Monetary Policy Communication Shocks and the Macroeconomy*

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Abstract

Using high-frequency identification, we distinguish between monetary policy action and communication shocks in the U.S. We clean both of potential "information effects", whereby the Fed might release information about its internal forecasts. We compare the macroeconomic effects of Fed communication surprises relating to varying horizons into the future, orthogonal to both surprise actions and to Fed-internal information. Information effects are strongest for surprises relating to rates less than one year into the future. We find robust evidence that communication surprises about future interest rate decisions have a stronger impact on macroeconomic variables than surprise policy actions. **(JEL codes: E52, E58, G23, C32)**

Keywords: Federal Funds Futures, FOMC, Monetary Policy, VAR Model.

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1 Introduction

The idea that central bank statements regarding future interest rates affect macroeconomic outcomes has been very influential for the conduct of monetary policy in recent decades. Policymakers have sought to transmit increasingly detailed forms of information regarding their projected future rate paths to market participants and the public. At the effective lower bound, central banks employed forms of forward guidance to deliver additional stimulus when their short-rates were constrained from below. Indeed, in the New Keynesian paradigm, on which a large majority of modern applied macroeconomic models are based, statements regarding future rates have a large impact on macroeconomic variables for reasons that relate to core features of such models. Woodford (2003) states that in the New Keynesian framework "a central bank's primary impact on the economy comes about not through the level at which it sets current overnight interest rates, but rather through the way it affects private sector expectations about the likely future path of overnight rates". The question of how statements about future policy rate decisions influence the macroeconomy is therefore of great interest.

The argument that central bank statements regarding future actions are likely to be highly influential received important empirical support in the study of Gürkaynak et al. (2005). This study documented evidence for the role of both "target" and "path" factors for explaining high-frequency variation in asset prices in response to policy information releases by the Federal Reserve (Fed) during narrow time windows around these events. Gürkaynak et al. (2005) developed on earlier monetary policy event studies that examined only the role of surprise changes in the policy rate itself (Kuttner, 2001). A key insight of Gürkaynak et al. (2005) is that one may miss important features of the nature of transmission, were one to consider only a target surprise, or mistakenly aggregate information from the target and path surprises together. A series of studies have extended the decomposition of Gürkaynak et al. (2005) to include alternative forms of monetary surprise, such as those relating to asset purchases (Swanson, 2021) or "timing" forward guidance surprises (Gürkaynak, 2005; Altavilla et al., 2019).

However, when subsequent empirical studies sought to map asset price movements from event days to changes in survey expectations regarding macroeconomic data, or to realised macroeconomic data itself, a number of "puzzles" emerged. Campbell et al. (2012) found that ostensibly contractionary monetary policy surprises deliver *decreases* in private sector forecasts of unemployment, while Nakamura and Steinsson (2018) report that forecasted output growth rises. The study of Barakchian and Crowe (2013), when investigating the response of prices to monetary policy shocks derived from high-frequency surprises, reported consistent evidence for a price puzzle.[1]

One hypothesis put forward by numerous studies is that such effects stem from a Fed "information

[1] Ramey (2016) also documents unstable results in specifications using high-frequency surprises in Proxy VARs and local projections.

effect" (Campbell et al., 2012; Nakamura and Steinsson, 2018; Jarociński and Karadi, 2020).[2] Under this hypothesis, the reason for movements in forecasted and realised macroeconomic data that contravene theory is that the Fed publicly releases internal information regarding fundamentals during the event window. The measure of the asset price response is therefore biased by such effects. A recent literature has proposed different means to partial out such information effects from high-frequency surprises. One popular approach is to regress the high-frequency movements on measures of Fed-internal information, and take the residual as a "true" measure of the monetary surprise (Barakchian and Crowe, 2013; Miranda-Agrippino, 2017; Miranda-Agrippino and Ricco, 2021; Zhang, 2021). One can think of this as "purging" the information content of the surprise via orthogonalisation. Alternative methods impose sign-restrictions on the responses of inflation-linked swaps or equities within the narrow window to extract information effects (Andrade and Ferroni, 2021; Jarociński and Karadi, 2020; Cieslak and Schrimpf, 2019; Goodhead, 2022).[3]

However, when removing information effects, a number of influential studies do not separately consider the role of orthogonalised action and communication surprises. Researchers have tended to examine measures of monetary policy surprises that aggregate both actions and communication about the future, arguing that such surprises will simply reflect the role of both. We can understand these surprises to be reduced-form, in the sense that they may incorporate multiple forms of structural monetary policy surprise. For example, Barakchian and Crowe (2013) and Nakamura and Steinsson (2018) study the first principal component of bundles of asset prices linked to future interest rates. Other studies choose to employ a single futures contract at a relatively short term horizon to encapsulate changed expectations regarding interest rates. Jarociński and Karadi (2020) or Miranda-Agrippino and Ricco (2021), for example, focus on the fourth federal funds futures contract (FF4), which relates to interest rates three months into the future.[4] In these studies no distinction is made between action and communication surprises. Indeed, one reason for this may be a preference for the use of Proxy VAR models. Researchers using Proxy VARs have often reported weak instruments issues when attempting to utilise orthogonalised surprises as instruments, justifying their focus on more reduced-form measures of the surprise (Gertler and Karadi, 2015).[5]

In this paper we contribute by studying how orthogonalised action and communication surprises

[2]Campbell et al. (2012) distinguish between "Delphic" forward guidance, which refers to communication regarding responses to state-variables, and "Odyssean" forward guidance implying commitment.

[3]See also Matheson and Stavrev (2014). Additional approaches to extract information effects that make alternative identification assumptions have recently been developed. Zhu (2022) employs information from macroeconomic announcements outside of Fed announcement days to inform shock extraction. Jarocínski (2021) identifies four shocks from Fed announcements based on the assumption that they are leptokurtic, one of these surprises is observed to move equities and interest rates in the same direction, and can therefore be interpreted as a form of Delphic forward guidance.

[4]Note that the futures contract for the concurrent month is labelled FF1 and that for the first month in the future FF2. Miranda-Agrippino (2017) and Miranda-Agrippino and Rey (2020) also use FF4 as an instrument in Proxy VARs. For an additional recent study using only a single monetary policy shock derived from futures data see Bu et al. (2021).

[5]This issue is also reported in the Appendix of Bundick and Smith (2020), and discussed in Bauer and Swanson (2022).

influence macroeconomic variables in a VAR framework, in line with the early treatment of Barakchian and Crowe (2013)—this has been termed a "Hybrid VAR" specification in the literature. We adopt a medium-scale Bayesian specification, to permit the study of the transmission mechanisms at play. We investigate the effect of a number of communication surprises defined at different horizons on macroeconomic variables. Importantly, using Greenbook data, we purge each individual surprise of Fed-internal information in a pre-stage before entering the surprise into the VAR, in order to understand the ways in which information effects change the transmission of communication shocks defined at different horizons. This distinguishes our approach from other treatments that focus only on aggregate measures of surprises when studying the transmission of information effects to the macroeconomy. Under this logic, we are able to provide important evidence regarding which horizons of communication tend to have the largest macroeconomic impact, in a manner that is robust to information effects.

In our first investigations we study the period before the Global Financial Crisis in 2008, using surprises linked to futures contracts relating to the federal funds rate. In this sense we explore whether the finding of Gürkaynak et al. (2005), namely that communication regarding the future path of policy has a greater effect on longer-maturity interest rates, implies that such communication also has a greater effect on macroeconomic variables. For these investigations we restrict ourselves to a short spectrum of futures, reaching out a maximum of five months into the future. From these near-term futures, we distinguish two components of monetary policy surprises using a simple recursive approach.

In the pre-2008 sample we show robustly that the communication component of monetary policy has stronger effects on macroeconomic variables than does the action component. This is true whether we purge the surprises of information effects or not. When we study (unpurged) action and communication surprises that have comparable effects on expectations regarding the federal funds rate next month (implying an increase by 2.4bps), the action surprise contracts industrial production by 0.14% after 29 months. In contrast, a communication surprise of comparable size leads to a contraction by 0.40% after 23 months, almost three times larger than for the action surprise. Moreover, and somewhat surprisingly given the results of Campbell et al. (2012) and Nakamura and Steinsson (2018), we robustly do *not* find real activity puzzles to unpurged shocks, suggesting that information effects are not too strong for these variables. However, we do observe weak or puzzling price responses to action and communication surprises prior to their orthogonalisation with respect to Greenbook forecasts, suggesting a stronger relationship between nominal responses and information effects.

When controlling for Fed-internal information, we find that macroeconomic responses to the action surprise are largely unchanged. We observe a greater difference in results when the communication surprise is orthogonalised. In this case we observe that both prices and real activity fall in response to a contractionary surprise. Therefore, and although the price puzzles for the unpurged communication surprise are limited to the short run, and are not present at longer horizons (where responses are consistent with theory), we show that purging regressions lead to price responses that are consistently negative. In response to the purged communication shock, the median price response becomes negative after 6 months, whereas in the unpurged case it becomes negative only after 17 months. When we examine transmission mechanisms, we observe greater and more persistent effects on one-year Treasury bond yields in response to communication surprises, as well as a "hump"-shaped response of the Excess Bond Premium (EBP) of Gilchrist and Zakrajšek (2012). These findings suggest that a more persistent financial tightening can explain the difference in the strength of the surprises.

We show that results for industrial production are broadly robust to alternative measures of Fed-internal information that utilise estimates of the "gap" between Fed and private sector forecasts. The study of Barakchian and Crowe (2013) used controls based on such an information gap, whereas the study of Miranda-Agrippino and Ricco (2021) employs controls based simply on Greenbook data.[6] We find that purging regressions using controls based on such forecast differences result in less negative price responses, relative to regressions that use only the Fed forecasts. We conclude that the use of raw Greenbook data in purging regressions may serve a dual role, controlling for Fed-internal information while also partialling out the portion of the surprise that is predictable with respect to past data (Miranda-Agrippino, 2017; Bauer and Swanson, 2022).

We next examine how information effects vary with the horizon of the communication signal. We create a sequence of communication shocks by orthogonalising price movements of assets of progressively longer duration with respect to the action surprise. We then infer the strength of information effects at given points of the yield curve by examining the extent to which a second orthogonalisation with respect to Fed-internal information alters impulse responses. Again, we find limited evidence for strong information effects when studying the responses of industrial production. We additionally document that the effect on real activity tends to decrease in the horizon of the surprise studied. This contravenes predictions from standard theoretical frameworks by which surprises regarding interest rates at longer horizons have greater effects (Del Negro et al., 2012). We additionally find that, while the unpurged high-frequency surprises do deliver price puzzles, these are confined to shorter-horizon surprises. We do not find price puzzles for unpurged communication surprises with horizons more than one year into the future. Moreover, controlling for information revelation strengthens price decreases in the medium term, particularly around the two-year frequency, but not in the longer term.

Moving beyond the pre-2008 sample, we document the importance of central bank communication during the recent effective lower bound (ELB) episode by incorporating information from Eurodollar

[6] Bauer and Swanson (2021) argue that a better model for understanding responses of forecast data to Fed monetary policy event days is in terms of policy reactions to news revealed after the date of the private sector forecast, but before the meeting itself.

futures. These refer to longer horizons than federal funds futures and therefore remained liquid even during the ELB period from December 2008 to December 2015 in the U.S. Using a decomposition of different Eurodollar futures contracts, we can gauge the effect of longer-term communication shocks at different horizons. Specifically, we look at responses to Eurodollar contracts 4, 8 and 12 quarters out (ED4, ED8 and ED12), corresponding to communication surprises with an horizon of 1, 2 and 3 years into the future. Each Eurodollar surprise is identified on the basis of a sequential recursive approach, meaning the ED8 surprise is orthogonal to ED4 movements, and the ED12 surprise is orthogonal to both ED4 and ED8 movements. Importantly, we are among the first to show results of such orthogonal communication shocks purged by Fed-internal Greenbook forecasts, which became available up to 2015 only recently. We contrast results for the whole Eurodollar sample for which Greenbook purging is feasible (March 1994 to December 2015) to those from the ELB subsample (July 2008 to December 2015)—in line with recent work emphasising that information effects in the U.S. case may be confined to sub-periods (Lunsford, 2020; Hoesch et al., 2020).

