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Monetary policy communication shocks and the macroeconomy

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Non-technical summary

Research Question

What role does monetary policy communication play for the business cycle? How important is it relative to surprise monetary policy actions? And is the effect of communication driven by revealing internal central-bank forecasts or by hinting at future monetary policy decisions? We investigate these questions for the U.S. from 1994 to 2018.

Contribution

We assume that certain financial contracts, here Federal funds futures, reflect market expectations of future U.S. monetary policy. We investigate changes in the price of these futures during small time windows around press conferences by the Federal Reserve. This allows us to obtain announcements which come as a surprise to market participants. We propose a novel decomposition of futures price movements across different maturities between 1994 and 2008, which helps us to distinguish surprise monetary policy actions (unanticipated changes in the Federal funds rate) from surprise communication about the near-future course of monetary policy. For both components, we analyse the effect on macro variables, which we also isolate from the impact of revelations of internal central-bank forecasts. An extension using another type of futures contract allows us to examine the period until 2018, covering the period when U.S. nominal interest rates reached near zero.

Results

Only the surprise monetary policy communication leads to a significant expected reaction of industrial production, while the surprise monetary policy action does not. Moreover, longer-term communication significantly affects inflation in the period until 2018. This finding is robust to various different technical specifications. We therefore argue that communication about monetary policy has been and is still highly important for the transmission of U.S. central bank policies, both before and after 2008.

Nichttechnische Zusammenfassung

Fragestellung

Welche Rolle spielt die Kommunikation der Zentralbankpolitik für die Konjunktur? Wie bedeutend ist diese Kommunikation verglichen mit unerwarteten geldpolitischen Entscheidungen? Und entfaltet diese Kommunikation ihre Wirkung durch die Bekanntmachung interner Zentralbank-Prognosen oder aber durch Andeutungen zu zukünftigen geldpolitischen Entscheidungen? Wir untersuchen diese Fragen für die USA im Zeitraum von 1994 bis 2018.

Beitrag

Wir nehmen an, dass sich in bestimmten Finanzkontrakten (hier: Futures auf den US-Leitzins) die Markterwartungen zukünftiger US-Geldpolitik widerspiegeln. Wir untersuchen Änderungen im Kurs dieser Futures während kurzer Zeitfenster um Pressekonferenzen der US-Zentralbank und können so Mitteilungen der amerikanischen Zentralbank herausfiltern, die für die Marktakteure überraschend sind. Wir schlagen eine neuartige Zerlegung von Kursbewegungen der Futures unterschiedlicher Laufzeit zwischen 1994 und 2008 vor, welche uns hilft, überraschende geldpolitische Handlungen (unangekündigte Änderungen des amerikanischen Leitzinses) von überraschender Kommunikation über den kurzfristigen geldpolitischen Kurs zu unterscheiden. Für beide Komponenten betrachten wir den Effekt auf Makrovariablen, den wir auch von den Auswirkungen von Bekanntmachungen interner Zentralbank-Prognosen isolieren. Eine Erweiterung mit anderen Futures erlaubt es uns zudem, den Zeitraum bis 2018 zu betrachten und damit auch die Zeit, in der die Zinssätze in den USA nahe null lagen.

Ergebnisse

Überraschungen bei der geldpolitischen Kommunikation, nicht aber bei der unmittelbaren Umsetzung der Geldpolitik, führen zu einer ökonomisch intuitiven Reaktion der Industrieproduktion. Zudem beeinflusst die längerfristige Kommunikation im Zeitraum bis 2018 messbar die Inflation. Diese Ergebnisse halten verschiedenen technischen Spezifikationen stand. Wir folgern daraus, dass die Kommunikation der Geldpolitik für die Transmission der US-Zentralbankpolitik sowohl vor als auch nach 2008 wichtig war und ist.

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Monetary Policy Communication Shocks and the Macroeconomy*

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Abstract

Using federal funds futures data, we show the importance of surprise communication as a component of monetary policy for U.S. macro variables, both before and after 2008. While Gürkaynak et al. (2005) stress the importance of monetary policy communication for asset prices, much of the subsequent VAR literature attributes all effects of monetary policy on macro variables to surprise changes in the policy rate. Instead, we distinguish between monetary policy action and "communication shocks" (surprise announcements about future policy moves), both orthogonal to internal Fed information. To do so, we use a decomposition of futures price movements exploiting variation across contract maturities. In a monthly sample from 1994 to 2008, our results indicate that it is mainly communication shocks—as opposed to actual rate-change surprises—that affect production in the ways traditionally associated with monetary policy shocks. We also use Eurodollar futures to cover the zero-lower bound period and find strong effects on inflation for long-horizon communication shocks.

JEL Classification: E52, E58, G23, C32.

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

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1 Introduction

The question of how a central bank should communicate with the public has confronted policy makers for decades. There has been a general tendency towards transparency and clarity over the years.[1] In fact, after around the year 2000 communication has been (re-)discovered as a tool for central bank policy (for an overview prior to the financial crisis, see Blinder et al., 2008). Recently, forward guidance has been employed first to overcome the zero-lower bound and then to prepare the exit from other unconventional monetary policies. In this paper, we use federal funds futures data to investigate the effects of Federal Reserve (Fed) communication on the U.S. business cycle and document its powerful role both before and after 2008. In fact, we find that surprise communication is a more important driver of macro variables than surprise rate changes themselves.

