year *USSO1*; 2-year *USSO2*; 5-year *USSO5*; and 10-year *USSO10*.
Survey-Augmented GADTSM Decomposition	The survey-augmented GADTSM decomposition is due to Kim and Wright (2005). The data is available at: `http://www.federalreserve.gov/econresdata/researchdata/feds200533.xls`.
Survey Data	Survey data is from the *Survey of Professional Forecasters* at the Federal Reserve Bank of Philadelphia, accessible here: `http://www.philadelphiafed.org/research-and-data/real-time-center/survey-of-professional-forecasters/`.

SVAR Data Sources	
Var.	**Description and Source**
ip	Monthly US industrial production series from St. Louis FRED.
p	Monthly consumer price index (CPI) from the US Bureau of Labor Statistics (BLS) (`www.bls.gov/cpi/#data`; ID: *CUSR0000SA0*).
ffr	Effective federal funds rate from the Federal Reserve website.
$exp^{(j)}$	Risk-Neutral Component of j-year US Treasury Yield — author's own calculation, except for Kim and Wright (2005) decomposition
$tp^{(j)}$	Term Premium Component of j-year US Treasury Yield — author's own calculation, except for Kim and Wright (2005) decomposition
$cred$	US Bank credit from the Federal Reserve (`www.federalreserve.gov/releases/h8/current/`; table H.8, *Assets and Liabilities of Commercial Banks in the US*).
rer	Broad effective real exchange rate for the US against 60 other economies from the Bank of International Settlements (BIS): `www.bis.org/statistics/eer/`.

B Event Study

B.1 Event-Specific Explanations

Table 9: Detailed Explanation of Increase in Bond Yields on Event Days IV, VII, IX and XVI

#	Date	Explanation
IV	28/01/2009	On this date, the Fed announced continued asset purchases and a readiness to expand the programme if conditions warranted. The increase in bond yields and OIS rates on this date can be rationalised when considering the pre-announcement expectations of market participants. Anecdotal evidence indicates that market participants were disappointed by the lack of concrete language regarding the possibility and timing of purchases of longer-dated Treasury securities. Sources: Neely (2010); Bauer and Rudebusch (2014).
VII	27/08/2010	On this date, Chairman Bernanke spoke at Jackson Hole, stating that "additional purchases [...] would be effective." According to Reuters, ""[T]he overall tone [of the speech] was one of watch and wait," Goldman Sachs economist Jan Hatzius wrote in a note to clients. [...] Stocks initially fell after Bernanke's remarks, but reversed course and three major indexes closed up 1.7 percent." On the same day, the US Commerce Department cut its estimate for US GDP in 2010 Q2 from 2.4% to 1.6%, but this was higher than the 1.4% surveys had predicted. Source: `in.reuters.com/article/columns-us-usa-fed-bernanke-idINTRE67O0MF20100828`.
IX	15/10/2010	On this date, Chairman Bernanke said the central bank has "a case for further action" to stimulate the economy, citing high unemployment and low inflation. However, markets did not learn specifics on future LSAPs from the speech. "We're still no closer to knowing exactly what the so-called QE2 program might involve, in particular what amount of Treasury securities the Fed could end up buying," said Paul Ashworth, an economist at Capital Economics. Although stocks opened higher after Chairman Bernanke's speech, the tone cooled as investors received other economic news, including US sales growth of 0.6% in September 2010, which was higher than anticipated. Source: `money.cnn.com/2010/10/15/markets/markets_newyork/index.htm`.
XVI	12/12/2012	On this date, the Fed announced state-dependent threshold-based forward guidance. Contemporary news reports stated that this was "aggressively dovish", indicating that the policy was perceived to be expansionary. However, on the same day, the FOMC downgraded its forecast for the US economy in 2013 2.5-3.0% year-on-year to 2.3-3.0%. "Stock prices jumped after the Fed released its policy statement at midday, then began falling during Mr Bernanke's news conference about two hours later as he insisted the Fed was not significantly increasing its efforts to bolster the economy." Source: `www.bloomberg.com/news/articles/2012-12-12/the-fed-turns-aggressively-dovish-with-evans-rule` and `www.nytimes.com/2012/12/13/business/economy/fed-to-maintain-stimulus-bond-buying.html?mcubz=1`.

B.2 Event Significance

To assess the significance of daily changes in actual yields yld, OIS rates i^{ois}, fitted yields $\widehat{yld}$, risk-neutral yields $\widehat{exp}$ and term premia $\widehat{tp}$ at the 2, 5 and 10-year maturities on specific event days (considered in tables 4-7), I estimate regressions of the following form:

$$\Delta x_{n,t} = \alpha_{x,n} + \mathbf{Event}_t \boldsymbol{\beta}_{x,n} + \mathbf{D}_t \boldsymbol{\gamma}_{x,n} + \varepsilon_{x,n,t} \tag{5}$$

where $x = \left\{yld, i^{ois}, \widehat{yld}, \widehat{exp}, \widehat{tp}\right\}$ and $n = \{2, 5, 10\}$. $\mathbf{Event}_t$ is a 1×16 vector of 16 dummy variables each pertaining to a specific unconventional monetary policy announcement date listed in table 3. The dummies are set equal to 1 on the announcement date they are linked with, and 0 otherwise. $\boldsymbol{\beta}_{x,n}$ is a 16×1 vector of parameters to be estimated. The control variables are included in $\mathbf{D}_t$, a $1 \times K$ vector of K dummy variables pertaining to other macroeconomic data releases, set equal to 1 on release dates and 0 otherwise, where K is the number of different types of macroeconomic data releases (12). $\boldsymbol{\gamma}_{x,n}$ is a $K \times 1$ vector of parameters to be estimated. The twelve macroeconomic data releases, from the US Bureau of Economic Analysis and Bureau of Labour Statistics, included are: Advanced US GDP; Preliminary US GDP; Final US GDP; International Trade; US Personal Income and Outlays; US International Transactions; US Employment Situation; US Job Openings and Labour Turnover; US Producer Price Index; US Consumer Price Index; Preliminary US Productivity and Costs; and Revised US Productivity and Costs.

The i-th element of $\boldsymbol{\beta}_{x,n}$ represents the difference between the change in x on unconventional monetary policy announcement day i, where $i = 1, 2, ..., 16$, and the average daily change in x on other dates, excluding other unconventional monetary policy announcements and other US macroeconomic data releases. If the i-th element of $\widehat{\boldsymbol{\beta}}_{x,n}$ is statistically significant, then unconventional policy announcement i is said to have a significant effect on x at the n-year horizon. The additional macroeconomic data release dummies $\mathbf{D}_t$ are included to ensure that the significance of daily changes in x are compared to dates with no significant news pertaining to the US economy. This empirical specification underpins the significance levels associated with daily changes in variables in tables 4-7.

Table 10 presents the significance of all 16 event dates together. To assess the significance of daily changes in fitted yields $\widehat{yld}$, risk-neutral yields $\widehat{exp}$ and term premia $\widehat{tp}$ at the 2, 5 and 10-year maturities on all event days, I estimate regressions of the following form:

$$\Delta x_{n,t} = \alpha_{x,n} + \beta_{x,n} event_t + \mathbf{D}_t \boldsymbol{\gamma}_{x,n} + \varepsilon_{x,n,t} \tag{6}$$

$event_t$ is a dummy variable equal to 1 on the LSAP and forward guidance event dates in table 3, and 0 otherwise. $\beta_{x,n}$ is a scalar to be estimated.

$\beta_{x,n}$ represents the difference between average daily changes in x on unconventional monetary policy announcement days and on other dates that exclude other US macroeconomic data releases. If $\widehat{\beta}_{x,n}$ is statistically significant, then the 16 unconventional monetary policy announcements are said to have a cumulative significant effect on x at the n-year horizon.

Table 10: Significance of Daily Changes in US Treasury Yields and Their Sub-Components from Equation (6)

Model	$\widehat{\beta}_{yld,n}$	$\widehat{\beta}_{exp,n}$	$\widehat{\beta}_{tp,n}$
		2-Year Maturity	
Bias-Corrected	−5.06***	−2.85***	−2.21
Survey-Augmented	−4.53***	−0.84*	−3.70**
OIS-Augmented	−4.65***	−4.36***	−0.29***
		5-Year Maturity	
Bias-Corrected	−7.73**	−3.17**	−4.56
Survey-Augmented	−7.86**	−2.29***	−5.57**
OIS-Augmented	−6.96***	−6.26***	−0.70*
		10-Year Maturity	
Bias-Corrected	−8.00*	−2.75	−5.26
Survey-Augmented	−9.28**	−2.69***	−6.59**
OIS-Augmented	−6.51**	−4.84***	−1.67

Note: Estimates of $\beta_{x,n}$ from (6) using daily frequency changes in fitted yields, risk-neutral yields and term premia from the bias-corrected, survey-augmented and OIS-augmented GADTSMs using data from January 2, 2008 to April 31, 2013. Estimates that are significant at the 1%, 5% and 10% significance level are denoted with asterisks ***, ** and * respectively. Significance is determined by t-statistics calculated using Newey and West (1987) standard errors. All figures are reported in basis points to two decimal places.

Table 10 presents the results of estimation of (6). The results indicate that the daily changes of fitted yields from all three models at all three maturities on unconventional monetary policy announcement days were significantly different to their daily change on other dates, excluding other macroeconomic data release dates. Moreover, changes in interest rate expectations from the OIS-augmented decomposition were also significantly different on unconventional monetary policy announcement dates at all horizons.

