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Abstract

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JEL Classification: E52, E58

Keywords: N/A

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What are the Macroeconomic Effects of State-Dependent Forward Guidance?

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October 2022

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We examine the macroeconomic effects of Bank of England (BoE) state-dependent forward guidance (SDFG). The timing of the BoE's SDFG permits separate identification of SDFG from QE macroeconomic effects, which is impossible in US and EA data. A standard New Keynesian model shows that SDFG reduces uncertainty about the future policy rate. We use this prediction and the timing of the BoE's SDFG, to identify SDFG shocks with a narrative sign restriction BVAR, proxy SVAR and local projection approach. Output and prices rise in response to SDFG, despite no econometric restrictions on these variables. The effects are small and consistent with the NK model.

Keywords: Monetary policy, State-dependent Forward Guidance, Inflation Expectations.
***JEL* classification**: E52, E58, E31.

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'The Committee decided to keep the target range for the federal funds rate at 0 to 1/4 percent and expects it will be appropriate to maintain this target range until labor market conditions have reached levels consistent with the Committee's assessments of maximum employment and inflation has risen to 2 percent and is on track to moderately exceed 2 percent for some time.'

- **FOMC statement, September 2020**

'It's striking that this "Odyssean" guidance has received much more attention in the economics literature – but, in the real world, and despite often being right up against the lower bound, central banks have used it only rarely. This may be because, in practice, it's quite difficult to make credible commitments of this sort (and because central banks have also been able to use QE). Whatever the reason, most "forward guidance" has been of the "Delphic", more conditional form.'

- **Ben Broadbent, Deputy Governor of the Bank of England, March 2022**

1 Introduction

G-7 central banks have relied on quantitative easing (QE) and state-dependent forward guidance (SDFG) to lean against the Covid-19 pandemic recession[1]. The Federal Reserve adopted SDFG in September 2020 to support the recovery, but now the FOMC is concerned about rising long-term inflation expectations. Despite the prominent role of this policy in the response to the Covid-19 recession and the weak recovery from the 2008/2009 global financial crisis, no previous empirical work has studied the macroeconomic effects of SDFG. The main reason for this lack of evidence is the Fed's (ECB's) announcement of SDFG together with open-ended QE in the same statement in December 2012[2] (September 2019). Credibly separating these effects with time-series models in the US and Euro Area is therefore impossible. In this paper, we study the macroeconomic effects of the Bank of England's SDFG, where the

[1] Bernanke (2020) offers a general survey of both tools.
[2]This problem also applies to the Federal Reserve's more recent September 2020 SDFG announcement.

coincidence issue does not arise. This is therefore the first study to provide credible time-series estimates of SDFG on the macroeconomy, such as the impact on real activity, prices and long-term inflation expectations.

The Bank of England adopted SDFG, promising that Bank Rate[3] would stay at 0.5%, so long the unemployment rate remained above 7% and the CPI inflation forecast 18-24 months ahead below 2.5% (Bank of England, 2013a,b). This policy was announced in August 2013, more than a year after the Bank of England's July 2012 QE announcement. In February 2014, the Bank of England (2104) changed the policy, moving away from numerical targets to condition the path of interest rates on spare capacity[4]. Financial markets, professional forecasters and consumer surveys show a large reduction in the standard deviation of interest rate expectations after the first announcement. This implies that the policy was a shock to the dispersion of interest rate expectations and understood as a clarification of the Bank of England's reaction function at the zero lower bound (ZLB).

Studying the UK experience allows us to make several important contributions to the literature. This is the first paper to provide econometric estimates of SDFG, the main type of forward guidance used by central banks[5]. Our agnostic VAR and local projection approaches allow us to test directly whether SDFG has a statistically significant effect on output and prices or not. We are also the first to examine the empirical transmission mechanism of this policy. Unlike most studies, our sample covers only the ZLB period in the UK from March 2009 to May 2016. Most empirical studies attribute the estimated effects of Federal Reserve policy on US output and inflation to QE rather than forward guidance, but the Fed's announcement of these policies was often

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[3] Bank Rate is the Bank of England's policy rate. We use 'Bank Rate' and policy rate interchangeably throughout this paper.

[4] More detail on the Bank of England's SDFG, including an event study, can be found in appendix D.

[5] In a recent speech, surveying the theory and practice of forward guidance, Bank of England Deputy Governor Broadbent argued that while the academic literature has analyzed time-dependent guidance, in practice most central banks adopted State-dependent forward guidance.

simultaneous[6]. In contrast, economic theory suggests that forward guidance should be more powerful[7] than QE (Eggertsson and Woodford, 2003). Our estimates can help to resolve which instrument is more powerful in practice. We model SDFG in the New Keynesian (NK) model of Adam and Billi (2006) to derive our main empirical identification restriction. By comparing impulse responses from the proposed model to those estimated empirically we can assess whether there is a 'puzzle' with SDFG. Finally, SDFG announcements often commit to keep rates low until actual or projected inflation exceeds the target. The UK experience allows us to test if such promises raise long-term inflation expectations, the goal of the Federal Reserve's and ECB's recent SDFG policies.

While there is no previous empirical work of the macroeconomic consequences of SDFG, several papers have studied the effects of general forward guidance shocks on the macroeconomy. Most studies rely on data from before the ZLB and professional forecaster surveys to study forward guidance. Doh and Smith (2018) and D'Amico and King (2015) apply this approach to study forward guidance shocks for the US, while Bock, Feldkircher and Siklos (2020) and Chritstoffel, De Groot, Mazlies and Montes-Galdon (2020) provide estimates for the Euro Area. Other studies identified forward guidance shocks with financial markets data. Andrade and Ferroni (2021) identify Euro Area odyssean monetary policy shocks with options data and study their effect on the real economy in a model estimated from January 2002 to January 2016[8]. The only paper which estimates a model of forward guidance for the US on ZLB data only is Bundick and Smith (2020). They estimate the effect of forward guidance with the help of the path factor extracted from Federal Funds futures, following the approach of Gürkaynac, Sack and Swanson (2005)[9]. While Bundick and Smith (2020) show that the results are similar when QE observations are dropped

[6] Between 2008 and 2015, forward guidance was provided during 5 out of 11 QE announcements.
[7] Indeed, Federal Reserve Chair Bernanke famously said: 'The problem with QE is it works in practice, but it doesn't work in theory'.
[8] Three of the largest shocks in the odyssean forward guidance series in that study explicitly coincided with QE announcements.
[9] Swanson (2021) extends the approach of GSS (2005) to allow for a QE factor, but his study focuses on asset price reactions only.

from their sample, they do not formally test if QE announcements react to their identified forward guidance shock. Relative to all these studies, our work is the only study exploring SDFG empirically, the second study to rely on data during the ZLB only, the only paper to examine a SDFG announcement which can, at least in theory, be separately identified from QE, the only paper to test whether QE announcements react to the identified SDFG shock, and the only paper to study the SDFG transmission mechanism, including effects on long-term inflation expectations.

As a first step in our investigation, we present a stochastic NK model of SDFG to help interpret the empirical results. In NK models, the promise to keep the policy rate at the lower bound for a long time leads to large responses of output and prices. The discrepancy between these large model responses generated by time-dependent guidance and the perceived impact of his policy in the real world is referred to as the 'Forward Guidance Puzzle' (Del Negro, Giannoni and Patterson, 2012). Previous work proposed incomplete markets (McKay, Nakamura and Steinsson, 2016; Hagedorn, Luo, Manovski and Mittman, 2019), incomplete information (Angeletos and Lian, 2017), bounded rationality (Farhi and Werning, 2018), finite planning horizons (Woodford, 2019; Gabaix, 2020), imperfect central bank credibility (Haberis, Harrison and Waldron, 2017) and modifications to price stickiness assumptions (Carlstrom, Fuerst and Paustian, 2014; Kiley 2016) as solutions to this puzzle. In contrast to these models of time-dependent forward guidance, we explore a model of SDFG based on Adam and Billi (2006). The only difference from a standard NK model is the presence of a stochastic demand shock. In their reaction today, consumers therefore take into account that the current state of low demand may disappear at an unknown future date.

We model SDFG as a rule that keeps the policy rate at the ZLB until the Taylor rule implies that forward guidance thresholds are met. Calibrating the Bank of England’s SDFG in our model means that the Taylor rule implied interest rate needs to rise 50bps above the ZLB for forward guidance to end. In line with actual Bank of England policy, the interest rate only moves in 25bps steps in our model, taking the quarter point value closest to the value given by a standard Taylor rule. Finally, as a reflection of the commitment to raise rates only gradually when they start rising, the policy rate only rises in 25bps steps every quarter after lift-off from the ZLB instead of rising immediately to the quarter point value closest to the Taylor rule level. These modelling choices mean that the policy of keeping rates lower for longer is therefore entirely dependent on the stochastic evolution of demand and that rates only rise gradually after lift-off. To ensure the results are independent of parametrisation, we solve the theoretical model repeatedly with randomly chosen parameters from a plausible set. An important prediction from this model is that the introduction of SDFG reduces the near-term dispersion of beliefs around the future policy rate path.

We note that Bernanke, Kiley and Roberts (2019) and Bernanke (2020) also explore threshold forward guidance, assuming the policy rate is held down until inflation reaches a threshold. But they explore the effect of the policy using the FRB/US model rather than a model with clearer micro-foundations.

Measuring UK policy rate expectations during this time is challenging. As the theoretical effects of forward guidance are due to changes in consumer behaviour, the ideal measure of policy rate expectation and dispersion should be derived from consumer surveys. These are available for the UK, but at quarterly frequency and with only qualitative answers. Many studies rely on policy rate expectations derived from financial markets. The LIBOR market, from which measures of future UK policy rates are derived, was, however, subject to significant structural reform in July 2013, one week before SDFG was implemented. Finally, professional forecasters' expectations of the short-term rate do not suffer from these issues, but are farthest away from the theoretically ideal measure. We therefore extract the first principal component from all three measures, for both the mean and standard deviation of the interest rate expectation 12 months ahead. These two principal components are the main variables we use to identify forward guidance empirically.

In our empirical work, we rely on the model prediction that SDFG reduces the standard deviation of future policy rate beliefs to identify the relevant shock with VAR and local projection techniques. Many VAR studies propose models from scratch to suit the question of interest. In our case we want to examine whether SDFG can be identified separately from QE. Hence, to maintain consistency with previous QE studies, we add the principal component mean and standard deviation measure of interest rate expectations to the UK QE VAR model in Weale and Wieladek (2016)[10]. Tying our hands in this way ensures that any results about the interdependence of QE and forward guidance are not the consequence of empirical modelling choices made in this paper. For identification, we use the narrative sign restriction approach of Antolin-Diaz and Rubio-Ramirez (2018) and require that the SDFG shock explains a greater fraction of the historical decomposition of the standard deviation of interest rate expectations than the sum of all other shocks in August 2013, when the policy was introduced and in February 2014 when the policy was changed. Our second approach to examining narrative SDFG shocks is the proxy SVAR approach of Mertens and Ravn (2013). Our proxy is a series of zeros, with the change in the standard deviation of interest rate forecasts in August 2013 and February 2014 as the only non-zero observations[11]. Finally, we also use the local projection approach, with the shock series derived from the proxy SVAR method, to estimate the effects of UK SDFG. All identification schemes leave the response of output and prices unrestricted and are hence agnostic with respect to the main question of this paper.

Our main finding is that SDFG had a modest effect on the UK economy, broadly in line with the NK Model prediction. Empirical results from all three models show that despite agnostic identification schemes the Bank of England's

[10] Other studies, such as Kapetanios, Mumtaz, Theodoris and Stevens (2012) or Gambacorta, Hoffman and Peersman (2013) use outcome variables such as the yield term spread or the central bank balance sheet in their studies of UK QE. Since these outcome variables could also react to forward guidance, this approach is not suitable to test if forward guidance is separately identified from UK QE or not.

[11] Since this is a sparse indicator we rely on bootstrap methods to generate confidence bands, in line with most papers taking this approach.

SDFG had the effect of raising both output and prices. These results are robust to model specification and inclusion of many additional variables. Importantly, the response of QE is never statistically significant, and the exclusion of QE leaves the results largely unaffected. Our empirical results show that Bank of England's SDFG raised UK output and prices by about 0.4 per cent. This is quantitatively similar to the NK model simulations. Unlike with time dependent guidance, a departure from the standard assumptions of risk sharing or rational expectations is not necessary to generate this result. This suggests that there is no SDFG puzzle. While the modest effects could be due to the conservative calibration of SDFG in the UK, they are an order of magnitude smaller than the effects of the Bank of England's QE1.

Our analysis of the transmission mechanism revealed an under-appreciated effect of this policy. We find strong evidence that SDFG led to a reduction in short-term mortgage rates and raised firms and consumer expectations about future activity. However, there is also evidence that SDFG led to a rise in long-term financial markets and consumer inflation expectations by about 20 basis points. As the quotes at the beginning of this paper imply, raising inflation expectations and hence outcomes was a goal of both the ECB's and Federal Reserve's recent SDFG policies. To our knowledge, this is the first paper to empirically document that state-dependent forward guidance can achieve this goal.

In the next part of the paper, we present the theoretical model and simulations of SDFG. We then discuss measurement, identification and the empirical effects of SDFG. Our conclusion summarises our findings.

2 Theory

This section presents our proposed NK model of SDFG, calibration, parametrisation and resulting model simulations.

Within the standard parameters of NK models, it is hard to generate cirucmstances that lead to the interest rate falling to the zero lower bound. A popular way of doing this is therefore to assume that the effect of the interest rate is augmented by a headwind, z_t, which can be thought of as a risk premium. Some authors assume that this headwind is is a persistent deterministic shock which pushes the economy into the effective zero lower bound (Guerrieri and Iacoviello, 2017). Such a shock, if deterministic and persistent but not permanent, is equivalent to the assumption that consumers, firms and the central bank all understand that the economy is going to stay at the zero lower bound for some time and that everyone knows precisely when the lower bound will cease to constrain the short-term interest rate. But this is where the theory diverges from the circumstances that forward guidance policies were implemeted in, as in real time it is not at all certain how long and whether the economy will stay at the zero lower bound. This might be one reason why even time-based forward guidance was accompanied by statements such as 'conditional on the inflation outlook' (Bank of Canada, 2009) or 'exceptional economic circumstances' (Federal Reserve, 2009). This makes it clear that central banks were not commiting to a specific interest rate path, but were presenting an interest rate forecast conditional on a scenario, which may or may not correspond to future reality.

Allowing the headwind z_t to be stochastic instead as in Adam and Billi (2006, 2007) provides a means of introducing this uncertainty about the exit from the zero lower bound into the model. One interpretation of z_t, proposed by Evans, Fisher, Gourio and Krane (2015), is as a natural rate shock, which is a linear function of zero mean demand shocks and exogenous log changes in potential output. For simplicity, we treat z_t as exogenous, but in our case the interpretation is that of a risk-premium or headwind, which depresses demand in the economy. We argue that this modification of the standard model, while conceptually simple, brings the model much closer to the reality faced by the central bank, consumers and firms when forward guidance was implemented and is therefore more suitable to study the impact of this policy than the standard NK model. When forward guidance was introduced, the policy was very much intended to support demand because the interest rate had reached its floor. Accordingly we focus on the demand side, with z_t as the sole source of shocks in the economy.

We set up a standard NK model which follows Adam and Billi (2006, 2007) and allows for a stochastic headwind. The model is one in which output, y_t, depends on expected output, $E_t y_{t+1}$, the interest rate, i_t, adjusted for expected inflation, $E\pi_{t+1}$, the headwind, z_t, and the steady state real interest rate, $\bar{\imath} - \bar{\pi}$. The IS curve is, with σ the intertemporal elasticity of substitution:

$$y_t = -\frac{1}{\sigma}(i_t + z_t - E\pi_{t+1}) + E_t y_{t+1} + (\bar{\imath} - \bar{\pi})/\sigma \tag{1}$$

We model the headwind as

$$z_t = \lambda z_{t-1} + u_t \qquad u_t \sim N(0, \sigma^2) \tag{2}$$

Supply conditions are represented by a forward-looking NK Phillips curve explaining inflation, π_t, in terms of expected future inflation, $E_t\pi_{t+1}$.

$$\pi_t = \beta E_t \pi_{t+1} + \kappa y_t + (1 - \beta)\bar{\pi} \tag{3}$$

Here β is the discount factor and $\kappa = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\frac{\omega+\sigma}{1+\omega\theta}$, with α is the degreee of price stickiness, ω the Frisch elasticity of labour supply and θ the elasticity of substitution between the different goods produced by imperfectly competitive producers.

In the absence of forward guidance, the interest rate is set by a policy rule which departs from the standard Taylor rule in two important respects. First, we define a floor to the interest rate, i^Z. We set this to ½ per cent per annum rather than zero. This reflects the fact that, during the period in which forward guidance was introduced in the United Kingdom, the Monetary Policy Committee was concerned that, because of the impact on bank profitability, a reduction of Bank

Rate below ½ per cent per annum would offer less stimulus than one of ½ per cent[12]. Secondly, we assume that the interest rate moves in multiples of quarter point steps, so that, subject to the lower bound, the rate adopted is the rate closest to that given by the Taylor rule but an integer multiple of one quarter percentage point. This reflects the fact that, almost everywhere, policy interest rates do move in quarter point or larger[13] steps. The model is, however, set out with inflation and the interest rate measured at quarterly rates. Thus we have

$$i_t^* = (1-\rho)(\phi_y y_t + \phi_\pi(\pi_t - \bar{\pi}) + \bar{\imath}) + \rho i_{t-1} \tag{4}$$

$i_t = \frac{N}{16}$ where *N* is the integer solution to min $(\frac{N}{16} - i_t^*)^2$ subject to *N≥2.* (5)

ϕ_y and ϕ_π and ρ are policy parameters.

One other feature of the model merits comment. The Phillips curve allows, unless $\beta = 1$, for a long-run trade-off between inflation and output. This means that, while there is a unique real interest consistent with stable output, the level of output, the long-run nominal interest rate and the long-run inflation rate are all functions of the actual policy rule in place. Such a situation arises, of course, from the fact that, in the derivation of the basic new Keynesian Phillips Curve, costs arise to changing nominal rather than "real" prices.

Output is measured relative to the value it takes when inflation is stable at $\bar{\pi}$. $\bar{\imath}$ is the steady-state nominal interest rate consistent with this. The model is defined in quarterly terms, but when we come to present the simulation results we convert these to an annual basis so as to facilitate comparison with our econometric impulse response functions.

[12] Improvements in bank balance sheets meant that, in 2016, the MPC did feel Bank Rate could safely be reduced to 0.25 per cent per annum.

[13] Beyond the period studied in this paper the adverse effects of very low interest rates on bank profitability became of less concern, as banks had gradually revised their lending terms. The perceived floor dropped to 0.1 percentage point by march 2020 and the first increase from this was to ¼ percentage point in December 2021. But since this lay outside the period we study it is not necessary to model this feature of monetary policy.

We model state dependent forward guidance as a rule which says that the monetary authority sets the policy rate to i^Z unless the Taylor rule indicates that $i_t^* > i^G$ where i^G is the interest rate guidance threshold. This approach allows us to capture the idea that the central bank's promise of lower for longer is dependent on the state of the economy. It should be noted, in this context that the lag term in the Taylor rule itself extends the period of low interest rates, because if i_{t-1}=i^Z it is less likely that $i_t^* > i^G$ than would have been the case if the actual interest rate had been allowed to rise above its floor. We also assume that, when forward guidance is in place, increases in interest rate are limited to 1/16 percentage point (at a quarterly rate) in each quarter until the actual interest rate reaches i^G. Thus if $i_t^* > i^G$ but $i_{t-1} < i^G$ then $i_t = i_{t-1} + 1/16$. This slows the rise in the interest rate both because changes are gradual and because it, as a result, depresses i_{t-1} further below what would happen in the absence of this guidance.

This approach also allows us to capture the fact that forward guidance can cease to apply both because of a rapid rise in output, and also if inflation rises significant above target. This reflects the Bank of England's approach to forward guidance, as the MPC highlighted both the unemployment rate threshold and risks to inflation could mean that the policy would stop applying.

The idea of using the Adam and Billi (2006, 2007) model to study SDFG is not new. Boneva, Harrison and Waldron (2018) were the first paper to model threshold-based forward guidance in the NK model of Adam and Billi (2006, 2007). They base the state-dependence of the policy on output and inflation threshold and study the macroeconomic effect of this policy relative to optimal discretion in the theoretical model based on one particular parametrisation. In contrast, we express the state-dependence in form of an interest rate threshold. The purpose of the model is also different in our paper relative to theirs. While they study the effects of state-dependent forward guidance relative to other policy options in theory, our model is solved across many different parameterisations to help derive robust identification restrictions and help assess if SDFG is subject to the same puzzle as time-dependent forward guidance.

2.1 Model Solution

We assess the effects of forward guidance by comparing the path of the economy after an initial head-wind[14] of 2.4 percentage points at an annual rate which then decays stochastically according to equation (2) with the standard deviation of the shock process set at 3.6 percentage points at an annual rate. We find that for values of λ, much above 0.85, the economy does not converge. Demand is weak causing prices to fall. This pushes up the real interest rate even when the nominal interest rate is fixed at i^Z. The increase in the real interest rate weakens demand further which aggravates the deflationary process. Such a situation cannot be avoided by forward guidance because the nominal interest rate is held at i^Z in any case. In the base case one can think of the guidance threshold equal to the lower bound, $i^G= i^Z$. This provides our base simulation. We then compare this with an alternative in which $i^G> i^Z$. Comparison of these two simulations then allows us to determine effect of raising i^G from ½ per cent per annum to the threshold implied by the Bank of England's forward guidance parameters.

This approach contrasts with Blake (2012), who assumes that the policy ends at some particular date and is never reintroduced. Similarly Carlstom, Fuerst and Paustian (2014) assume that there is a known, constant probability of the policy ending, but that once it has ended it will never be re-introduced. Unlike these studies, our approach assumes that the guidance policy remains in place indefinitely, so that the interest rate is reduced to i^Z if the Taylor rule gives a

[14] To measure the cyclical headwind (in deviation from trend) to demand, we apply a Hodrick-Prescott filter to UK real consumption from 1955Q1 to 2019Q4, the whole sample UK quarterly data is available for. We then regress the hp-filtered consumption on its own lag on the sample from 1972 to 2019, the period of floating exchange rates. The autoregressive coefficient is highly statistically significant with a value of 0.81. The standard deviation of the residuals from the equation is 0.9%. Finally, the hp-filtered series suggests that the headwind to consumption in the year before forward guidance was introduced was 2.4%.

value $i_t^* < i^G$ and is not raised above i^Z until $i_t^* > i^G$. As explained earlier, even when this happens, the increase in the interest rate is gradual.