To distinguish monetary-policy action from communication shocks, we use a recursive identification scheme on futures price movements on FOMC meeting days, exploiting the institutional set-up of FOMC conferences post-1994. Our finding regarding the importance of central-bank communication is in the spirit of Gürkaynak et al. (2005, GSS in the following). The authors also study futures price movements on announcement days and show that a "path factor" (orthogonal to movements in the federal funds futures for the concurrent month and interpreted as central-bank communication) has larger effects on asset prices than a "target factor" (interpreted as surprise action). However, our communication shocks are more precisely defined than factors, in the sense that they pertain to given dates in the future and lend themselves to be used as shocks in a parsimonious SVAR specification of the Romer and Romer (2004) type. Moreover, we extend the multi-dimensional analysis of monetary policy shocks of GSS to macro variables, while authors such as Faust et al. (2004), Thapar (2008), Barakchian and Crowe (2013) and Gertler and Karadi (2015) investigate the effect of only a single monetary policy shock on macro aggregates.[2] Similarly, Nakamura and Steinsson (2018) also study just one factor of futures movements, however they use a small structural model to distinguish two counteracting effects of FOMC announcements: In response to a surprise tightening of rates (for example), markets could infer that the Fed forecasts stronger growth than they expected.

[1]This shift can be seen in the changing self-perception of Fed chairmen, from Alan Greenspan, who in 1987 famously noted "Since becoming a central banker, I have learned to mumble with great incoherence. If I seem unduly clear to you, you must have misunderstood what I said" (speaking to a Senate Committee in 1987, as quoted in the Guardian Weekly, November 4, 2005) to Ben Bernanke, who in 2013 declared "Nearly eight years ago, when I began my time as Chairman, one of my priorities was to make the Federal Reserve more transparent—and, in particular, to make monetary policy as transparent and open as reasonably possible" (see https://www.federalreserve.gov/newsevents/speech/bernanke20131119a.htm).

[2]Out of these papers, only Gertler and Karadi (2015) use an external-instruments approach, in order to safeguard against simultaneity in a high-frequency VAR including both a monetary policy shock measure and credit costs. However, the authors note that when no further financial variables are considered, a recursive VAR such as ours is appropriate for an analysis of monetary policy shocks.

The authors find this (expansionary) Fed "information" effect on the natural interest rate to be in fact larger than the (tightening) increase in real rates over the natural rate. We show that our communication shocks are not driven by this information effect: When we orthogonalise our shocks with respect to internal Fed (Greenbook) forecasts, the communication shock still yields the macro reactions typically associated with monetary policy shocks, while the action shock does not. Moreover, our futures-based communication shocks explain a larger share of variance in production and can be more easily aligned with historical narratives of Fed policy. We thus argue that monetary policy shocks from the high-frequency literature derive their power over macro variables from the communication component much more than from the action component.

Our analysis is based on federal funds futures, which have been widely used to examine the effects of changes in monetary policy rates on financial and macroeconomic variables.[3] Given that the available futures maturities span the dates of several future policy meetings, we can use differences in futures price reactions to policy statements across the maturity spectrum to discern changes in market expectations about future monetary policy moves. Specifically, we employ a linear decomposition of futures price movements on FOMC meeting days in combination with an institutional arrangement: Since 1994, the FOMC has published its meeting days well in advance, so that market participants know the earliest possible date when future policy actions can be taken. We can therefore transform the movements in the various maturities of monthly federal funds funds rates (reflecting anticipated average target rates in future months) into movements in anticipated rates before and after the next FOMC meeting.

In a second step, we decompose these movements into action and communication shocks. Since changes in the target rate tend to persist, surprise rate changes today affect rates across the whole spectrum of available maturities in the same direction. However, additional information about potential policy changes in future meetings ("surprise communication") should not affect the futures rates of maturities that expire before that date. We are therefore able to employ a simple yet credible recursive scheme to orthogonalise monetary policy "action shocks" (surprises about the actual target rate decision announced at an FOMC meeting) from monetary policy "communication shocks" (anything that changes market expectations about potential target rate decisions taken at future FOMC meetings during the current meeting).[4] In fact, our approach is similar to the one in Gürkaynak (2005), who identifies "timing", "level" and "slope" surprises by orthogonalising movements in individual futures maturities. In our robustness section, we show that incorporating extra information from months in which no

[3]This so-called "high-frequency identification" literature goes back to Rudebusch (1998), Kuttner (2001), and Söderström (2001). In general, we expect interest by economic researchers in the federal funds futures market to increase in the near future, as the time series available after the end of the zero-lower bound episode will soon be sufficiently long for analysis.

[4]Note that these shocks represent changes in expectations that may or may not be accurate *ex post* (i.e., our shocks represent combinations of news and noise shocks).

meeting took place, as we do, leads to a sharper and less noisy quantification of action and communication shocks. Also, like GSS, Gürkaynak (2005) does not investigate the effects on macro variables.[5]

Barakchian and Crowe (2013) rightly point to the increasingly forward-looking nature of monetary policy, insofar as the Fed relies more heavily on forecasting when designing policy: After the 1980s, policy rates react contemporaneously to, or even before, changes in economic activity (for a similar argument, see Cochrane and Piazzesi, 2002). However, we argue that there is also an important reverse anticipation effect: If financial markets are similarly forward-looking in their judgment of FOMC communication, and given that Fed communication has become more detailed about its future policy course, markets should react to announcements in a way that is reflected systematically over the spectrum of federal fund future maturities. In fact, when explicitly distinguishing between action and communication shocks, we find only the latter to cause the movements in macro aggregates usually expected from a "monetary policy shock".

We also show that our monetary policy communication shocks remain meaningful when controlling for potential information transmission by the Fed on FOMC meeting days.[6] Communication shocks orthogonal to internal Fed ("Greenbook") forecasts create contractions of industrial production which are larger and more significant than for action shocks.[7] Moreover, central-bank communication explains a larger share of variation in industrial production and can be more easily aligned with narratives about the monetary policy stance over our sample. These findings are robust to a variety of specifications. We argue that over and above information revelation, communication about the near-future course of monetary policy matters, as markets update their expectations about the future Fed actions.