C Signalling, Portfolio Rebalancing and the Real Economy: Additional Results

C.1 Robustness of Results for Model 1: 5 Variable SVAR

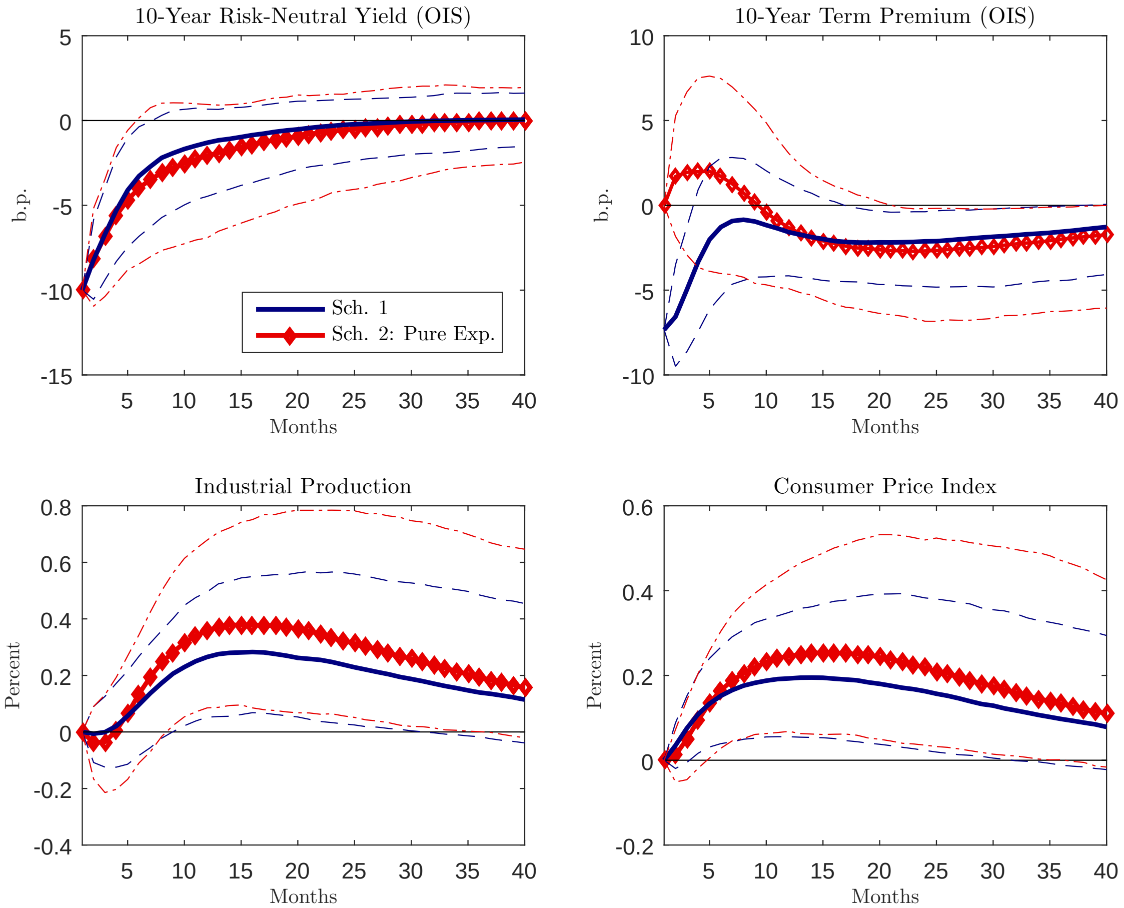
In this appendix, I show that the findings in section 5.3.1 are robust to: (i) sample length; (ii) interest rate maturity considered; and (iii) term structure decomposition (including the use of the 2-year OIS rate, instead of the 2-year risk-neutral yield, alongside the term premium).

(i) Sample Length Figures 9 and 10 depict the impulse response functions for signalling and portfolio rebalancing shocks from model 1, estimated using the 10-year OIS-augmented yield decomposition between November 2008 and December 2015 — the entire ELB period. The primary result of this paper is unaffected by the sample period extension: the signalling shock has significantly positive lagged effects on industrial production, while the responses of the same variables to the portfolio rebalancing shock is insignificantly different from zero at all horizons.

Figure 9 demonstrates that effects of the signalling shock. The responses of industrial production are significantly positive 9 to 31 months after the shock under scheme 1, and 9 to 36 months after the shock under scheme 2. The peak increase in industrial production with the longer sample is slightly larger than in section 5.3.1. Here, the industrial production response peaks at 0.28% and 0.38% after 15 months under schemes 1 and 2 respectively. Similarly, the impulse response of CPI is significantly positive 4 to 31 months after the shock, peaking at 0.20% after 14 months, with scheme 1. Under scheme 2, the response peaks at 0.26% after 15 months, and is statistically significant from 5 to 36 months after the shock.

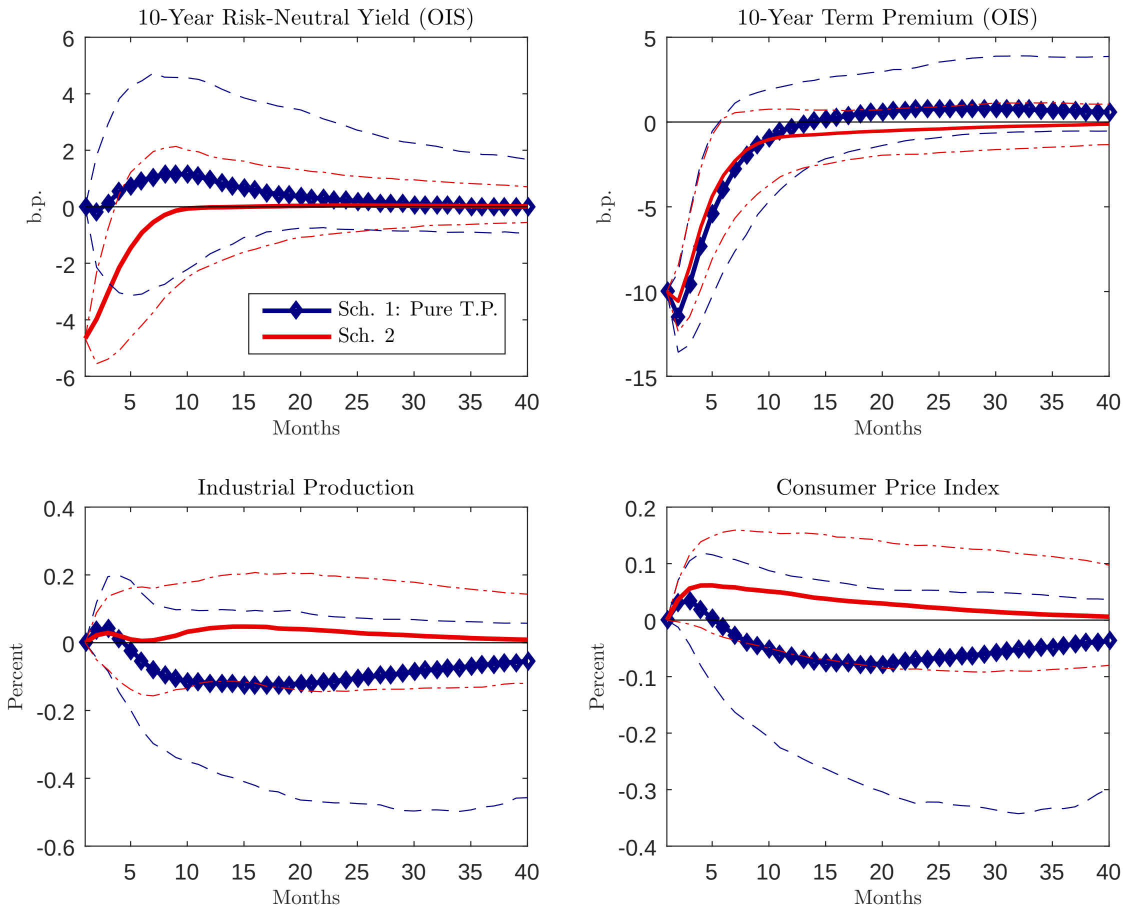
In contrast, figure 10 presents the impulse responses of variables in model 1 to the portfolio rebalancing shock. The industrial production and CPI responses are insignificantly different from zero at all horizons, as in section 5.3.1. Similarly, the (insignificant) peak increases are smaller than their corresponding peak increases in response to the signalling shock.