We are unable to use the methods for addressing models subject to the zero lower bound as set out by, for example Guerrieri and Iacoviello (2015) and Aruboa, Cuba-Borda, Higa-Flores, Schorfheide and Villalvazo (2021). These rely on the interest rate being a continuous variable while our modelling sees it making discrete changes. This feature is of course in keeping with widespread central bank practice, but it does mean that we can solve our model only by straightforward dynamic programming as described in Appendix C. A greater degree of tolerance than usual is required in the solution, because we realistically represent the policy rate as moving in quarter point steps rather than assuming that it is varied continuously.

2.2 Model calibration

We follow the approach in Dedola and Neri (2007) and Peersman and Straub (2009) and solve with the parameters drawn randomly from the ranges described in Table 1, rejecting non-convergent parameter combinations. Our results come from 116 solutions which satisfy the convergence criteria of Appendix C.3. With each set of parameters we solve for twenty thousand realisations of the disturbance term, u_t. We retain the mean values of these simulations for the variables in question. The fact that we focus on the average across these realisations means, of course, that while in each simulation the Bank Rate moves in quarter points, the average of the realisations moves almost continuously. We can also calculate the dispersion (standard deviation) of each variable across the realisations, and we do this for the Bank Rate.

Table 2. Model Calibration

Description	**Parameter**	**Range *ex ante***	**Median**	**Range *ex post***
Price stickiness parameter	α	0.5-0.9	0.83	0.69-0.89
Discount factor	β	0.985-0.995	0.99	0.985-0.995
Inverse of the Frisch elasticity of labour supply	ω	1-3	2.14	1.03-3
Intra-temporal elasticity of substitution	θ	3-11	8.02	3.1-10.86
Risk aversion coefficient	σ	1-5	3.86	1.62-4.97
Inflation Target	$\bar{\pi}$	2% p.a.		Fixed
Steady state Interest Rate	$\bar{\imath}$	4% p.a.		Fixed
Monetary policy rule parameters:				
Interest rate sensitivity to CPI inflation	ϕ_π	1-3	2.34	1.06-2.99
Interest rate sensitivity to Output	ϕ_y	0-0.25	0.116	0.0-0.25

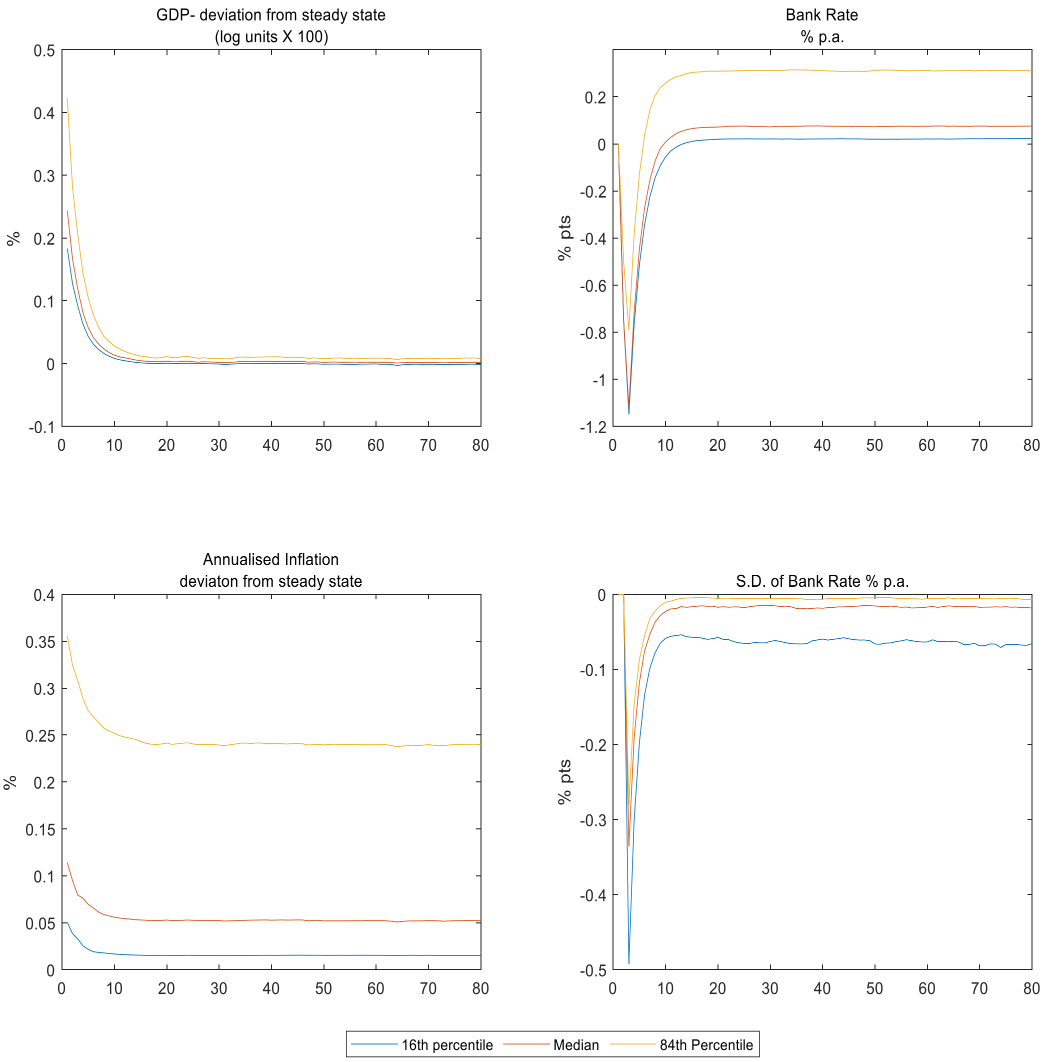
The median and 68% confidence band for the mean realisations derived from that exercise allow us to infer which predictions of the model are robust to parametrisation and how large the impact on GDP and CPI is likely to be. In Table 2 we show first the parameter range from which our draws were taken. Each variable was assumed to be uniformly distributed over the permitted range. We also show the median values, for each of the parameters, from those draws which produced successful runs, and lower and upper values of the successful parameter draws as the range *ex post*. In addition, we kept two parameters constant. The lag coefficient in the interest rate rule, ρ, was set to 0.7 and, as noted earlier, the rate at which the headwind died away, λ, was set to 0.85.

One of the most important modelling choices is the calibration of i^G, the threshold below which interest rate guidance is binding. We set this threshold based on the Bank of England's announced thresholds at which forward guidance would stop. The Bank of England said that guidance would remain in place until the unemployment rate fell below 7% or the CPI inflation forecast 18-24 months ahead exceeded 2.5%. At the time of the announcement the unemployment rate was 7.8% and the Bank of England reported in its *Inflation Report* labour market slack of 1.5%. Reported other spare capacity was 0.5%. The Bank of England considered the sum of these two components to be the output gap at the time. A reduction in the unemployment rate from 7.8% to 7% would therefore reduce the output gap from -2% to -1.2%. With ϕ_y at a value of 0.125, the output gap component of the Taylor rule implies an interest rate of -0.15. However, with $\phi_\pi = 2$ and $\pi_t - \bar{\pi} = 0.5$, the inflation component of Taylor rule implies an interest rate of 1. The sum of these two components is 0.85. Since we move in quarter steps, we set $i^G = 1$ per annum.

2.3 The Effects of Forward Guidance

Figure 1 shows the effects of forward guidance relative the conventional policy provided by the Taylor rule but subject to the lower bound when the economy has been hit by a headwind of 2.4 percentage points. It can be seen that the state-contingent policy of keeping the interest rate low has a material positive effect on both GDP and CPI. The Bank Rate is materially lower than in the absence of the policy, an effect which persists for up to thirty quarters. In the short term after the policy is introduced the standard deviation of the Bank Rate declines; in most of the simulations it will be held at i^Z. Further out, however, it increases compared with the reference simulations, because, as the number of realisations in which the Bank Rate is at i^G or above increases, the dispersion is greater with the Bank Rate held at i^Z than it would be in the absence of forward guidance. The theoretical result that the dispersion (standard deviation) of Bank Rate declines in response to the forward guidance announcement, and is very robust across parametrisation, is the key assumption in the SVAR identification schemes we present in section 4.

Figure 1: NK model responses to state-dependent forward guidance across different parameter values



Notes: The figures above show impulse responses for GDP, CPI and Bank Rate in response to the implementation of state dependent guidance, promising that the interest rate will only rise if the Taylor rule is 50 basis points above the zero lower bound (set here at ½ per cent per annum). Under the expectations theory of the term structure, the forward rate is the expected policy rate two years ahead. This allows us to interpret the 'Bank Rate' panel as saying that expected policy rate, and hence forward rate, two years ahead will decline by about 1% or 100 basis points in response to the guidance anouncement. The dispersion of bank rate one-year ahead declines by about 33bps in the short term. This is the same size of the shock that the impulse responses in the VAR model have been calibrated to. **Short Interpretation:** The NK model with state dependent forward guidance, when simulated across 100 random draws of the parameter ranges in table 2, shows a material impact on both GDP and the consumer price index.

3 Measuring and estimating the effects of state-dependent forward guidance

In this section, we describe how to measure forward guidance based on the theory in the previous section and the empirical modelling approach taken in this paper; we conclude by summarizing the results and several robustness exercises.

3.1 Measuring Forward Guidance

The theory in section 2 shows that measures of the mean and standard deviation of interest rate expectations are required to identify state-dependent forward guidance shocks. In this section, we summarise previous work, the challsenges with measuring forward guidance in UK data and how we address them to derive summary measures of the mean and standard deviation of interest rate expectations.

Previous empirical work has constructed measures of forward guidance policies from options data and surveys of professional forecasters. Bundick and Smith (2020) use options to extract the future path of the Federal Funds rate. Bundick, Herriford and Smith (2017) use euro-dollar options to derive a measure of implied volatility of the Federal Funds rate. Bauer, Mueller and Lakdawala (2019) propose a model-free measure of uncertainty about future monetary policy. An alternative approach to measuring forward guidance policies is to rely on surveys of professional forecasters mean and dispersion of short-term interest rate expectations. Doh and Smith (2018) and Chritstoffel, De Groot, Mazlies and Montes-Galdon (2020) use professional forecasts of short-term interest rates to help identify general forward guidance shocks in SVAR models for the Federal Reserve and the ECB, respectively. D'Amico and King (2015) explore forward guidance shocks in a VAR model of anticipated monetary policy with quarterly data from 1985 to 2015. Bock, Feldkircher and Siklos (2020) rely on shocks to the mean interest rate of consensus economics professional forecasts to examine the international impact of general Euro Area forward guidance shocks. On the other hand, Ehrmann, Gaballo, Hoffmann and Strasser (2019) examine the effects of specific central bank forward guidance announcements on professional forecasters' expectations during the zero lower bound period. They find that only state-dependent forward guidance reduces the dispersion of professional forecasters' interest rate expectations.

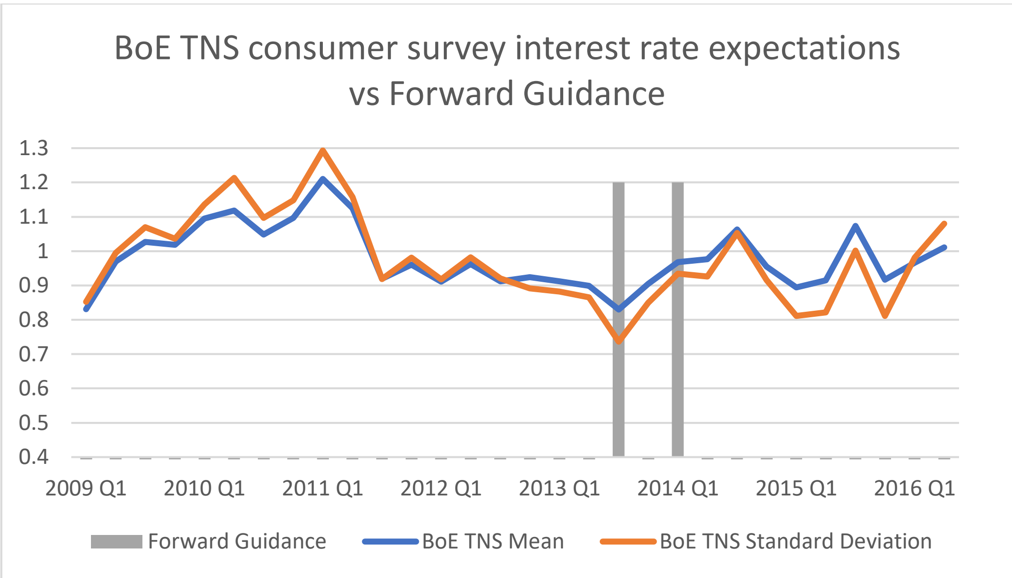
Measuring forward guidance in UK data is subject to several practical challenges. While UK interest rate expectations can be derived from consumer surveys, financial market data and surveys of professional forecasters, all of these are subject to idiosyncratic measurement problems. We therefore rely on principal component summary measures of both the mean and standard deviation of interest rate expectations. The extracted common components will be less affected by these idiosyncratic issues and are likely to be more reflective of general interest rate expectations.

The theory laid out in section 3 implies that forward guidance operates through changes in consumers mean and standard deviation interest rate expectations. Ideally, these measures should be derived from consumer surveys. For the UK, the Bank of England/TNS Inflation Attitudes survey provides this information. An important advantage of this survey is that it is carried out shortly after the publication of the Bank of England's quarterly *Inflation Report*, when major policy announcements are usually made, but it is available only at quarterly frequency. From 1999, respondents can choose five different qualitative answers to a question on where they see interest rates in 12 months from now: i) a lot lower, ii) a little lower, iii) unchanged, iv) a little higher and v) a lot higher. From 2014 onwards, the survey also collects numerical responses which correspond to these five categories. The Bank of England also provides the underlying individual responses of survey participants on its website. This allows us to map the pre-2014 qualitative responses to quantitative values based on the 2014 numerical answers[15]. This mapping allows us to compute the mean and standard

[15] A key assumption behind this mapping is that participants views of what large and a small rise in interest rates remained invariant over time. However, we only require data from 2009 Q1 onwards only. During this time, Bank rate remained at 0.5%, the effective lower bound in the UK at the time. We therefore map the response of

deviation of this qualitative indicator in each period of time. We show the results in Figure 2. These show that both the mean and the standard deviation of consumers 12-month ahead interest rate expectations derived from the Bank of England's TNS survey decline significantly in response to the first forward guidance announcement in August 2013. Most of the movement in these indicators over time is the result of respondents switching category, rather than individuals changing their view on the expected 12-month ahead interest rate. The large decline in the mean rate expectation and the standard deviation in response to the 2013 forward guidance announcement can therefore also be seen in the qualitative data.

Figure 2: Forward Guidance and UK consumer interest rate expectations



Source: Bank of England TNS survey. Timing of Bank of England forward guidance is taken from the BoE Website.

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unchanged to 0.5% (the perceived ZLB since 2009), a little lower to 0.25% and a lot lower to 0.1% for these responses from 2009 Q1 onwards. For the responses of rise a little and rise a lot, we assign the average of the numerical answer for that category in 2014. After February 2014, we rely on the actual numerical answers. Average responses do not vary much between 2014-2016, suggesting that views of what a small and a large rise in interest rates is haven't changed much during this time.

An alternative transmission mechanism of forward guidance is through financial markets. In the UK, historical short-term rate expectations can only be constructed from LIBOR options, rather than options on Bank Rate directly. The LIBOR will be the sum of the Bank of England's policy rate and bank credit risk. In normal times, the second component is negligible. Previous work relied on LIBOR options data to examine the effect of conventional monetary policy shocks on the macroeconomy (Cesa-Bianchi, Thwaites and Vicondoa, 2020). However, as a result of regulatory and criminal investigations in 2011 and 2012, it emerged that the LIBOR was systematically manipulated by collusion among traders in several investment banks. Early reports of this collusive behaviour first emerged in 2008. It is therefore likely that implied volatility in LIBOR options presented a systematically distorted picture of the actual dispersion in UK short-term rate expectations from the beginning of the ZLB period in the UK onwards. A major reform of LIBOR oversight in response to the scandal was then implemented at the end of July 2013, only a week before the Bank of England's first forward guidance announcement. All of these effects are likely to add an idiosyncratic error term to any measure of mean and standard deviation of future interest rates derived from LIBOR options. As a result, using a series derived from LIBOR options as the only representation of future interest rate beliefs is not suitable in our econometric model.[16]

Finally, professional forecasters' mean, and standard deviation of, short-term rate expectations are a last option to measure forward guidance related variables for the purpose of our study. For the UK, Consensus Economics provides the mean and standard deviation of professional forecasters' expectations of the interbank (LIBOR) rate 12 months ahead. This series is provided at monthly frequency and has been used extensively in previous research on forward guidance[17]. Conceptually, this series is the farthest away

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[16] The event study earlier in this paper also relied on LIBOR data. However, the events took place after the LIBOR reform, so that exercise is probably still valid. However, it seems unlikely that series derived from LIBOR options after the reform are comparable with those before.

[17] This is the series used by Ehrmann, Gaballo, Hoffmann and Strasser (2019) in their study of forward guidance.

from the theoretical ideal. While professional forecasts should be broadly reflective of firms and consumers interest rate expectations, it is uncertain whether that is the case. Although the forecasters in the panel always report a GDP growth forecast, not all report an interest rate forecast every month. This makes the Consensus Economics standard deviation of rate expectations series potentially subject to distortion as the interest rate observations for some forecasters drop out in one month, only to re-enter the panel a month or two later.

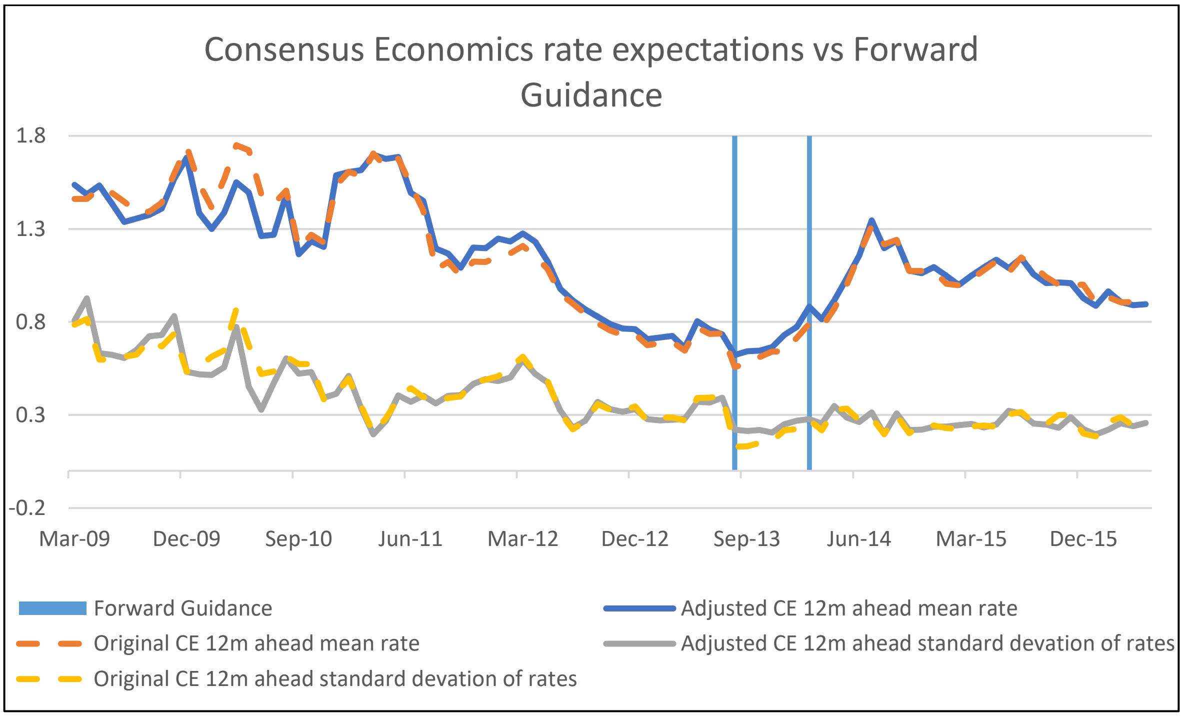
We deal with this issue in two stages. First, we drop forecasters that report interest rate forecasts less than 25% of the time. For those that remain in this smaller panel, we impute their interest rate response from their historical relationship with the average interest rate forecast, when a growth, but not interest rate forecast, is reported. The result of this adjustment, relative to the original consensus series, is shown in Figure 3. There are clear reductions in both the expected future short-term rate and its standard deviation at the time of the August 2013 forward guidance announcement[18]. However, Figure 3 shows that the proposed adjustment results in smaller movements around this announcement than the original Consensus Economics series. If anything, this adjustment would therefore reduce the probability of detecting a statistically significant effect from this policy.

While each one of the forward guidance measures presented in this section is a plausible candidate for econometric analysis, each has idiosyncratic issues. We therefore extract the common component among from all three of them. There is also a mixed frequency problem: While the Consensus Economics and LIBOR series are at a monthly frequency, the Bank of England survey is at quarterly frequency. To address this issue, we adopt the mixed frequency

[18] Consensus Economics data is published the second Monday of the month, with forecasts submitted by the first Thursday of the month. It is unclear when forecasts are updated. During the time under study, the Bank of England usually announced its policy decision on the first Wednesday of the month, with more information on the decision was provided in the minutes, published 7 days later. It is unclear if the policy decision can be taken into account at such short notice and relevant information about future interest rates movements was revealed in the minutes, only after the Consensus Economics interest rates forecasts were published for that given month. To ensure that Consensus Economics data is therefore fully reflective of all the key information for a given month, we therefore lag these data by one month in our analysis, i.e. the observation for August 2013 in our dataset is the September 2013 observation in the original dataset.

principal components approach of Stock and Watson (2002) and estimate this model with the Expectations Maximisation algorithm[19]. We repeat this exercise for the mean and standard deviation of rates separately.

Figure 3: Forward Guidance and UK Professional Forecasters interest rate expectations



Source: Original 12m ahead mean rate and 12m ahead standard deviation of rates are the 12 month ahead mean and standard deviation of series taken from Consensus Economics. 'Adjusted' series are estimated based on Consensus Economics individual forecasts and the approach described in the main text.

3.2 Empirical Approach

Our aim in this paper is to identify UK state-dependent forward guidance shocks. Unlike previous work on forward guidance, we include QE announcements in our model to demonstrate that the identified forward guidance shock is independent of QE. To ensure that our results about the interaction of UK QE and forward guidance are not purely due to econometric strategy, consistency with previous work is key. To tie our hands, we therefore add the principal components of mean and dispersion of interest rate expectations to the

[19] See the appendix of their paper for details of the Expectations Maximisation algorithm to estimate this model.