Relation to forward guidance. Since our baseline sample runs from 1994 to 2008, we analyse communication shocks during times of conventional monetary policy. In an extension, we also cover the zero-lower bound (ZLB) period using Eurodollar futures, which are available at

[5]Moreover, while Gertler and Karadi (2015) reject the GSS shocks as weak instruments in their analysis, we are able to show the importance of communication using a different methodology.

[6]Romer and Romer (2000) are the first to show that the Fed transmits important internal information during FOMC meetings. Romer and Romer (2004) control for such information using the internal Fed Greenbook forecasts, and Thapar (2008) introduces this approach to the high-frequency literature. Miranda-Agrippino (2016) shows that controlling for the information effect by orthogonalising high-frequency changes to Greenbook forecasts matters, as only the orthogonalised changes yields intuitive results in an instrumental-variable VAR on monetary policy effects. Miranda-Agrippino and Ricco (2017) adjust the instrument in Gertler and Karadi (2015) to account for autocorrelation and central-bank information revelation (again via Greenbook forecasts).

[7]Jarocinski and Karadi (2018) distinguish monetary-policy action and information shocks for the euro area and U.S. by their different high-frequency effects on interest rates and stock prices. Kerssenfischer (2018) shows that such an identification scheme solves several puzzling responses for the euro area. Ben Zeev et al. (2017) identify "monetary policy news shocks" as in the TFP literature, but do not distinguish between information revelation and communication. While these authors do not distinguish between central-bank information or news shocks and communication, we identify communication shocks orthogonal to information revelation.

longer maturities than the federal funds futures. Importantly, the contracts remain sufficiently liquid for analysis during the period 1994 to 2018, which captures the episode of forward guidance from 2012 to 2015. In our Eurodollar analysis, we find no significant effects of communication on IP, but report a stabilising effect on inflation, particularly at longer horizons.[8] Campbell et al. (2012) distinguish between "Delphic" forward guidance, or transmission of private central-bank information, and "Odyssean" forward guidance, which represents explicit commitments to a future policy course.[9] To isolate the Odyssean component of our shocks based on Eurodollar futures, we again control for central-bank information (the Greenbook forecasts). Results remain essentially unchanged, which we take as tentative evidence that the effectiveness of communication up to 2018 stems more from its Odyssean than Delphic component. This contrasts to findings in Lakdawala (2016), who uses a proxy SVAR with the two GSS shocks to distinguish between federal funds rate and forward guidance shocks, and finds an expansionary effect for contractionary forward guidance, which is rendered insignificant when controlling for the Fed information set.[10] Finally, Swanson (2017) uses a factor analysis similar to GSS to distinguish between the effects of surprises in federal funds rate changes, forward guidance and LSAP on asset prices, and clearly shows the importance of monetary policy communication for asset prices during the ZLB episode. Similarly, our Eurodollar results for a sample until 2018 underline our key message that central-bank communication has important macroeconomic effects.

2 Methodology

This section introduces our data, and outlines how we obtain changes in anticipated policy rates from changes in the price of futures contracts defined over calendar months. We then present a Cholesky decomposition that delivers identification of both the monetary-policy action and communication shock. Finally, we explain how we incorporate our shocks into a structural VAR model in order to examine their effect on macroeconomic variables.

[8] This strong effect on inflation, which increases in the horizon of communication, is in line with the predictions of DSGE models as studied by Del Negro et al. (2016), McKay et al. (2016) and Bundick and Smith (2016).

[9] Andrade and Ferroni (2016) differentiate Delphic and Odyssean forward guidance for the euro area as follows: For a high-frequency increase in the term structure (measured by overnight-index swaps), inflation expectations (measured by inflation-linked swaps) will increase for Delphic, but fall for Odyssean forward guidance. See also Hansen and McMahon (2016) for a complementary approach using computational linguistics to distinguish FOMC communication regarding current economic conditions and forward guidance. Leombroni et al. (2017) distinguish between rate and communication shocks in the euro area using the fact that the target rate decision is given some time before the ensuing press conference starts. They also find stronger effects of communication than of action shocks on asset prices.

[10] The difference to our results might be explained by the shorter horizon of our communication shocks (within six months instead of one year), or by the way the external instruments approach includes data from earlier periods (back to 1979).

2.1 Federal Funds Futures

Federal funds futures contracts were introduced on October 3rd, 1988, by the Chicago Board of Trade, and are the most widely used futures contract tied to the federal funds rate. The use of these futures limits our sample to the period before the ZLB, since trading in the shorter maturity contracts effectively ceased at the onset of this period.[11]

Federal funds futures contracts allow market participants to place a bet in month t on the average effective federal funds rate during the concurrent or future months, denoted by $\bar{r}_{t+m}$, with $m \geq 0$. A buyer of the contract on day d in month t can commit to borrow federal funds at a fixed rate at the end of the month $t+m$, and we denote this futures rate by $f_{d,t}^{(m)}$. Under the assumption of efficient markets, we have that the futures rate $f_{d,t}^{(m)}$ reflects the market expectations of the average effective federal funds rate $\bar{r}_{t+m}$:

$$f_{d,t}^{(m)} = \mathbb{E}_{d,t}[\bar{r}_{t+m}] + \delta_{d,t}^{(m)}, \quad \forall m \geq 0,$$

where $\delta_{d,t}^{(m)}$ is a risk-premium term. Since Kuttner (2001), many authors have argued that the movements in the federal funds futures market observed on FOMC meeting days (referred to as "jumps" in the following) capture a surprise component of monetary policy. Let us assume no change in the risk-premium $\delta_{d,t}^{(m)}$ for that short time window.[12] Then, a policy surprise can be computed as the difference in the futures rate at the end of the FOMC meeting day from that at the end of the previous day:[13]

$$\Delta f_{d,t}^{(m)} \equiv f_{d,t}^{(m)} - f_{d-1,t}^{(m)} = \Delta \mathbb{E}_{d,t}[\bar{r}_{t+m}], \quad \forall m \geq 0$$

Although federal funds funds contracts are now available for maturities as far as three years into the future, only the first six maturities of futures are generally considered liquid enough to be treated as efficient financial markets over our time period (see Barakchian and

[11] Our short sample reduces, however, the likelihood of structural breaks in the transmission of monetary policy (see e.g. Boivin and Giannoni, 2006, and D'Amico and Farka, 2011).