Figure 9: Impulse Response Functions to a Signalling Shock for Model 1 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield



Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 10-year risk-neutral yield, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to December 2015. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

Figure 10: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 1 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield

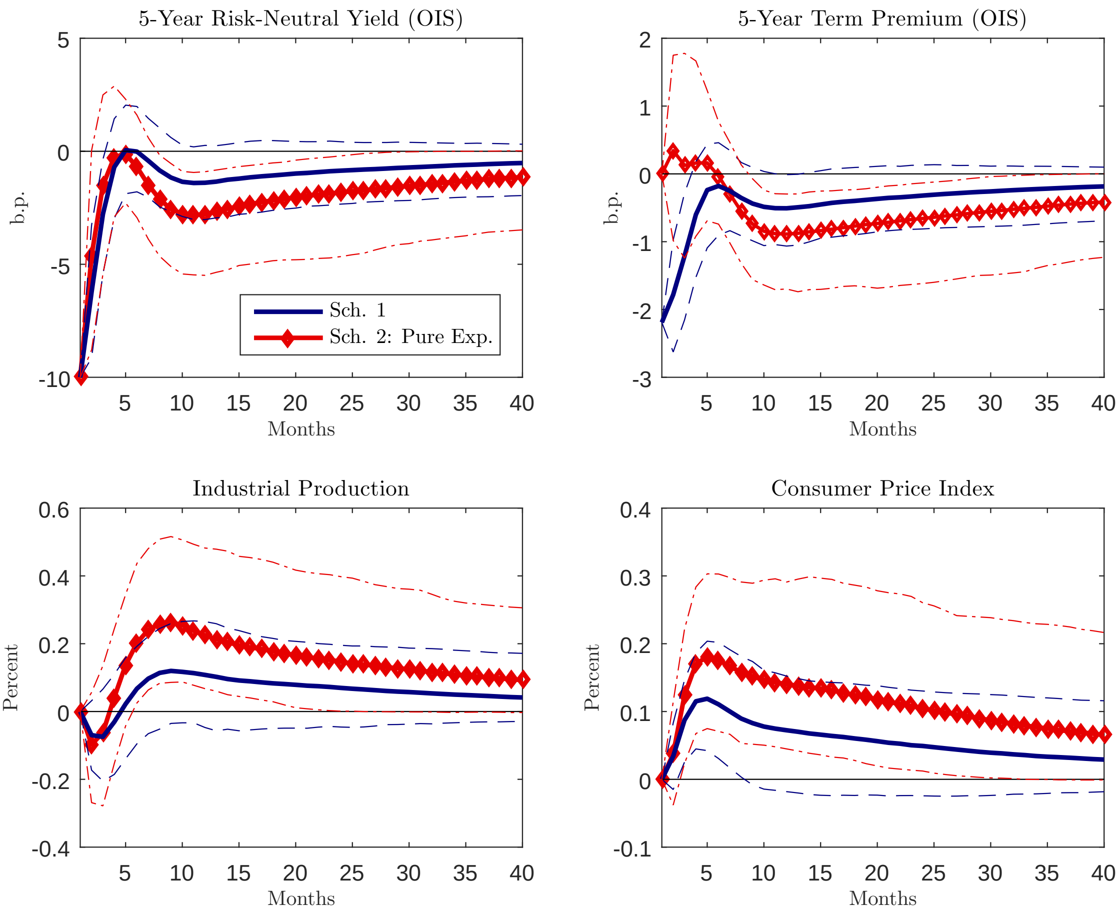


Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 10-year term premium, estimated using the 4-OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to December 2015. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

(ii) Interest Rate Maturity Figures 11 and 12 present the impulse response functions for the signalling and portfolio rebalancing shocks from model 1, estimated using the OIS-augmented decomposition of the 5-year Treasury yield. They illustrate that the headline results of section 5.3.1 are broadly robust to the alteration of yield maturity.

In figure 11, industrial production and CPI respond significantly positively to the pure expectations shock, identified with scheme 2. The response of industrial production peaks at 0.25% after 9 months, and is significant 6 to 25 months after the shock. The CPI response is significant 3 to 32 months after the shock, and peaks at 0.18% 5 months after the shock.

Figure 11: Impulse Response Functions to a Signalling Shock for Model 1 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 5-Year Treasury Yield

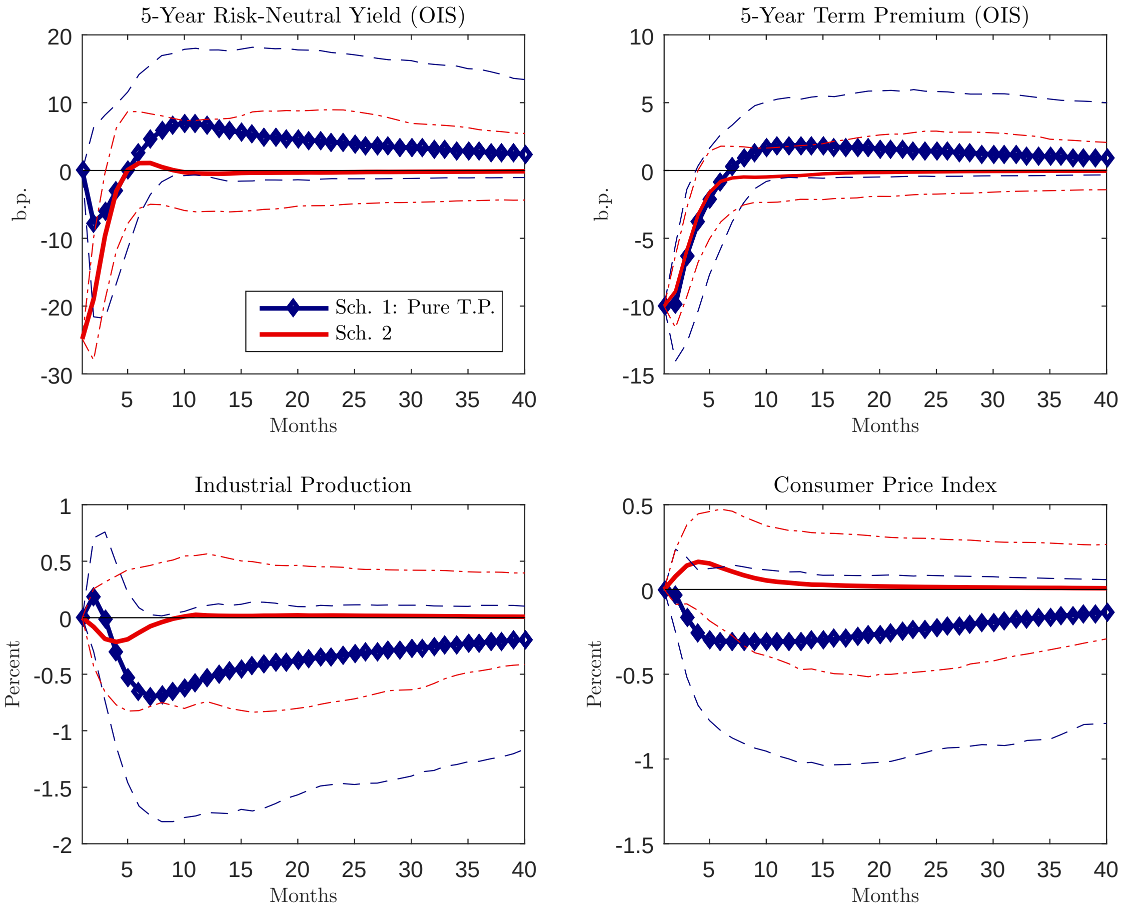


Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 5-year risk-neutral yield, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

Under scheme 1, the CPI response to the signalling shock is also significantly positive 3 to 8 months after the shock. The industrial production response peaks at 0.12% in the ninth month after the shock. Although the impulse response of industrial production is not significantly positive at any horizon using a 5-95% confidence interval, the peak response is significant using a 10-90% interval.

Figure 12 documents that the impulse responses of industrial production and CPI from model 1, using the 5-year Treasury yield, are insignificantly different from zero, as in section 5.3.1. Thus, the results support the primary conclusion of the paper: as a result of reductions in longer-term interest rates between November 2008 and April 2013, the greatest benefits for industrial production were attributable to the signalling channel.

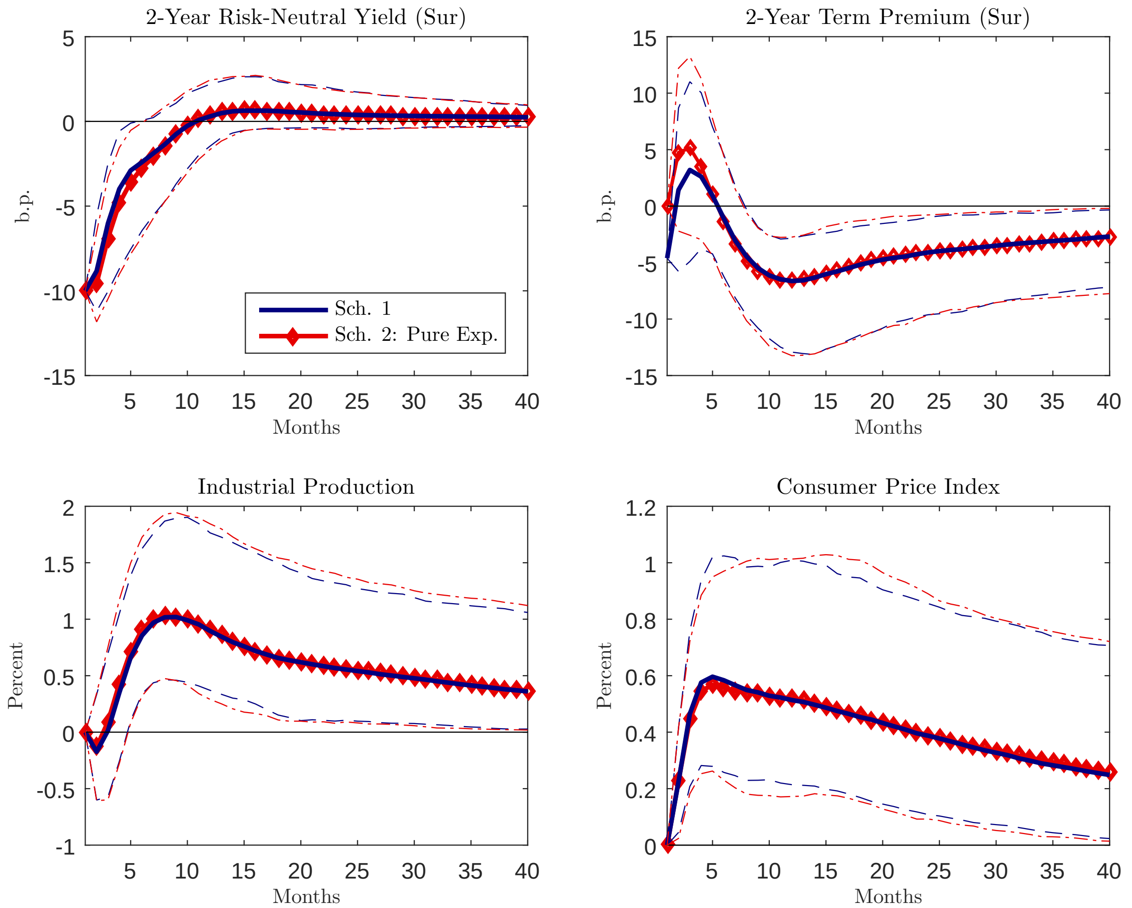
Figure 12: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 1 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 5-Year Treasury Yield



Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 5-year term premium, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

(iii.a) Term Structure Decomposition: Survey-Augmented The primary conclusion of the paper is also robust to the yield curve decomposition used in the SVAR. Even with the survey-augmented Kim and Wright (2005) decomposition of Treasury yields, which places a lower relative weight on the signalling channel in the event study (section 4.2), I find that the signalling channel had greater expansionary effects on industrial production.

Figure 13: Impulse Response Functions to a Signalling Shock for Model 1 using Sign Restriction Schemes 1 & 2 and the Survey-Augmented Decomposition of the 2-Year Treasury Yield

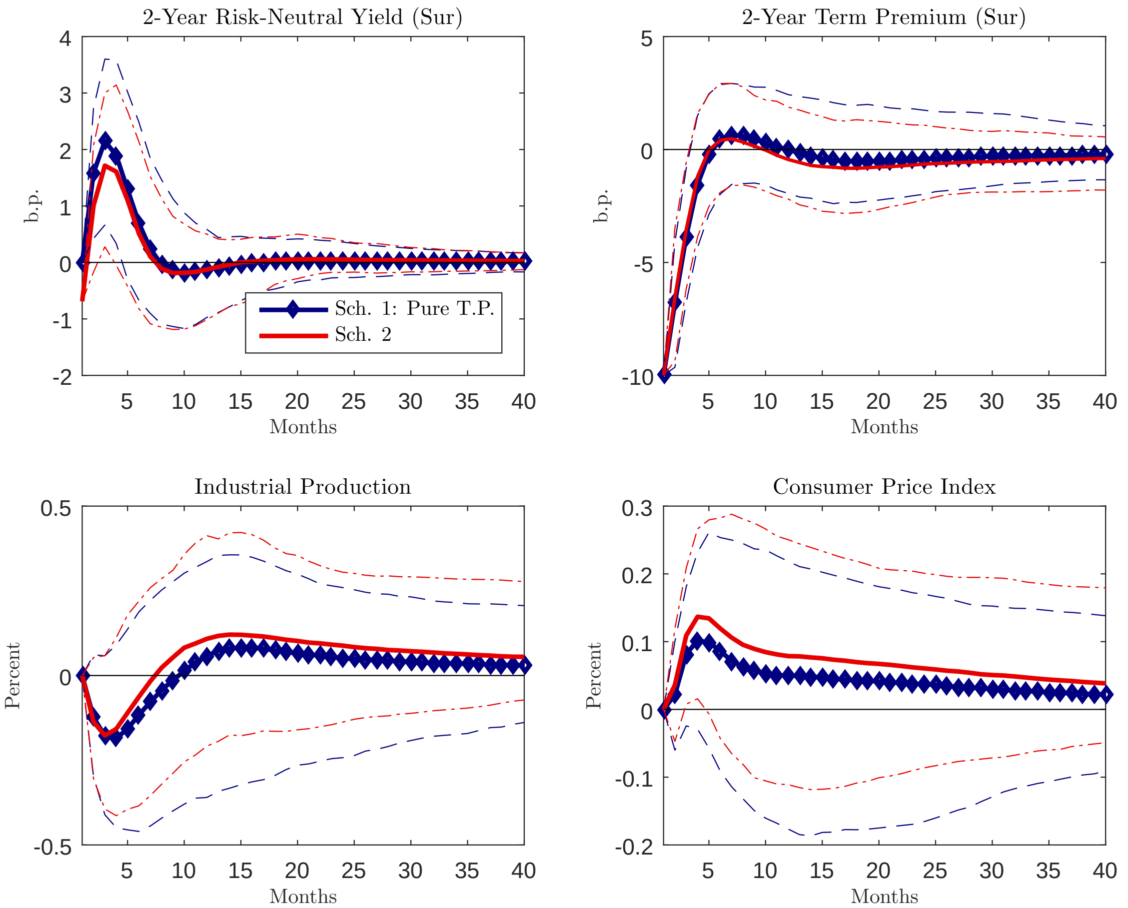


Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 2-year risk-neutral yield, estimated using the survey-augmented decomposition (Kim and Wright, 2005). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

Figures 13 and 14 present the impulse response functions for the signalling and portfolio rebalancing shocks from model 1, estimated using the survey-augmented decomposition of the 2-year Treasury yield. Recall that in section 5.3.1, the survey-augmented model attributed the lowest relative weight to signalling at the 2-year horizon, of the three horizons considered. Therefore, in light of the event study results, this robustness exercise poses the greatest challenge for the paper's headline conclusion.

Figure 13 demonstrates that, even with the 2-year survey-augmented decomposition, an expansionary signalling shock has a significant positive effect on industrial production and CPI. In fact, the peak expansionary effect (1.0% after 8 months under schemes 1 and 2) is over double that estimated with the OIS-augmented model, and is significant from the fifth month after the shock onwards under both identification schemes. The same is true for CPI, which is significantly positive from the second month after the shock onwards. Notwithstanding these differences, the quantitative results from this VAR should be given less credence in light of the identification problem underlying the survey-augmented decomposition series.

Figure 14: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 1 using Sign Restriction Schemes 1 & 2 and the Survey-Augmented Decomposition of the 2-Year Treasury Yield

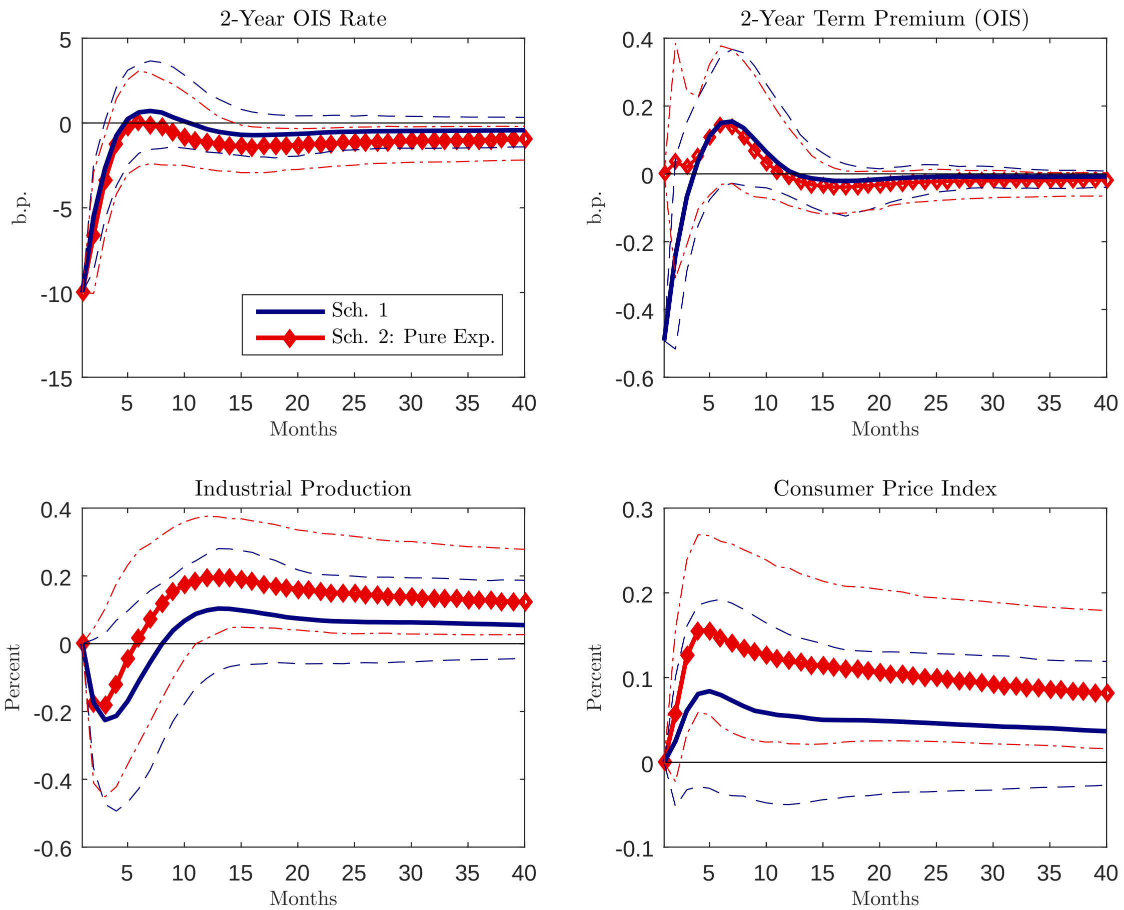


Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 2-year term premium, estimated using the survey-augmented decomposition (Kim and Wright, 2005). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

In contrast, figure 14 indicates that an expansionary portfolio balance shock has statistically insignificant effects on industrial production and CPI at all horizons, except for the response of CPI three to four months after the shock under scheme 2. The peak industrial production and CPI responses to the portfolio rebalancing shock are considerably smaller than their peak responses to the signalling shock.