VAR model of UK QE presented in Weale and Wieladek (2016). To our knowledge, this is the only UK QE VAR model which includes a QE announcement term[20]. This allows us to test formally whether QE announcements are unaffected by the forward guidance shock, a necessary condition for any credible forward guidance identification scheme. We identify the forward guidance shock with the narrative sign restrictions and the Proxy SVAR approach to ensure that the results are robust across identification schemes. We also estimate the impulse responses with a local projection to completement the VAR approach.

To identify UK forward guidance shocks, we estimate the following VAR model:

$$\boldsymbol{Y_t} = \boldsymbol{\alpha_c} + \sum_{k=1}^{L} \boldsymbol{A_k Y_{t-k}} + \sum_{k=0}^{L} \boldsymbol{B_k X_{t-k}} + \boldsymbol{e_t} \qquad \boldsymbol{e_t} \sim \boldsymbol{N(0, \Sigma)} \tag{6}$$

where $\boldsymbol{Y_t}$ is a vector of the following endogenous variables: the log of UK real GDP; the log of UK CPI; the Bank of England's QE announcements scaled by 2009 Q1 UK GDP, the 10-year rate on government bonds, the log of real share prices, the first principal component of each of the mean and standard deviation of the UK short-term rate expectation at time $\boldsymbol{t}$. The first five variables are those of the model of Weale and Wieladek (2016). $\boldsymbol{A_k}$ is the array of coefficients associated with the corresponding lagged vector of variables for Lag $\boldsymbol{k}$. $\boldsymbol{e_t}$ is a vector of residuals at time $\boldsymbol{t}$. This is assumed to be normally distributed with variance-covariance matrix $\boldsymbol{\Sigma}$. The parameters are estimated either via a Bayesian approach with a non-informative Normal Inverse-Wishart prior[21] or OLS, depending on whether forward guidance is identified with the narrative sign

[20] Kapetanios, Mumtaz, Stevens and Theodoris (2012) provide an alternative VAR model to examine the impact of UK QE. They rely on the spread of the long-term to short-term interest rate as a proxy for unconventional monetary policy. A compression of this spread will likely reflect both QE and forward guidance. This spread is therefore not a suitable variable to test if QE reacts to forward guidance or not.

[21] Uhlig (2005) sets the hyper-parameters for the prior equal to zero to ensure that it is non-informative. This is identical to estimating the mean parameters via OLS and generating Bayesian credible sets through Monte Carlo simulations, which is the approach that we follow.

restrictions or the proxy SVAR approach. We set the lag length, L, to two.[22] The model is estimated on data from March 2009 to May 2016.[23] In Weale and Wieladek (2016), the data spanned March 2009 to May 2014. During these two additional years, the world economy was subject to large commodity price fluctuations. We therefore add real commodity prices expressed in GBP at time t and with two lags as exogenous control variables, $\boldsymbol{X_t}$, to account for these important developments.

3.3 Identification

The challenge for structural VAR models is to disentangle orthogonal, structural economic shocks, $\boldsymbol{\varepsilon_{c,t}}$, from the correlated reduced form shocks $\boldsymbol{e_{c,t}}$. This is typically achieved using a matrix $\boldsymbol{C_0}$, such that $\boldsymbol{C_0 e_{c,t}} = \boldsymbol{\varepsilon_{c,t}}$. Our aim in this paper is to identify forward guidance shocks separately from asset purchase shocks. We rely on the NK model prediction and the timing of UK SDFG to identify a state-dependent forward guidance shock in two different SVAR models below.

Our first proposed identification scheme is based on the narrative sign restrictions approach of Antolin-Diaz and Rubio-Ramirez (2018). This approach relies on the idea that a shock can be identified when there is great 'narrative' certainty that it is the dominant determinant of a move in the variable at a point in time. For example, Antolin-Diaz and Rubio-Ramirez (2018) identify a monetary policy shock by requiring that this shock explains a greater fraction of the historical decomposition in the Federal Funds rate during the early 1980s Volcker monetary policy contraction than the sum of all other shocks. Similarly, in the UK, as can be seen in Figures 2 and 3, the standard deviation (dispersion)

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[22] *Ex ante* lag length tests such as the Hannan-Quinn or BIC criterion suggest a lag length of 1. If the VAR is estimated with the correct lag length, the residuals should follow a white-noise process, and autocorrelation tests on the residuals of each equation of the VAR suggests that this is the case only with two lags or more. We therefore estimate the VAR with two lags.

[23] This time period captures the effective zero lower bound in the UK. Bank rate was cut to 0.5% in March 2009 and was perceived as the effective lower bound until after the Brexit vote in June 2016, when the Bank of England said that rates could be cut further.

of one-year ahead rate forecasts fell significantly when the Bank of England announced forward guidance. We use this information and identify state-dependent forward guidance with three restrictions:

i) The shock explains a greater fraction of the historical decomposition of the *standard deviation of rate forecasts* than the sum of all other shocks in August 2013 & February 2014.

ii) The shock explains a greater fraction of the historical decomposition of *the mean of interest rate forecasts* than all other shocks taken together in August 2013 & February 2014.

iii) The signs of the standard deviation and mean interest rate forecasts are not positive upon impact and for five periods thereafter.

Restriction iii) of requiring these variables to be non-positive upon impact and five periods subsequently follows the approach of Uhlig (2005), Weale and Wieladek (2016) and Antolin-Diaz and Rubio-Ramirez (2018), the only other monetary policy VAR papers to remain agnostic about the effects on output and prices. Importantly, this agnostic approach allows us to directly test whether there is a macroeconomic impact of forward guidance or not. This identification scheme is implemented with the algorithm of Antolin-Diaz and Rubio-Ramirez (2018).

An alternative approach to exploit the presence of narrative information in SVAR identification is the proxy SVAR approach, proposed in Mertens and Ravn (2013). Our proxy is a series of zeros, with the change in the dispersion of interest rate forecasts in August 2013 and February 2014 as the only non-zero observations. With only two observations, this is a sparse instrument. Bayesian approaches to proxy SVAR typically rely on distributional assumptions around the proxy indicator[24]. Frequentist approaches which estimate the VAR coefficients with OLS use the wild bootstrap approach to generate confidence bands, as in Mertens and Ravn (2013), are much better suited to inference with spare instruments. Furthermore, relying on both frequentist and Bayesian

[24] See Arias, Rubio-Ramirez and Waggoner (2018), Caldara and Herbst (2018) and Giacomini, Kitagawa and Read (2019) for examples.

approach to VAR estimation and identification helps to ensure that the results are broadly robust to econometric technique and identification approach.

These two identification schemes provide important complimentary information[25]. An important advantage of proxy SVARs is that they allow for measurement error in the proxy variable. This approach also allows for explicitly testing the strength of the proposed instrument. However, the instrument needs to be exogenous by assumption. On the other hand, with the narrative sign restrictions approach the only assumption necessary is that the identified shock has a certain sign and explains a greater fraction of the historical decomposition than all other shocks at that point in time. If the result of the narrative sign restriction and proxy SVAR approach are similar, this provides indirect evidence in favour of the exogeneity assumption embedded in the proxy SVAR approach. The proxy SVAR approach can therefore yield insight on the strength of the proposed instrument, while the narrative sign restriction approach provides indirect evidence for or against the exogeneity assumption.

Relying on these two different approaches also has important advantages with respect to inference. Most work based on sign restrictions, including narrative sign restrictions, relies on the algorithm of Rubio-Ramirez, Waggoner and Zha (2010) to find candidate rotations of the VAR impact matrix. Baumeister and Hamilton (2015, 2018) and Watson (2019) argue that the Haar distribution used to find candidate rotations in this algorithm is only uninformative with respect to the proposed rotations, but not impulse responses, as they are a non-linear function of the proposed rotation. As a result, the algorithm can assign higher probability to certain impulse responses randomly. One solution proposed by Baumeister and Hamilton (2020) is to rely on the proxy SVAR approach as well, as implemented in this paper. Mertens and Ravn (2013) use the Wild Bootstrap to generate uncertainty bands in their proxy SVAR model. However, Brueggeman, Jentsch and Trenkler (2016) show that Wild Bootstraps are not

[25] Piffer and Podstowski (2018) propose a proxy SVAR that allows the econometrician to control the proportion that the proxy explains any point in time. Results from this method, a hybrid between the methods in this paper, would likely be very similar to those in this paper.

asymptotically valid for inference about VAR innovations. Jentsch and Lunford (2018) have proposed the Moving Block Bootstrap arguing that this better reflects the uncertainty around impulse responses in proxy SVARs. Mertens and Ravn (2019) point out that the difference between this and other Bootstrap approaches is smaller with 68% confidence bands, as there is smaller risk of outliers in the simulated distribution of confidence bands (Mertens and Montiel-Olea, 2018). While we therefore adopt a 68% confidence band throughout, we always show results from the Moving Block Bootstrap approach, since this generates the widest possible confidence bands[26].

VARs are not the only approach available to estimate impulse responses to macroeconomic shocks. In recent years, the local projection approach by Jorda (2006) has become a popular alternative. In large samples, Plagborg-Moeller and Wolf (2021) show that VARs and local projections estimate the same impulse response function. However, in small samples, Miranda-Agrippino and Rico (Forthcoming) provide evidence for a variance-bias trade-off and these methods can hence provide complimentary information. VARs produce more efficient estimates, but can be subject to significant bias, especially if the model is mis-specified or doesn't fully capture the data generating process. Local projections, on the other hand, tend to lead to less efficient estimates, but are robust to bias from potential misspecification. With short time series, medium run dynamics may be due to the VAR structure rather than the dynamics in the underlying data (Nakamura and Steinsson, 2018b). At the same time, Nakamura and Steinsson (2018a) point out that direct methods can be subject to a power problem since macroeconomic variables are hit by a variety of other shocks in the future. In our local projections analysis, we augment the projection with its own lags as proposed by Olea and Plagborg-Moeller (forthcoming). To ensure that the local projection is in response to the same shock as in the VAR, and that hence impulse responses from these two methods are comparable, we use the shock series

[26] Montiel-Olea, Stock and Watson (Forthcoming) propose alternative methods to generate proxy SVAR confidence bands such as the Delta method, the Parametric Bootstrap and asymptotic weak instrument bands. Our results are robust to these other methods.

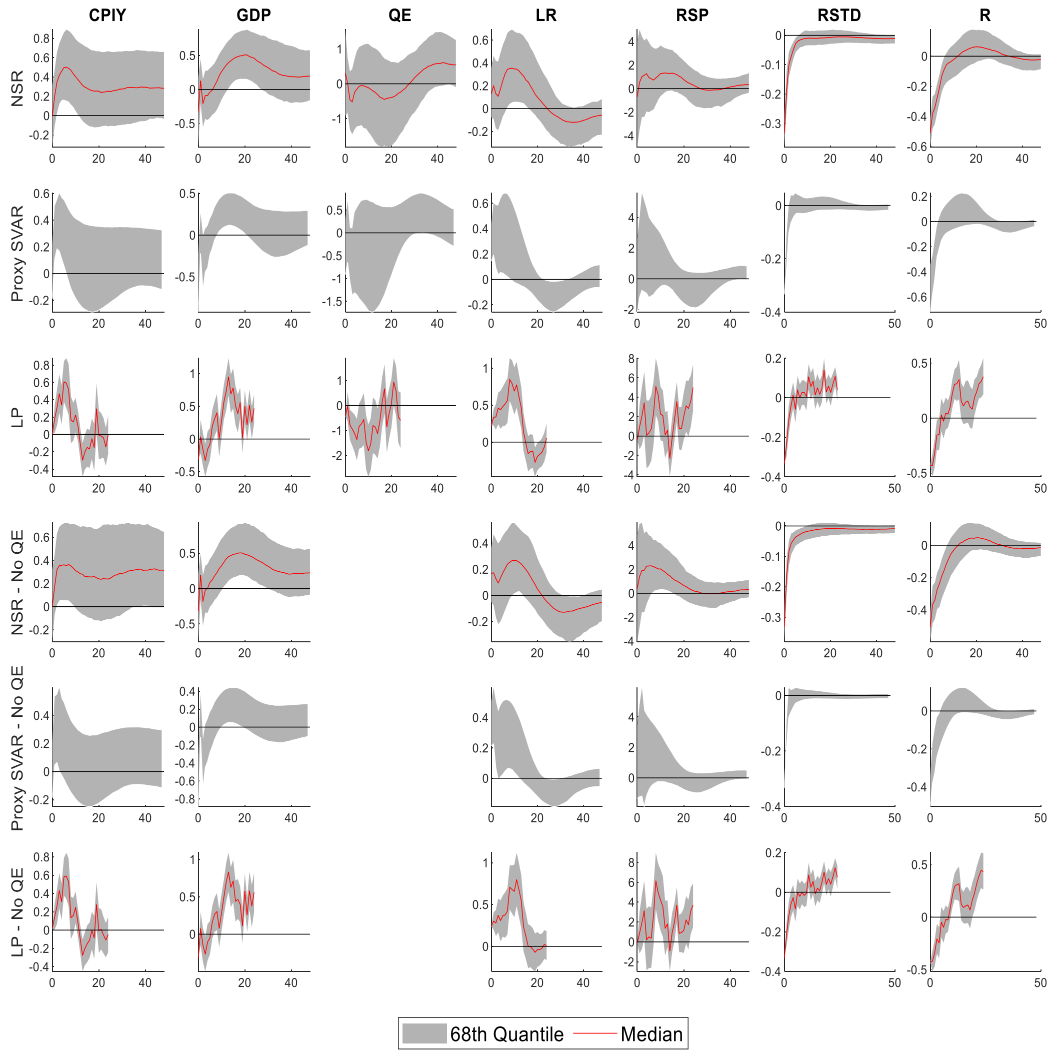
generated by the Proxy SVAR external instrument approach to estimate the IRFs via local projections. The confidence bands are generated with the wild bootstrap. For all of these reasons, we adopt the local projection approach to impulse response estimation as a complement, rather than a substitute for, the VAR analysis.

3.4 Results

We first present our baseline results and then add a number of variables of interest one-by-one to each model to examine the transmission mechanism. In what follows, all our impulse responses are standardised to a 33bps reduction in the dispersion of interest rate expectations, in line with the simulation results presented in section 3.

Figure 4 shows the impulse responses from the full VAR and local projection models with and without QE. The first row 'NSR' shows results from the narrative sign restrictions identification scheme. This shows that, in response to a 33bps forward guidance shock, CPI and GDP rise by about 0.4%, although these variables were left completely unrestricted in the identification scheme. Furthermore, the long-term interest rate rises in response to state-dependent forward guidance. The 68% quantiles for all of these variables clearly exclude zero, which means that they are statistically significant. Real equity prices rise as well, but here the response is only marginally statistically significant at 68% quantile level. Interestingly, the response of QE is not statistically significant. This is a necessary, but not sufficient, condition for our claim that the UK's unique timing of these policies allows us to credibly identify state-dependent forward guidance separately from QE. The corresponding results from the proxy SVAR model in row 2 are qualitatively and quantitatively almost identical to those from the narrative sign restrictions approach. This suggests that the results are robust to choice of frequentist or Bayesian estimation approach, as well as different identification schemes. Finally row 3 shows the results from the local projection approach. These results are broadly similar to the VAR models. The only difference is a slightly stronger response of real GDP and the long rate. In the local projection approach, the response of QE is statistically significant. However, the analytical HAC confidence bands used in this model probably severely understate the true degree of uncertainty, relative to VAR models. Since VAR confidence bands are not subject to this issue, it is likely that statistical significance of QE in the local projections model is due to understated econometric uncertainty. In any case, results from the local projections model are only meant to verify the magnitude of effects estimated in the VAR models, not their statistical significance. Dropping QE from these models (rows 4-6) doesn't change any of these results. In fact, in line with dropping a variable which does not add information to either the identification or propagation of the forward guidance shock, the remaining results become slightly more statistically significant. Overall, these results show that output and prices rise in response to a state-dependent forward guidance shock, even if these variables are left unrestricted. This result is robust across different identification schemes (narrative sign restrictions vs proxy SVAR), different estimation philosophies (Bayesian vs frequentist) as well different underlying models (VAR vs LP). Finally, these empirical estimates are quantitatively very similar to our proposed NK model. This suggests that, at least with state-dependent forward guidance, there is no 'puzzle'.

Figure 4: UK impulse responses to a forward guidance shock in response to different identification approaches

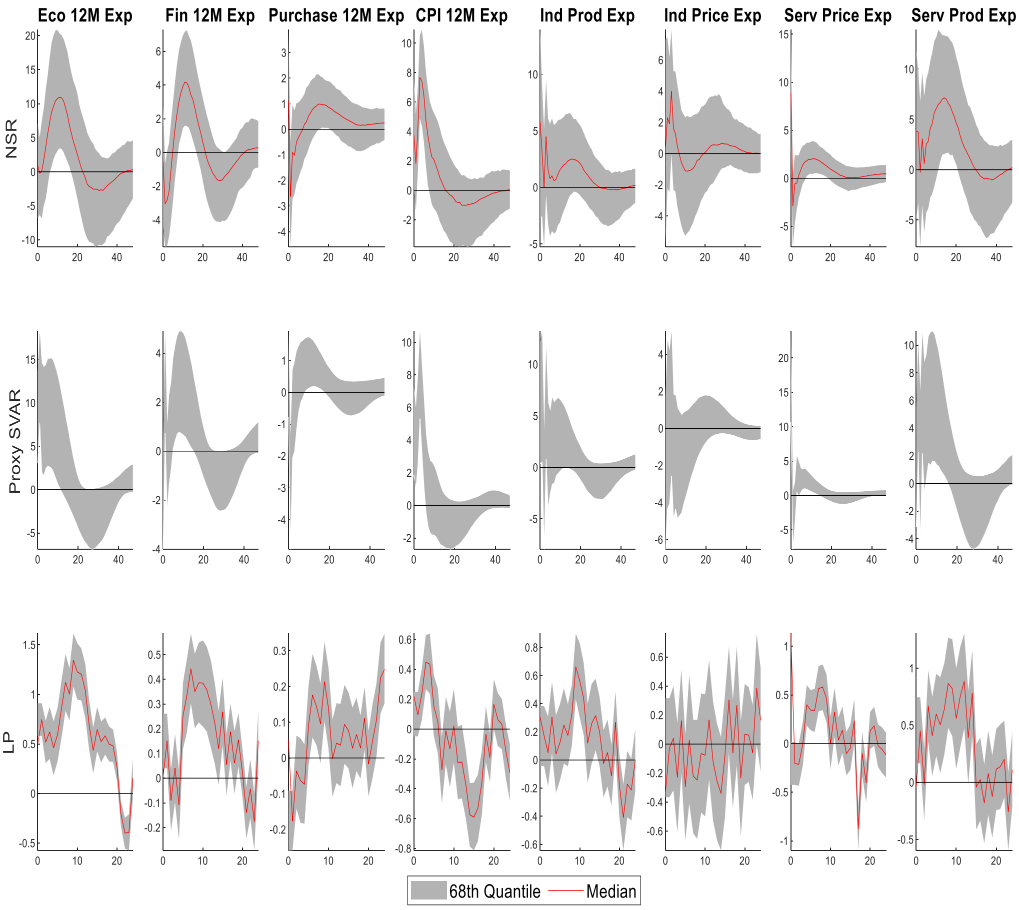


Notes: This figure shows impulse responses to a 33bps forward guidance shock across three identification approaches with and without the QE variable. **Row 1** shows results from a forward guidance shock identified with narrative sign restrictions identification scheme approach. The label above each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. **Row 2** presents the results from a forward guidance shock identified with a Proxy SVAR, with confidence bands generated with the wild bootstrap approach. **Row 3** repeats this exercise with local projections, where the shock is identified with the Proxy SVAR approach and confidence bands generated with the wild bootstrap approach. **Rows 4-6** repeat **rows 1-3** exercise but with the QE variable dropped from the model. **Short Interpretation:** Across different IRF estimation approaches, there is always a statistically significant rise in UK real GDP and UK CPI to UK forward guidance shocks, while QE never reacts to UK forward guidance. This shows that UK forward guidance has an effect on output and prices, even when these variables are left unrestricted, probably independent of the QE policy.

Economic theory suggests that forward guidance affects the macroeconomy through at least two different transmission channels. The reason that forward guidance can be so powerful in theory is because consumers and firms act today based on an expectation of strong economic growth in the future, as a result of the central banks' promise for interest rates to be lower than they would otherwise be. The other transmission channel is that retail short-term interest rates will be lower if lenders believe that the central bank will keep the short-term rate lower than it would have been without the forward guidance policy. We explore these different transmission channels next.

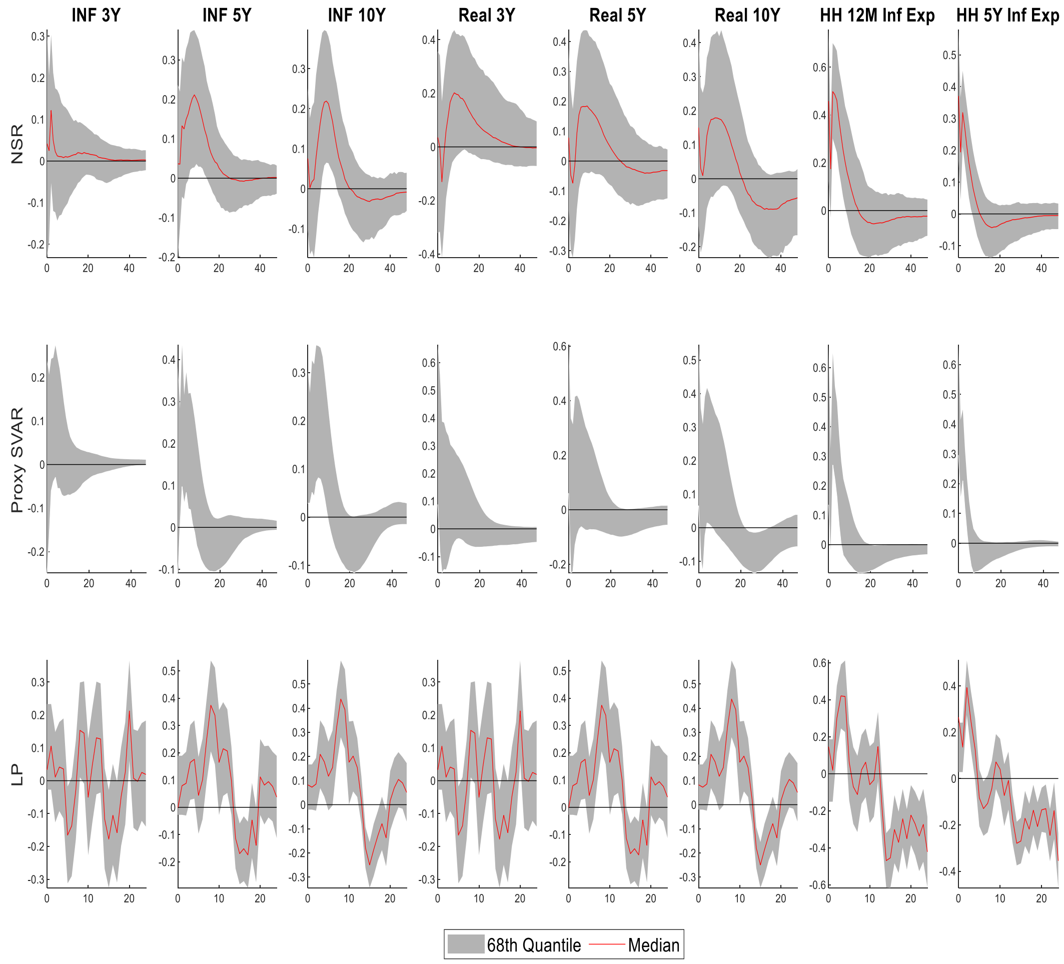
Figure 5 shows the effects of forward guidance on different measures of consumer and firm expectations. For direct surveys of firms and consumers, these are only available as net balances. They only report the net balance of respondents reporting a decrease or an increase in their expectation of a given variable. However, they can nevertheless still be useful in assessing whether agents' expectations changed in response to forward guidance. The net balance of consumers reporting an improvement in their economic outlook, personal financial situation, and a rise in durable goods purchases in 12 months, is statistically significant at the 68% quantile (columns 1-3) across all three models (rows 1 – 3). For firms, only firms in the services sector show a statistically significant response (columns 7 and 8). However, since 80% of the UK economy is made up of service activity, this shows that that majority of firms in the economy changed their production and price expectations after SDFG was announced.