In the extended data sample we again observe little evidence for puzzling responses to communication surprises defined over horizons of one to two-years, even prior to purging the surprises of Fed-internal information. The response of the yield curve to the three forms of surprise is qualitatively different. All the surprises raise long term Treasury yields at impact, with the ED8 surprise displaying a counter-reaction in the shorter term. Further, it is the communication surprises at the ED8 and ED12 horizons that have a greater effect on measures of credit frictions and uncertainty, relative to ED4. When considering the response of key macroeconomic variables to the purged ED4 surprise, we can observe that restricting estimation to the post-crisis sample results in several puzzles, including a robust increase in industrial production, and a surprisingly strong positive reaction of the price level in the medium run. One explanation for this result is that during the post-crisis period, expectations regarding future short-rates were increasingly pinned to the ELB, given the guidance of the Fed. The innovations in ED4 that did occur are potentially more likely to relate to short term policy "mistakes" in Fed communication, rather than persistent changes in policy. In this sense results for the ED4 surprise become closer to the pre-crisis action surprise when we focus only on the period of the ELB. Responses of the macroeconomic variables to the ED8 surprise are consistent with theoretical predictions of the effects of Fed forward guidance (which was thought to have a horizon of around two years), in both the full sample and the post-crisis sample.

The most closely related studies to our work are those of Lakdawala (2019) and Degasperi and Ricco (2021). While the majority of studies of the impact of information effects on the macroeconomic impact of monetary policy shocks study aggregated surprises that are not orthogonalised by the horizon, and do not allow information effects to change with the yield curve, these two studies do orthogonalise factors based on those of Gürkaynak et al. (2005) with respect to Fed-internal information, before using them in Proxy VARs. Our approach differs to that of Lakdawala (2019) and Degasperi and Ricco (2021) chiefly in terms of specification. We study different instruments, based on a recursive extraction of surprises at different horizons. Our Hybrid BVAR approach does not suffer from weak instrument issues, as reported in Gertler and Karadi (2015), and we are thus able to consider the effects of numerous surprises in a comparable manner, without having to search for particular points of the yield curve for which instruments are not weak. Some authors have argued that Proxy VARs may not be appropriate for the case of forward guidance surprises, since they represent a form of non-fundamental shock that cannot be recovered from the vector of data in the VAR (Ramey, 2016; Bundick and Smith, 2020). Ramey (2016) argues that for the case of forward guidance, specifications in which measures of news are treated as endogenous variables are preferred. Plagborg-Møller and Wolf (2021) have also argued that surprises are best modelled endogenously within the VAR system. Further, our approach also has the advantage of implicitly controlling for revealed macroeconomic data, unlike typical Proxy VAR specifications. Bauer and Swanson (2022) have recently argued in favour of using lagged realised data in order to control for confounding effects relating to the ability of market participants to differentiate between monetary policy surprises and changes to the central bank reaction function.

To understand the importance of our specification for the results, we also report responses estimated using a Proxy VAR approach. We examine cases where we relax the recursivity assumptions that apply in our baseline system, in the sense that the surprises were orthogonalised with respect to contemporaneous values of macroeconomic variables. For our investigations, results for macroeconomic variables are typically not in line with theory for Proxy VAR specifications, though this could be a feature of the abbreviated time-period we study relative to the related investigation of Miranda-Agrippino and Ricco (2021).

A comparable Hybrid VAR specification is employed in the baseline empirical investigations of Bundick and Smith (2020). However, in our study, unlike that of Bundick and Smith (2020), we chart differences between action and communication surprises in the pre-ELB period, and examine the influence of information effects by orthogonalising shock series with respect to Fed-internal information. The results of our study also relate to investigations in Paul (2020), who examines responses of private sector forecasts to monetary policy surprises at different points on the yield curve, finding statistically significant information effects for expected output growth only beyond five months after given meetings. Our investigations complement this analysis by quantifying the role of information effects at influencing estimated responses to communication surprises for realised data.

We now briefly summarise the layout of this paper. Section 2 introduces our empirical approach. Section 3 presents results for the pre-ELB period and Section 4 those for the effects of communication across horizons. Section 6 discusses the ELB period results. Section 7 concludes.

2 Empirical Specification

We assume that two different exogenous components drive the behaviour of the federal funds futures spectrum during Federal Reserve Open-Market Committee (FOMC) meetings: Firstly, an *action shock* component of surprise actions moving the whole futures spectrum spanning six months up or down; Secondly, a *communication shock* component only affecting expectations regarding federal funds rates for the month of the next FOMC meeting and those after. To disentangle the two, we first need to carefully construct a measure of expectational shifts about rates before and after the next FOMC meeting from the available federal funds futures. This section thus outlines how we map futures price changes into changes in anticipated policy rates before and after the next FOMC meeting. We then present a simple Cholesky decomposition that identifies our monetary policy action and communication shock. The structural shocks are purged of the effects of Fed information transmission by orthogonalising these movements with respect to Fed-internal Greenbook forecasts. Finally, we outline the medium-sized Bayesian VAR which we use to estimate the dynamic effects of central bank actions and communication.

From futures prices to anticipated rate changes between future FOMC meetings. The federal funds futures market allows participants to place bets on the average level of the federal funds rate in future months. The Fed has been explicitly announcing its federal funds rate decisions since March 1994, which marks the start of our sample. From March 1994 to June 2008, six futures contracts, betting on the federal funds rate level in the concurrent month until five months into the future ("FF1" to "FF6"), are liquid enough to be used in our analysis.[7] Our treatment of the futures contracts here is very close to that of Gürkaynak (2005), with the exception of the introduction of an iterated weighted averaging procedure to incorporate information from months without meetings.

We are interested in the shifts in market expectations during an FOMC meeting regarding the level of the federal funds rate before and after the next scheduled FOMC meeting. While federal funds futures refer to averages during calendar months, FOMC meetings take place eight times a year (around every six weeks), so we need to carefully transform information from the monthly futures to expectational changes with respect to the next meeting. At any FOMC meeting day d in month t, the shift in market expectations about the prevailing interest rate *before* the next future meeting can be constructed as a weighted average of changes in futures rates pertaining to the concurrent month. As this expectational change during the FOMC meeting will only be affected by central bank *actions* today, we will denote it

[7] See Barakchian and Crowe (2013). For more details on the federal funds futures market, see Appendix 1.

by $\Delta\rho^A_{d,t}$. Moreover, let $\Delta\rho^C_{d,t}$ denote the change in the expected rate at the next meeting—the superscript referring to the fact that this expectational change will be also be affected by central bank *communication* today about potential changes in the next meeting. Our aim here is to obtain the change in market expectations on policy rates valid between FOMC meetings, $\Delta\rho^j_{d,t}$ $j \in [A,C]$, from observed changes in federal funds futures prices $\Delta f^{(m)}_{d,t}$, where the superscript m refers to the month in the future to which the contract pertains, starting with the concurrent month 0. We work iteratively forward, starting with $\Delta\hat{\rho}^A_t$ (our initial estimate for $\Delta\rho^A_{d,t}$), which is set equal to the jump in the futures rate for the concurrent contract,

$$\Delta\hat{\rho}^A_{d,t} = \Delta f^{*(0)}_{d,t},$$

where the asterisk refers to the fact the first contract was corrected for the number of days already passed before the initial meeting.[8] Since contracts are defined over average interest rates for calendar months, we know that the price change of the futures contract for the month of the next meeting n, $f^{(n)}_{d,t}$, must be a weighted average of the expected interest rate carried forward from the previous meeting, $\Delta\hat{\rho}^A_{d,t}$, and that expected to be set in the next one, $\Delta\hat{\rho}^C_{d,t}$,

$$\Delta f^{(n)}_{d,t} = \frac{d_n - 1}{M_n} \cdot \Delta\hat{\rho}^A_{d,t} + \frac{M_n - (d_n - 1)}{M_n} \cdot \Delta\hat{\rho}^C_{d,t}.$$

In this expression, d_n refers to the day of the next meeting, and M_n to the number of days in the month of the next meeting. Therefore:

$$\Delta\hat{\rho}^C_{d,t} = \frac{M_n}{M_n - (d_n - 1)} \left(\Delta f^{(n)}_{d,t} - \frac{d_n - 1}{M_n} \cdot \Delta\hat{\rho}^A_{d,t} \right)$$

Since the futures rate jumps are likely to be noisy, and because such noise could be weighted up by the scaling terms, we utilise the extra information represented by changes in futures rates for calendar months without meetings. Thus, if there is no meeting in the second month, we create a new jump measure labelled $\Delta\tilde{\rho}^A_{d,t}$ by taking a weighted average of $\Delta\hat{\rho}^A_{d,t}$ and the jump in the futures rate next month as follows:

$$\Delta\tilde{\rho}^A_{d,t} = \frac{M_n - (d_n - 1)}{M_n - (d_n - 1) + M_{n+1}} \cdot \Delta\hat{\rho}^A_{d,t} + \frac{M_{n+1}}{M_n - (d_n - 1) + M_{n+1}} \cdot \Delta f^{(n+1)}_{d,t}$$

[8] For contracts on the current month, agents will already have observed a component of the policy-rate realization, because $d-1$ days of that month have already elapsed ($d-1$ as the overnight rate refers to the night *after* day d, see Hamilton, 2008, p. 378). We follow Kuttner (2001) in scaling the futures rate for the concurrent month, $\Delta f^{(0)}_{d,t}$, by the ratio of number of days in the month, M, over the number of days remaining after the meeting, $M-(d-1)$. Thus we obtain a corrected measure $\Delta f^{*(0)}_{d,t} = \frac{M}{M-(d-1)} \cdot \Delta f^{(0)}_{d,t}$. The scaling factor becomes very large at the end of the month (up to 31 for $M = d = 31$). We thus again follow Kuttner (2001, pp. 529f.) and use the change in the futures rate on the next month ($\Delta f^{(1)}_{d,t}$ in place of $\Delta f^{*(0)}_{d,t}$) for meetings within the last three days of a month, provided there is no meeting next month.

We are therefore using the fact that the jump in the price of the contract for the next month is an equally valid measure of the surprise in the cases that there is no meeting next month (since a single target rate will hold over the whole period). We employ the same strategy to create a second measure, $\Delta\tilde{\rho}^{C}_{d,t}$, whenever there is no meeting in the month following a given future meeting.[9] This approach ensures that the futures rate changes that occur towards the end of the month (with higher d) will get a smaller weighting in the convex combination. Thus, the procedure reduces idiosyncratic noise in the futures changes. We only rely on scheduled meetings here.[10] As there is never more than one scheduled meeting per month, we can neglect the d subscript in $\Delta\rho^{j}_{d,t}$ for the following.

Action and communication shocks. Given the market surprises about the policy rates expected before ($\Delta\rho^A_t$) and after the next meeting ($\Delta\rho^C_t$), we want to identify the structural shocks that generate these changes in expectations. Target rate changes by the Fed are highly persistent (as shown for example by Coibion and Gorodnichenko, 2012), and therefore any rate decision announced during the FOMC meeting will shift market expectations across our six-month spectrum of maturities. In other words, any surprise shifting $\Delta\rho^A_t$ will equally shift $\Delta\rho^C_t$: Without additional information about the future course of policy actions, markets will likely take the policy rate to be the new status quo. This is what Gürkaynak et al. (2005) and Barakchian and Crowe (2013) refer to as their "target factor" and "level factor", respectively. Thus an unexpected policy rate change by the FOMC will lead to an updating of expectations about the current as well as about future rates, and therefore both of our expectations measures $\Delta\rho^A_t$ and $\Delta\rho^C_t$ will be affected. We refer to these surprise announcements of immediate policies as *action shocks*.