[12] Piazzesi and Swanson (2008) show that the risk-premium in the federal funds futures market is sizeable and time-varying, but only at business-cycle frequencies.

[13] Note that for contracts on the current month, agents will already have observed a component of the realization of $\mathbb{E}_{d,t}[\bar{r}_t]$, 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, $\Delta f_{d,t}^{(0)}$, 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 $\Delta f_{d,t}^{*(0)}$:

$$\Delta f_{d,t}^{*(0)} = \frac{M}{M-(d-1)} \cdot \Delta f_{d,t}^{(0)}$$

This scaling factor becomes very large at the end of the month (up to 31 for $M = d = 31$). We therefore again follow Kuttner (2001, pp. 529f.) and use the change in the futures rate on the next month ($\Delta f_{d,t}^{(1)}$ in place of $\Delta f_{d,t}^{*(0)}$) for meetings within the last three days of a month, provided there is no meeting next month.

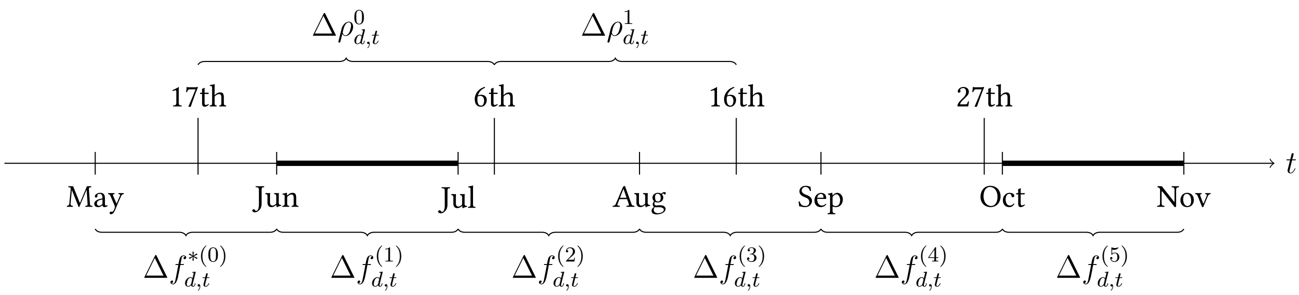
Crowe, 2013, BC in the following, p. 959). We use daily changes in futures rates around FOMC dates for the maturities $m \in \{0, 5\}$, i.e. from those futures related to the average federal funds rate valid in the concurrent month to five months into the future. GSS find that using intraday or daily data makes virtually no difference after 1994.[14]

2.2 From Futures Rate Changes to Expected Policy Rate Changes

The federal funds futures prices give us changes in market expectations about policy rates during FOMC meeting days. To analyse surprises regarding current monetary policy actions and communication about future rate decisions, we first need to extract the corresponding changes in market expectations of average rates within two intervals: between the current and the next FOMC meeting, and after the next meeting.

The futures maturities are defined over calendar months, while meeting days are unevenly spread out across the maturity spectrum.[15] Although we are able to use six rate jumps that span the next five months into the future (and therefore at least three future meetings), the futures contracts cannot represent six individual policy surprises, since monetary policy can change at most another three times. To obtain average rates expected by the markets between meeting dates, we employ a linear extraction method. Similar methods are used in GSS and Gürkaynak (2005), however we add an iterative weighted averaging procedure to reduce noise and use all available information.

Figure 1: Illustration of the Conversion of $\Delta f_{d,t}^{(m)}$ to $\Delta \rho_{d,t}^{j}$



Notes: The timeline shows the months May to November 1994, as labelled below the axis. Above the axis are the days of FOMC meetings. Months without FOMC meetings are marked by a thick line. The jumps in the monthly futures rates, $\Delta f_{d,t}^{(m)}$, are indicated below the axis, above it are the jumps in expected federal funds rates between meetings, $\Delta \rho_{d,t}^{j}$.

[14]"[F]or samples that exclude employment report dates, or samples that begin in 1994, the surprise component of monetary policy announcements can be measured very well using just daily data." (GSS, p. 66). Nakamura and Steinsson (2018) argue for the use of shorter time windows, but they employ longer-term interest rates and a sample that covers more long-term forward guidance.

[15]FOMC meetings take place roughly every six weeks, usually in late January, April, July and October and mid March, June, September and December. The meetings for late July and October often take place in early August and November instead.

Let $\Delta\rho^0_{d,t}$ denote the change in the expected policy rate between the current and next FOMC meeting, and $\Delta\rho^1_{d,t}$ the change in the expected rate after the next meeting.[16] Figure 1 illustrates the timing with an example: the FOMC meeting taking place on May 17th, 1994, and the three meetings that followed (on July 6th, August 16th and September 27th). The figure displays the five future calendar months and the jumps in the futures rate for each month.