Figure 5: Effects of forward guidance shocks on survey measures of firm and consumer expectations



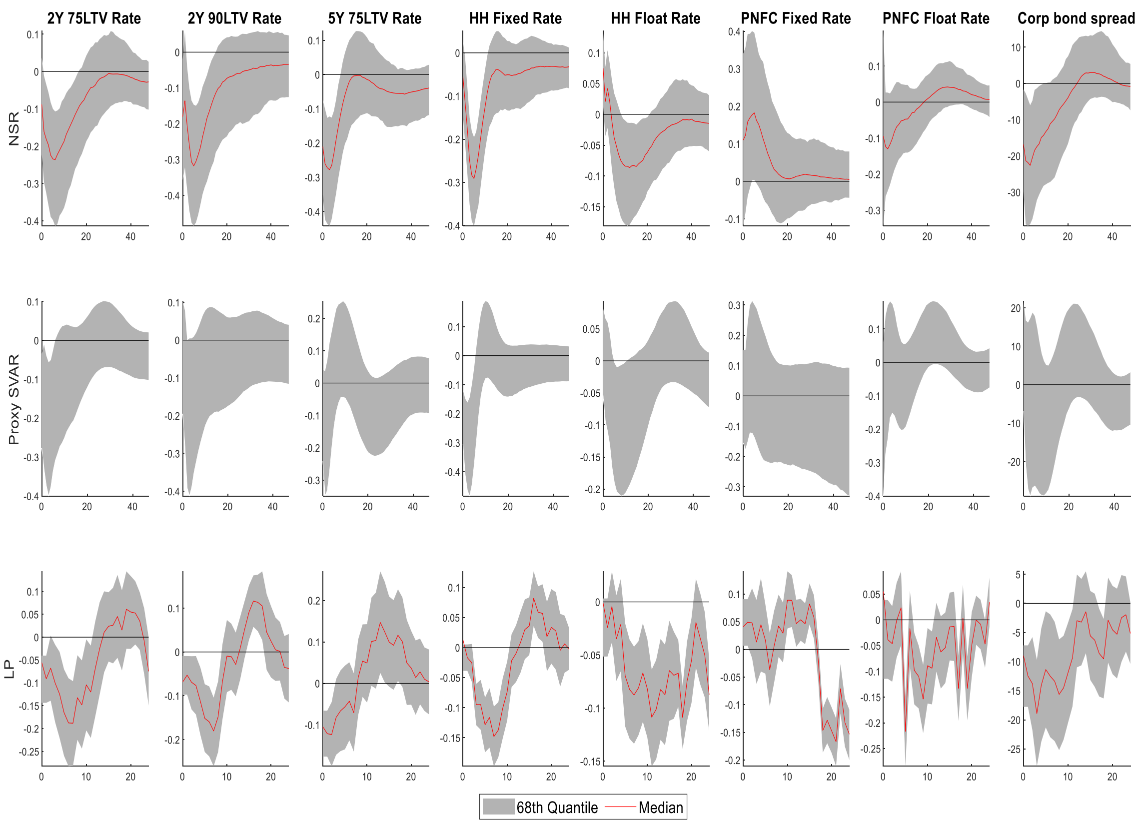
Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock across three different identification and estimation approaches. We only show the response of the 8th variable in the econometric model. The **column label** indicates the additional variable which has been included in the baseline model. The rows indicate the estimation and identification approach. **Row 1** shows results from including the relevant variable into the BVAR model identified with narrative sign restrictions. **Row 2** shows results from including the relevant variable into the proxy SVAR model. **Row 3** shows the results from including the relevant variable into the Local Projections model. **Column 1** shows results for the net balance of a consumer survey participants indicating a positive state of the general economic situation economy in 12 months. **Column 2** shows results for the net balance of a consumer survey participants indicating a positive state of their personal financial situation in 12 months. **Column 3** shows results for the net balance of a consumer survey participants indicating to purchase durable goods in 12 months. **Column 4** shows results for the net balance of consumer survey participants indicating higher CPI inflation in 12 months. **Column 5** shows results for net balance of industrial firms expecting higher production in 3 months. **Column 6** shows results for net balance of industrial firms expecting higher prices in 3 months. **Column 7** shows results for net balance of services firms expecting higher prices in 3 months. **Column 8** shows results for net balance of services firms expecting higher production in 3 months. **Short Interpretation:** Consumers expectations of their personal financial situation and the economy are statistically significant within the 68th percent quantiles. For firms, only the reaction of services firms price and production expectation is statistically significant across all three approaches.

Figure 6: Effects of forward guidance shocks on financial market and household inflation expectations



Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock across three different identification and estimation approaches. We only show the response of the 8th variable in the econometric model. The **column label** indicates the additional variable which has been included in the baseline model. The rows indicate the estimation and identification approach. **Row 1** shows results from including the relevant variable into the BVAR model identified with narrative sign restrictions. **Row 2** shows results from including the relevant variable into the proxy SVAR model. **Row 3** shows the results from including the relevant variable into the Local Projections model. **Column 1** shows results for the implied UK RPI inflation-linked 3-year government bond inflation expectation (difference between nominal and inflation-linked yield). **Column 2** shows results for the implied UK RPI inflation-linked 5-year government bond inflation expectation (difference between nominal and inflation-linked yield). **Column 3** shows results for the implied UK RPI inflation-linked 10-year government bond inflation expectation (difference between nominal and inflation-linked yield). **Column 4** shows results for the yield on UK RPI inflation-linked 3-year government bond. **Column 5** shows results for the yield on UK RPI inflation-linked 5-year government bond. **Column 6** shows results for the yield on UK RPI inflation-linked 10-year government bond. **Column 7** shows results for the Citibank consumer survey of CPI inflation expectations 12 months ahead. **Column 8** shows results for the Citibank consumer survey of CPI inflation expectations 5 years ahead. **Short Interpretation:** Only financial market measures of implied inflation expectations and consumer CPI inflation expectations are statistically significant at the 68th quantile level across all three approaches.

Figure 7: Effects of forward guidance shocks on different interest rate variables



Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock across three different identification and estimation approaches. We only show the response of the 8th variable in the econometric model and refer the reader to Appendix A for the responses of all 8 variables. The **column label** indicates the additional variable which has been included in the baseline model. The rows indicate the estimation and identification approach. **Row 1** shows results from including the relevant variable into the BVAR model identified with narrative sign restrictions. **Row 2** shows results from including the relevant variable into the proxy SVAR model. **Row 3** shows the results from including the relevant variable into the Local Projections model. **Column 1** shows results for the average rate quoted on a 2-year fixed rate mortgage with 75% LTV. **Column 2** shows results for the average rate quoted on a 2-year fixed rate mortgage with 90% LTV. **Column 3** shows results for the average rate quoted on a 5-year fixed rate mortgage with 75% LTV. **Column 4** shows results for effective (lend not just quoted) fixed rate on household mortgages. **Column 5** shows results for effective (not just quoted) floating rate on household mortgages. **Column 6** shows results for effective (not just quoted) fixed rate on PNFC lending. **Column 7** shows results for effective (not just quoted) floating rate on PNFC lending. **Column 8** shows results for BAA-AAA GBP corporate bond spreads. **Short Interpretation:** Regardless of approach, UK forward guidance has a statistically significant effect on quoted and effective household mortgage rates at shorter maturity.

Figure 6 shows the effects of forward guidance on financial market and consumers inflation expectations. Columns 1, 2 and 3 of figure 6 show the impulse responses of implied RPI inflation expectations by the Gilt market at various time horizons. Columns 3 to 6 shows the response of RPI-linked Gilt yields (real long-term interest rates). Out of these six variables, only implied inflation expectations at the 5 year and 10 year horizon show a clear statistically significant response to our identified forward guidance shock. This suggests that there is more evidence that inflation expectations rise in response to state-dependent forward guidance as opposed to real long-term rates. Similarly, only the responses of consumer survey 12 months and 5-year inflation expectations are highly statistically significant in response to forward guidance. Overall, these results suggest that the SDFG implemented by the Bank of England raised inflation expectations by about 20 basis points.

Figure 7 adds several short-term interest rates facing UK households and firms to the proposed empirical models to explore the transmission mechanism through short-term rates. Column one shows the response of the mean rate quoted on a 2 year, 75% LTV mortgage. This is negative and statistically significant across all three rows, meaning across all three models proposed in this paper. Quoted rates on riskier 90% LTV mortgages also decline and are statistically significant in all of the models. This is not the case for quoted rates on 5 year mortgages. This suggests that the policy was mostly transmitted to short-term mortgage interest rates. Column 4 and 5 shows the impulse response of fixed and floating bank lending rates to households, which is statistically significant and negative. This suggests that the decline in quoted mortgage rates is reflected in effective rates at which households have actually borrowed. However, effective rates to private non-financial corporates do not show any statistically significant effect in response to forward guidance. Overall, this suggests that a 33bps state-dependent forward guidance shock in the UK reduced mortgages rates to households by about 30bps.

3.5 Examining the robustness of our results

In this section, we examine the robustness of our results to changes in the identification scheme, definition of interest rate expectations, a number of potentially omitted variables and weak instruments.

We rely on narrative sign restrictions to identify state-dependent forward guidance. There is some degree of flexibility in identifying state dependent forward guidance shocks with this approach. We explore if this makes a difference in Figure A1 in appendix A. Changing both narrative sign restriction to weak, as defined in Antolin-Diaz and Rubio-Ramirez (2018), i.e. requiring that the forward guidance shock explains only the greatest fraction of the historical decomposition of the mean and dispersion of interest rate expectations, rather than greater than the sum of all shocks, does not change the results. Identifying a QE shock, as in Weale and Wieladek (2016), in addition to the forward guidance shock leaves the impulse responses to a forward guidance shock unchanged. Finally, Jarocinski and Karadi (2018) recently propose the identification of a central bank information shock. Identifying this shock in addition to our proposed forward guidance shock does not change the main results either.

We used the mixed frequency principal components approach to extract the common component from measures of the mean and the standard deviation of interest rate expectations. A popular alternative to extract a dynamic component in a mixed frequency setting is the Kalman Filter. Similarly, we show results when the original rather than adjusted consensus series are used in the mixed-frequency PCA EM algorithm. Finally, we also estimate the model on the sample used in Weale and Wieladek (2016). Figures A2, A6 and A10 show the results for narrative sign restriction, proxy SVAR and local projections models, respectively. None of these changes affect the results meaningfully.

Figures A3, A7 and A11 show results when we add a number of domestic variables to our proposed models, such as the exchange rate, measures of the VIX and UK policy uncertainty to the Narrative Sign restrictions, Proxy SVAR and local projection models, respectively. There is always a risk, however, that impulse responses reflect economic or policy developments in foreign countries. We add a number of foreign variables to explore if this is the case. These are the 10-year Bund yield, the 10-year yield spread between Italian and German government debt, the ECB's balance sheet as a share of Euro Area GDP, Federal Reserve QE and the US 10-year government bond yield. These variables were chosen to reflect that shocks from both the Euro Area and the United States can have a significant impact on UK economic dynamics. Since the UK is a small open economy with respect to these much larger economies, we include these variables as contemporaneous exogenous variables in the proposed models one-by-one. Figures A4, A8 and A12 show the results for the narrative sign restrictions, proxy SVAR and local projection models, respectively. Overall, the results are robust to including all of these different variables to our empirical framework, which suggests that omitted variable bias is not a problem.

Proxy SVARs sometimes suffer from instruments that are weak, which means that the results are typically not reliable. Stock and Yogo (2002) recommend an F-test statistic of 10 or more in the first stage regression to reject the possibility of a weak instrument. Alternatively, Mertens and Ravn (2013) propose the squared correlation of the narrative instrument and the true shock as a reliability measure for the instrument.

Table 3 **s**hows the regression result from the first stage regression. In most specifications, the F-statistic is around 10 or slightly above. This suggests that we can reject the null hypothesis of a weak instrument. Lee, McCrary, Moreira and Porter (2022) argue that maintaining 10 as the weak instrument threshold required replacing the critical value for the t-statistics with 3.43 rather than 1.96. The t-statistics are above 3.43 in all but one specification, which is just slightly below this value.

Table 3: Weak Instrument tests

	The dependent variable is the R-STD residual from the following models:			
	Baseline VAR model	Weale & Wieladek sample	Kalman Filter	PCA with Consensus original series
FG – Instrument	0.89**	0.89**	1.08**	0.80**
	[3.51]	[3.49]	[3.27]	[3.84]
Observations	85	61	85	85
F-statistic (1st stage)	12.05	11.79	10.43	14.38
Reliability	0.58	0.58	0.59	0.56

Note: This table shows the regression results from regressing the Proxy SVAR instrument on the residual of the principal component standard deviation of rate expectations VAR equation across several different specifications. The F-statistic is always above 10, the recommended level in Stock and Yogo (2002) to reject the null hypothesis of a weak instrument. The reliability statistic shows a correlation of 0.75 between the proxy and the proposed shock.

Finally, the reliability statistic in the range of 0.56-0.58 implies a 0.75 correlation between the narrative proxy and the true shock.This is a high value by the standard of the original Mertens and Ravn (2013) work and the literature in general. Overall, this analysis suggests that the instrument we employ is reliable and leads to statistically significant findings, even by criteria proposed in recent work.

An important maintained assumption in SVAR studies is informational sufficiency. This means that the variables in the VAR model provide all of the necessary information to identify the structural shock of interest. If this assumption is violated, the structural shock cannot be identified without additional variables. Forni and Gambetti (2014) propose a multi-variate Granger-Causality test to test for informational sufficiency. We rely on this approach to show that we can reject the null hypothesis of informational insufficiency in our proposed VAR model (see appendix B for details).

The most challenging aspect of identifying a new macroeconomic shock is to show credibly that the identified shock is new, rather than a previously explored shock with a different identification scheme. We have shown that our identified forward guidance shock is separate from QE. But there is a risk that we are identifying central bank information instead of SDFG shocks.

Several reasons suggest that this risk is small. First, an event study of the August 2013 forward guidance announcement, the event we show is behind the VAR results, is not consistent with a central bank information shock (See appendix D). Second, identifying a separate Central Bank identification shock, based on the sign restrictions presented in Jarocinski and Karadi (2020), has no effect on our results (see figure A1 in appendix A). Third, Nakamura and Steinsson (2018) show that the information effect leads to a rise in the real long-term rate, but not implied inflation expectations. Our VAR results in Figure 6 show a statistically significant rise in long-term inflation expectations, but not real long-term rates. Finally, the Bank of England provides inflation and GDP forecasts of professional forecasters collected one week before the Bank of England's forecast is published. The difference between the consensus and the Bank of England forecasts provides a direct measure of the information effect. We include the variables as exogenous variables in the VAR model. These results are shown in Figures A5/A9/A13 in appendix A for the narrative sign restrictions/proxy SVAR/local projection model. Our results remain unchanged. All of this evidence strongly supports the interpretation of our identified shocks as forward guidance[27].

4 Conclusion

Since the onset of the ZLB for interest rates, QE and forward guidance have entered central banks' arsenal to stimulate demand. The Federal Reserve's recent adoption of state-dependent forward guidance, and subsequent concern about rising long-term inflation expectations, shows that understanding the macroeconomic effects of this policy is at the heart of the current policy debate. But, unlike for QE, there are no previous empirical studies which examine the macroeconomic effects of SDFG because the Federal Reserve (December 2012/September 2020) and the ECB (September 2019) announced this policy

[27] We refer the reader to appendix B for a more in-depth discussion of all these arguments.

together with open-ended QE. Separating the effects of SDFG from QE in US and EA data is therefore practically impossible. This is the first paper to credibly estimate the macroeconomic effects of SDFG, including on real activity and long-term inflation expectations, based on the experience of the Bank of England, where this problem does not arise because SDFG was announced more than a year after the last QE announcement.

We begin our analysis by proposing a NK model with a stochastic demand shock that can push the economy to the ZLB, as in Adam and Billi (2006). SDFG is represented by an interest rate threshold, with the policy rate held at the ZLB until a Taylor rule exceeds the threshold. The exit from guidance is therefore entirely dependent on the path of CPI inflation and the output gap. This approach offers a straightforward means of modelling SDFG as adopted by the Bank of England. Simulations from this model show that an SDFG shock reduces the dispersion (standard deviation) of interest rate expectations across many plausible model parametrisations. This finding is the foundation block of the empirical identification strategies used in this paper.

We then proceed to estimate the effects of the Bank of England's forward guidance in August 2013 and February 2014 with the narrative sign restriction (Antolin-Diaz and Rubio-Ramirez, 2018), proxy SVAR (Mertens and Ravn, 2013) and local projection approach to ensure that our conclusions are robust to identification and estimation method. The key assumption underlying our identification strategies is that changes in the standard deviation of interest rate expectations at the August 2013 and February 2014 policy announcements were mainly due to forward guidance. Importantly, while we adopt agnostic identification schemes with respect to real activity and prices, the results confirm that the policy had the effect of raising both CPI and GDP by about 0.4%. This conclusion is robust to the inclusion of additional variables and to the precise identification scheme adopted. In line with macroeconomic theory, price and activity expectations of consumers and services firms react to this policy. SDFG also leads to reductions in interest rates charged to households, but not to private firms. Finally, the empirical results are quantitatively similar to the simulations from the proposed NK model. This suggests that with SDFG, there does not appear to be a 'forward guidance puzzle'. But we also find evidence that UK SDFG raised financial market and consumer long-term inflation expectations. Our conjecture is that this finding reflects the Bank of England's announcement that guidance will cease to bind when the Bank's inflation forecast exceeds 2.5%. To our knowledge this is the first paper to provide evidence that long-term inflation expectations can rise in response to SDFG.

SDFG was one of the most prominent tools to support the economic recovery from the Covid-19 recession. But there is no previous work which examines the macroeconomic effects of this policy. This is the first paper to examine this important issue, exploring the experience of the Bank of England. Our empirical work shows that SDFG had a modest effect on CPI and real GDP of about 0.4%. Since the effects of QE1 in the UK were an order of magnitude larger, this suggests that SDFG alone is probably insufficient to mitigate large demand shocks. But there is also strong evidence that this policy led to a 0.2% rise in financial market and consumer inflation expectations. Indeed, raising inflation expectations to increase actual inflation is a stated goal of both the ECB's and Federal Reserve's recent forward guidance policies. To our knowledge, this is the first paper to show that SDFG can achieve this goal. Although our reported effects are small, this could be the result of the Bank of England's conservative calibration of this policy. It is certainly plausible the inflation expectation effects of ECB and Federal Reserve SDFG are larger than those reported here.