On the other hand, the Fed may simultaneously deliver independent surprise information relating to future policy. Surprise communication about potential policy actions in the next meeting (referred to as *communication shocks*) ought to affect all futures rates after this next meeting, i.e. $\Delta\rho^C_t$, but not rates before them, $\Delta\rho^A_t$.[11] This recursive feature motivates the use of a Cholesky decomposition of the vector of expectational changes $[\Delta\rho^A_t, \Delta\rho^C_t]$. We enter a zero value to the shock series for the months without meetings, as in Barakchian and Crowe (2013).

[9] In case there is a meeting next month we do not perform the weighting. Further, we perform this operation during the iterative extraction, in the sense that where appropriate the weighted version of the previous surprise is used to extract the next, which then may be weighted, etc.

[10] Given that we rely on futures rate changes on meeting days, the occurrence of unscheduled meetings will only bias our shock measures if the market expectations about the likelihood of an unscheduled meeting are changed *during the day* of the previous (scheduled) FOMC meeting. From inspection of the minutes, the committee has never hinted at unscheduled meetings during the preceding meetings (see Appendix 1.2). Therefore, we do not believe the effect of unscheduled meetings presents a concern. We could additionally create measures of expectation changes for policy rates between the next meeting and the one after that. Experimentation showed that a second communication shock, orthogonal to the first communication shock, did not yield meaningful impulse responses, in line with the finding by Gürkaynak et al. (2005) that two factors are enough to capture the dynamics in the futures maturity spectrum for our baseline sample until June 2008.

[11] In a setup based on factors, equivalent assumptions are made in Gürkaynak et al. (2005), Swanson (2021) and Altavilla et al. (2019).

Formally, the changes in expectations about the future monetary policy rate, $\Delta\rho_t^A$ and $\Delta\rho_t^C$, are decomposed into two orthogonal shocks: surprises about monetary decisions today (the action shock, ε_t^A) and surprise communication about potential futures actions (the communication shock, ε_t^C) as follows:

$$\Delta\mathbf{R}_t \equiv \begin{bmatrix} \Delta\rho_t^A \\ \Delta\rho_t^C \end{bmatrix} = \begin{bmatrix} m_{11} & 0 \\ m_{21} & m_{22} \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_t^A \\ \varepsilon_t^C \end{bmatrix} \equiv \mathbf{M} \cdot \varepsilon_t. \tag{1}$$

Rearranging, we obtain the expression for the vector of structural shocks:

$$\varepsilon_t = \mathbf{M}^{-1} \cdot \Delta\mathbf{R}_t,$$

where $\mathbf{M}$ is the lower-triangular Cholesky decomposition of the variance-covariance matrix of $\Delta\mathbf{R}_t$.

Purging of Fed information effects. Next, we orthogonalise the changes in expectations ε_t^j, $j \in$ [A, C] with respect to Fed Greenbook forecasts in order to remove any potential transmission of Fed-internal information. Greenbook forecasts are made public with a lag of five years and therefore unknown by market participants at the time of FOMC announcements. The final, purged shocks, labelled $\tilde{\varepsilon}_t^j$, are the residual from an OLS regression of ε_t^j on a vector of Greenbook forecasts for month of the FOMC meeting day, GB_t. We include the following Greenbook variables: (1) contemporaneous unemployment, (2) contemporaneous output growth and its lag and first two forecasts; (3) the GDP deflator and its lag and first two forecasts; (4) the previous values of the output growth forecasts; (5) the previous values of the GDP deflator forecasts. We include lagged values of the Greenbook values following observations in Campbell et al. (2017) that information from Greenbook data appears to transmit to high-frequency surprises around FOMC statements with a slight delay, meaning that lagged values are significantly correlated with the surprises. The purged shock measures are therefore constructed as:

$$\tilde{\varepsilon}_t^j \equiv \varepsilon_t^j - \hat{\beta}_{GB} \cdot \text{GB}_t, j \in A, C. \tag{2}$$

We show the results from our purging regression in Table 1 in Appendix 2.1. Although individual explanatory variables are significantly correlated with both surprises, the p-value associated with the F-statistic of our purging of the communication surprise is only borderline significant with a value of 0.12. However, we choose to follow a conservative approach by adding many potential Greenbook variables. The R^2 of the regressions is rather low, which is a common finding of the literature (see e.g. Miranda-Agrippino and Ricco, 2021, or Lakdawala, 2019). Nevertheless, despite the low R^2, we will establish that the purging regressions do influence the estimated responses of variables in our system, and markedly so. Appendix 3.1 displays our unpurged and purged shock measures and documents their correlation to other measures of monetary policy shocks identified via futures data. Note that unlike Miranda-Agrippino and Ricco (2021), we do not use a second-stage purging regression on the lags of the extracted surprise. This is because, in our Hybrid VAR specification, we examine responses to shock series that are internally orthogonalised with respect to lagged values of the shock, since the shock is included as an endogenous series. This is conceptually very similar to the second-stage purging operation of Miranda-Agrippino and Ricco (2021).[12]

Our empirical BVAR model. We gauge the effect of our two measures of policy surprises on a set of monthly macroeconomic variables using a structural Bayesian VAR model of the following form:

$$\mathbf{Y}_t = \mathbf{C}_c + \sum_{l=1}^{p} \mathbf{C}_l \mathbf{Y}_{t-l} + \mathbf{D} \cdot \nu_t, \tag{3}$$

where $\mathbf{Y}_t = [\mathrm{Y}_t^{macro}\ S_t\ \mathrm{Y}_t^{fin}]'$ is of dimension $(n \times 1)$, and where the variance-covariance matrix of the $(n \times 1)$ vector of Gaussian errors, ν_t, is given by Σ_ν. We take $\{\mathbf{Y}_t\}_{t=1}^{p}$ to be given as initial conditions. We assume $\mathbf{C}_c$ is an $(n \times 1)$ vector of intercepts, and $\{\mathbf{C}_l\}_{l=1}^{l=p}$ are the $(n \times n)$ coefficient matrices associated with each lag l of the vector of endogenous variables. Here Y_t^{macro} denotes the set of (slow-moving) macroeconomic variables, and Y_t^{fin} denotes the set of (fast-moving) financial variables. The set of variables within Y_t^{macro} are (log) industrial production (IP), (log) CPI, the unemployment rate, and (log) real-estate loans. The set of variables within Y_t^{fin} are the federal funds target rate, the one-year Treasury yield, the EBP, and the VIX.[13] We cumulate the shocks over time to form a monthly time series of policy surprises in levels, $S_t^j = \sum_{i=0}^{t} \varepsilon_t^j$ for unpurged shocks and $\tilde{S}_t^j = \sum_{i=0}^{t} \tilde{\varepsilon}_t^j$ for shocks purged by Greenbook forecasts, and we use respectively action and communication shocks in place of ε_t^j or $\tilde{\varepsilon}_t^j$.[14] We only ever enter one surprise into the BVAR systems at a time, meaning that when we compare responses to different surprises, we do so in different systems.

We make the assumption that $\mathbf{D}$ has a recursive structure, which implies, as in Romer and Romer (2004) and Barakchian and Crowe (2013), that monetary policy surprises do not affect the macroeconomic variables in the same period. We order the shocks before the financial and interest rate variables in the vector, meaning these surprises are allowed to affect these series contemporaneously (see for example Bundick and Smith, 2020). We choose twelve lags ($p = 12$).

[12] Indeed, this was also a property of the Hybrid VAR examined in Barakchian and Crowe (2013).

[13] Data are taken from the monthly macro-dataset of McCracken and Ng (2016) and the FRED database of the Federal Reserve St. Louis. The VIX and EBP are monthly averages. The two interest rate variables are converted to monthly frequency using end-of-month values. This ensures that our identified shock precedes the monthly interest rate observations chronologically. Were we to use monthly averages, we would bias our estimate of the impact effect of the shock downward, since the average would include n days of data from the period before the shock, when the shock comes from a meeting on the nth day.

[14] All months with no meetings are set to zero. These series are I(1) by construction, and will be entered directly into the VAR in this form (as in Romer and Romer, 2004, and Barakchian and Crowe, 2013). Here the argument of Sims et al. (1990) should hold that "the OLS estimator is consistent whether or not the VAR contains integrated components, as long as the innovations in the VAR have enough moments and a zero mean, conditional on past values of the endogenous variables" (p. 113).

We estimate the VAR using Bayesian methods, using a Normal-Inverse-Wishart prior according to the standard Minnesota scheme, implemented using dummy observations. We provide detailed information about the implementation of the prior in Appendix 4, and only briefly summarise the main features of the estimation strategy here. We set the prior mean for each variable to imply that variables depend only on their own first lag. We vary the prior for the mean of the first auto-correlation coefficient according to whether the variable is stationary (when the prior mean is set to zero) or non-stationary (in which case the prior mean is set to equal one). In this we follow Bańbura et al. (2010). Although our system has a large number of parameters, the use of Bayesian methods handles this by allowing for a degree of shrinkage towards the prior. In our scheme the overall level of shrinkage is determined by the parameter λ, which we set to 0.2. The prior for the intercept has a zero mean, and a large variance (10^5). We set the scale matrix for the Inverse-Wishart prior distribution of the error term to $\text{diag}(\sigma_1^2, \ldots, \sigma_n^2)$, where σ_j indicates the standard deviation of the residual from OLS estimation of a p-order auto-regressive process. We set the parameter governing the degrees of freedom of the Inverse-Wishart distribution, υ_0, to 2. To construct posterior densities we draw directly from the posterior distribution, which can be expressed analytically, using Monte Carlo sampling. .

3 Baseline Results

3.1 The Unpurged Action and Communication Surprises

Figure 1 displays the impulse responses of two key macroeconomic variables, for BVAR systems in which we include the unpurged action and communication surprises, i.e. surprises that have *not* been purged of Fed-internal information. We initially describe the responses of (log) industrial production and (log) CPI, and discuss the responses of other variables subsequently. We report impulse responses to one-standard deviation contractionary innovations in the shock series.[15] For comparison, we also include responses to the monetary policy surprise of Barakchian and Crowe (2013), defined as the first principal component of daily movements in the first six federal funds futures.

From Figure 1 we observe that the responses of industrial production are in line with theory for all of the surprises. A one standard deviation action surprise, which is equivalent to a 3.0bp increase in FF1 at meeting day frequency, leads to a contraction in industrial production, which takes a minimum value of -0.14% after 29 months. A one standard deviation communication surprise, which leads to an increase in FF2 of 2.4bp on the meeting day, however, leads to a contraction in industrial production by of 0.40% after 23 months. The action surprise happens to lead to an increase in FF2 of 2.4bp, making the two surprises comparable in terms of their effects on this contract. The zero line does not lie within

[15] Technically, here we refer to the standard deviation of the residual from the BVAR equation containing the shock series.

the 68% credible set for these responses. We conclude that the communication surprise has an effect on industrial production that is about three times as large as that of the action surprise.

Next we examine the responses of the contractionary action and communication surprise on prices. The median response of the price level to the action shock is positive, contradicting theory, though the zero line lies within the credible set. For the case of the communication surprise, however, we find that the sign of the price reaction differs across the horizon of the response. In the short run, we do report evidence for a significant price puzzle, since an ostensibly contractionary surprise leads to an increase in the price level of 0.04% after 4 months. However, from 17 months onwards the sign of the response is negative, and the price level continues to fall in the medium run, reaching a minimum of -0.06% after 39 months. Therefore, from inspection of the impulse responses to the action and communication surprises, we observe no puzzles in the response of industrial production, even prior to orthogonalising the surprises with respect to Greenbook data. Further, we only observe statistically robust price puzzles for the case of the communication surprise in the short term.