Our aim here is to obtain the change in market expectations on policy rates valid between FOMC meetings, $\Delta\rho^j_{d,t}$, from changes in futures prices $\Delta f^{(i)}_{d,t}$. To do so, we work iteratively forward, starting with $\Delta\tilde{\rho}^0_t$, which is set equal to the jump in the futures rate for the concurrent contract (corrected for the number of elapsed days as outlined in footnote 13),[17]

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

Since contracts are defined over average interest rates for calendar months, we know the price change of the futures contract for the month of the next meeting, I, (July in our example), $f^{(I)}_{d,t}$, must be a weighted average of the expected interest rate carried forward from the previous meeting, and that expected to be set in the next (indexed 0 and I, respectively),

$$\Delta f^{(I)}_{d,t} = \frac{d_I - 1}{M_I} \cdot \Delta\tilde{\rho}^0_{d,t} + \frac{M_I - (d_I - 1)}{M_I} \cdot \Delta\tilde{\rho}^1_{d,t},$$

where d_I refers to the day of the next meeting, and M_I to the number of days in the month of the next meeting. Therefore:

$$\Delta\tilde{\rho}^1_{d,t} = \frac{M_I}{M_I - (d_I - 1)} \left(\Delta f^{(I)}_{d,t} - \frac{d_I - 1}{M_I} \cdot \Delta\tilde{\rho}^0_{d,t} \right)$$

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 (as for June in our example), we create a final version of $\Delta\rho^0_{d,t}$ by taking a weighted average of this measure with the jump in the futures rate next month as follows:

$$\Delta\rho^0_{d,t} = \frac{M_0 - (d_0 - 1)}{M_0 - (d_0 - 1) + M_1} \cdot \Delta\tilde{\rho}^0_{d,t} + \frac{M_1}{M_0 - (d_0 - 1) + M_1} \cdot \Delta f^{(1)}_{d,t} \tag{1}$$

We are therefore using the fact that the jump in the price of the contract for the next month (June in our example) is an equally valid measure of the surprise in the cases that there is no

[16] We could potentially also create measures of expectation changes for policy rates between the next meeting and the one after that. Experimentation showed that the results for the second communication shock did not depict a meaningful pattern, in line with the GSS finding that two factors are enough to capture the dynamics in the six futures maturities.

[17] $\Delta\tilde{\rho}^0_{d,t}$ and $\Delta\tilde{\rho}^1_{d,t}$ would correspond to $mp1$ and $mp2$ in the notation of GSS.

meeting next month (since a single target rate will hold over the whole period). We employ the same strategy to create $\Delta\rho^1_{d,t}$ whenever there is no meeting in the month following a given meeting.[18] 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 potential idiosyncratic noise in the futures changes.

As mentioned by Gürkaynak (2005), a potential limitation of this method is the possibility of rate changes during unscheduled meetings. The FOMC can deviate from its published meeting schedule if circumstances require it and has done so several times in our sample.[19] We only rely on scheduled meetings here. If markets were to incorporate an endogenous probability of emergency meetings into their pricing, this could be problematic for our identification scheme. However, 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 F). Therefore, we do not believe the effect of unscheduled meetings presents a serious concern.

2.3 From Expected Policy Rate Changes to Structural Shocks

Given the surprises in the policy rates before and after the next meeting, $\Delta\rho^j_{d,t}$, we want to obtain 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 the spectrum of maturities. 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 GSS and BC 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: Both expectations $\Delta\rho^0_{d,t}$ and $\Delta\rho^1_{d,t}$ will be affected in the same way. 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. $\Delta\rho^1_{d,t}$, but not rates before them, $\Delta\rho^0_{d,t}$. This recursive system motivates the use of a Cholesky decomposition of the expectations jump vector. Note that these operations are

[18]In the case that 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.

[19]The dates were 04/18/1994, 10/15/1998, 01/03/2001, 04/18/2001, 09/17/2001, 08 and 17/10/2007, 01 and 22/09/2008, 03/11/2008 and 10/08/2008, see Appendix F for details.

conducted at the frequency of the meetings, in the sense that we extract structural shocks from a vector of observations only on meeting days. Since we restrict our analysis to days with scheduled meetings, there is never more than one meeting per month, so we can drop the d subscript from our shock series. We enter a zero value to the shock series for the months without meetings, as in BC.

Formally, the changes in expectations about the future monetary policy rate, $\Delta\rho_t^0$ and $\Delta\rho_t^1$, are decomposed into two orthogonal shocks: surprises about monetary decisions today (the action shock, $\tilde{\varepsilon}_t^A$) and surprise communication about potential futures actions (the communication shock, $\tilde{\varepsilon}_t^C$) as follows:

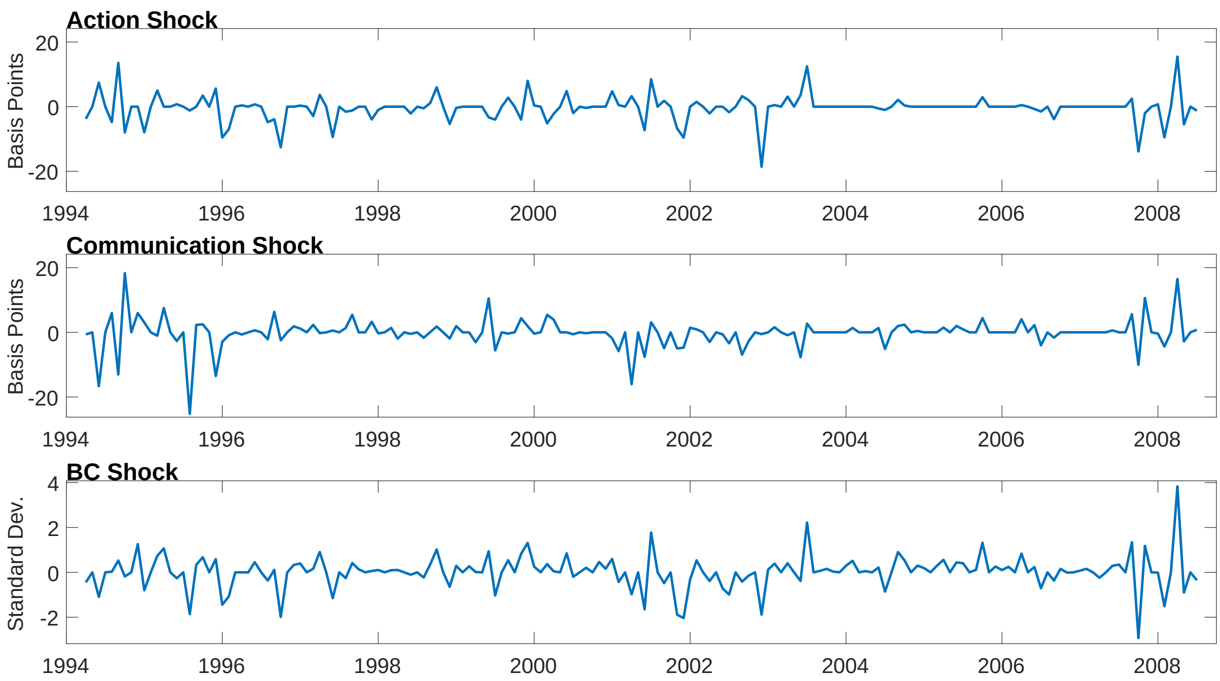
$$\mathbf{\Delta R}_t \equiv \begin{bmatrix} \Delta\rho_t^0 \\ \Delta\rho_t^1 \end{bmatrix} = \begin{bmatrix} m_{11} & 0 \\ m_{21} & m_{22} \end{bmatrix} \cdot \begin{bmatrix} \tilde{\varepsilon}_t^A \\ \tilde{\varepsilon}_t^C \end{bmatrix} \equiv \mathbf{M} \cdot \tilde{\mathbf{E}}_t \tag{2}$$

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

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

where $\mathbf{M} = \text{chol}\,(\text{var}(\mathbf{\Delta R}_t))$.

Figure 2: Shock Series



Notes: Our action and communication shock series, $\tilde{\epsilon}_t^A$ and $\tilde{\epsilon}_t^C$. We also display the shock series of Barakchian and Crowe (2013, "BC"), formed of the first principal component of the six federal funds rate maturities, for reference. The correlation of the BC shock with the action and communication shock is 0.74 and 0.59, respectively.

Figure 2 shows the action and communication shock series, as well as the BC shock series (one factor over all maturities) for comparison. First, we see that the size of both action and communication surprises during FOMC meetings is relatively small (with standard deviations of 3.91 and 4.42 basis points). This implies that markets generally anticipate decisions with a high precision. The shock series show increased volatility after the bursting of the dot-com bubble and September 11, and during the immediate run-up to the financial crisis. Generally, the factor approach amalgamates the more idiosyncratic movements of our two shock series. The larger movements in the communication shock series in the early part of the sample are not present in the BC shock, however.[20]

2.4 VAR Setup

We gauge the effect of our two measures of policy surprises on (seasonally adjusted) monthly (log) industrial production (IP) and consumer price index (CPI) with a recursive structural VAR. Given the recursiveness, it is more efficient to employ the cumulated jumps in the VAR, instead of employing $\tilde{\mathbf{E}}_t$ from Equation (2) and thus orthogonalising our shocks twice unnecessarily. Without controlling for internal Fed information, these cumulated jump series are denoted by $\tilde{S}_t^A = \sum_{i=0}^t \Delta\rho_t^1$ and $\tilde{S}_t^C = \sum_{i=0}^t \Delta\rho_t^0$.

Moreover, in a second step we will orthogonalise our jumps $\Delta\rho_t^j$ with respect to internal Fed Greenbook forecasts. This will purge the potentially superior central-bank information which could be transmitted to the public during FOMC meetings.[21] Greenbook forecasts are made public with a lag of five years and therefore are not known by markets at the time of central bank announcements.The purged jumps, labelled $\Delta\rho_t^{p,j}$, are the residual from an OLS regression of $\Delta\rho_t^j$ on a vector of Greenbook forecasts GB_t:[22]

$$\Delta\rho_t^{p,j} \equiv \Delta\rho_t^j - \hat{\boldsymbol{\beta}}^{OLS} \cdot \text{GB}_t \tag{3}$$

For the use in the VAR, we again cumulate the shocks over time to form a monthly time

[20] Our action shock is significantly positively correlated with both factors in BC and the first GSS factor, while our communication shock is positively correlated with only the first BC factor and the second GSS factor. Both shocks are positively correlated with the shock of Nakamura and Steinsson (2018) and with an updated Romer and Romer (2004) shock series. We conclude that our shocks capture information from these existing shock series, but are not reducible to any of them. Furthermore, the "level factor" interpretation of BC regarding their shock may be questioned, given its significant positive correlation with our communication shocks. For details, see Appendix A.

[21] If the FOMC had a tendency to reveal new positive forecasts regarding output and inflation at the same time as it increased interest rates, then this would likely bias our estimated contractionary effects of policy towards zero (for a similar argument, see Nakamura and Steinsson, 2018).