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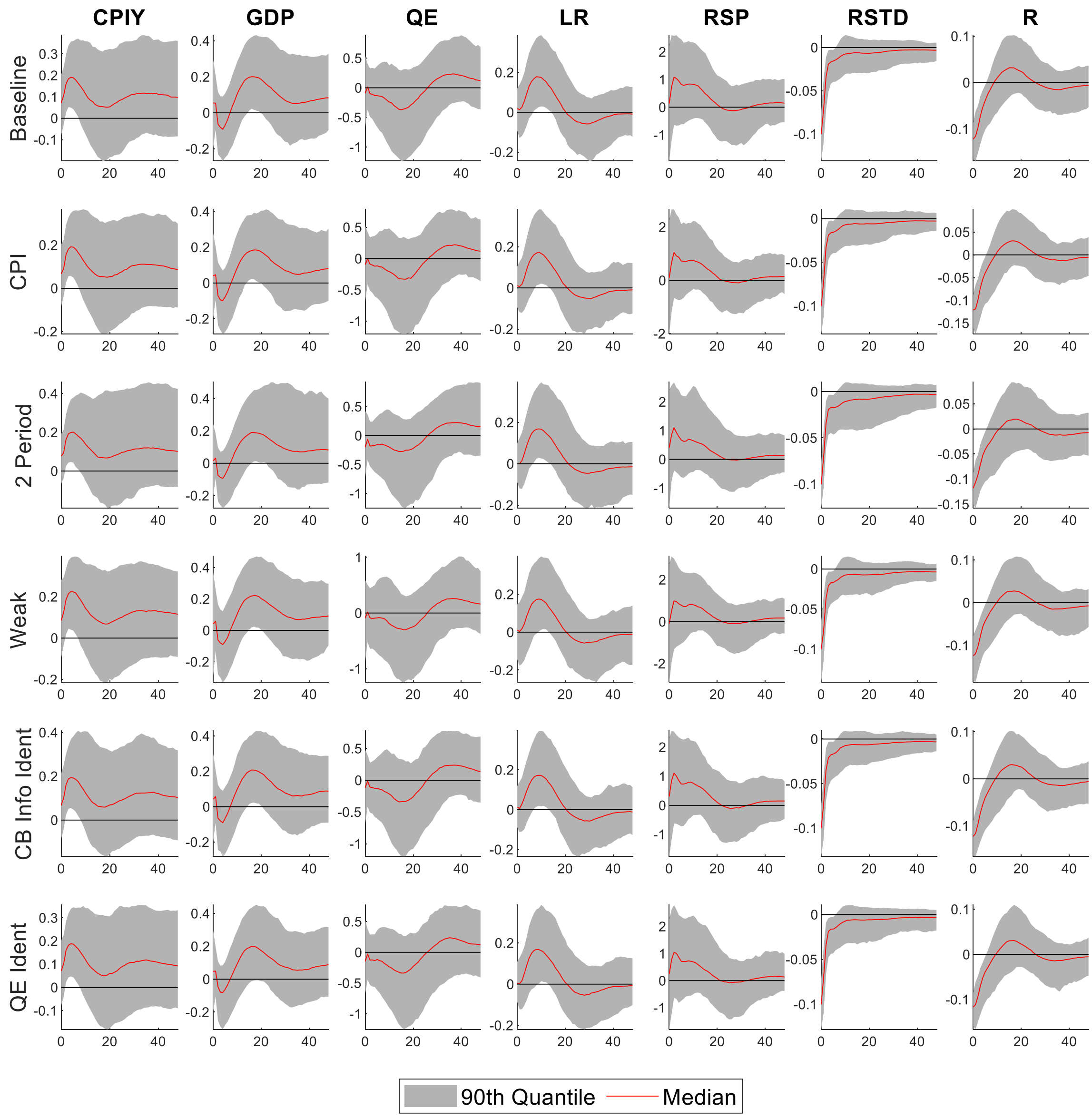
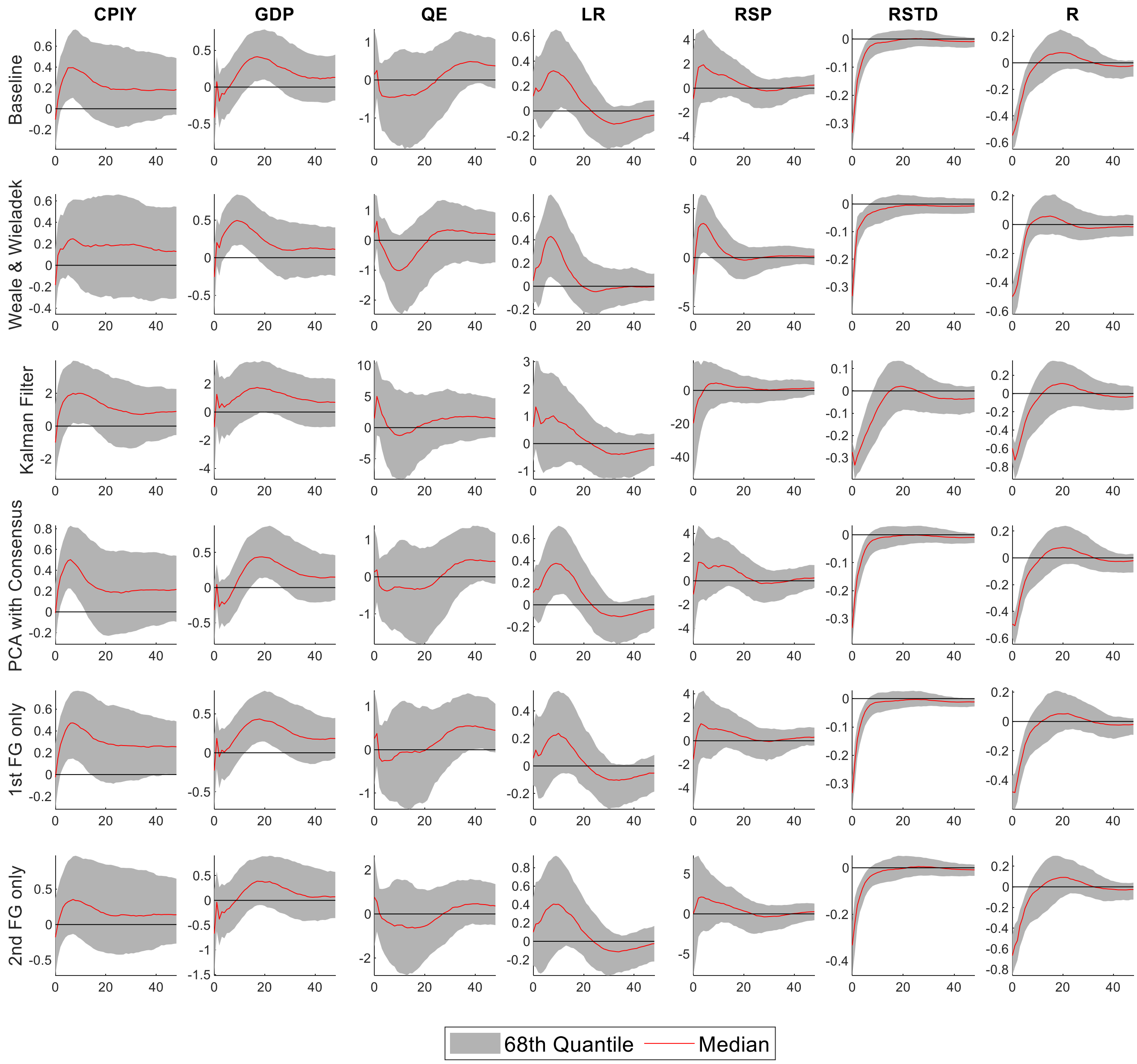
Appendix A – Exploring the robustness of the econometric approach

Figure A1: Exploring robustness to perturbations of the Narrative Sign Restriction identification scheme



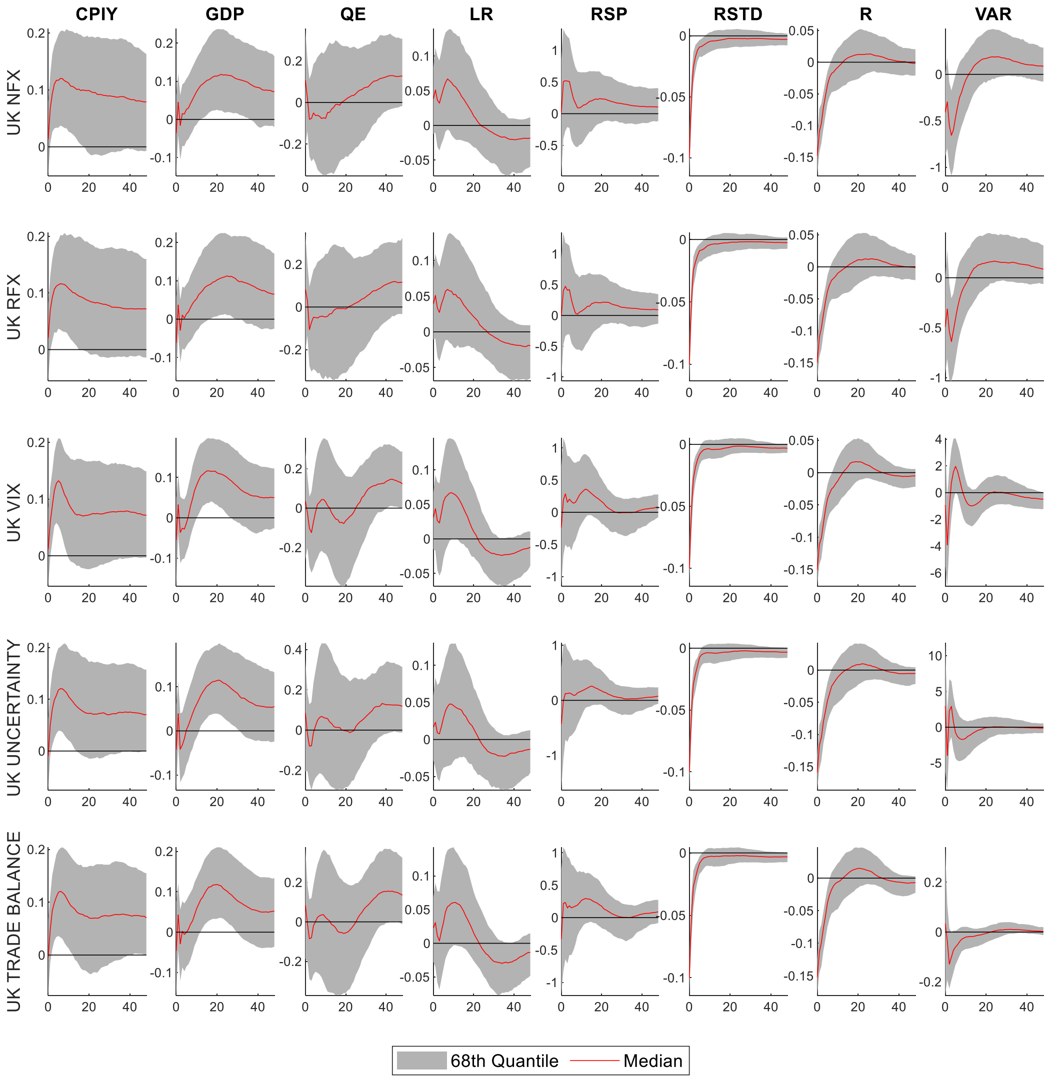
Notes: This figure shows impulse responses of UK variables to a 10bps forward guidance shock across different perturbations of the narrative sign restrictions identification scheme approach presented in Antolin-Diaz and Rubio-Ramirez (2018). The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses to a forward guidance shock identified with the baseline narrative sign restrictions identification scheme described in section 1. **Row 2** repeats row 1 but uses the conventional headline CPI, rather than CPIY. **Row 3** uses the strong historical decomposition identification restriction described in Antolin-Diaz and Rubio-Ramirez (2018) for both forward guidance dates. **Row 4** uses the weak historical decomposition identification restriction described in Antolin-Diaz and Rubio-Ramirez (2018) for both forward guidance dates **Row 5** shows impulse responses to the forward guidance shock, but from an SVAR where we also identified the QE shock is identified as in Weale and Wieladek (2016). **Row 6** shows impulse responses to the forward guidance shock, but from an SVAR where we also identified the Central Bank Information shock defined in Jarocinski and Karadi (2020). **Short Interpretation:** This robustness exercise shows that UK forward guidance has an effect on output and prices, even when these variables are left unrestricted, across a number of different perturbations to the standard sign restriction identification scheme.

Figure A2: Exploring robustness to perturbations of Forward Guidance Indicators/ Sample – Narrative Sign Restriction approach



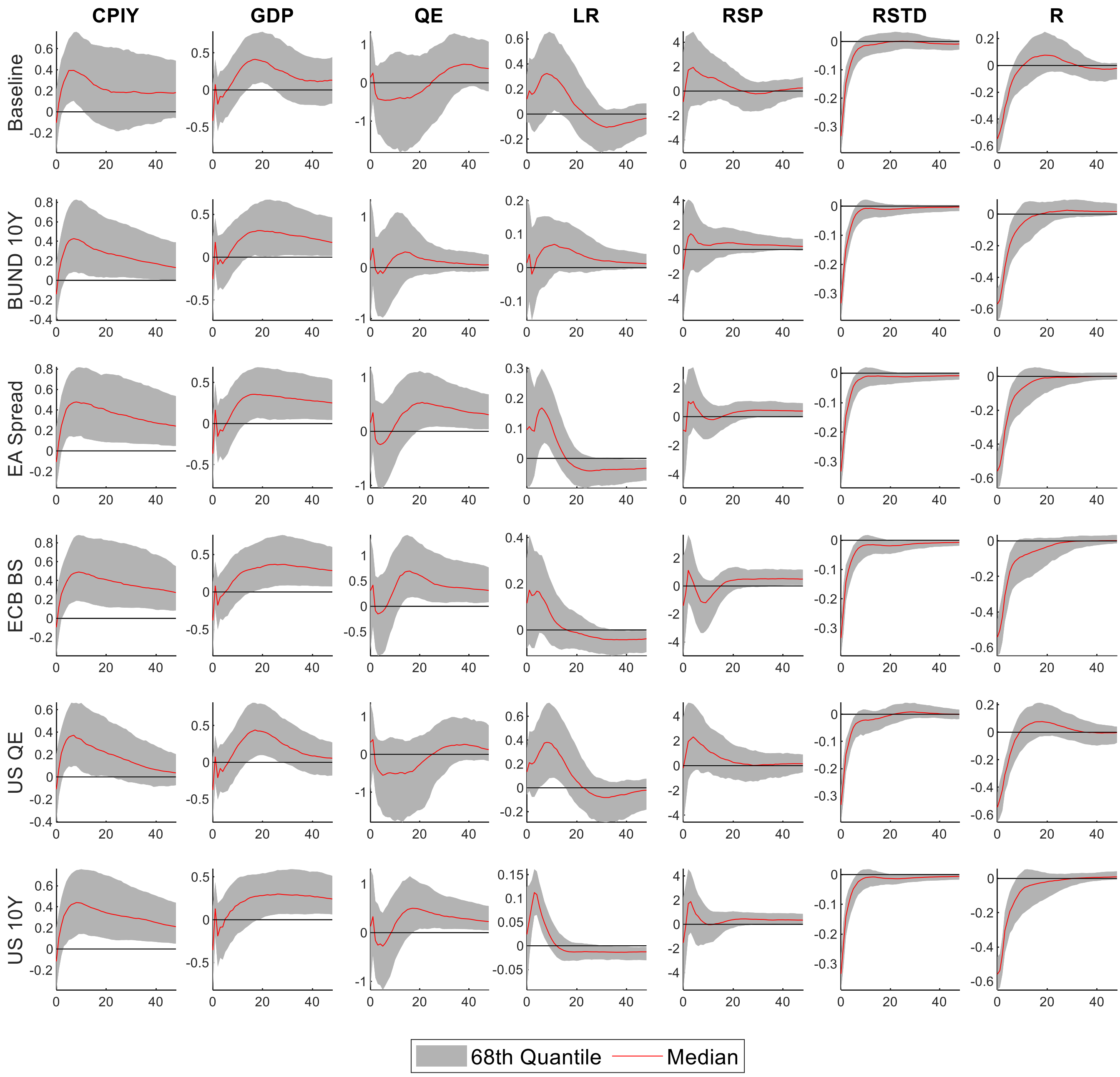
Notes: This figure shows impulse responses of UK variables to a 10bps forward guidance shock across different perturbations of the narrative sign restrictions identification scheme approach presented in Antolin-Diaz and Rubio-Ramirez (2018). The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses to a forward guidance shock identified with the baseline narrative sign restrictions identification scheme described in section 1. **Row 2** repeats row 1 but estimated on the sample from March 2009 to May 2014 in Weale and Wieladek (2016). **Row 3** uses a Kalman filter rather than principal component approach to extract mean and standard deviation expectations. **Row 4** uses the original consensus series, rather than our proposed adjusted series, in the principal component extraction of mean and standard deviation interest rate expectations. **Short Interpretation:** The results are robust to a smaller sample period and different ways of measuring interest rate expectations variables.

Figure A3: Exploring robustness to inclusion of other domestic macroeconomic variables – Narrative Sign Restriction approach



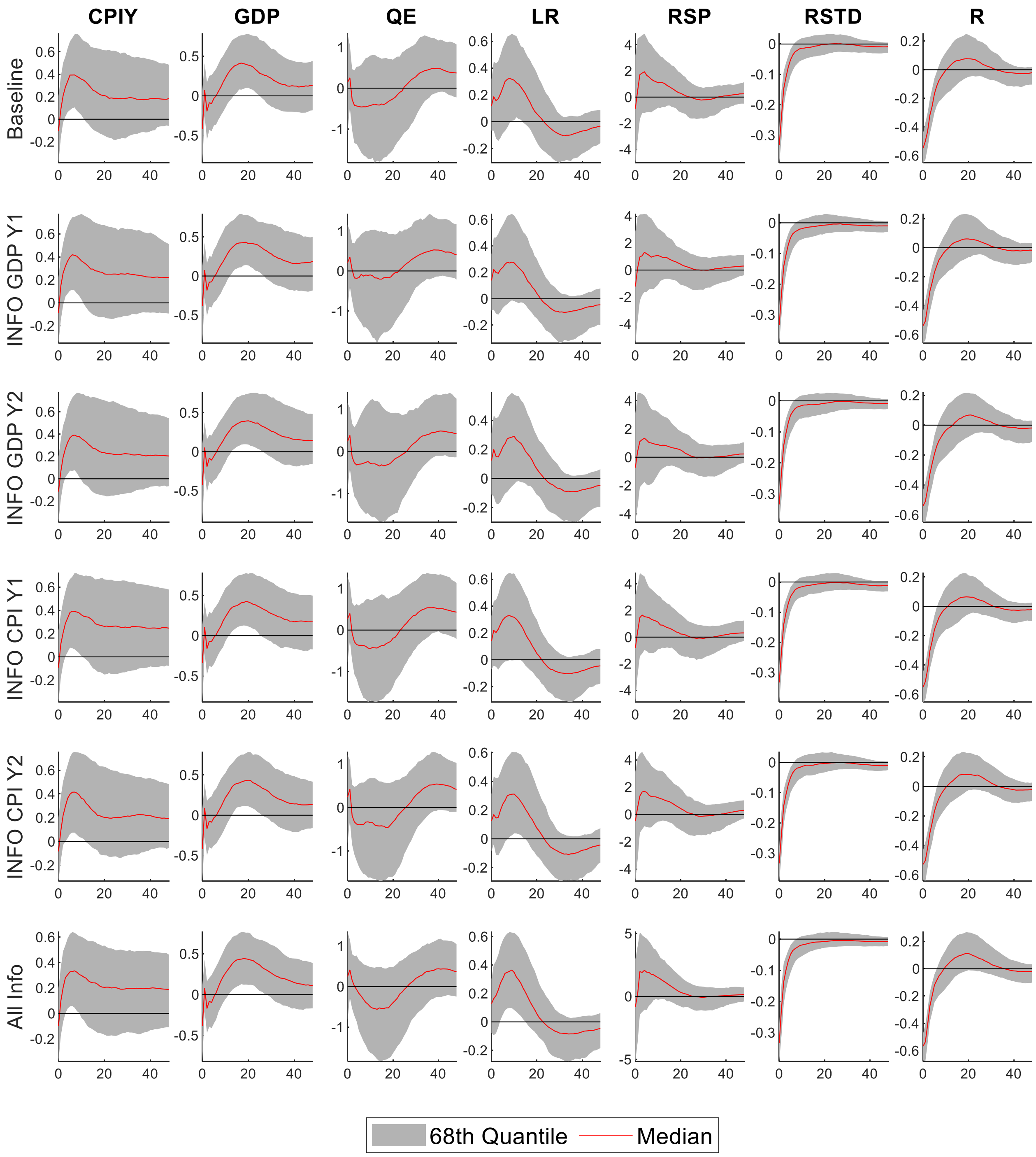
Notes: This figure shows impulse responses of UK variables to a 10bps forward guidance shock when different macroeconomic variables are included, identified with the narrative sign restrictions identification scheme approach presented in Antolin-Diaz and Rubio-Ramirez (2018). The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses to a forward guidance shock with the log of a UK nominal exchange rate index included as an 8th variable in the model. **Row 2** shows impulse responses to a forward guidance shock with the log of a UK real exchange rate index included as an 8th variable in the model. **Row 3** shows impulse responses to a forward guidance shock with the log of the UK VIX included as an 8th variable in the model. **Row 4** shows impulse responses to a forward guidance shock with the log of the UK uncertainty index included as an 8th variable in the model. **Row 5** shows impulse responses to a forward guidance shock with the UK Trade Balance as a share of GDP as an 8th variable in the model. **Short Interpretation:** The results are robust to including additional variables into the model.

Figure A4: Exploring robustness to inclusion of external macroeconomic variables – Narrative Sign Restriction approach



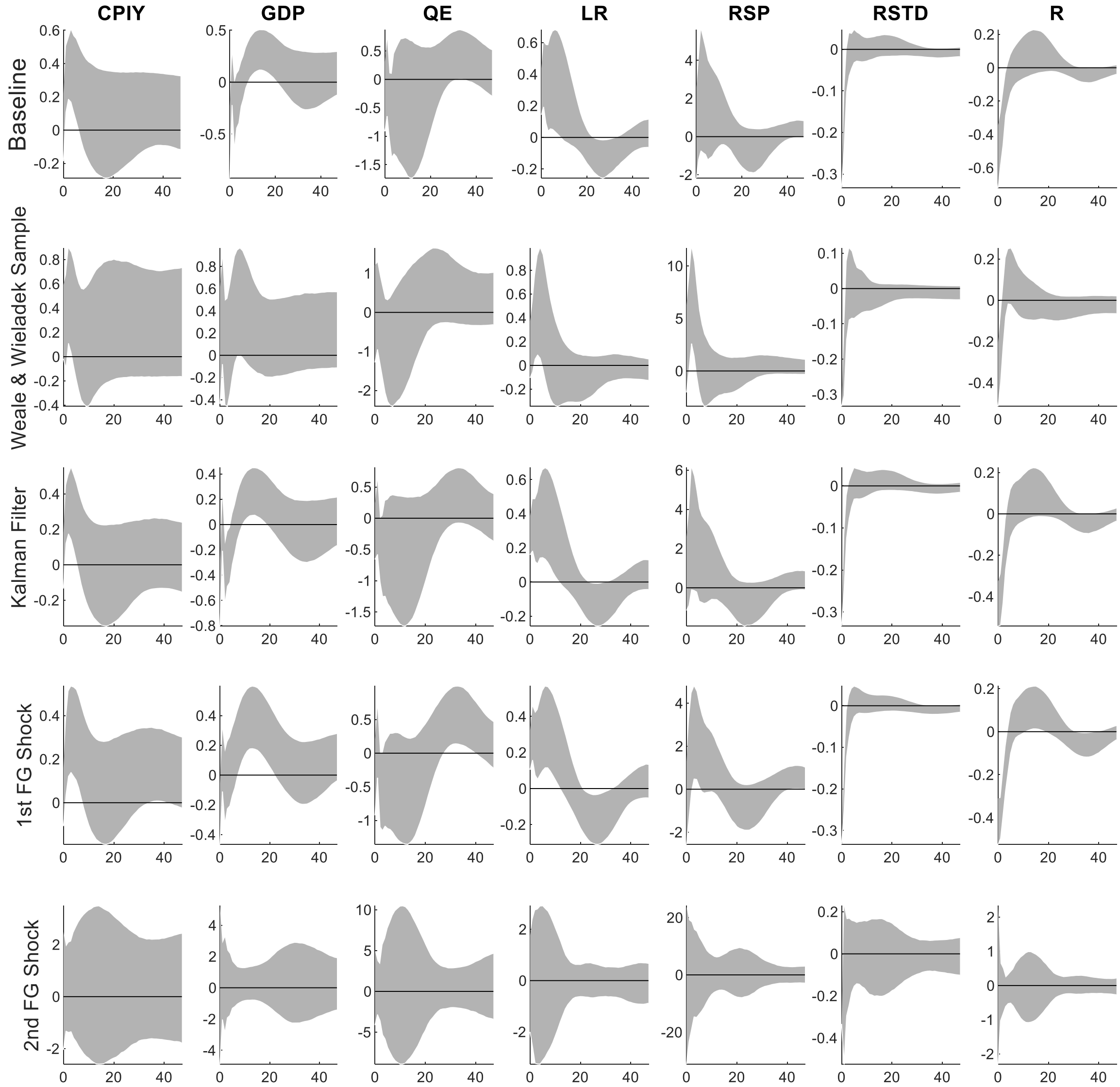
Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock when different information effect variables are included as exogenous in the model. The SDFG is identified with the narrative sign restrictions identification scheme approach presented in Antolin-Diaz and Rubio-Ramirez (2018). The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses from the Baseline model. **Row 2** shows impulse responses to a forward guidance shock with the 10-year Bund yield as a contemporaneous exogenous variable. **Row 3** shows impulse responses to a forward guidance shock with the spread between Italian and German government bond yields as a contemporaneous exogenous variable. **Row 4** shows impulse responses to a forward guidance shock with the ECB's Balance sheet as a share of GDP as a contemporaneous exogenous variable. **Row 5** shows impulse responses to a forward guidance shock with the US QE series from Weale and Wieladek (2016) as a contemporaneous exogenous variable. **Row 6** shows impulse responses to a forward guidance shock with the US Treasury 10-year yield as a contemporaneous exogenous variable.
Short Interpretation: The results are broadly robust to including a number of global exogenous variables.