(iii.b) Using OIS Rates to Measure Interest Rate Expectations In this section, I demonstrate that the SVAR results are also robust to using the 2-year OIS rate, instead of the 2-year risk-neutral yield, alongside the 2-year term premium in the VAR. This robustness check accounts for the possibility that, because both the risk-neutral yield and the term premium are estimated within the same GADTSM, they do not vary independently. This robustness exercise is only valid at the 2-year horizon, as longer-horizon OIS rates include statistically significant term premia (Lloyd, 2017b).

Figure 15: Impulse Response Functions to a Signalling Shock for Model 1 using Sign Restriction Schemes 1 & 2, the 2-Year OIS Rate and the 2-Year Term Premium from the OIS-Augmented Model

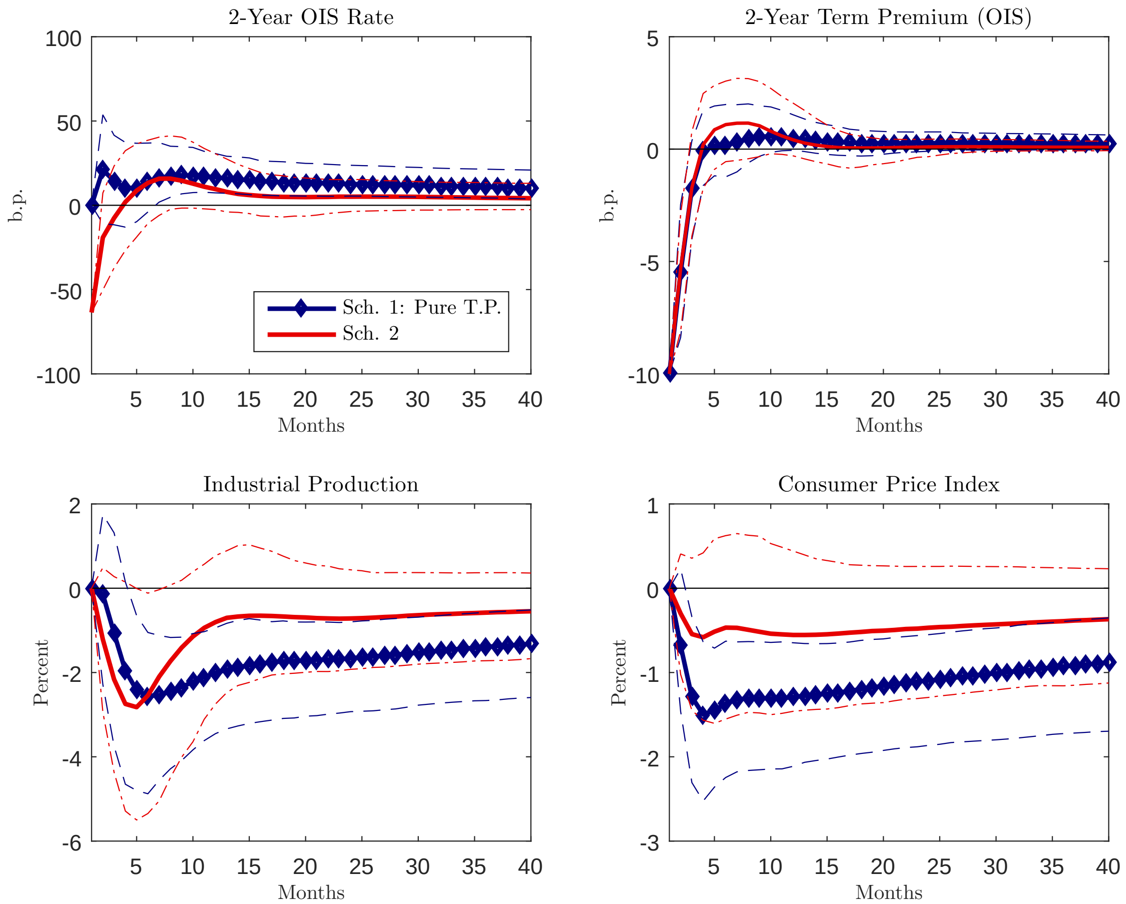


Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 2-year OIS rate. The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

Figures 15 and 16 present the impulse responses to the signalling and portfolio rebalancing shocks, respectively. Figure 15 demonstrates that the pure expectations shock, from scheme 2, has a significantly positive lagged impact on industrial production and CPI. Here, the industrial production response is significant from the twelfth month after the shock and peaks at

0.19% after 13 months. CPI's response is significant from the third month onwards, peaking at 0.15% after 4 months. Under scheme 1, the responses of industrial production and CPI are only significantly positive using a 16-84% confidence interval. Nevertheless, the median responses of industrial production and CPI to the signalling shock exceed their responses to the portfolio rebalancing shock (figure 16) at all horizons. In fact, under scheme 1, the expansionary portfolio rebalancing shock has a significantly negative impact on industrial production and CPI. Although the responses of industrial production and CPI under scheme 2, which are quantitatively preferable as they allow the OIS rate to react contemporaneously to the portfolio rebalancing shock, are insignificantly different from zero at all horizons, except for the response of industrial production in the sixth month after the shock which is briefly significantly negative.

Figure 16: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 1 using Sign Restriction Schemes 1 & 2, the 2-Year OIS Rate and the 2-Year Term Premium from the OIS-Augmented Model



Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 2-year term premium from the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

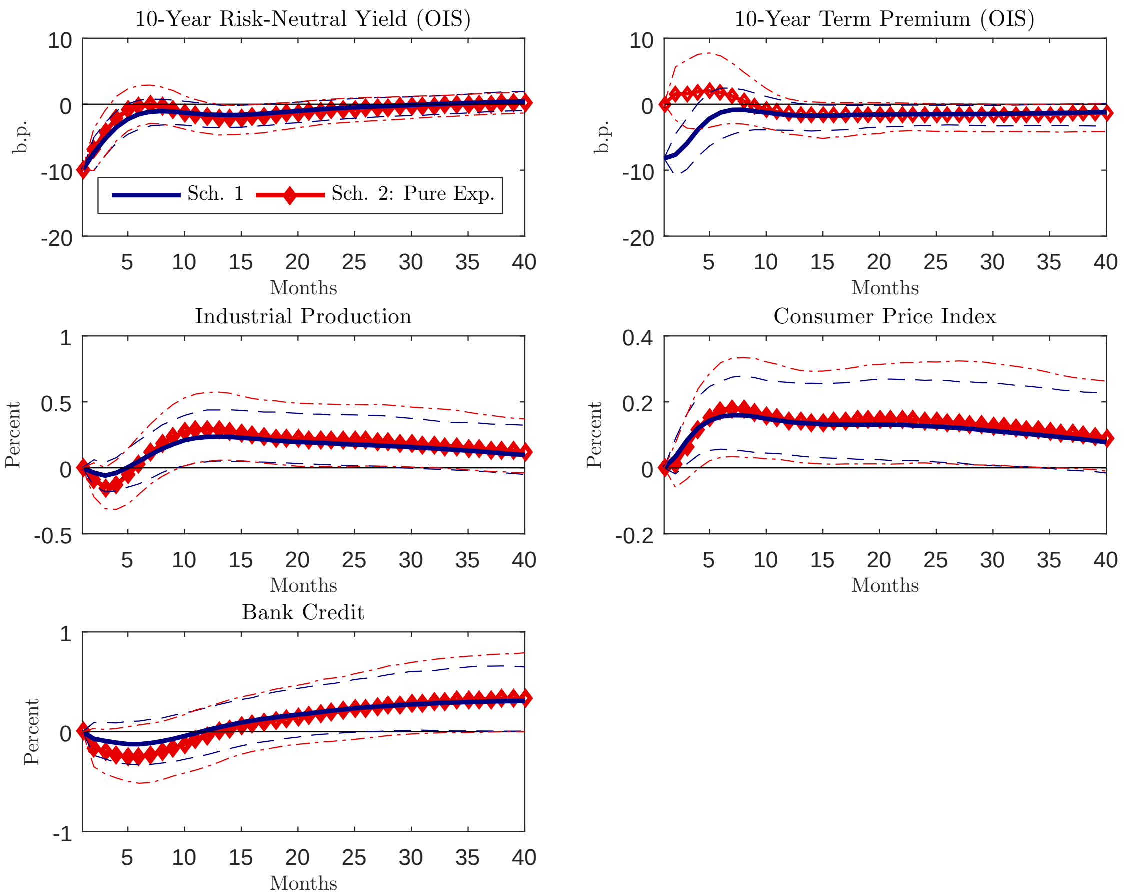
C.2 Models 2 and 3: Adding Controls

In this appendix, I provide evidence showing that the findings from models 2 and 3 in section 5.4 are robust to: (i) the sample length; (ii) the interest rate maturity considered; and (iii) the term structure decomposition used.