[22] We include similar Greenbook variables as BC, although like Ramey (2016) we use only the Greenbook forecasts, while BC employ the difference between Blue Chip and Greenbook indicators. The variables used are: (1) contemporaneous unemployment, (2) contemporaneous output growth and its lag and first two leads; (3) the GDP deflator and its lag and first two leads; (4) the previous values of the output growth forecasts; (5) the previous values of the GDP deflator forecasts.

series of policy surprises in levels, so $S_t^A = \sum_{i=0}^{t} \Delta\rho_t^{p,1}$ and $S_t^C = \sum_{i=0}^{t} \Delta\rho_t^{p,0}$.[23] Our VAR specification is as follows:

$$\mathbf{Y}_t = \mathbf{C}_c + \mathbf{C}_d \cdot t + \sum_{l=1}^{12} \mathbf{C}_l \mathbf{Y}_{t-l} + \mathbf{D} \cdot \epsilon_t, \tag{4}$$

where $\mathbf{Y}_t = [\log(\text{IP}_t)\ \log(\text{CPI}_t)\ S_t^A\ S_t^C]'$. We estimate the model with a constant $\mathbf{C}_c$ and a deterministic trend $\mathbf{C}_d$, using twelve lags.[24] As in Romer and Romer (2004) and BC, the VAR is recursive, so that monetary policy surprises cannot affect IP and CPI in the same period (but are allowed to react to them). We need to make the assumption that markets do not observe the monthly observations on industrial production and inflation in real time (as e.g. also in Bundick and Smith, 2016), which we find plausible. Confidence bands for the VAR need to be adjusted for the Greenbook regression, Equation (3), as we create a generated regressor here. Appropriate confidence intervals are computed via a system bootstrap procedure with 5,000 draws, employed for all VAR specifications involving purged shocks.

Given the limited size of our VAR (which follows many studies in the literature), one could be concerned that our four-variable VAR might be too small to be informationally sufficient. Therefore we run the fundamentalness test suggested by Forni and Gambetti (2014) on our system. The test fails to reject the null of informational sufficiency of the system—and thereby also the shocks—in various specifications (for details, see Appendix B).

3 Results

Here, we present evidence that short-term Fed surprise communication matters substantially for the U.S. business cycle. Based on impulse responses, forecast-error variance and historical decompositions, we argue that the macro effects of what are generally termed "monetary policy shocks" by the empirical literature seem much more driven by communication about the short-term path of policy than by surprise actions. This result holds also when controlling for potential transmission of internal Fed information during FOMC press conferences (the information-revelation channel).

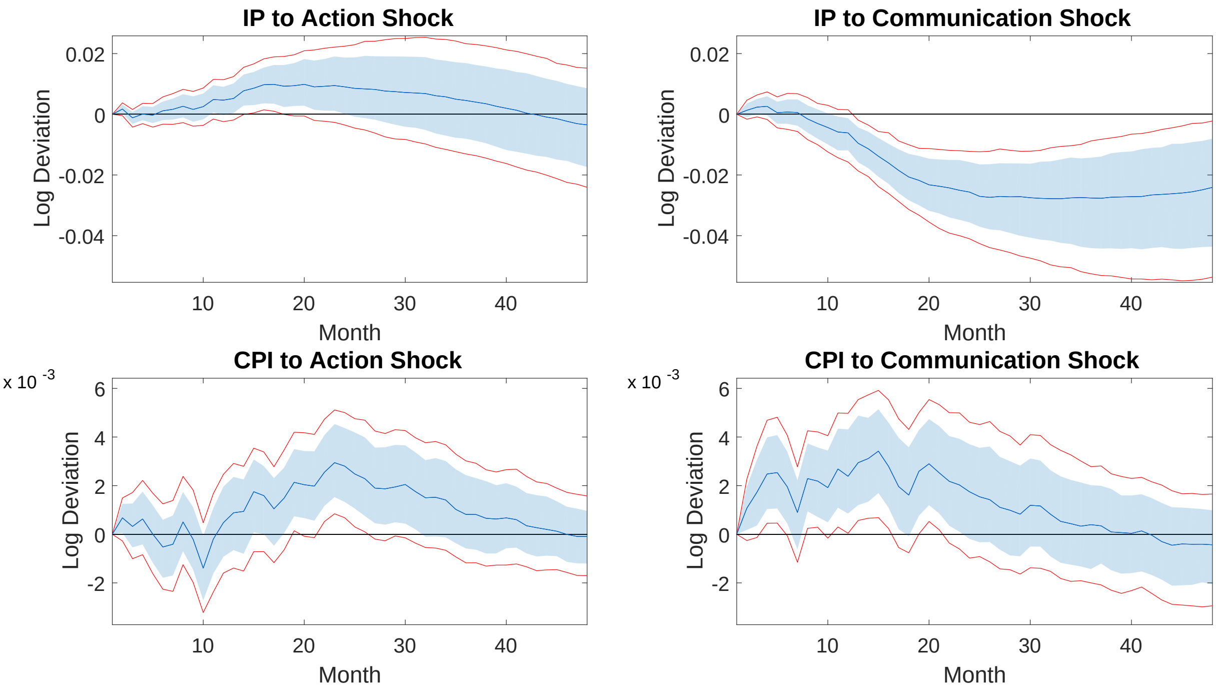
[23] These series are I(1) by construction, and will be entered directly into the VAR in this form (as in Romer and Romer, 2004, and BC). Here the argument of Sims et al. (1990) should hold, insofar that "the OLS estimator is consistent whether or not the VAR contains integrated components, as long as the innovations in the VAR have enough moments and a zero mean, conditional on past values of [the endogenous variables]" (p. 113).

[24] The Bayesian Information Criterion proposes one lag, and the likelihood ratio test 14. We settle for twelve lags as in Faust et al. (2004). We show that our results are robust to different numbers of lags in Section 3.3. We gratefully acknowledge the use of code from the VAR toolbox by Ambrogio Cesa-Bianchi, made available on his personal website: `https://sites.google.com/site/ambropo/MatlabCodes`.