In Figure 1 we also display responses to the first principal component surprise of Barakchian and Crowe (2013). The responses are qualitatively comparable to the baseline system of their paper, and any difference in the shape of the responses will be driven by our use of a Bayesian approach to estimation, and our inclusion of additional variables. As might be anticipated, responses to this surprise appear to lie somewhere between responses to the action and communication surprise, since the first principal component surprise is correlated with both. Our results indicate that the near-term price puzzle in response to the Barakchian and Crowe (2013) surprise is driven by the communication component.

[Figure 1 about here]

3.2 The Purged Action and Communication Surprises

Figure 2 shows responses to action and communication surprises, which have been orthogonalised with respect to FOMC Greenbook data. For comparison, we also report the responses to the unpurged shock series, which are identical to those of Figure 1. The impulses are again set to be contractionary and of one standard deviation, with the purged action and communication respectively increasing FF1 by 2.6bp and FF2 by 2.2bp on meeting days.

[Figure 2 about here]

Orthogonalising the action surprise with respect to Fed-internal information has little impact on the responses of industrial production, which remain negative. The purging regression, rather than in any sense bringing the price response to the action surprise in line with theory, actually seems to increase it further into positive territory relative to the unpurged case, however the zero-line remains within the 68% credible set.

Turning to the orthogonalised communication surprise, we see that the response of industrial production is actually slightly less negative than was the case for the unpurged surprise, with the minimum value being equal to -0.34% at the 18-month horizon. However, the median response to the orthogonalised communication surprise lies within the credible set for the unpurged case. When we examine the response of the price level, we observe that the orthogonalisation of the communication surprise leads to the removal of the short run price puzzle previously observed, and the negative medium run effect increases in absolute value. In response to the purged communication shock, the median response takes a minimum value of -0.07%, and the median value becomes negative after 6 months, whereas in the unpurged case this takes place after only 17 months. These results are consistent in a broad sense with the event day regressions of Campbell et al. (2012), who find greater evidence for information effects relating to the Gürkaynak et al. (2005) path factor relative to the target factor in their 1994 to 2007 sample, when considering the responses of private sector forecasts. However, Campbell et al. (2012) document more statistically precise counter-intuitive reactions for unemployment, not prices, in this sub-sample. In contrast, for our VAR system the purging of Fed information removes price puzzles from responses to the communication shock, while real activity puzzles were not evident from the beginning.[16] Thus we conclude that the communication surprise has a greater effect on industrial production than the action surprise, regardless of whether it is orthogonalised with respect to FOMC private information, and that the communication surprise affects prices in line with theory when it is purged of information effects.

Transmission channels. In Figure 3 we plot the responses of the other variables in the VAR system in order to study the transmission mechanisms that help explain the above results. When we consider the response of the federal funds rate, we note that both the unpurged and purged action surprises increase this rate at impact, which is entirely in line with their interpretation as action surprises. The end-of-month increase in the federal funds rate to the purged action shock is 2.9bp, which is close to the 2.6bp increase in FF1 at meeting frequency associated with a shock of this scale. The estimated response of the federal funds rate to the communication surprise is very close to zero at impact. This effect was not imposed econometrically within the VAR system, but follows from the fact that the communication surprises are orthogonal to movements in FF1 contracts on meeting days. The maximum response of the federal funds rate to the purged communication shock is 1.4bp after 2 months, consistent with our interpretation of the communication surprises as relatively near-term forward guidance surprises

[16] Nakamura and Steinsson (2018) report evidence that their measure of a monetary policy surprise reduces market-based measures of inflation expectations at the longer-end of the term structure, but is insignificant for short term expectations.

relevant for imminent meetings. There is a relatively persistent endogenous decrease of the federal funds rate in the medium run, reaching a minimum of -12.3bp after 20 months in the purged case. It seems that the Fed reacts to the macroeconomic contraction prompted by the communication surprise with some monetary expansion in the medium term. Generally, we also observe that the one-year Treasury yield closely tracks the dynamics of the federal funds rate responses, with the main important qualitative difference being that the communication surprises affect this yield at impact, since they are not designed to be orthogonal to the prices of such contracts.

The responses of the EBP yield several important qualitative features of the transmission of surprises through the risk-channel of monetary policy. All the contractionary surprises raise the EBP on impact. The purged action shock increases the EBP by 3.7bp at impact, and has a very persistent effect, with the median response remaining positive for 27 months.[17] For the communication surprise, the effects on the EBP are even stronger, and display a pronounced "hump" shape irrespective of whether the purged or the unpurged surprises are used. The purged communication surprise increases the EBP to a maximum value of 5.0bp, and the median response remains positive for 18 months.

These results are broadly comparable to those of Gertler and Karadi (2015), who also study the effects of high-frequency surprises on corporate spreads and find an important role for this transmission channel. However, since we study two orthogonalised action and communication surprises, as opposed to the use of FF4 in their paper, we are able to shed light on the exact structural components of monetary policy surprises that are likely to give rise to their result. As to the differences due to Fed-internal information, it seems to dampen the effect of the action surprise on EBP. For communication surprises, the response is greater, although it takes place with a delay, and information effects appear to enhance, rather than dampen, the magnitude of the estimated effect. After purging, the two surprises have a comparable effect on the EBP, though as mentioned the effect of the communication surprise has more of a "hump" shape.

Another means to assess the impact of the surprises on financial uncertainty and risk aversion is to study their effects on measures of the implied volatility of equity markets, the VIX. Both the unpurged and purged action surprise lift the VIX sharply at impact, with the series rising by 36.2bp and 27.8bp respectively. For the unpurged action surprise, the effect on the VIX is quickly reversed, with the median response taking a minimum value of -42.0bp after 3 months. This dynamic is not evident for the unpurged or purged communication surprises. While the purged action surprise lifts the VIX sharply at impact, this response is statistically significant only for two periods. A similar pattern holds for the purged communication surprise, so we conclude that both shocks raise implied volatility, but

[17] Caldara and Herbst (2019) also find that action surprises based on the contemporaneous federal funds futures contract raise corporate spreads in their Bayesian Proxy VAR. Moreover, they find an important role for the endogenous reaction of monetary policy to corporate spreads.

only for a very short time. We also conclude that the information component of the action surprise leads to a counter-reaction in the response of the VIX in the relatively short run.

The response of unemployment is consistent with theory in response to all four shocks. In line with the responses of industrial production, the effect of the communication surprise on unemployment is greater than that for the action surprise. Again, consistent with the responses of real activity, the purged communication surprise appears to raise unemployment by less than for the unpurged case, though the effects are similar in a statistical sense when one takes into account the width of the credible sets. The purged communication surprise increases the unemployment rate by 0.06pp after 21 months.

[Figure 3 about here]

Finally, for the case of real estate loans, action and communication surprises tend to have different effects. The contractionary action surprise actually appears to stimulate real estate loans, irrespective of whether it is purged or unpurged. The contractionary communication surprise appears to reduce real estate loans in the case that it is purged of information effects, and we observe a fall of 0.23% for this series after 19 months.

There are important differences between our results and those of Lakdawala (2019), who studies the responses to monetary policy shocks identified using the target and path factors of Gürkaynak et al. (2005) in a Proxy VAR setup. Lakdawala (2019) examines the effects on macro variables of a path factor shock that is orthogonalised with respect to measures of Fed-internal information, which is conceptually similar to our study of the purged communication surprise. Across our study and that by Lakdawala (2019), the responses of macroeconomic variables to the unpurged action surprise are very much comparable—contractionary actions reduce industrial production and lead to a positive but insignificant effect on prices. However, our findings for communication surprises are very different. We find little evidence for the industrial production puzzle reported in Lakdawala (2019)—our response is significantly negative and large, irrespective of whether the surprise is purged with respect to internal information. We do find a price puzzle, which however disappears for the purged communication surprise. In contrast, when Lakdawala (2019) uses a purged path factor as an instrument in a Proxy VAR, the drop of industrial production in response to the purged path surprise is statistically not different from zero at 68% confidence and there is no mitigation of the price puzzle. We believe that our results and conclusions differ because the use of a Hybrid BVAR specification in place of a Proxy VAR specification does lead to different estimates of the effects of forward guidance surprises (see also Section 5). Another explanation is that Lakdawala (2019) uses a measure of FOMC private information that is constructed as the difference between Greenbook and private sector (Blue Chip) forecasts, following Barakchian and Crowe (2013), whereas we favour the use of Greenbook data (as do Miranda-Agrippino and Ricco, 2021). When we make use of forecast differences between Greenbook and Blue Chip as orthogonalisation controls, the drop in industrial production becomes weaker, although results for the purged communication surprise remain comparable (see Section 5).

4 Information Surprises and Information Revelation across Horizons

In the previous subsection we charted evidence that the communication surprise is contaminated by information effects with respect to its short term impact on prices, since we observed a price puzzle at the closer horizons (though there is a significant drop in prices in the medium term, consistent with theory, also in the unpurged case). This issue was mitigated by an orthogonalisation regression controlling for a Fed information effect. These observed differences in the role of the purging regressions naturally lead to the question as to exactly which part of the yield curve the information channel affects most. In this section we document the changing role of the information effect for communication surprises at different horizons.

Specifically, we extract a communication shock at an extended horizon by increasing the maturity of the forward contract in the Cholesky decomposition of Equation (1), i.e. changing its value from $\Delta\rho_t^C$ to changes in increasingly "far ahead" interest rate futures contracts or Treasury yields. We compare unpurged and purged cases as before. In Figures 4 and 5 we document the impulse responses of key macroeconomic variables as we extend the horizon of the second contract in our orthogonalisation scheme.[18]

In columns (2) and (3) of Figure 4 we observe little qualitative change from the baseline for responses generated by shocks that orthogonalise FF3 and FF4 with respect to the action shock. This suggests that the effects of extending the horizon of the communication shock by small amounts into the future are small. There is an important exception, however. The positive response of prices one month after the shock, which is not significantly different from zero in the case of the purged baseline communication shock, is slightly greater under these specifications. Further, the zero values lie outside the credible region for these two surprises, in both cases for the horizons of around 2 to 5 months after the surprise.[19] The weighting in our baseline case hence seems to improve the ability of the purging regressions to fully remove the observed short horizon price puzzle.[20]

In columns (4) and (5) of Figure 4, we see that the magnitude of the response of industrial production to orthogonalised innovations in FF5 and FF6 is somewhat more muted here than in the baseline case. The purging regression appears to make this effect weaker still, though the median values for this

[18] Daily data on U.S. Treasury yields are taken from the dataset of Gürkaynak et al. (2007).

[19] For the unpurged case the horizons are 2 to 5, for the purged case 2 to 6.

[20] A discussion of the impact of the iterative weighted averaging procedure on the responses of macroeconomic variables can be found in the earlier version of this study for a smaller frequentist VAR (Goodhead and Kolb, 2018).

surprise lie within the credible region for the unpurged surprise.

We start to detect more substantial differences to our baseline results when we extend the measure of the communication surprise to the ED4 contract, i.e. surprises based on market expectations for Eurodollar interest rates four quarters or one year ahead, see column (6). In the unpurged case for this surprise, there is no evidence for either an industrial production or a price puzzle. The median responses of industrial production to the unpurged surprise is consistently negative across the response horizon and of a size around half the size of the baseline response to an unpurged communication surprise. The price response to this surprise is positive for the first four months, but not significantly so. Purging for Fed information weakens the industrial production response substantially, while shortening the duration of the effect. However, purging strengthens the response of prices. In column (7) of Figure 4 and column (2) of Figure 5, we observe that similar qualitative dynamics are observed for Eurodollar contracts defined at further forward horizons. One qualitative difference is that the median response of prices to the unpurged communications shock defined over ED8 and ED12 are negative, even before we purge these surprises of information content. Again we conclude that there is little evidence for industrial production or price puzzles even prior to our purging regressions, for communication surprises defined over these intermediate portions of the yield curve.