Figure A5: Exploring robustness to inclusion of exogenous information effect shocks – Narrative Sign Restriction approach



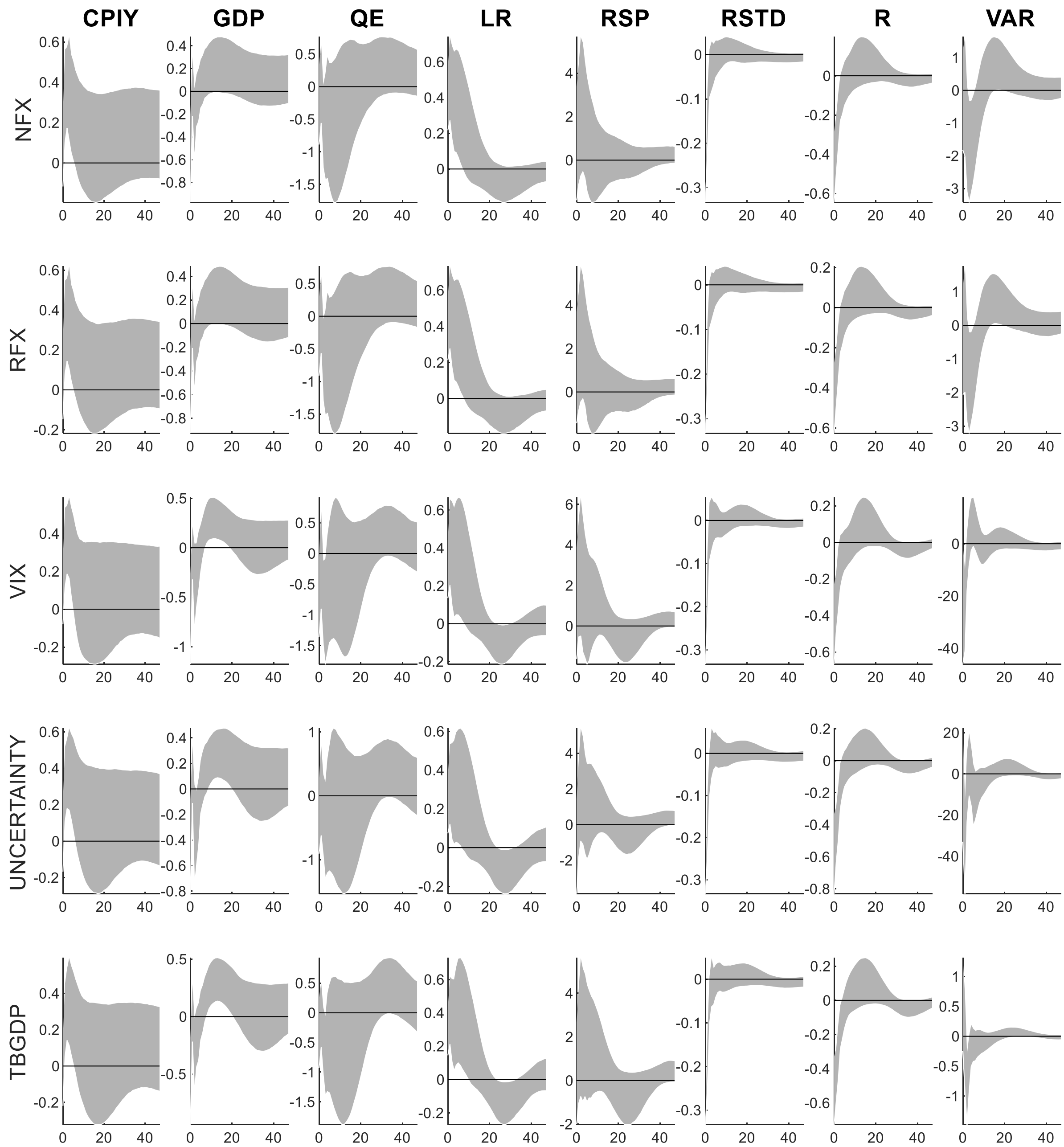
Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock when different information effect variables are included as exogenous in the model. The SDFG is identified with the narrative sign restrictions identification scheme approach presented in Antolin-Diaz and Rubio-Ramirez (2018). The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses from the Baseline model. **Row 2** shows impulse responses to a forward guidance shock with the information effect for GDP one year ahead included as an exogenous variable. **Row 3** shows impulse responses to a forward guidance shock with the information effect for GDP two year ahead included as an exogenous variable. **Row 4** shows impulse responses to a forward guidance shock with the information effect for CPI inflation one year ahead included as an exogenous variable. **Row 5** shows impulse responses to a forward guidance shock with the information effect for CPI inflation two years ahead included as an exogenous variable. **Row 6** shows impulse responses to a forward guidance shock with all four Information effect variables included as exogenous variables. **Short Interpretation:** The results are robust to including information effect variables, which suggests the identified shock is likely reflective of forward guidance rather than information effects.

Figure A6: Exploring robustness to perturbations of Forward Guidance Indicators/ Sample – Proxy SVAR approach



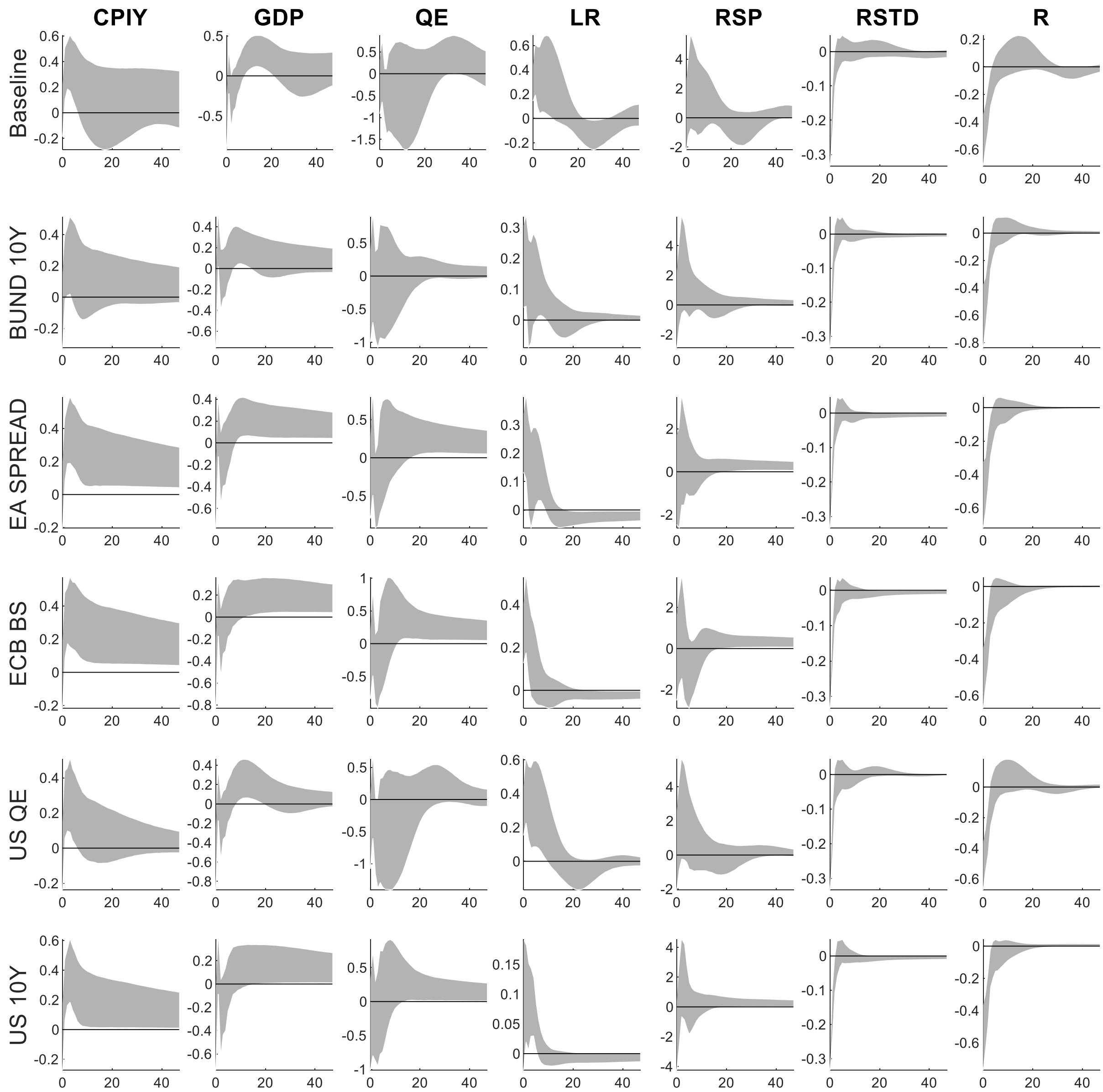
Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock across different perturbations of the proxy SVAR scheme presented in Mertens and Ravn (2013). The 68% quantile bands were constructed with the Moving Block Bootstrap approach presented in Jentsch and Lunsford (2018). The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses to a forward guidance shock identified with the baseline Proxy SVAR identification scheme. **Row 2** repeats row 1 but estimated on the sample from March 2009 to May 2014 in Weale and Wieladek (2016). **Row 3** uses a Kalman filter rather than principal component approach to extract mean and standard deviation expectations. **Row 4** uses the original consensus series, rather than our proposed adjusted series, in the principal component extraction of mean and standard deviation interest rate expectations. **Short Interpretation:** The results are robust to a smaller sample period and different ways of measuring interest rate expectations variables.

Figure A7: Exploring robustness to inclusion of other domestic macroeconomic variables – Proxy SVAR approach



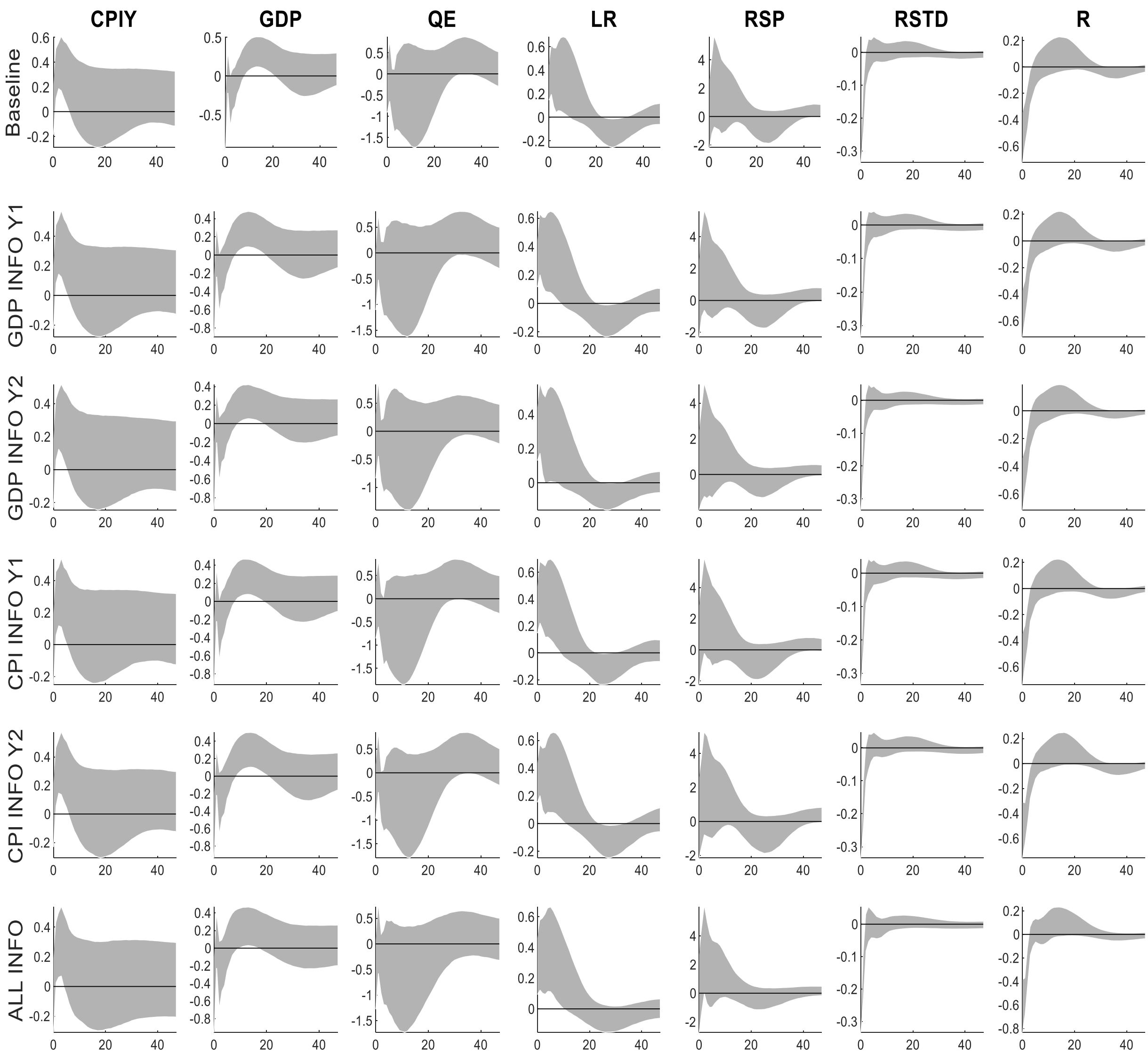
Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock across different perturbations of the proxy SVAR scheme presented in Mertens and Ravn (2013). The 68% quantile bands were constructed with the Moving Block Bootstrap approach presented in Jentsch and Lunsford (2018). The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses to a forward guidance shock with the log of a UK nominal exchange rate index included as an 8th variable in the model. **Row 2** shows impulse responses to a forward guidance shock with the log of a UK real exchange rate index included as an 8th variable in the model. **Row 3** shows impulse responses to a forward guidance shock with the log of the UK VIX included as an 8th variable in the model. **Row 4** shows impulse responses to a forward guidance shock with the log of the UK uncertainty index included as an 8th variable in the model. **Row 5** shows impulse responses to a forward guidance shock with the UK Trade Balance as a share of GDP as an 8th variable in the model. **Short Interpretation:** The results are robust to including additional variables into the model.

Figure A8: Exploring robustness to inclusion of foreign exogenous macroeconomic variables – Proxy SVAR approach



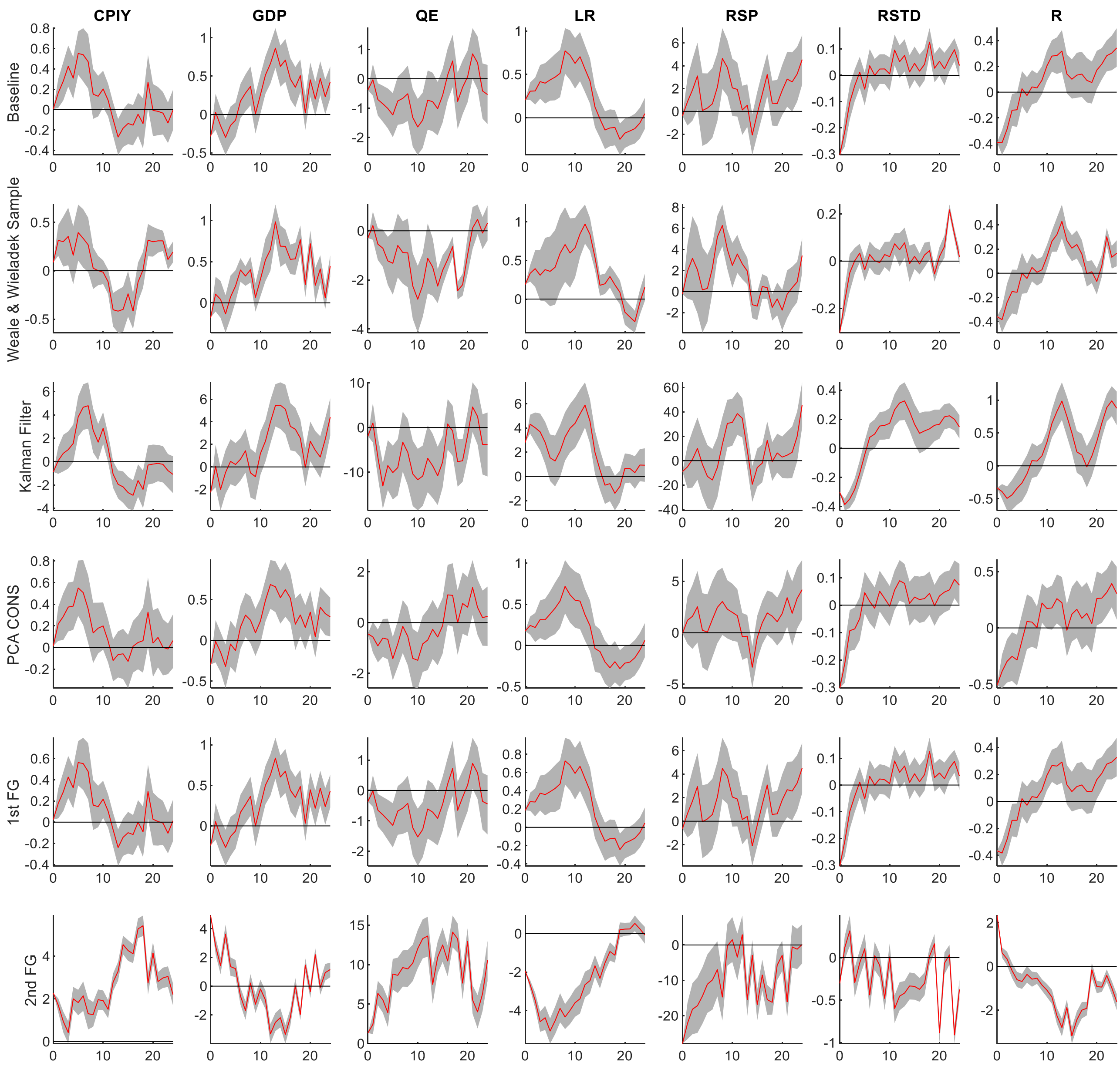
Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock across different perturbations of the proxy SVAR scheme presented in Mertens and Ravn (2013). The 68% quantile bands were constructed with the Moving Block Bootstrap approach presented in Jentsch and Lunsford (2018). The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses from the Baseline model. **Row 2** shows impulse responses to a forward guidance shock with the 10-year Bund yield as a contemporaneous exogenous variable. **Row 3** shows impulse responses to a forward guidance shock with the spread between Italian and German government bond yields as a contemporaneous exogenous variable. **Row 4** shows impulse responses to a forward guidance shock with the ECB's Balance sheet as a share of GDP as a contemporaneous exogenous variable. **Row 5** shows impulse responses to a forward guidance shock with the US QE series from Weale and Wieladek (2016) as a contemporaneous exogenous variable. **Row 6** shows impulse responses to a forward guidance shock with the US Treasury 10-year yield as a contemporaneous exogenous variable. **Short Interpretation:** The results are broadly robust to including a number of global exogenous variables.