(i) Sample Length As for model 1, the results for model 2 are robust to the extension of sample period to November 2008 to December 2015 — the entire ELB period.

The impulse response functions for the signalling and portfolio rebalancing shocks from model 2, estimated using the OIS-augmented decomposition of the 10-year yield are presented in figures 17 and 18.

Figure 17: Impulse Response Functions to a Signalling Shock for Model 2 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield

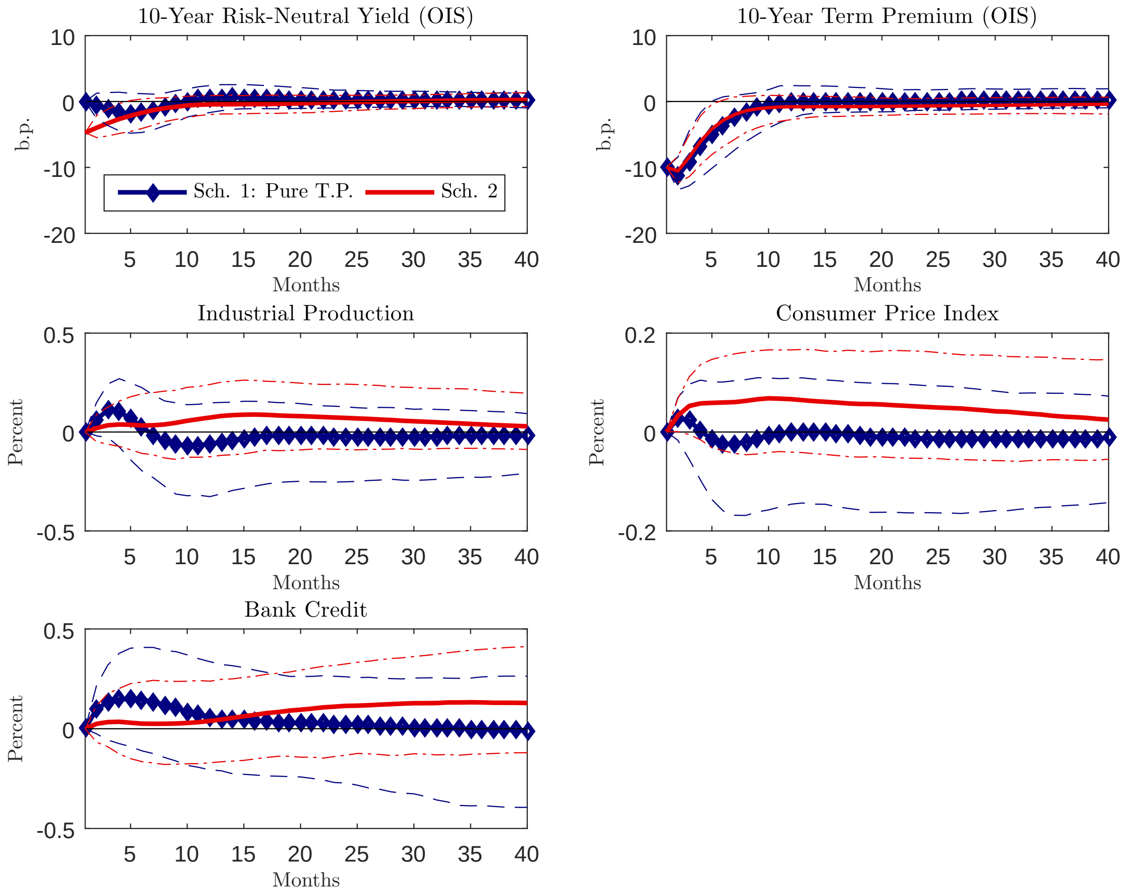


Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 10-year risk-neutral yield, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to December 2015. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

Figure 17 demonstrates that the expansionary signalling shock has significantly positive effects on industrial production and CPI under both restriction schemes. The impulse responses of industrial production are significantly positive for 10 to 29 months after the shock under scheme 1, and 10 to 32 months after the shock with scheme 2. The CPI response is significant for 3 to 34 months after the shock under scheme 1, and 5 to 35 months after the shock with scheme 2. The response of bank credit is significantly positive after 26 months under scheme 1 and 38 months with scheme 2.

Figure 18 shows that, with the longer sample, the portfolio rebalancing shock still has no significant impact on industrial production and CPI at any horizon, with the exception of CPI under scheme 2 in the second month after the shock. The response of bank credit is insignificantly different from zero under both restriction schemes at all horizons.

Figure 18: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 2 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield

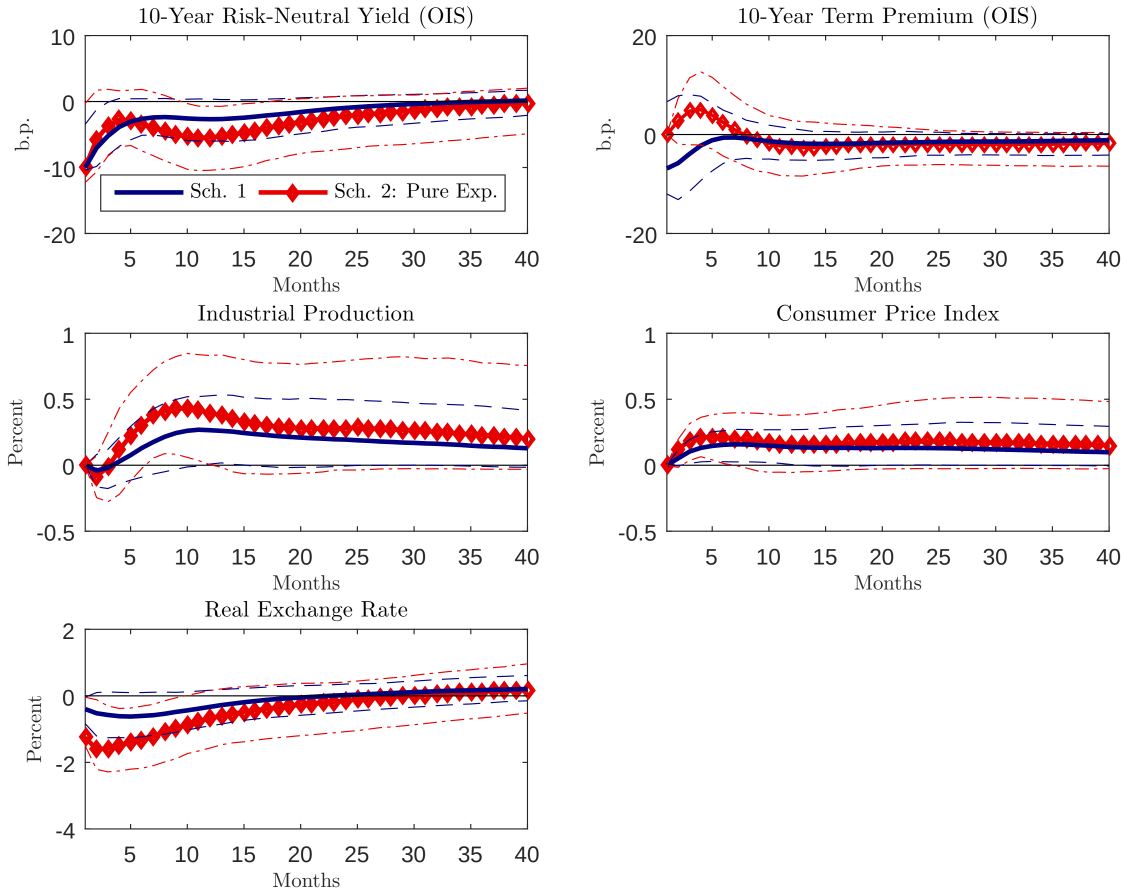


Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 10-year term premium, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to December 2015. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

As for models 1 and 2, the results for model 3 are robust to the extension of sample period to November 2008 to December 2015 — the entire ELB period.

The impulse response functions for the signalling and portfolio rebalancing shocks from model 3, estimated using the OIS-augmented decomposition of the 10-year yield are presented in figures 19 and 20.