Predictably, the response of the two-year Treasury yield, displayed in column (3) of Figure 5, is qualitatively similar to that of the two Eurodollar contracts, as are the responses to the 5-year Treasury yield displayed in column (4). We can observe that the minimum response of industrial production to the unpurged communication surprise derived from 5-year Treasuries is -0.15% after 11 months, which is much smaller than our baseline estimates—displayed again for reference in column (1)—and adds further evidence to the idea that communication surprises have smaller effects on industrial production at longer horizons. When we examine the response of a surprise in the 10-year Treasury in column (5), we observe that while the industrial production response remains comparable, the price response is somewhat weaker, in both the purged and unpurged cases, and zero values lie within the credible set. We therefore do not see evidence at the 10-year horizon that the purging regression significantly strengthens an already negative price response, as we have seen consistently for communication surprises at shorter horizons.

Finally, we study the responses to an alternative measure of a communication surprise, the forward guidance (FG) factor developed in Swanson (2021). This surprise shares the property of our surprises that it is orthogonal to changes in contemporaneous federal funds futures by construction, and is thus uncorrelated with action surprises. In column (6) of Figure 5, we examine responses to the FG surprise computed over all event days studied in Swanson (2021), i.e. inclusive of unscheduled meetings. The industrial production responses to this surprise look very similar to those documented in response to the other surprises, and a purging regression again seems to weaken the response of real activity. However, the response of prices to the Swanson (2021) surprise is stronger and more sustained than the further forward communication surprises we have previously studied. Again, the purging repression appears to make the depth of the response greater. However, we can observe that the price response of the unpurged FG shock is also negative, in a more persistent manner relative to the longer-horizon communication surprises studied previously. This effect seems to be driven by the inclusion of unscheduled meeting days. When we plot responses to the Swanson (2021) shock defined only over scheduled days in column (7), we note that the price response in the unpurged case is comparable to the response of the unpurged orthogonalised Treasuries responses studied in columns (3) to (5). Overall, the responses to the Swanson (2021) FG surprise look very similar to those following shocks to Eurodollar futures (which are included in the bundle of contracts used for its estimation).

This analysis leads to several important conclusions regarding the nature of the information effect. First, in our Hybrid BVAR specification we robustly do not observe industrial production puzzles to unpurged surprises. This suggests that the responses of real activity are not too strongly affected by information effects of the kind documented in Campbell et al. (2012) and Nakamura and Steinsson (2018). Also, our purging regressions do not typically increase the magnitude of the response of industrial production in absolute value—in fact the response is typically reduced. Second, with respect to one-standard deviation surprises, the magnitude of the effect on industrial production tends to attenuate with the horizon of the surprise studied. This is true irrespective of whether we purge these surprises or not. This evidence is of interest to those researchers in the theoretical literature attempting to reconcile New Keynesian frameworks with the data, since these models tend to make the opposite prediction, i.e. that communication with a longer horizon is more effective. Third, the evidence for puzzling responses of prices to high-frequency surprises, while stronger than for industrial production, is nevertheless largely confined to surprises constructed from shorter horizons. Surprises derived from futures contracts based on interest rates beyond one year do not exhibit strong evidence of price puzzles. However, the purging regressions do tend to strengthen the magnitude of the effect across the yield curve. This is some evidence that information effects do play a role at longer maturities, although the magnitude of the difference is frequently similar in a statistical sense.

[Figure 4 about here]

[Figure 5 about here]

5 Specification Robustness

We consider robustness to two central modifications to our empirical approach: (1) we use alternative controls for our purging regressions; (2) we alter ways in which our shock series enter the VAR system.

For the first robustness exercise, we use a measure of the information gap between markets and the Fed as controls for the purging regression. The logic behind this is that a portion of the Greenbook data used as a measure of Fed private information in the baseline specification can be forecasted by market participants, and that one may argue that only the unknown component can be revealed by the Fed during the press conference window. For this reason we collect survey expectations based on Blue Chip data and subtract these from the associated Greenbook forecast for each event day (as in Barakchian and Crowe, 2013) for an identical selection of variables. Results are displayed in Figure 6.[21] While the responses of industrial production are comparable, the responses of inflation tend to show a somewhat slower decline and lie close to the unpurged case for most surprises. Therefore the tendency of the purging regressions to reduce the price response downwards does not appear to be robust to the use of Greenbook subtract Blue Chip series as controls. One explanation for this finding is that the Greenbook data controls allow one to partial out effects that stem not only from information revelation channels, but also from channels relating to the tendency of high-frequency surprise series to be predictable given realised data series (Miranda-Agrippino, 2017; Bauer and Swanson, 2021, 2022).

In our second robustness investigation, we reproduce the results of Figure 3 for some core macroeconomic variables using alternative specifications of our VAR system. We examine a case where we relax the recursivity assumption that applies in our baseline system, in the sense that within the VAR the surprises were orthogonalised with respect to contemporaneous values of slow-moving macroeconomic variables. To do this we simply order the shock series first in the vector. We refer to this system as a Hybrid Non-Recursive VAR. In our second system we employ a form of Proxy VAR, which follows the VAR-X specification of Paul (2020). It is shown in Paul (2020) that one can simply enter contemporaneous values of the instrument into an exogenous block and thereby compute impulse response functions that are isomorphic to a full Proxy VAR of the Mertens and Ravn (2013) and Stock and Watson (2012) form. This approach requires that one normalise the response of one of the endogenous variables in the system. We normalise the impact response of the federal funds rate to equal that of the baseline Hybrid BVAR for the case of the action surprise, and the response of the impact effect on the one-year Treasury yield to the communication surprise in the baseline case.[22] The Proxy VAR-X approach does not impose any recursivity assumptions. To assess the importance of these assumptions in the VAR-X case, we additionally orthogonalise the surprises with respect to the endogenous variables in the

[21]The coefficient estimates and diagnostic statistics for the purging regressions are reported in Table 2 in Appendix 2.1.
[22]We also do this for the previously discussed Hybrid Non-Recursive VAR, for simplicity.

baseline system, before entering the surprise as an instrument in the exogenous block. Specifically, we regress the surprises on (1) the first lag of all of the endogenous variables; (2) lags one to 12 of the shock itself; (3) the contemporaneous value of the macroeconomic variables. In principle, this places identical structural restrictions on the behaviour of the responses to the surprise as was the case in the Hybrid BVAR, which also ensures that the surprises are orthogonal to lagged data for the endogenous series (including the shock), and the contemporaneous value of macroeconomic variables.

We report results from these exercises in see Figure 7.[23] We observe that responses to the Hybrid Non-Recursive VAR are close to those for the baseline system, implying that the recursivity assumptions implicit in the baseline scheme do not overly affect results (such assumptions were also applied in Barakchian and Crowe, 2013 and Bundick and Smith, 2020). In contrast, the responses to the Proxy VAR-X differ substantially to the baseline, with markedly weaker effects in industrial production and prices recorded throughout, despite the fact the responses are normalised to affect the federal funds rate (for action shocks) and the one-year Treasury yield (for communication shocks) to the same degree. These differences are not only confined to the unpurged case, but also to the purged case, as can be observed in Figure 7.[24] The use of an instrument that has been additionally orthogonalised with respect to contemporaneous values of slow-moving endogenous variables tends to influence the median responses in the direction of our baseline estimates (particularly evident in the responses of the communication surprise in Figure 7), however the magnitudes of the estimates are still not comparable. We conclude that the use of a Hybrid BVAR specification does impact results, and indeed this specification was chosen on account of the fact that it is well suited to handle communication surprises about the future, and also implicitly controls for the ability of realised data to predict high-frequency surprises (Bauer and Swanson, 2022).

6 Communication Surprises at the Effective Lower Bound

In this section we examine the role of communication surprises at longer horizons before and after the ELB period. To construct surprises from this period, we utilise Eurodollar futures contracts at horizons greater than or equal to one year. During the ELB period, markets did not tend to expect imminent changes in short-rates, and none were realised, meaning that federal funds futures at short horizons display little volatility. For this reason we do not orthogonalise our Eurodollar derived surprises to changes in short-rates, as implemented in the previous analysis. We prefer to recursively regress surprise movements in the Eurodollar contract eight quarters out (ED8) on the Eurodollar contract four quarters out

[23]Results for shocks that are not purged with respect to Greenbook data (under the baseline control selection) are displayed in Figure 1 in Appendix 2.2.

[24]One explanation for the weakness of the Proxy VAR findings relative to Gertler and Karadi (2015) or Miranda-Agrippino and Ricco (2021) is that we restrict the data sample to the 1994-2008 period for all systems for consistency with the baseline, and do not utilise earlier data to estimate the parameters of the VAR system.

(ED4), taking the residual as a measure of a communication surprise at the two-year horizon. We then define a communication shock relating to ED12 as the component of ED12 that is orthogonal to the ED4 and ED8 communication surprises. This operation is implemented using a lower-triangular Cholesky decomposition of the variance-covariance matrix formed by daily movements in ED4, ED8, and ED12:

$$\Delta \mathbf{R}_t \equiv \begin{bmatrix} \Delta \text{ED4}_t \\ \Delta \text{ED8}_t \\ \Delta \text{ED12}_t \end{bmatrix} = \begin{bmatrix} m_{11} & 0 & 0 \\ m_{21} & m_{22} & 0 \\ m_{31} & m_{32} & m_{33} \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_t^{C,1} \\ \varepsilon_t^{C,2} \\ \varepsilon_t^{C,3} \end{bmatrix} \equiv \mathbf{M} \cdot \varepsilon_t. \tag{4}$$

In the subsequent discussion we will refer to the surprises $\varepsilon_t^{C,1}$, $\varepsilon_t^{C,2}$, and $\varepsilon_t^{C,3}$ as the ED4, ED8, and ED12 surprises respectively. It should be borne in mind that these surprises are the output of a recursive decomposition, and not the raw movements in Eurodollar contracts themselves. We keep the VAR system and estimation approach identical to that of the baseline, with one exception. Since the federal funds rate does not move for a sizeable portion of the full sample, to capture monetary policy we include only a measure of long term rates in the system, namely 10-year Treasury yields.

The Full Sample. Figure 8 shows the results for the whole sample period from March 1994 to December 2015. Here we display impulse responses to one-standard deviation innovations in the recursively defined Eurodollar communication surprises. For the unpurged case, a one-standard deviation contractionary ED4 surprise, which is associated with a 5.7bp rise in ED4 on scheduled FOMC days, leads to a maximal reduction in industrial production of 0.14% in absolute value, 8 months after the impact of the surprise. With respect to CPI, the level of prices falls to a minimum of -0.07% after 39 months. The unpurged ED8 communication shock, which is associated with a 2.9bp increase in ED8, leads to a slightly stronger industrial production response, reaching a minimum of -0.20% after 12 months. However, the response of prices is quantitatively similar to the ED4 surprise, though the fall in prices occurs much faster. The industrial production responses to the ED12 surprise, which is associated with a 1.8bp increase in ED12, are comparable in magnitude to the ED4 surprise, though the reduction occurs in a somewhat delayed manner. We observe a small price puzzle for this surprise in the short run in the unpurged case. Purging these surprises with respect to internal Fed information makes little difference qualitatively or quantitatively to the responses of these two macroeconomic variables, in line with the responses to communication shocks derived from Eurodollar futures in the shorter sample above.