Figure A9: Exploring robustness to inclusion of exogenous information effect shocks – Proxy SVAR approach



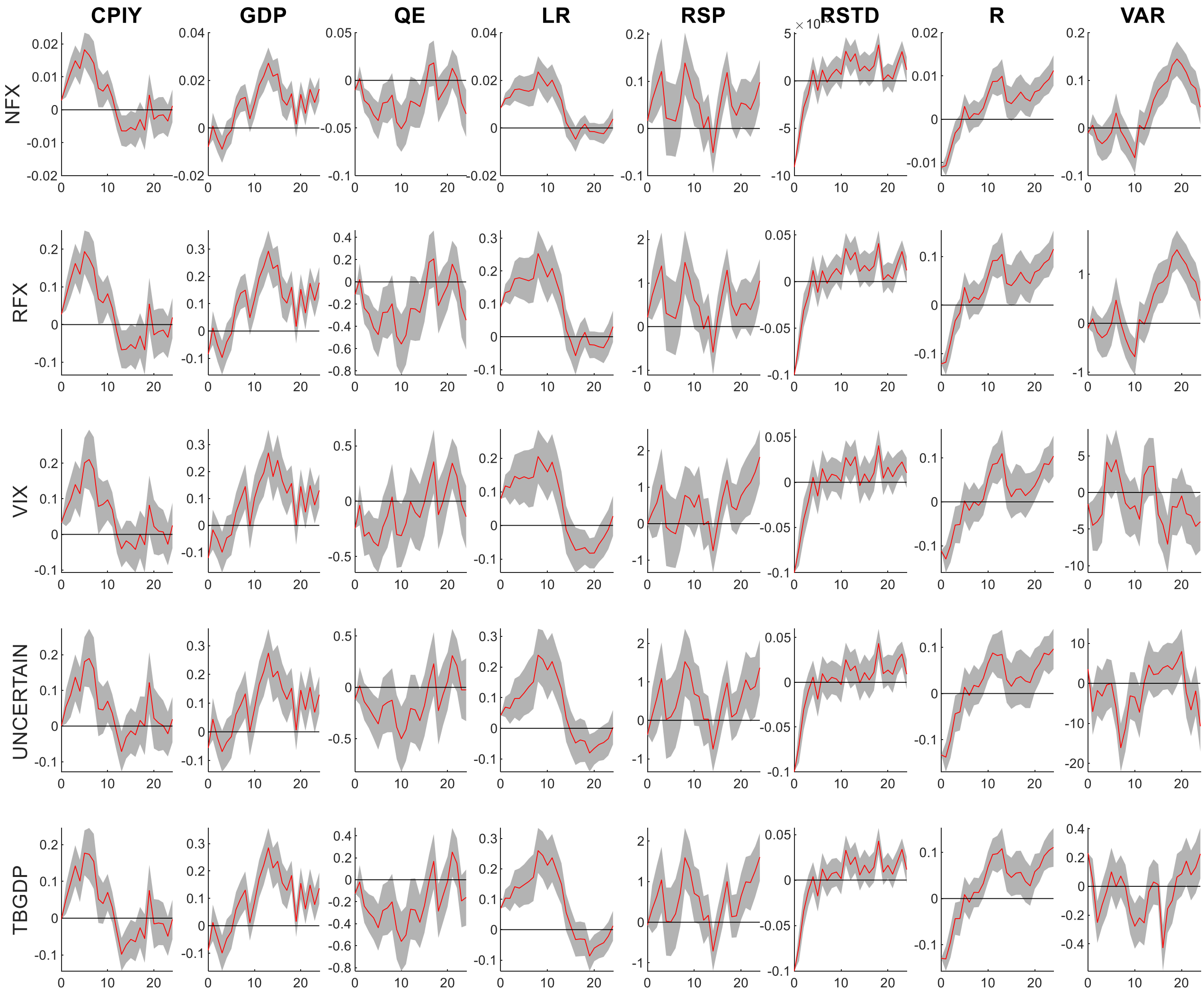
Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock across different perturbations of the proxy SVAR scheme presented in Mertens and Ravn (2013). The 68% quantile bands were constructed with the Moving Block Bootstrap approach presented in Jentsch and Lunsford (2018). The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses from the Baseline model. **Row 2** shows impulse responses to a forward guidance shock with the information effect for GDP one year ahead included as an exogenous variable. **Row 3** shows impulse responses to a forward guidance shock with the information effect for GDP two year ahead included as an exogenous variable. **Row 4** shows impulse responses to a forward guidance shock with the information effect for CPI inflation one year ahead included as an exogenous variable. **Row 5** shows impulse responses to a forward guidance shock with the information effect for CPI inflation two years ahead included as an exogenous variable. **Row 6** shows impulse responses to a forward guidance shock with all four Information effect variables included as exogenous variables. **Short Interpretation:** The results are robust to including information effect variables, which suggests the identified shock is likely reflective of forward guidance rather than information effects.

Figure A10: Exploring robustness to perturbations of Forward Guidance Indicators/ Sample – Local Projections approach



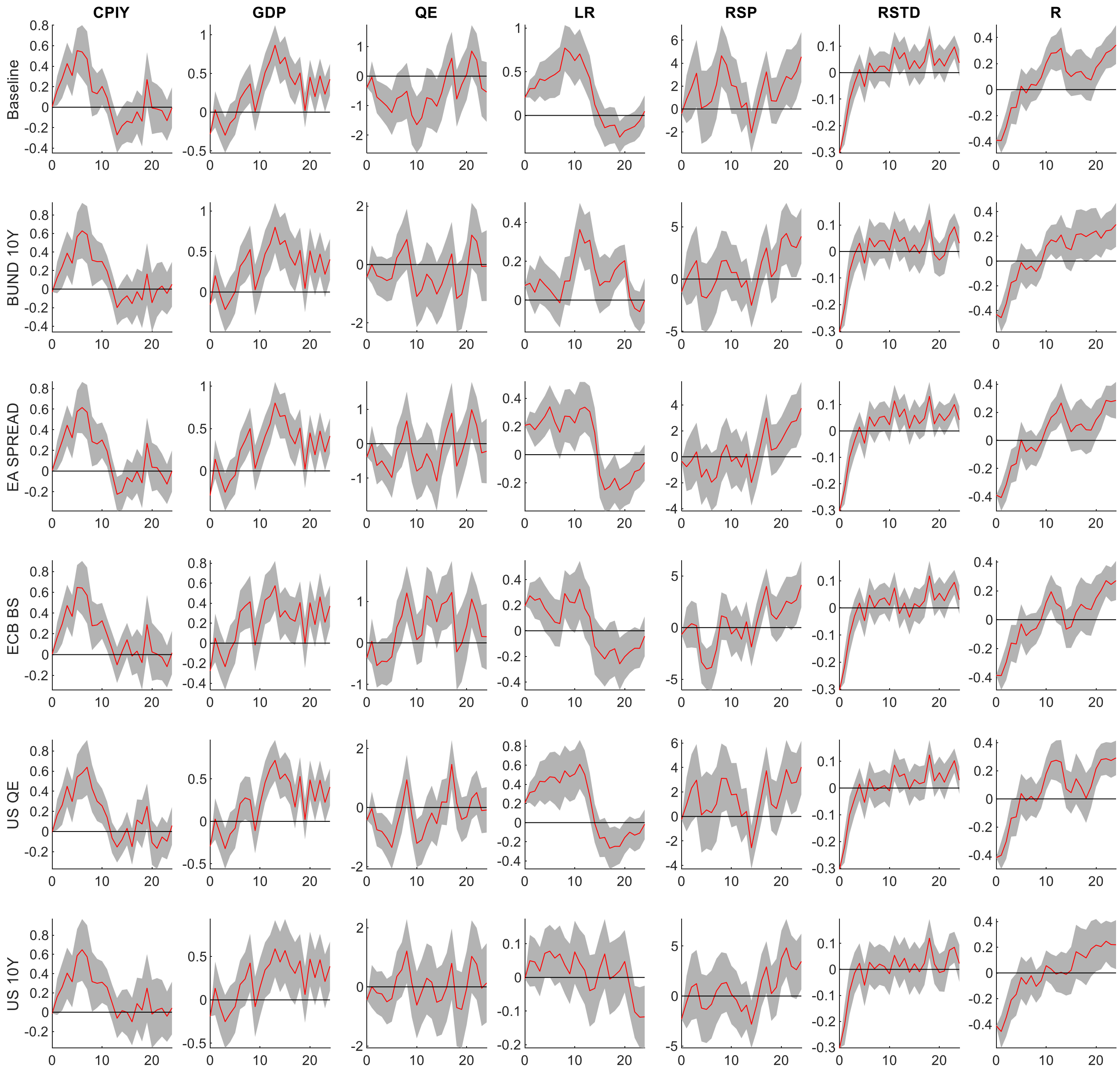
Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock estimated with local projections and identified with the proxy instrumental variable approach. The 68% confidence bands are generated with the wild bootstrap approach. The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses to a forward guidance shock identified with the baseline Proxy SVAR identification scheme. **Row 2** repeats row 1 but estimated on the sample from March 2009 to May 2014 in Weale and Wieladek (2016). **Row 3** uses a Kalman filter rather than principal component approach to extract mean and standard deviation expectations. **Row 4** uses the original consensus series, rather than our proposed adjusted series, in the principal component extraction of mean and standard deviation interest rate expectations. **Short Interpretation:** The results are robust to a smaller sample period and different ways of measuring interest rate expectations variables.

Figure A11: Exploring robustness to inclusion of other domestic macroeconomic variables – Local Projections approach



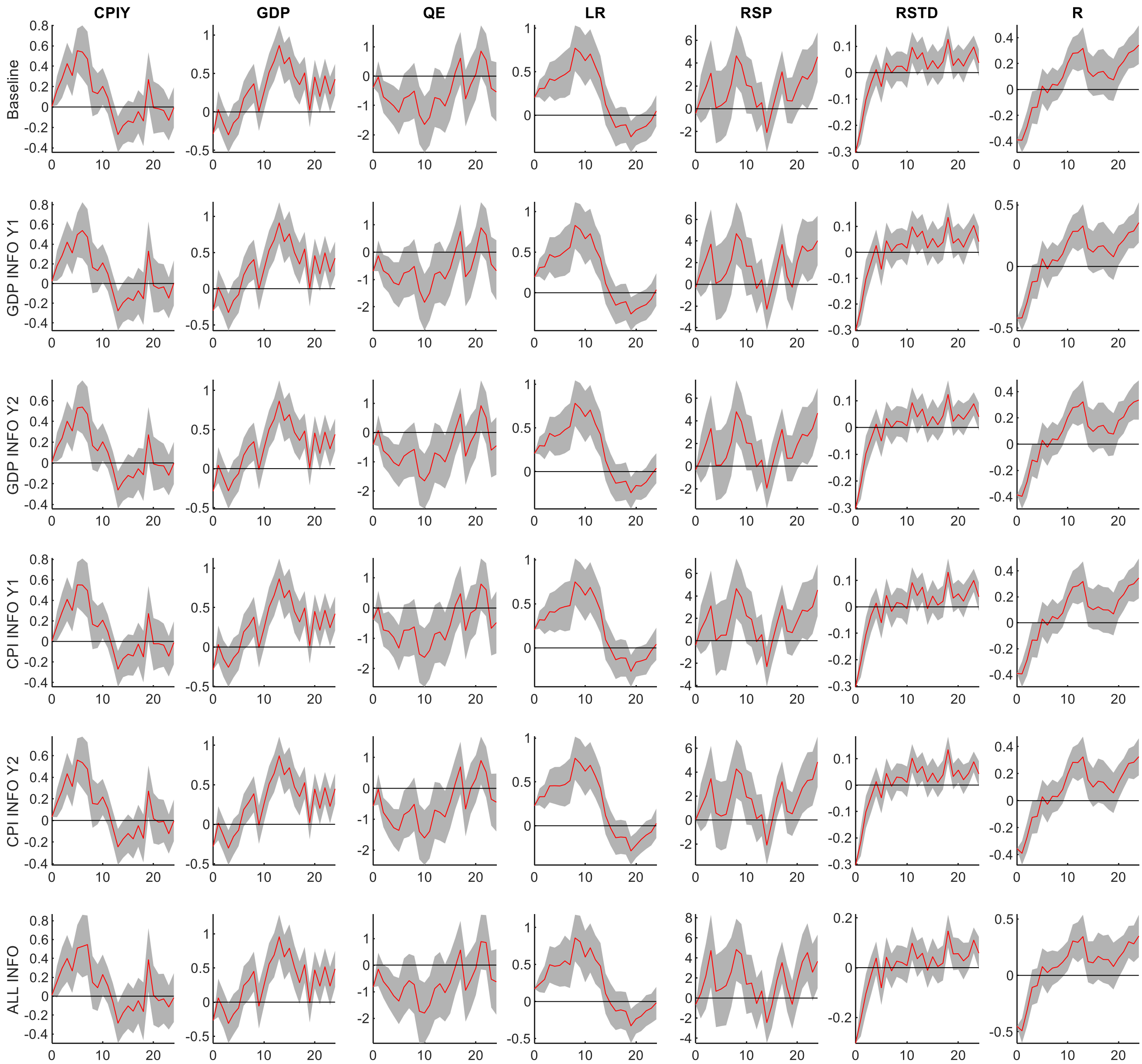
Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock estimated with local projections and identified with the proxy instrumental variable approach. The 68% confidence bands are generated with the wild bootstrap approach. The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses to a forward guidance shock with the log of a UK nominal exchange rate index included as an 8th variable in the model. **Row 2** shows impulse responses to a forward guidance shock with the log of a UK real exchange rate index included as an 8th variable in the model. **Row 3** shows impulse responses to a forward guidance shock with the log of the UK VIX included as an 8th variable in the model. **Row 4** shows impulse responses to a forward guidance shock with the log of the UK uncertainty index included as an 8th variable in the model. **Row 5** shows impulse responses to a forward guidance shock with the UK Trade Balance as a share of GDP as an 8th variable in the model. **Short Interpretation:** The results are robust to including additional variables into the model.

Figure A12: Exploring robustness to inclusion of foreign exogenous macroeconomic variables – Local Projections approach



Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock estimated with local projections and identified with the proxy instrumental variable approach. The 68% confidence bands are generated with the wild bootstrap approach. The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses from the Baseline model. **Row 2** shows impulse responses to a forward guidance shock with the 10-year Bund yield as a contemporaneous exogenous variable. **Row 3** shows impulse responses to a forward guidance shock with the spread between Italian and German government bond yields as a contemporaneous exogenous variable. **Row 4** shows impulse responses to a forward guidance shock with the ECB's Balance sheet as a share of GDP as a contemporaneous exogenous variable. **Row 5** shows impulse responses to a forward guidance shock with the US QE series from Weale and Wieladek (2016) as a contemporaneous exogenous variable. **Row 6** shows impulse responses to a forward guidance shock with the US Treasury 10-year yield as a contemporaneous exogenous variable. **Short Interpretation:** The results are broadly robust to including a number of global exogenous variables.

Figure A13: Exploring robustness to inclusion of exogenous information effect shocks – Local Projections approach



Notes: This figure shows impulse responses of UK variables to a 33bps forward guidance shock estimated with local projections and identified with the proxy instrumental variable approach. The 68% confidence bands are generated with the wild bootstrap approach. The label below each impulse response figure indicates the name of the variable that is reacting to the forward guidance shock. The rows indicate different model specifications. **Row 1** shows impulse responses from the Baseline model. **Row 2** shows impulse responses to a forward guidance shock with the information effect for GDP one year ahead included as an exogenous variable. **Row 3** shows impulse responses to a forward guidance shock with the information effect for GDP two year ahead included as an exogenous variable. **Row 4** shows impulse responses to a forward guidance shock with the information effect for CPI inflation one year ahead included as an exogenous variable. **Row 5** shows impulse responses to a forward guidance shock with the information effect for CPI inflation two years ahead included as an exogenous variable. **Row 6** shows impulse responses to a forward guidance shock with all four Information effect variables included as exogenous variables. **Short Interpretation:** The results are robust to including information effect variables, which suggests the identified shock is likely reflective of forward guidance rather than information effects.

Appendix B: Exploring informational sufficiency and information effects

An important maintained assumption in SVAR studies is informational sufficiency. This means that the variables in the VAR model provide all of the necessary information to identify the structural shock of interest. If this assumption is violated, the structural shock cannot be identified without additional variables. In the case of Proxy SVAR, Miescu and Mumtaz (2019) show that proxy SVAR models tend to significantly under-estimate the effects of monetary policy on the real economy in the US. Our result that state-dependent forward guidance has a moderate effect on the real economy could therefore be due to econometric bias stemming from informational insufficiency.

Forni and Gambetti (2014) propose a multi-variate Granger-Causality test to for this informational sufficiency in VAR models. Their test relies on testing whether principal components from a large macro-financial dataset do not Granger-cause the variables in the VAR model. They illustrate their test with a productivity growth VAR model and extract principal components from 63 US series for the test. For the US, the standard dataset to extract principal components today is the FRED-MD dataset, first described in McCracken and Ng (2015). For the UK, the only comparable dataset is described in Miranda-Agrippino (2016), which is what we rely on in this paper. This is the dataset that we extract principal components from.

Table B1 shows the results from the Forni and Gambetti (2014) multi-variate Granger-Causality test. The null hypothesis is that the principal components do not Granger-cause the variables in the VAR. If the null-hypothesis is rejected, this indicates the presence of informational insufficiency. The p-values shown in table C1 are far above conventional statistical significance levels, meaning that the null-hypothesis cannot be rejected. This indicates that the VAR model adopted in this paper is likely to be informationally sufficient over the time period under consideration.

Table B1: Informational insufficiency tests

# of PCs	1	2	3	4	5	6	7	8	9	10
P-values	0.782	0.537	0.848	0.543	0.517	0.512	0.557	0.705	0.89	0.629

Note: This table shows results from the Multi-variate Granger Causality test of Forni and Gambetti (2014). The first row shows the number of Principal Components in the test. The second row shows the p-values. The null-hypothesis of no Granger-Causality cannot be rejected in any specification.

B.1 Are we identifying Central Bank Information rather than Forward Guidance shocks?

In the UK, major policy decisions, including SDFG, have been announced at the quarterly *Inflation Report* meeting, during which the Bank of England also released its updated quarterly forecasts. Nakamura and Steinsson (2018a,b) and Jarocinski and Karadi (2020) argue that the release of updated central bank forecasts affects agents' beliefs about economic fundamentals and hence future economic activity. The presence of these central bank information effects could therefore be a significant challenge to our study: At best our estimates over-estimate the effects of forward guidance; at worst all of the estimated effects are due to information effects and not forward guidance. This issue is particularly relevant in our study since we rely only on events for identification. Lunsford (2020) examines changes in Federal Reserve communication and shows that forward guidance about the state of the economy is associated with much stronger information effects than forward guidance about policy. But it is unclear if the same conclusion applies to the Bank of England. In this section we therefore examine whether our estimates of state-dependent forward guidance are affected by the presence of information shocks.

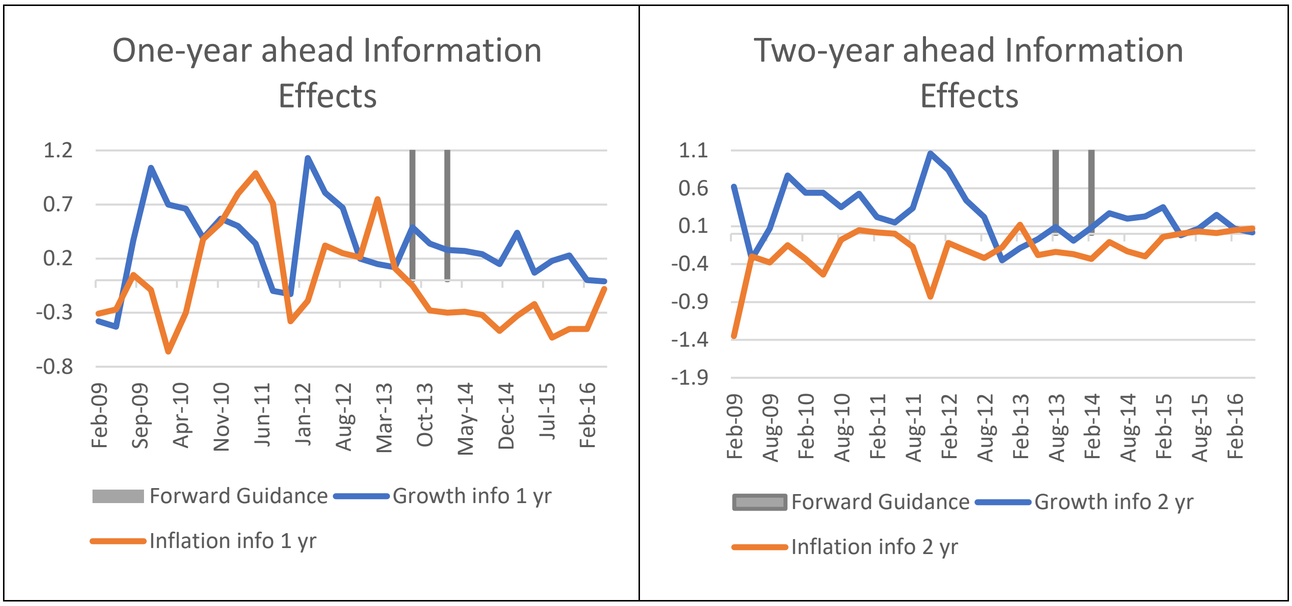
The key conceptual question is whether the identification restrictions used in this paper can help distinguish forward guidance shocks from central bank information shocks. In their VAR model for the US, Jarocinski and Karadi (2020) identify a monetary policy shock by requiring that the one-year rate falls while share prices rise. A central bank information shock is identified by requiring the one-year rate to rise while share prices also rise. In our work, the rate expected in 12 months from now declines and leads to a rise in share prices, but this not statistically significant. The fact that a decline in interest rate expectations leads to a rise in output and prices supports the interpretation of a monetary (SDFG) policy shock over a central bank information shock based on the identification restrictions. However, Figure 5 shows that firms and consumers expectations of the future improve in response to forward guidance. Furthermore, the long-term interest rate rises and this is statistically significant in almost every specification. Indeed, Nakamura and Steinsson (2018b) show that long-term interest rates can rise in response to information shocks. While the identification restrictions are not necessarily consistent with a central bank information shock, some of the results presented in this paper suggest that the presence of central bank information shocks can not be ruled out a priori. We explore this in greater detail below.

Both Nakamura and Steinsson (2018b) and Jarocinski and Karadi (2020) rely on financial market event studies to examine whether information shocks are present during a Federal Reserve monetary policy announcement. Our event study in Table 1 shows no statistically significant effect of the long-term interest rate in response to the August 2013 forward guidance announcement. In response to the forward guidance announcement in February 2014, there is a statistically significant rise in the 12 months ahead and the long-term interest rate. The implied volatility rises in response to the February 2014 announcement. This suggests that the rise in interest rates could be due to an unwinding of the August 2013 SDFG announcement instead of an information shock. Overall, the evidence from financial market event studies is ambiguous: While it seems less likely that information effects played a role in the August 2013 announcement, the results are less clear for the February 2014 forward guidance announcement.

The VAR results provide additional evidence in favour of the forward guidance shock interpretation. Figures A1 identifies a separate Central Bank information shock based on the restrictions presented in Jarocinski and Karadi (2020), in addition to the forward guidance shock. This leaves the forward guidance results unaffected. Furthermore, the VAR results in Figures A1 and A6, consensus forecast and consumer survey interest rate expectation all show that the August 2013 announcement is responsible for most of the forward guidance effect. As discussed in the previous paragraph, the event study suggests a central bank information effect is less likely at that time. Finally, Nakamura and Steinsson (2018b) show that the information effect leads to a rise in the real long-term rate, but not implied inflation expectations. Our VAR results in Figure 6 show a statistically significant rise in long-term inflation expectations, but not real long-term rates.

UK data allows us to go even further and directly measure Bank of England information effects and hence econometrically test if the inclusion of these shocks into our model makes a difference to the results. The Bank of England releases its forecasts for the UK economy every quarter. However, one week before the announcement the Bank of England surveys all UK professional forecasters for their real GDP growth and inflation forecasts over the next two years. Subtracting the Bank of England's actual forecasts from these professional forecaster expectations allows us to measure by how much Bank of England forecasts surprise public expectations. With this approach, we can directly measure the information effect shocks from the Bank of England's release of forecasts. Figure C1 shows these information effect shocks for both output and inflation one and two years ahead. This shows that the August 2013 forward guidance announcement is associated with a one-year ahead real GDP growth information effect shock, but this is modest relative to the size of the previous information effect shocks in the sample. However, in the United Kingdom, the Monetary Policy Committee sets the inflation and growth forecast. The MPC probably raised the growth forecast to reflect the implementation of SDFG. It is therefore unclear whether this particular real GDP growth surprise forecast reflects a pure information effect. To test this hypothesis, we include these inflation and growth forecast surprises as exogenous variables in the VAR model. These results are shown in Figures A5/A9/A13 in appendix A for the narrative sign restrictions/proxy SVAR/local projection model. Including information effects into our proposed empirical model does not affect our baseline estimates at all. This evidence strongly supports the interpretation of our shocks as forward guidance rather than central bank information shocks.