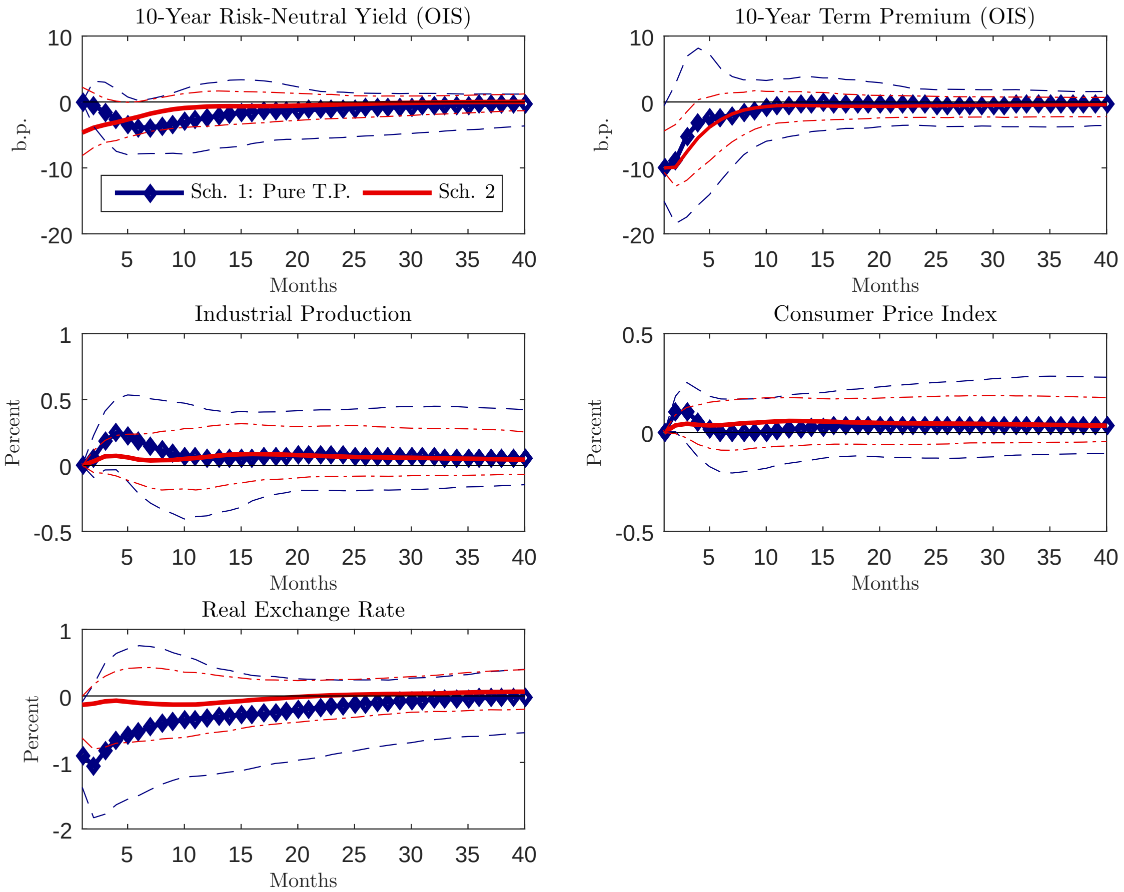
Figure 19: Impulse Response Functions to a Signalling Shock for Model 3 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield



Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 10-year risk-neutral yield, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to December 2015. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

Figure 19 demonstrates that the expansionary signalling shock has significantly positive effects on industrial production and CPI under both restriction schemes. Under scheme 2, the real exchange rate depreciates significantly in the 9 months immediately after the shock. In contrast, figure 20 shows that, with the longer sample, the portfolio rebalancing shock still has no significant positive impact on industrial production and CPI at any horizon in model 3. The real exchange rate significantly depreciates on impact, as both restriction schemes require, but the response thereafter is insignificantly different from zero.

Figure 20: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 3 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 10-Year Treasury Yield

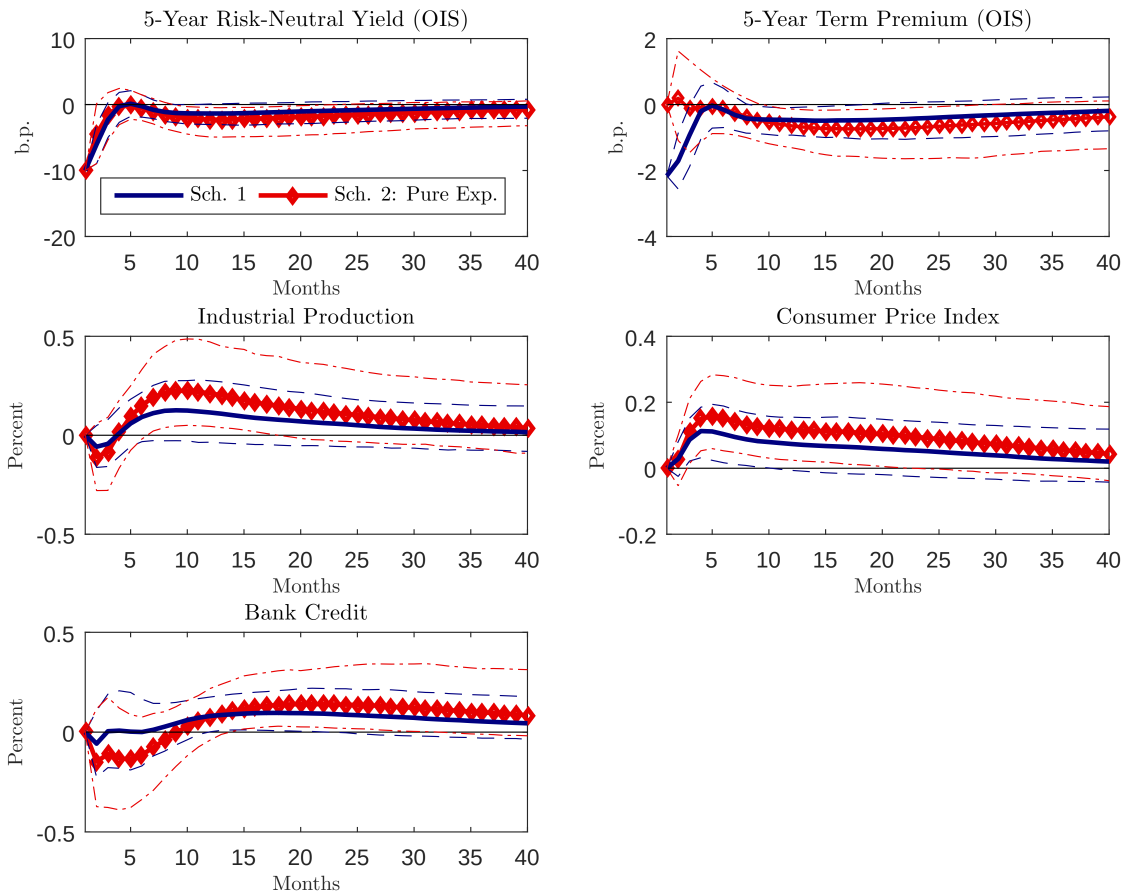


Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 10-year term premium, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to December 2015. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

(ii) Interest Rate Maturity The results from model 2 are robust to the use of the OIS-augmented decomposition of the 5-year yield.

Figure 21 demonstrates that an expansionary signalling shock has significantly positive lagged effects on industrial production and CPI when the OIS-augmented decomposition of the 5-year yield is used in model 2 with scheme 2. Under scheme 1, the signalling shock has significantly positive lagged effects on CPI, but the response of industrial production is only significantly positive when 10% and 95% confidence intervals are used. Nevertheless, the shock has significantly positive lagged effects on bank credit under both restriction schemes.

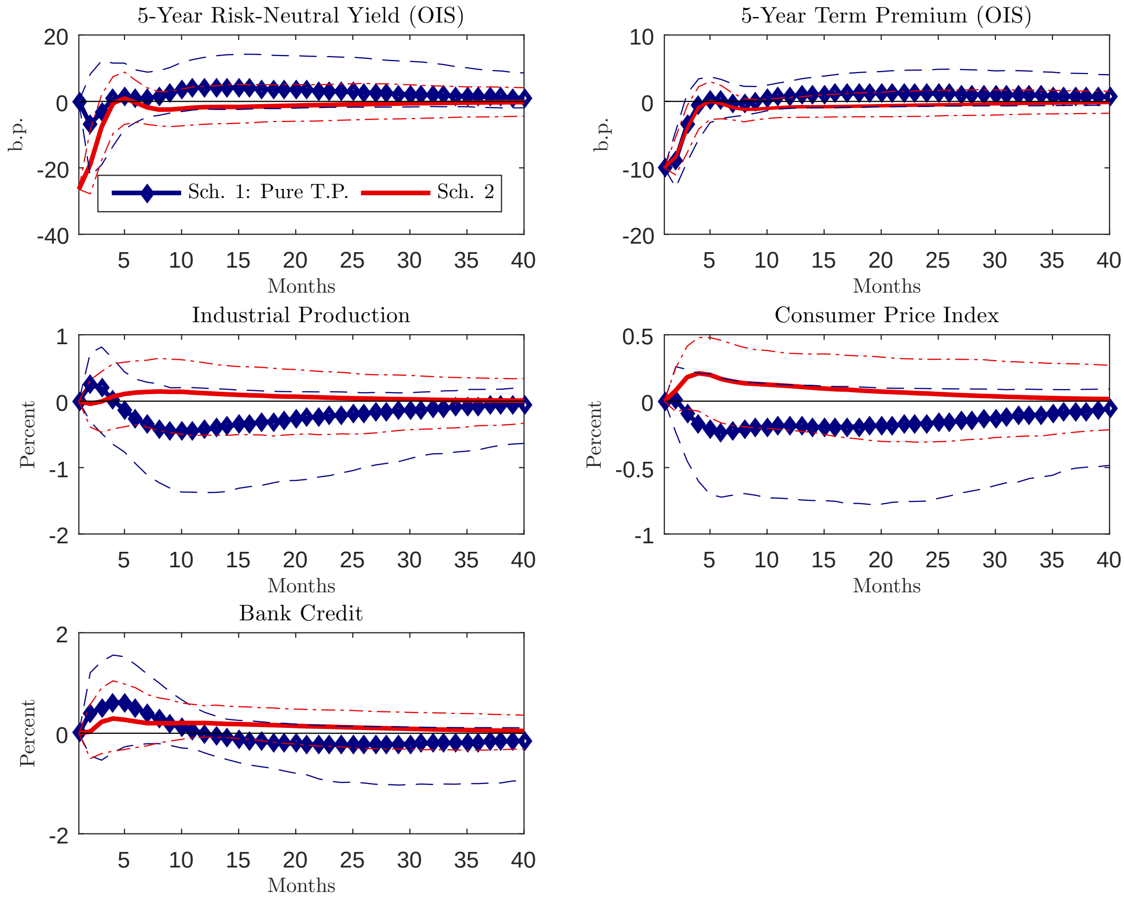
Figure 21: Impulse Response Functions to a Signalling Shock for Model 2 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 5-Year Treasury Yield



Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 5-year risk-neutral yield, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

Figure 22 shows that the industrial production, CPI and bank credit responses to a portfolio rebalancing shock are not significantly different from zero at any horizon when the OIS-augmented decomposition of the 5-year yield is included in model 2.