As for Treasuries and the yield curve, we can observe that all three communication surprises raise the 10-year Treasury yield at impact. In this sense, each surprise does lead to a contractionary effect from the perspective of longer-term yields. The responses are shown to be persistent for the case of the ED4 surprise, with zero values lying outside the credible set as far as 17 months after the unpurged version of this surprise. Responses are somewhat less persistent for the ED12 surprise, where the maximum value is 4.1bp after 5 months. Interestingly, responses of 10-year bond yields to ED8 shows an varying dynamic for early horizons. The response takes a value of 3.7bp at impact in the unpurged case, before the path falls to a value of -4.4bp in month 8, before rising to take positive values by month 17. One explanation for this finding is the endogenous reaction of balance sheet policies to forward guidance at this horizon. The Fed potentially reacts to contractionary effects of forward guidance surprises with offsetting increases in QE programmes, leading to expansionary movements in yields.

Turning to the responses of the two variables associated with financial uncertainty, we observe that the ED4 surprise has an unclear relationship with the EBP, though in the unpurged case the surprise does appear to raise this measure of credit frictions, after a short lag. The ED8 surprise raises the EBP at impact. However, in the medium term, irrespective of whether the surprise is purged or not the EBP falls. This behaviour is not observed for the ED12 shock, which robustly raises EBP, with the unpurged surprise raising this variable to a level of 5.5pp after 12 months. With respect to implied volatility, the ED4 surprise raises the VIX, however the statistical significance of the response is low. We observe stronger responses of the VIX in response to the ED4 and ED8 communication surprises. In particular, the ED12 innovation raises the VIX persistently, with a peak response of 0.46pp after about one year.

We are therefore able to draw a number of conclusions from our investigations into the nature of the Eurodollar surprises over the full sample. As before, we find little evidence of industrial production or price puzzles for communication surprises defined over horizons of one to two-years, even prior to purging the surprises of Fed-internal information. The response of the yield curve to the three forms of surprise is qualitatively different. The ED4 and ED8 surprises raise the one-year Treasury yield in a "hump"-shaped pattern, while the ED12 surprise actually reduces this yield. While all the surprises raise long term Treasury yields at impact, the ED8 surprise displays a counter-reaction in the shorter term. Further, it is the communication surprises at the ED8 and ED12 horizons that have a greater effect on measures of credit frictions and uncertainty, relative to ED4. Both of these surprises raise implied volatility when contractionary. However the ED8 surprise tends to have an inverse relationship with EBP, while the ED12 surprise raises this variable.

[Figure 8 about here]

The Effective Lower Bound. We now restrict the sample to the financial-crisis and ELB period, i.e. the period from July 2008 to December 2015. Figure 9 displays results for the purged Eurodollar surprises.[25]

[25] Results for the unpurged case are displayed in Figure 2 in Appendix 2.3.

For the purged ED4 surprise, restricting estimation to the post-crisis sample results in several puzzles, including a robust industrial production puzzle, and a strong positive reaction of the price level in the medium run. One explanation for this result is that during the post-crisis period expectations regarding future short-rates were increasingly pinned to the ELB. The innovations in ED4 that did occur are possibly related to short term policy “mistakes” in Fed communication, rather than persistent changes in policy. In this sense results for the ED4 surprise become closer to the 1994-2008 action surprise previously examined when we focus only on the ELB period. However, it is also of interest that the positive response of industrial production is less evident for the case of the unpurged ED4 shock, displayed in Figure 2 in Appendix 2.3. The tendency for purging regressions to weaken the response of industrial production in our specifications has been noted in previous discussions, and the effect seems particularly evident for the ED4 surprise in this sub-period. Responses of the macroeconomic variables to the purged ED8 surprise are consistent with theory. The response of industrial production is more persistent relative to the baseline (purged) case, with statistical significance for 21 months relative to 9 months for the full sample. The negative response of CPI is somewhat less pronounced, relative to the full sample estimates. The macroeconomic responses of the ED12 surprise again display puzzling results in the post-crisis period, with greater evidence of a positive industrial production response relative to the baseline.

With respect to the financial variables, the ED4 and ED8 surprises continue to raise the 10-year Treasury yield at impact. Though the ED12 surprise increases the 10-year yield only fractionally at impact, this variable rises in the subsequent months. The response of the EBP to the ED4 surprise appears to show some evidence for a fall in the short-to-medium run, though the impact effect is positive. This response is reminiscent of the response to the ED8 surprise in the full sample. The response of the EBP to the ED8 surprise are positive in the short to medium term, and do not show the negative correction observed in the full sample. In this sense the persistent component of the EBP response seems increasingly related to components further down the yield curve, as we move into the post-crisis period. We observe reductions in VIX in response to the ED4 surprise in the post-crisis period, and the same negative effect is present at impact for the ED8 surprises, though the effect quickly corrects with a rise in evidence in the short-to-medium run, as was the case in the full sample data.

[Figure 9 about here]

7 Conclusion

In this study we have used high-frequency futures data to quantify the effects of Fed action and communication surprises, with the latter allowed to vary by horizon. We inferred the impact of information effects by the ability of first-stage purging regressions of the surprises on Fed-internal information to alter the impulse responses we attain in our VAR systems. We have shown robustly that in the period up to 2008, irrespective of whether the surprises are purged or not, the communication component of monetary policy has a stronger effect on industrial production than the action component. We have found the size of the contraction to be three times larger in absolute value. We do not find evidence for real activity puzzles for this sample from 1994 to 2008, however we do observe a price puzzle. The response of the baseline communications surprise is brought in line with theory by the purging regression, while the response of the action surprise is largely unaffected.

When we examine how responses to communication surprises vary with the horizon of the surprise, we find that the effect on real activity tends to decrease for surprises defined with respect to long horizon interest rate expectations. We find that, while the unpurged high-frequency surprises do deliver price puzzles at near horizons, these price puzzles disappear for communication surprises for horizons more than one year into the future. We do find that controlling for information revelation strengthens price decreases in the medium term, particularly around the two-year frequency.

Moreover, we document the importance of central bank communication during the recent ELB episode by looking at Eurodollar futures, which remained liquid during this period. When considering the full sample, we again find that purging regressions do not affect responses by much, and that the unpurged surprises typically display responses that are consistent with theory. We do find some evidence for robust price puzzles when we limit attention to the period from 2008 to 2015, where responses to a surprise change in interest rates one-year ahead look qualitatively comparable to those of an action surprise in the pre-2008 period. One explanation for this finding is that at the ELB, expectations regarding future interest rate changes become increasingly pinned down, meaning the variation we do observe in such expectations relate to non-persistent policy "mistakes".

We have generally observed that information effects are often weak in our Hybrid VAR systems, in the sense that the responses of unpurged surprises are consistent with theory. This is particularly true for communication surprises relating to the intermediate portion of the yield curve (between one and ten years). We have however charted how the nature of observed information effects changes with the horizon of communication. As far as monetary policy is concerned, words might not only speak louder than actions, but speak with particular volume and clarity when they refer to certain horizons in the future.

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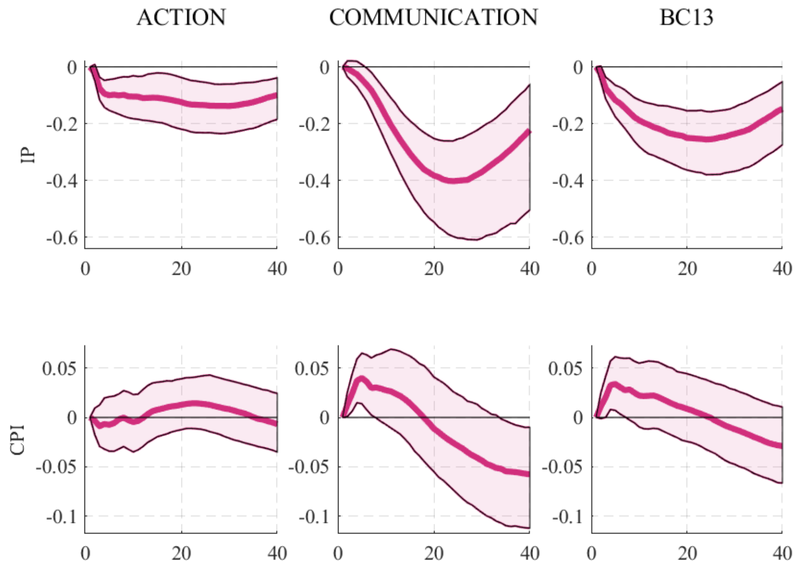
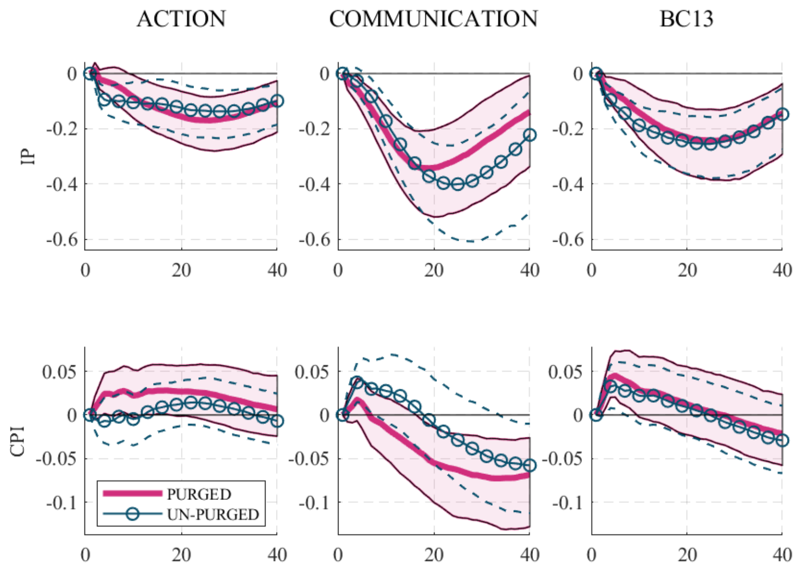
Figure 1: Responses to Baseline Surprises – Unpurged (1994-2008 Sample)



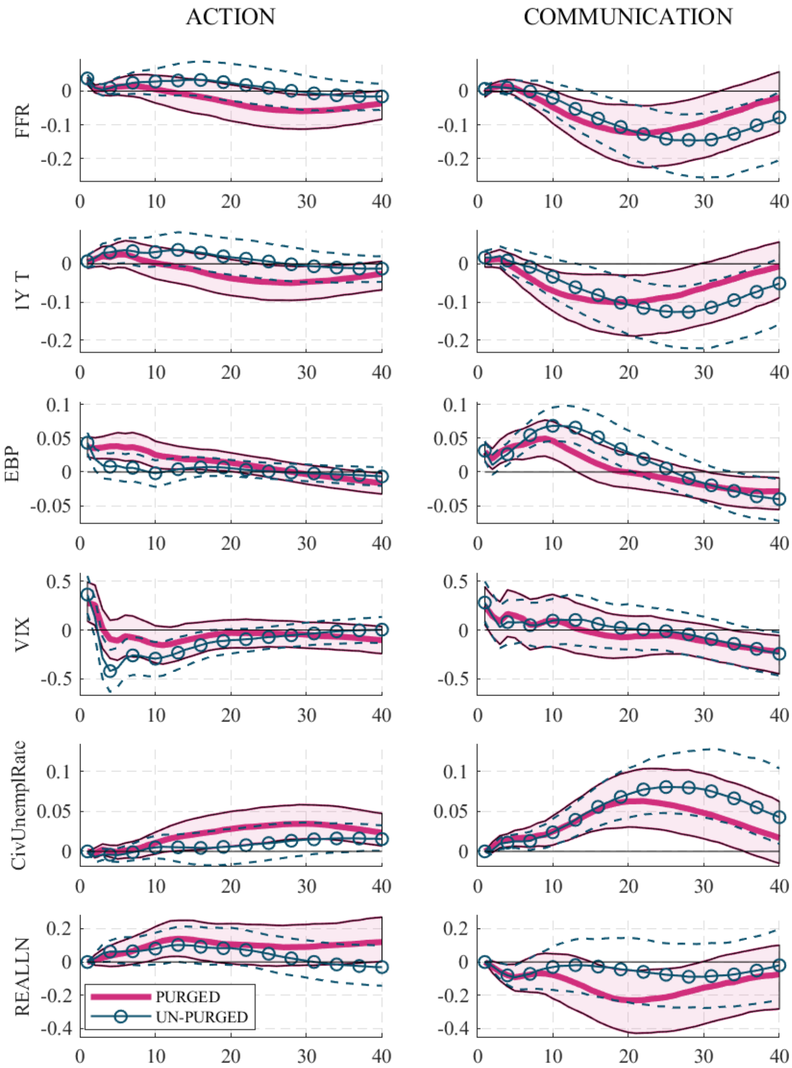
Notes: Selected results from baseline BVAR specification (sample period: 1994m3-2008m6). The first column shows the response to an action shock, the second column the response to a communication shock, the third column shows the response to the Barakchian and Crowe (2013) first principal component surprise. We display only the responses of (log) IP and (log) CPI from the 9-variable system. The shocks are one-standard deviation. We display the 68% credible set. Estimates are derived from 1,000 draws from the posterior.