Figure B1: Bank of England Information Effect Surprises over Time



Source: Bank of England quarterly inflation and monetary policy reports. **Notes:** The charts show information effect surprises, defined as the difference between the Bank of England's forecast announced in that quarter and professional forecasters forecast collected one week prior to publication of the Bank of England's forecast. The LHS chart shows this information shock for real GDP growth and CPI inflation forecasts one year ahead. The RHS chart this information shock for real GDP growth and CPI inflation forecasts two years ahead.

The most challenging aspect of any paper identifying a new macroeconomic shock is to demonstrate credibly that the identified shock is new, rather than a previously explored shock with a different identification scheme. We have shown that our identified forward guidance shock is separate from QE. However, there is a risk that we are actually identifying central bank information instead of SDFG shocks. As discussed in this section, there are several reasons to believe that this risk is probably much smaller than at first sight. An event study of the August 2013 forward guidance announcement, the event we show is behind the VAR results, is not consistent with a central bank information shock. VAR evidence shows that the results are unchanged when central bank information is identified as a separate shock and that inflation expectations, rather than real rates, are responsible for rise in the long-term rate. Finally, we measure central bank forecast (information) shocks directly and show that our VAR results are unchanged when these shocks are included as exogenous variables into the model. All of this evidence strongly supports the interpretation our identified shocks as forward guidance.

Appendix C: The Simulation Model

C.1 Specification

We set up a simple New Keynesian model which follows Adam and Billi (2006) and allows for a stochastic headwind. The model is one in which output, y_t, depends on expected output, $E_t y_{t+1}$, the interest rate, i_t, adjusted for expected inflation, $E\pi_{t+1}$, the headwind, z_t, and the steady state real interest rate, $\bar{\iota} - \bar{\pi}$. The IS curve is, with σ the intertemporal elasticity of substitution:

$$y_t = -\frac{1}{\sigma}(i_t + z_t - E\pi_{t+1}) + E_t y_{t+1} + (\bar{\iota} - \bar{\pi})/\sigma \qquad \text{(A1)}$$

We model the headwind as

$$z_t = \lambda z_{t-1} + u_t \qquad u_t \sim N(0, \sigma^{*2}) \qquad \text{(A2)}$$

Supply conditions are represented by a forward-looking new Keynesian Phillips curve explaining inflation, π_t in terms of expected future inflation, $E_t\pi_{t+1}$.

$$\pi_t = \beta E_t \pi_{t+1} + \kappa y_t + (1-\beta)\bar{\pi} \qquad \text{(A3)}$$

Here β is the discount factor and $\kappa = \frac{(1-\alpha)(1-\alpha\beta)}{\alpha}\frac{\omega+\sigma}{1+\omega\theta}$, with α is the degreee of price stickiness, ω the Frisch elasticity of labour supply and θ the elasticity of substitution between the different goods produced by imperfectly competitive producers.

In the absence of forward guidance, the interest rate is set by a policy rule which departs from the standard Taylor rule in two important respects. First, we set a floor to the interest rate, i^Z. We set this to ½ per cent per annum rather than zero. This reflects the fact that, during the period in which forward guidance was introduced in the United Kingdom, the Monetary Policy Committee was concerned that, because of the impact on bank profitability, a reduction of Bank Rate below ½ per cent per annum would offer less stimulus than one of ½ per cent[28]. Secondly, we assume that the interest rate moves in quarter point steps, so that, subject to the lower bound, the rate adopted is the rate closest to that given by the Taylor rule but an integer multiple of one quarter. This reflects the fact that, almost everywhere, policy interest rates move in quarter point steps. Thus we have, with the interest rate in quarterly terms

[28] Improvements in bank balance sheets meant that, in 2016, the Committee did feel Bank Rate could safely be reduced to 0.25 per cent per annum.

$$i_t^* = (1-\rho)(\phi_y y_t + \phi_\pi(\pi_t - \bar{\pi}) + \bar{\imath}) + \rho i_{t-1} \quad \text{(A4)}$$

$i_t = \frac{N}{16}$ where N is the integer solution to min $(\frac{N}{16} - i_t^*)^2$ subject to $N \geq 2$. (A5)

ϕ_y and ϕ_π and ρ are policy parameters.

We write the model in vector notation with

$$\boldsymbol{x_t} = \begin{bmatrix} y_t \\ \pi_t \end{bmatrix}; \quad \boldsymbol{A} = \begin{bmatrix} 1 & -1/\sigma \\ \kappa & \beta \end{bmatrix}; \ \boldsymbol{b} = \begin{bmatrix} -1/\sigma \\ 0 \end{bmatrix}; \quad c = \begin{bmatrix} (\bar{\imath} - \bar{\pi})/\sigma \\ (1-\beta)\bar{\pi} \end{bmatrix}; \ \psi = [(\phi_y \quad \phi_\pi]$$

$$\boldsymbol{x_t} = \boldsymbol{A}\boldsymbol{x^e_{t+1}} + \boldsymbol{b}(i_t + z_t) + \boldsymbol{c} \quad \text{(A6)}$$

$$i^*_t = (1-\rho)(\psi \boldsymbol{x_t} + \bar{\imath} - \phi_\pi \bar{\pi}) + \rho i_{t-1} \quad \text{(A7)}$$

Here it should be noted that i^*_t is a continuous variable from which the actual interest rate, i_t is calculated reflecting i) the fact that the interest rate moves in discrete steps, ii) the interest rate floor and iii) any forward guidance in operation.

C.2 Model Solution

To solve the model we first identify a terminal condition derived on the assumption that $i_t = i^*_t$ and $u_\tau = 0$ for $\tau \geq T$. This allows us to use the solution method set out by Blanchard and Kahn (1980) with i_{T-1} and z_T as predetermined variables, and the two elements of $\boldsymbol{x_T}$ as jumping variables.

We can now, for $\tau \geq T$ write equations (A6), (A7) and (A2) as

$$\boldsymbol{q_{t+1}} = \boldsymbol{G}\boldsymbol{q_t} + \boldsymbol{h}$$

where $\boldsymbol{q}_t = \begin{bmatrix} \boldsymbol{x_t} \\ i_{t-1} \\ z_t \end{bmatrix}$; $\boldsymbol{G} = \begin{bmatrix} \boldsymbol{A^{-1}} - \boldsymbol{A^{-1}b}(\boldsymbol{1}-\rho)\psi & -\boldsymbol{A^{-1}b}(\boldsymbol{1}-\rho) & -\boldsymbol{A^{-1}b} \\ (1-\rho)\boldsymbol{\psi} & \rho & 0 \\ 0 & 0 & \lambda \end{bmatrix}$;

and $\boldsymbol{h} = \begin{bmatrix} \boldsymbol{c} - \boldsymbol{A^{-1}b}(\boldsymbol{1}-\rho)(\bar{\imath} - \phi_\pi\bar{\pi}) \\ (\boldsymbol{1}-\rho)(\bar{\imath} - \phi_\pi\bar{\pi}) \\ 0 \end{bmatrix}$;

We draw our parameters from random distributions, as described on page ???? and accept only parameter combinations for which $\boldsymbol{G}$ has two eigenvalues outside the unit circle. This allows us to construct tables showing the values of the elements of $\boldsymbol{x_T}$ as functions of i_{T-1} and z_T, $\boldsymbol{x_T} = \boldsymbol{x_T}(i_{T-1}, z_T)$. We construct grids with 401 values of z_T covering the range -4.05 to 10.95 in steps of 0.0375, and i_{T-1}, at a quarterly rate, covering the range 0.125 to 2.625 in steps of 0.0625 per cent per quarter. Thus the interest rate steps are in quarter points at an annual rate.

At time *T-1* we can use equation (6) to evaluate $\boldsymbol{x_{T-1}}$

$$\boldsymbol{x_{T-1}} = \boldsymbol{A}\boldsymbol{x^e_T} + \boldsymbol{b}(i_{T-1} + z_{T-1}) + \boldsymbol{c}$$

We evaluate $\boldsymbol{x_T^e}$ by making use of the grid and the stochastic equation

$$z_T = \lambda z_{\mathrm{T}-1} + u_T$$

and integrating over values of u_T.

We write, with ϕ() representing the probability density function of the normal distirbution

$$\boldsymbol{x}_T^e = \int_{-\infty}^{\infty} \boldsymbol{x_T}(z_T, i_{T-1})\, \phi(\frac{z_T - \lambda z_{T-1}}{\sigma^*}) dz_T$$

We evaluate this with Simpson's rule using the sequence of equally spaced grid values of z_{T-1} denoted as $z_{T-1,j}$ with the interval between them Δz. Then

$$\int_{-\infty}^{\infty} \boldsymbol{x_T}(z_T, i_{T-1})\, \phi(\frac{z_T - \lambda z_{T-1}}{\sigma^*}) dz_T$$

$$= \sum_j \boldsymbol{x_T}\left(z_{T,j}, i_{T-1}\right)\ \phi(\frac{z_{T,j} - \lambda z_{T-1}}{\sigma^*})(\Delta z/6)$$

$$+4 \sum_j \frac{\left(\boldsymbol{x_T}\left(z_{T,j}, i_{T-1}\right) + \boldsymbol{x_T}\left(z_{T,j+1}, i_{T-1}\right)\right)}{2}\ \phi(\frac{z_{T,j} + z_{T,j+1} - 2\lambda z_{T-2}}{2\sigma^*})(\Delta z/6)$$

$$+ \sum_j \boldsymbol{x_T}\left(z_{T,j+1}, i_{T-1}\right)\ \phi(\frac{z_{T,j+1} - \lambda z_{T-1}}{\sigma^*})(\Delta z/6)$$

With the solution thus constructed for $\boldsymbol{x}_T^e$ conditional on i_{T-1} and z_{T-1} we can solve directly for $\boldsymbol{x}_{T-1}$ as

$$\boldsymbol{x_{T-1}} = \boldsymbol{A x_T^e} + \boldsymbol{b}(i_{T-1} + z_{T-1})$$

The values of $\boldsymbol{x}_T^e$ and $\boldsymbol{x}_{T-1}$ obviously depend on the choice of i_{T-1} allowing us to write $\boldsymbol{x_{T-1}} = \boldsymbol{x_{T-1}}(i_{T-1},\ z_{\mathrm{T}-1})$. It remains for us to determine i_{T-1}. We do this as follows.

Conditional on z_{T-1} and i_{T-2}, we evaluate $i^*{}_{T-1}$ for each possible value of i_{T-1}. Indexing the values of i_{T-1} in the vector of possible interest rates by the subscript *k*, and in the absence of forward guidance we choose the value of *k* which solves

$Min\left(i^*_{T-1,k} - i_{T-1,k}\right)^2$.

With forward guidance in place we set the interest rate to i_b if $i_{T-2,k} < \hat{\imath}$ and we also impose the constraint that the interest rate (at an annual rate) does not rise by more than ¼ percentage point (at an annual rate) per quarter until $i_{t-1} \geq \hat{\imath}$.

This step allows us to construct new tables $\boldsymbol{x_{T-1}} = \boldsymbol{x_{T-1}}(i_{T-2},\ z_{\mathrm{T}-1})$ showing $\boldsymbol{x_{T-1}}$ as a function of the pre-determined variables . We then repeat the process, evaluating $\boldsymbol{x_{T-1}^e}$ as a function of i_{T-2} and $z_{\mathrm{T}-2}$. We then once again explore all permitted values of i_{T-2} for each of the forty-one possible values of i_{T-3}, choosing the value closest to that given by the policy rule (A7).

In the evaluation of the expectations the issue arises of how to carry out the integration at the extreme values of *z*. We extrapolate the grids using the rate of change at the extreme values for a further eight hundred points in each direction so as to make possible the application of Simpson's rule at the extreme values of z.

C.3 Convergence and Simulation

We carry out this process for three hundred periods. The fact that the interest rate moves discretely means we cannot expect exact convergence. We retain those values for which the maximum absolute value of the deviation of output from equilibrium in period 300 relative to its value in period 290, max abs($x_{\mathbf{1},\mathbf{300}} - x_{\mathbf{1},\mathbf{290}}$)<0.005 both when forward guidance is in place and in its absence.

This provides us with a set of grids we can use to simulate the behaviour of the economy in response to a headwind shock both with and without forward guidance in place. We assume that the initial value of the headwind is 0.6 (at a quarterly rate) and that the interest rate is initially at the value of 0.125 (0.5 per cent per annum) implied by the zero lower bound.

For each set of model parameters which satisfies the convergence criteria above, we carry out twenty thousand simulations over eighty periods. We compare the trajectories with and without forward guidance. Each of the simulations has its own set of shocks to the headwind, but we use the same shocks for the simulations with and without forward guidance.

With our initial headwind and interest rate we use the grid tables to find values of output and inflation comprising $\boldsymbol{x_t}$. Linear interpolation is used between the grid points to deliver values of $\boldsymbol{x_t}$ consistent with the actual values of z_t. The Taylor rule interest rate, $i^*{}_t$, is then evaluated and we choose the actual discrete interest rate, i_t which is closest to $i^*{}_t$ but which also satisfies the forward guidance rules if relevant.

This provides us with twenty thousand trajectories. We store the mean of these, and also the standard deviation of the interest rate across the simulations. This allows us to show the impact of forward guidance on the standard deviation of possible interest rate outcomes.

Appendix D: Bank of England Forward Guidance and event study

This appendix provides a short summary of the implementation of the forward guidance policy in the UK. We also describe the initial reaction of financial markets with an event study.

In March 2013, the UK Chancellor of the Exchequer asked the Monetary Policy Committee (MPC) of the Bank of England to evaluate forward guidance. In response, the MPC (Bank of England 2013a, page 7) introduced a policy of forward guidance on 7th August 2013, setting out the conditions that would need to be met for the interest rate to be increased from the effective lower bound of ½ per cent per annum (see also Bank of England 2013b).

The guidance stated that Bank Rate would remain at the 0.50% lower bound, as long as the unemployment rate remained above 7%. There were several additional conditions, which if breached meant that guidance would cease to apply. These were if:

1. In the MPC's view it was more likely than not that CPI inflation 18 to 24 months ahead was 0.5 percentage points or more about the 2 per cent target.
2. Medium-term inflation expectations were no longer sufficiently well anchored.
3. The Financial Policy Committee judged that the stance of monetary policy posed a significant threat to financial stability that could not be contained by the substantial range of mitigating policy actions available to the FPC, the Financial Conduct Authority and the Prudential Regulation Authority in a way consistent with their objectives.

While the policy was announced on 7th August in the *Inflation Report* (Bank of England, 2013a), additional information was provided in the minutes of the monetary policy meeting (Bank of England, 2013b) released on 14th August. There it emerged that one member of the Committee (Weale) voted against the framework on the grounds that the policy suggested the Monetary Policy Committee was less committed than in the past to delivering the inflation target of 2% p.a. The minutes also further clarified the use of the 7% unemployment rate as the key threshold in UK forward guidance. The Governor, Mark Carney, repeated this message in his first speech after the meeting on 28th August, "providing you with certainty that interest rates will not rise too soon".

Although the Bank of England's MPC's forecast was that unemployment would reach the threshold only in 2016, a rapid recovery combined with very low labour productivity growth meant that the unemployment rate fell to 7.2 per cent in December 2013. Rather than re-set the unemployment threshold in response to this development, the MPC adopted a much less precise formulation of forward guidance (Bank of England, 2014). This was closer to the approach before the adoption of forward guidance in August 2013. The MPC stated that:

1. There remained scope to absorb further spare capacity before raising Bank Rate.
2. When Bank Rate did begin to rise, the path required to eliminate slack over the next two to three years and keep inflation close to target was expected to be gradual.

3. The actual path of Bank Rate over the next few years would, however, depend on economic circumstances.

Relative to other G-7 central banks, there are some important similarities and differences. The path of the UK policy rate was explicitly dependent on the state of the economy. In that sense, the Bank of England's 2013 guidance was broadly similar to the FOMC's conditioning of the Federal Funds Rate on an unemployment and inflation forecast threshold. However, the Fed's policy announcements, both in 2012 and in 2020, coincided with open-ended QE. This was also the case for the ECB in 2019. In contrast, the Bank of England was the only central bank to announce state-dependent forward guidance over a year after a QE announcement. Our study therefore focuses on the Bank of England's experience, since it is the only episode of state-dependent forward guidance that can actually be used to estimate the effects of the policy separately from QE and hence credibly answer the question of interest in this paper.

We examine the effects of these changes in policy on financial markets via an event study in Table D1. We rely on both yields on UK Gilts and measures of future short-term interest rates expectations. In the UK, the latter can be obtained only from LIBOR options. LIBOR is the sum of the Bank of England's policy rate and bank credit risk. In normal times, the second component is negligible. The Bank of England provides both the mean and implied volatility of expected LIBOR based on options using the Bachelier model (Clews, Panigirtzoglou and Proudman, 2000). Since the Bank of England provides these data at daily frequency, our event study is a one-day window around the time of the announcement. Statistical significance is assessed relative to the actual distribution of interest rate changes on monetary policy announcement dates. The first forward guidance announcement, on 7th August 2013, only led to a statistically significant decline in the implied volatility of LIBOR rates six months ahead. This suggests that financial markets priced out tail risks scenarios for interest rate rises, in line with the idea that SDFG helped to clarify the Bank of England's reaction function. The second forward guidance announcement, on 12th February 2014, led to a rise in the mean LIBOR rate and implied volatility 12 months ahead. The rise in implied volatility more than offset the decline during the first announcement. This suggests that the move away from explicit numerical thresholds, for the unemployment rate and the inflation forecast, led to greater uncertainty about the Bank of England's reaction function. The Funding for Lending Scheme had a larger impact on LIBOR rates and the implied volatility than Forward Guidance, but this was likely due to the reduction in bank credit risk rather than the policy rate. QE had a larger impact than Forward Guidance on long-term gilt yields.

Table D1 – Forward Guidance Event Study

	LIBOR 6m ahead	IVOL LIBOR 6m ahead	LIBOR 12m ahead	IVOL LIBOR 12m ahead	5Y Gilt yield	10Y Gilt yield
QE – March 2009	0.06	-0.08*	0.02	-0.05	-0.18*	-0.32*
FLS announcement	-0.20*	0.01	-0.17*	-0.12*	-0.08	-0.06
FG – August 2013	-0.01	-0.07*	0.00	-0.02	0.00	0.00
FG – February 2014	-0.02	0.00	0.12*	0.08*	0.11*	0.08

Note: This table shows changes in financial market prices on the day of the policy announcement relative to the previous day. LIBOR 6 and 12 month ahead is the expected LIBOR 6 and 12 month ahead. IVOL LIBOR 6 and 12 months ahead is the implied volatility of the expected LIBOR 6 and 12 months ahead. 5Y and 10Y Gilt yield are 5 year/10 year Gilt yields. * denotes statistical significance at the 5% level, relative to changes on monetary policy announcements days between March 2009 and May 2016.

Appendix E: Data

Series and Source	Transformation
Monthly GDP, Source: NIESR	Monthly GDP series from NIESR. Series enters VAR in natural logarithms multiplied by 100
CPIY, Source: ONS	Monthly CPI, excluding effects of indirect taxes such as VAT, seasonally adjusted via X12.
Asset purchases, Source: BoE	Bank of England stock QE announcements, expressed as a share of annualised Q1 2009 UK nominal GDP.
Long-term rate, Source: BoE	10-year yield on UK Gilts, expressed in percent.
Share prices, Source: Macrobond	FTSE100. To obtain real share prices, this variable is divided by CPI, expressed in natural logs and multiplied by 100.
Real Commodity Prices, Source: World Bank	Nominal non-energy commodity prices expressed in GBP. Divided by CPIY to obtain real series.
Household one-year ahead interest rate expectations, Source: Bank of England Inflation Attitudes survey	The Bank of England inflation attitudes survey provides asks participants for the view on the interest rate one year ahead. As described in the main text, we map qualitative into quantitative one-year ahead interest rate expectations by relying on numerical answers from the 2014 survey.
Professional forecasters one-year ahead interest rate forecasts. Source: Consensus Economics.	Consensus Economics provide individual interest rate forecasts each month. We remove individual outlier forecasts as described in the main text and use the resulting series to calculate the mean and standard deviation of one-year ahead interest rate forecasts.
UK NFX and RFX, Source: BIS.	Nominal and real effective exchange rate indices for the UK.
UK Uncertainty.	Policy uncertainty index for the UK.

UK VIX, Source: Macrobond	VFTSE, the implied volatility of the FTSE100.
UK qualitative surveys, Source: Eurostat.	All series in figure 5 were taken from the Eurostat database.
UK trade balance, Source: ONS.	Monthly UK exports less imports, divided by interpolated quarterly nominal GDP.
UK interest rates, Source: Bank of England	Quoted rates on certain mortgage type (I.e. 2-year 75 LTV) and effective rates (fixed HH interest rate) come from the Bank of England Bankstats database. The Sterling corporate bond rate is from the Bank of England Millennium database.
UK info shock variables, Source: Bank of England	The Bank of England publishes a survey of professional forecasts alongside its own forecast. The difference between these two variables provides a measure of the additional information that Bank of England forecasts reveal to the general public. We construct this measure for the inflation and real GDP forecast one and two years ahead.
UK household inflation expectations. Source: Citibank	UK household inflation expectations 12 months and 5 years ahead at monthly frequency.
UK financial market inflation expectations. Source: Bank of England	Gilt market Inflation expectations and real rates are taken from the Bank of England yield curve model.
LIBOR one year ahead rate and standard deviation. Source: Bank of England	The Bank of England provides LIBOR implied interest rates and standard deviations at various maturity at daily frequency.
EA Long-term rate, Source: Deutsche Bundesbank	10-year yield on German government debt (BUND), expressed in percent.
EA Spread, Source: Deutsche Bundesbank and ECB	10-year yield on Italian debt (BTP) less 10-year yield on German government debt (BUND), expressed in percent.
ECB Balance sheet, Source: ECB	The ECB's Balance sheet at monthly frequency expressed as a share of 2009Q1 EA nominal GDP.
US QE, Source: Federal Reserve and Weale and Wieladek (2016)	Cumulative sum of one-off Fed QE announcements, as a share of annualised Q1 2009 US nominal GDP.
US Long-term rate, Source: FRED	10-year yield on US Treasury bonds, expressed in percent.

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