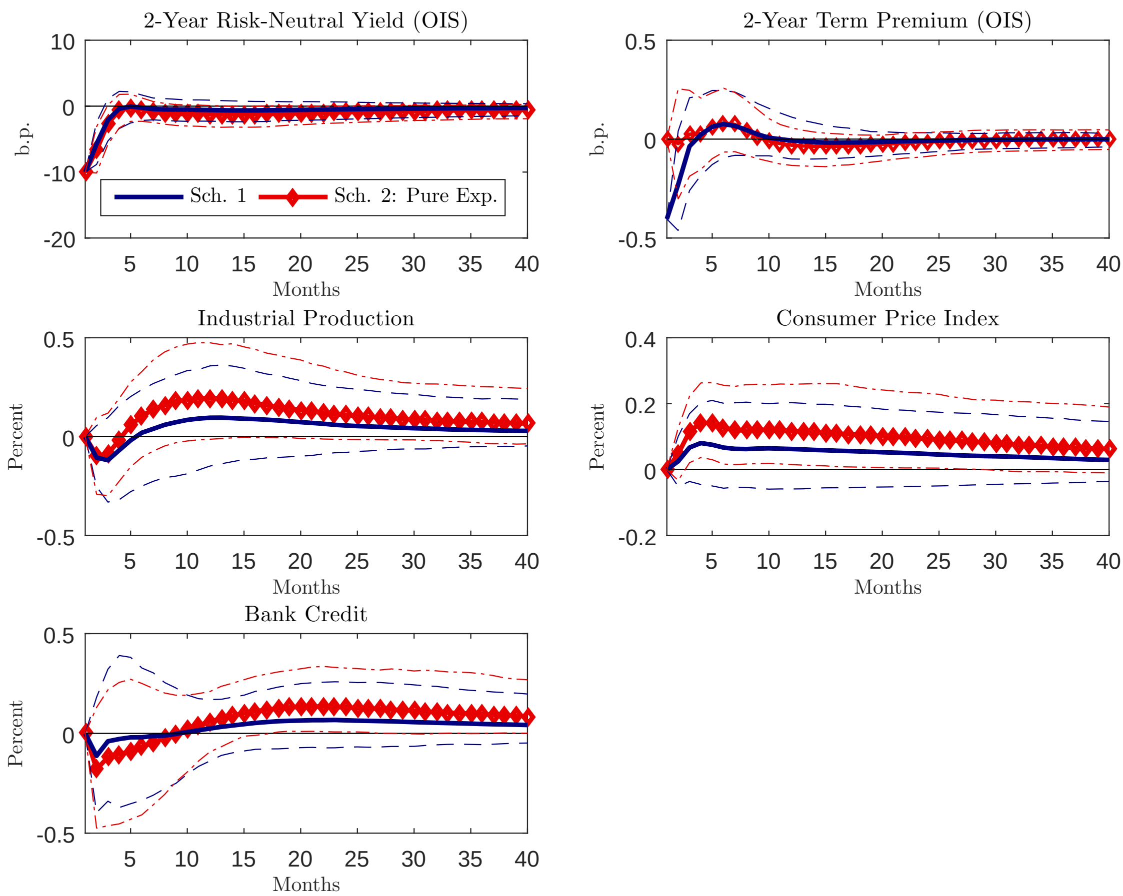
Figure 22: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 2 using Sign Restriction Schemes 1 & 2 and the OIS-Augmented Decomposition of the 5-Year Treasury Yield



Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 5-year term premium, estimated using the OIS-augmented decomposition (Lloyd, 2017a). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

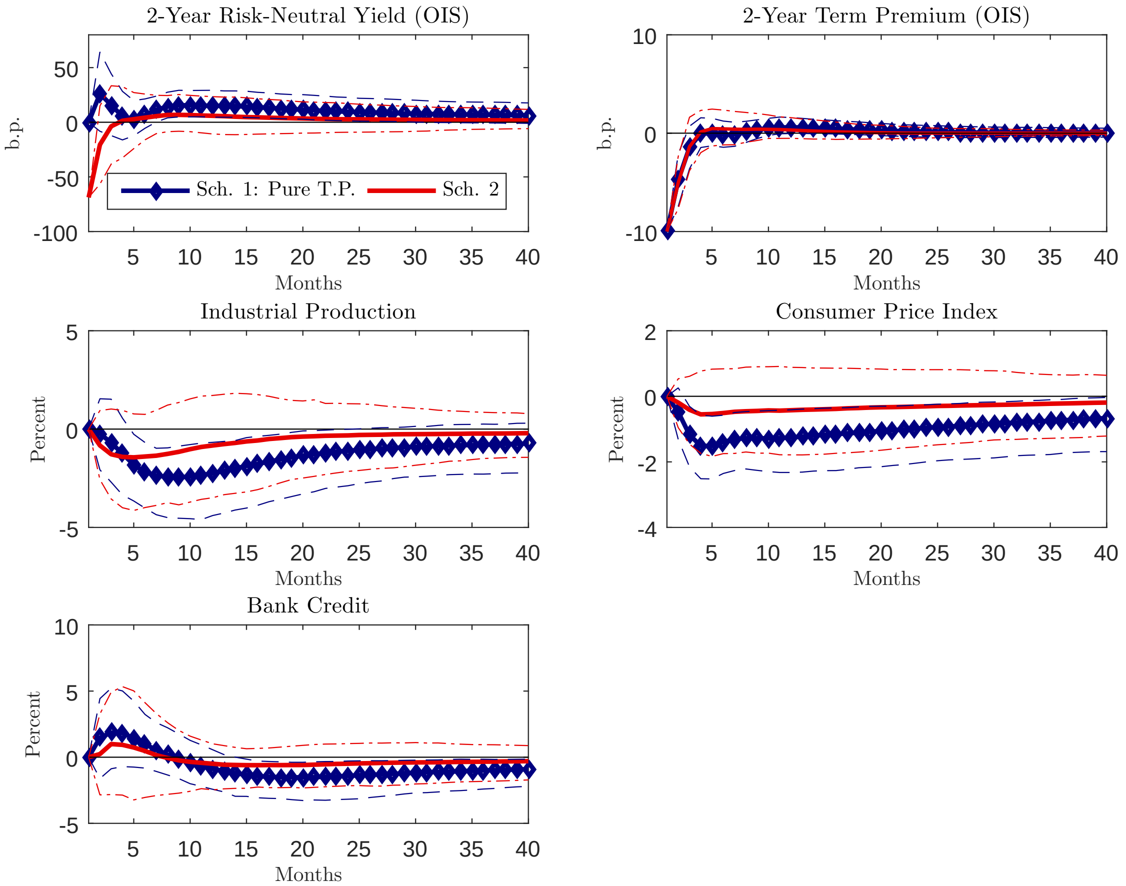
(iii) Term Structure Decomposition: Survey Augmented Figures 23 and 24 depict the impulse response functions to signalling and portfolio rebalancing shocks for model 2, estimated between November 2008 and April 2013 using the survey-augmented decomposition of the 2-year Treasury yield. Figure 23 demonstrates that an expansionary signalling shock has significantly positive lagged effects on industrial production, CPI and bank credit under scheme 2. With scheme 1, the responses are insignificantly different from zero with 5% and 95% confidence intervals. Figure 24 demonstrates that the responses of industrial production, CPI and bank credit to an expansionary portfolio rebalancing shock are not significantly positive at any horizon. Under scheme 1, the three variables fall significantly in response to the expansionary pure ter premium shock.

Figure 23: Impulse Response Functions to a Signalling Shock for Model 2 using Sign Restriction Schemes 1 & 2 and the Survey-Augmented Decomposition of the 2-Year Treasury Yield



Note: The plots show the impulse response functions to a signalling shock, normalised to represent a 10 basis point fall in the 2-year risk-neutral yield, estimated using the survey-augmented decomposition (Kim and Wright, 2005). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

Figure 24: Impulse Response Functions to a Portfolio Rebalancing Shock for Model 2 using Sign Restriction Schemes 1 & 2 and the Survey-Augmented Decomposition of the 2-Year Treasury Yield



Note: The plots show the impulse response functions to a portfolio rebalancing shock, normalised to represent a 10 basis point fall in the 2-year term premium, estimated using the survey-augmented decomposition (Kim and Wright, 2005). The VAR is estimated using data from November 2008 to April 2013. The two sign restriction schemes are detailed in table 8. The bold lines denote median impulse response draws. The thin dashed lines represent the 5% and 95% confidence intervals around median impulse responses, constructed using a residual-based block bootstrap.

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