Figure 2: Responses to Surprises Purged with respect to Fed-Internal Information (1994-2008 Sample)



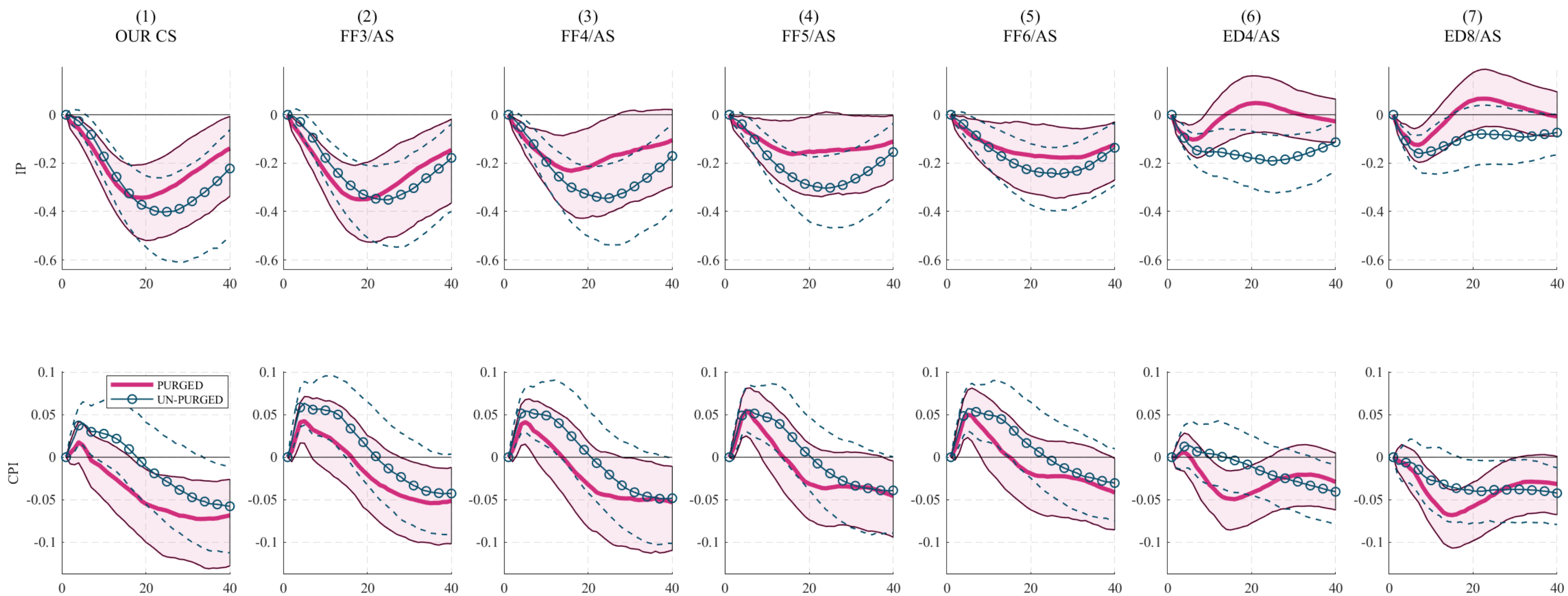
Notes: Selected results from baseline BVAR specification (sample period: 1994m3-2008m6). The first column shows the response to an action surprise, the second column the response to a communication surprise, the third column shows the response to the Barakchian and Crowe (2013) first principal component surprise. We display only the responses of (log) IP and (log) CPI from the 9-variable system. We display surprises that have been purged with respect to the internal information of the Federal Reserve. We display also the unpurged surprises for reference. We display the 68% credible set. Estimates are derived from 1,000 draws from the posterior.

Figure 3: Responses to Surprises, The Transmission Mechanism (1994-2008 Sample)



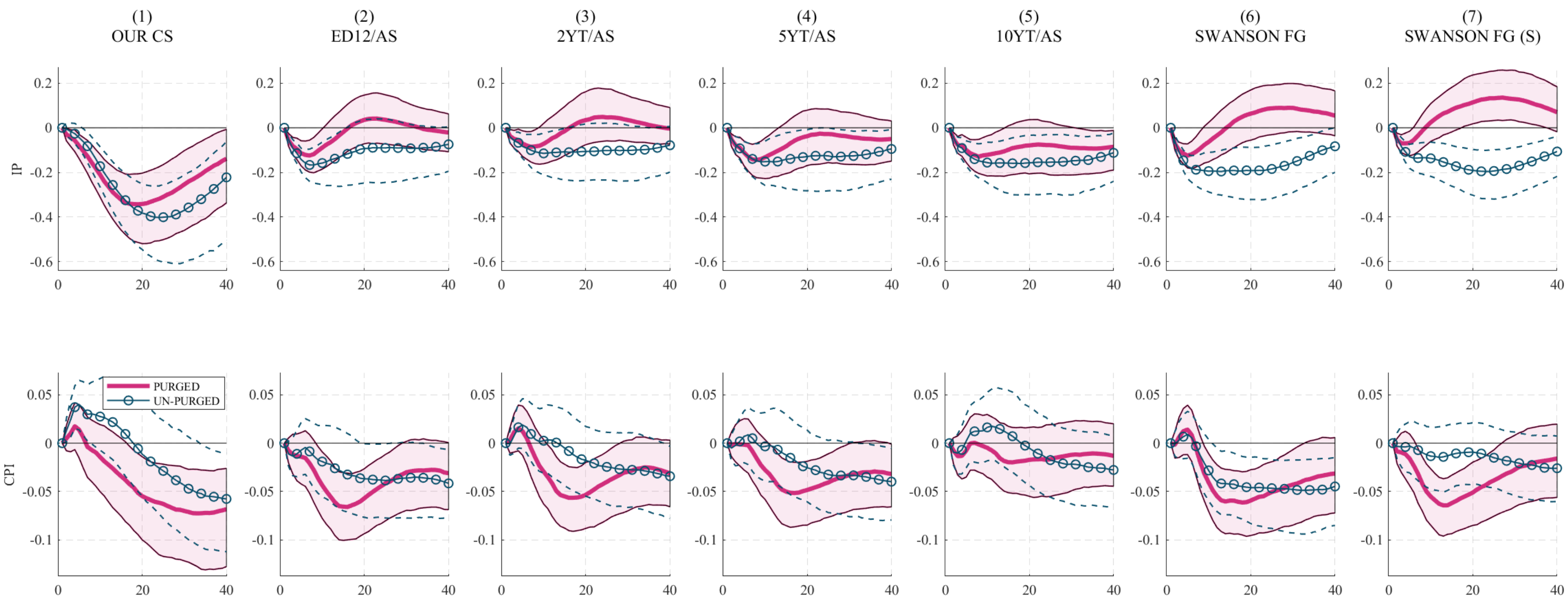
Notes: Results from the baseline BVAR model, for six of the macroeconomic and financial variables in the 9-variable system (sample period: 1994m3-2008m6). The left column displays impulse responses for the action shock, the right column for the communication shock. We display surprises that have been purged with respect to the internal information of the Federal Reserve. We display also the unpurged surprises for reference. We display the 68% credible set. Estimates are derived from 1,000 draws from the posterior.

Figure 4: Baseline IRFs Compared with Alternative Shock Measures (1994-2008 Sample), Part I



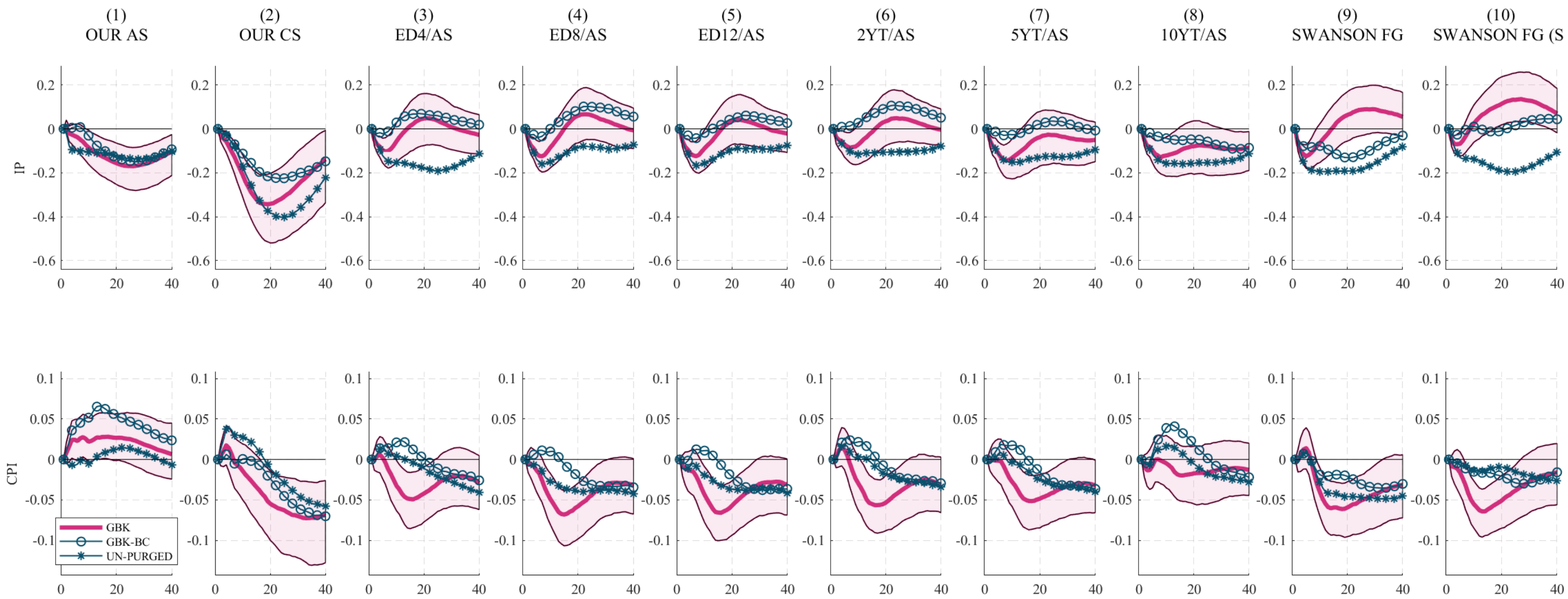
Notes: Results from the baseline BVAR model, for two of the macroeconomic variables in the 9-variable system (sample period: 1994m3-2008m6). We display responses to multiple measures of communication surprise. We display surprises that have been purged with respect to the internal information of the Federal Reserve. We display also the unpurged surprises for reference. We display the 68% credible set. Estimates are derived from 1,000 draws from the posterior.

Figure 5: Baseline IRFs Compared with Alternative Shock Measures (1994-2008 Sample), Part II



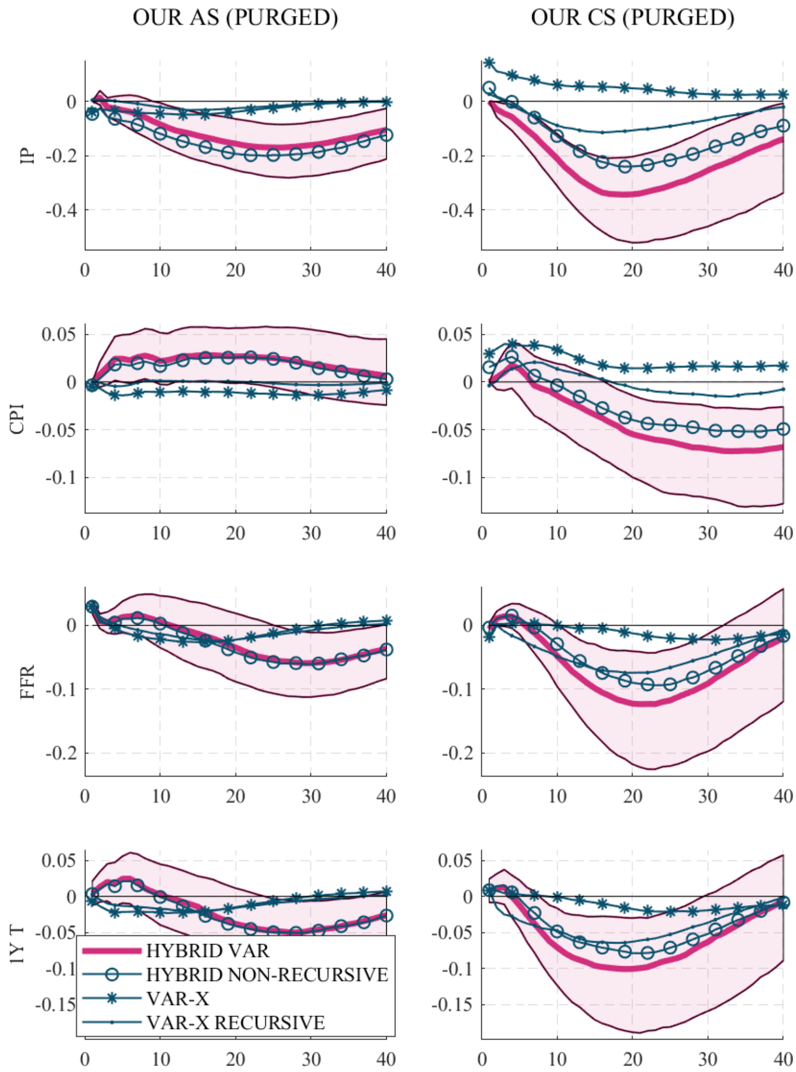
Notes: Results from the baseline BVAR model, for two of the macroeconomic variables in the 9-variable system (sample period: 1994m3-2008m6). We display responses to multiple measures of communication surprise. We display surprises that have been purged with respect to the internal information of the Federal Reserve. We display also the unpurged surprises for reference. We display the 68% credible set. Estimates are derived from 1,000 draws from the posterior.

Figure 6: Robustness to Purging With Respect to Greenbook Subtract Blue Chip Data (1994-2008 Sample)



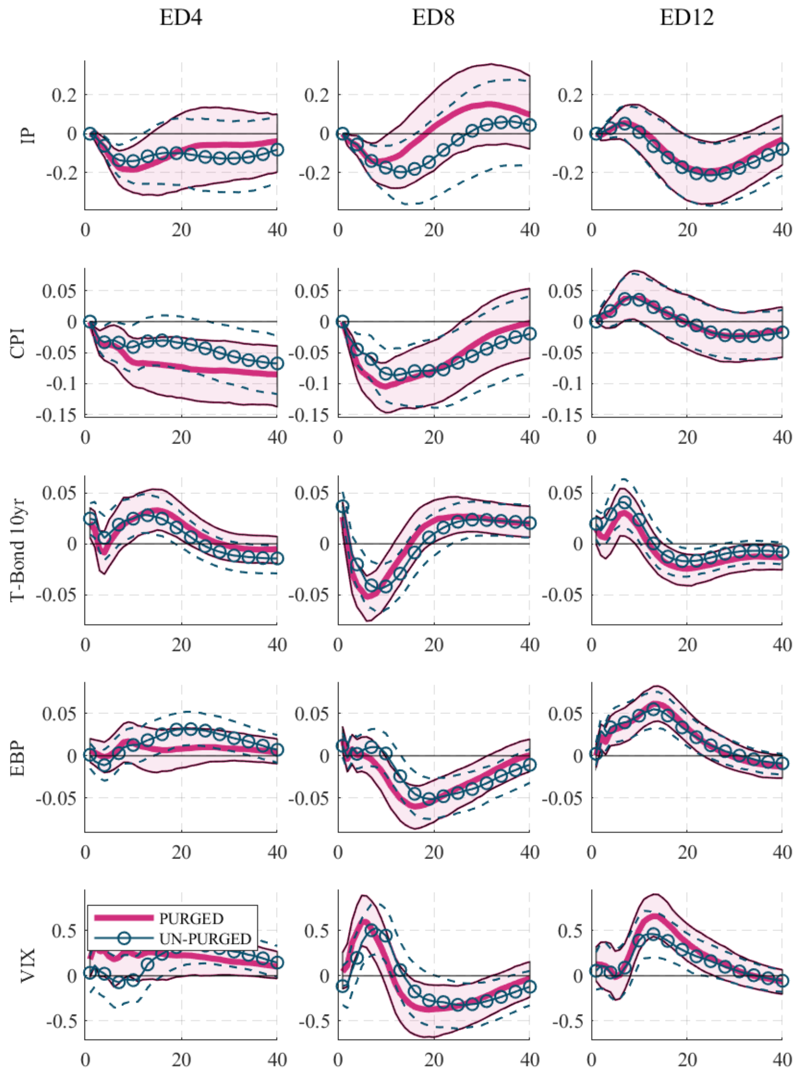
Notes: Results from the baseline BVAR model, for six of the macroeconomic and financial variables in the 10-variable system (sample period: 1994m3-2008m6). The left column displays impulse responses for the action shock, the right column for the communication shock (both purged with respect to central bank information). Solid lines without circles indicate the median response across posterior draws and the 68% credibility bands. The lines with circles indicate the median impulse response functions for a factor shock, and the lines with stars the case that the daily change in the FF4 contract is used as the dependent variable for our purging regressions (with the surprise taken as the residual). Estimates are derived from 1,000 draws from the posterior.

Figure 7: Comparison With VAR-X: Purged (1994-2008 Sample)



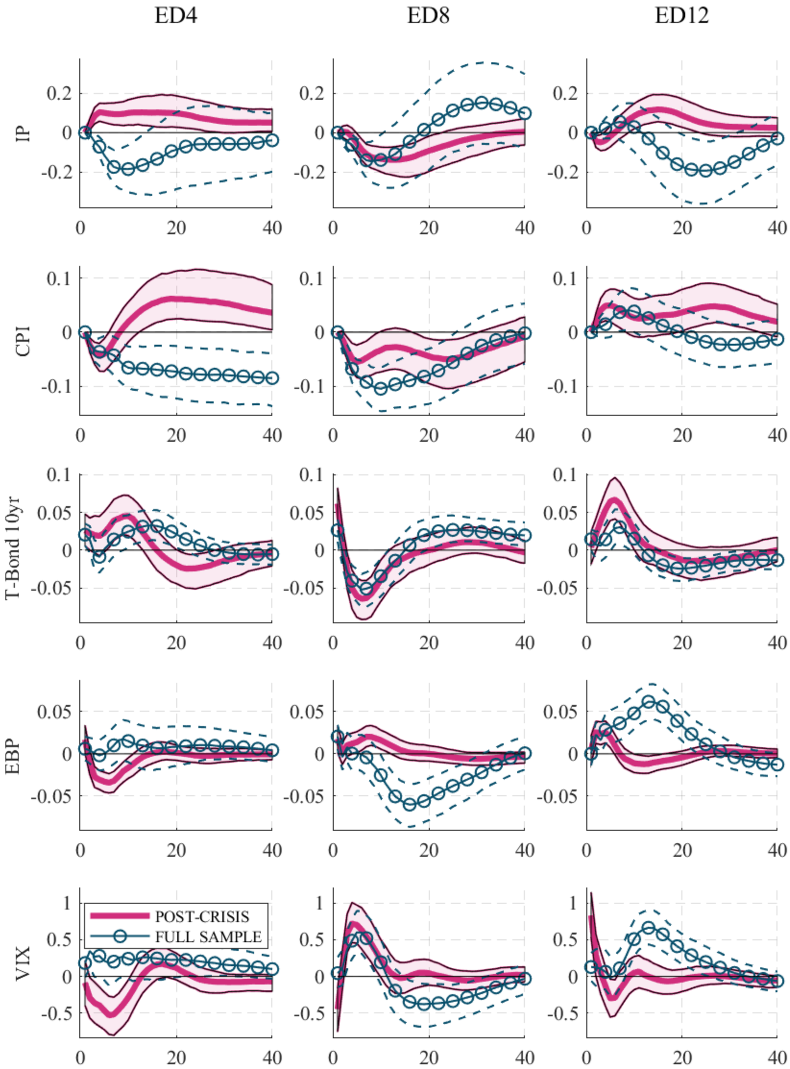
Notes: Sample period: 1994m3-2008m6. The first column shows the response to a purged action shock, the second column the response to a purged communication shock in our baseline Hybrid VAR. We display only the responses of (log) IP, (log) CPI, federal funds rate and the one-year Treasury yield from the 9-variable system. The shocks are one-standard deviation. Estimates are derived from 1,000 draws from the posterior. The Hybrid Non-Recursive specification is a Hybrid BVAR identical to the baseline with the instrument ordered first in the vector. The VAR-X specification uses the same variables as in the baseline Hybrid BVAR, however the shock is entered into an exogenous block. The VAR-X Recursive specification is identical to the VAR-X, however the instrument is first orthogonalised with respect to the first lag of all the endogenous variables, and contemporaneous values of slow-moving endogenous variables, and 12 lags of the shock itself.

Figure 8: Eurodollar Shocks – Purged and Unpurged (1994-2015 Sample)



Notes: Results from the Eurodollar BVAR model, for five of the macroeconomic and financial variables in the 9-variable system (sample period: 1994m3-2015m12). The three columns display respective impulse responses for ED4, ED8 and ED12 shocks. We display surprises that have been purged with respect to the internal information of the Federal Reserve. We display also the unpurged surprises for reference. We display the 68% credible set. Estimates are derived from 1,000 draws from the posterior.

Figure 9: Eurodollar Shocks – ELB (2008-2015) vs. Full Sample (1994-2015) – Purged



Notes: Results from the Eurodollar BVAR model, for five of the macroeconomic and financial variables in the 9-variable system (sample period: 1994m3-2015m12). The three columns display respective impulse responses for ED4, ED8 and ED12 shocks. We display only surprises that have been purged with respect to the internal information of the Federal Reserve. We compare responses to the full-sample and post-crisis periods (2008m7-2015m12). We display the 68% credible set. Estimates are derived from 1,000 draws from the posterior.