3.1 Results without Controlling for Information Revelation

First, we compare our results to BC using our cumulated shocks not orthogonalised with respect to the Greenbook forecasts, i.e. $\tilde{S}_t^A$ and $\tilde{S}_t^C$. This allows us to compare action and communication shocks to the single factor in the BC results, as well as to contrast the responses with our orthogonalised shocks purged of internal Fed information below.

Figure 3: Responses of $\log(\mathrm{IP}_t)$ and $\log(\mathrm{CPI}_t)$ to Our Shocks



Notes: Impulse responses from our four-variable VAR, with $\log(\mathrm{IP}_t)$, $\log(\mathrm{CPI}_t)$ and the cumulated action and communication shock series, $\tilde{S}_t^A$ and $\tilde{S}_t^C$ (not orthogonalised to Greenbook forecasts). The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are to a 10 basis point positive shock to the anticipated policy rate.

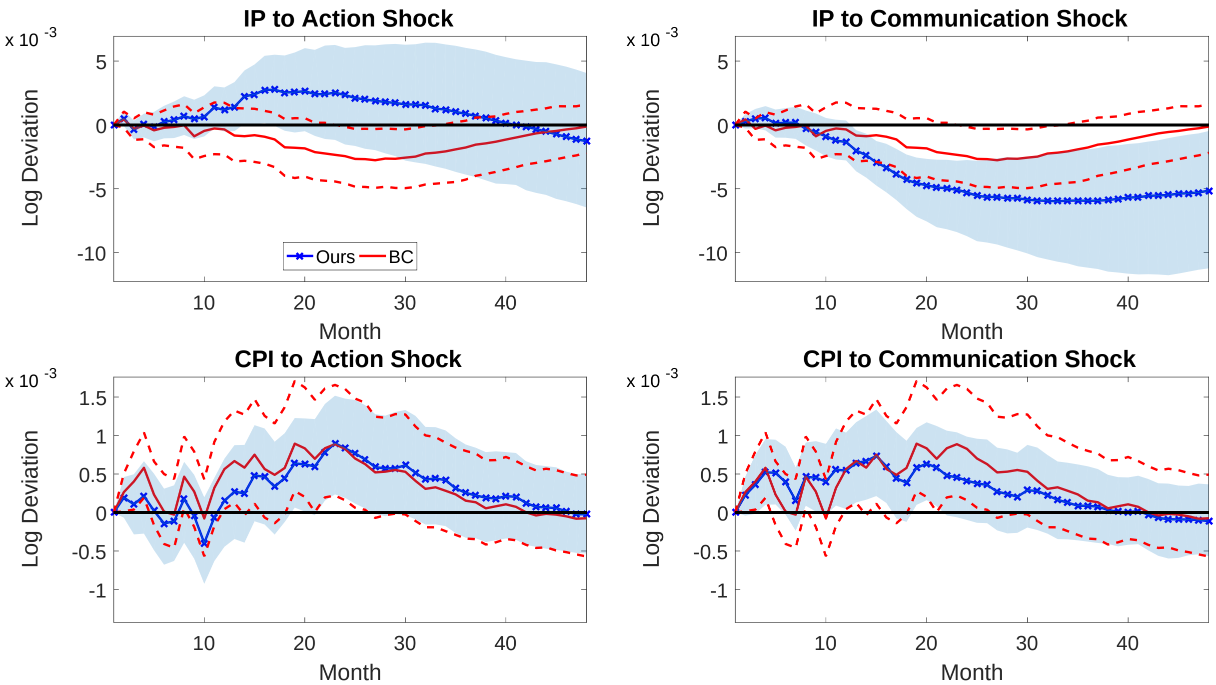
Figure 3 shows the impulse responses of IP and CPI to a (non-purged) action shock $\tilde{S}_t^A$ and a communication shock $\tilde{S}_t^C$. Throughout the structural shocks are scaled to 10 basis-point rate increases.[25] We see that the reaction of IP to a surprise increase in the expected policy rate is negative at the 90% confidence level only for the communication shock. Here IP falls by 2.8 percent after a 10 basis-point surprise increase in the funds rate, which is a sizable effect (we discuss the magnitudes of the responses below for our baseline model). The IP reaction to the action shock, on the contrary, displays a counter-intuitive, significant positive reaction after around 18 months. Inflation shows an equally counter-intuitive positive reaction to both

[25] 10 basis points correspond to more than two standard deviations of our shocks, which are 3.91 ($\tilde{S}_t^A$) and 4.42 basis points ($\tilde{S}_t^C$). A 10 basis-point increase can be straightforwardly translated into a 25 or 100 basis-point increase given the linearity of the model.

shocks. This price puzzle is a widespread finding, also in the high-frequency literature (see e.g. Thapar, 2008, and BC). The increase in production after a supposedly contractionary surprise monetary policy action is more problematic for our interpretation of the shock, but will be explained by information transmission by the Fed during FOMC meetings once we control for Greenbook data. However, here we already see that the communication shock does not display this counter-intuitive effect on production.

We compare our shock responses to those to a single factor over the six federal funds futures as used in BC in Figure 4, which superimposes the results from such a three-variable VAR (repeated across columns) on those from Figure 3 above. We see that the responses to the BC factor shock, in particular its significant negative effect on industrial production, are in line with our communication shock, but not the action shock.

Figure 4: Comparison to Barakchian and Crowe (2013)



Notes: Impulse responses from our four-variable VAR, with $\log(\mathrm{IP}_t)$, $\log(\mathrm{CPI}_t)$ and the cumulated action and communication shock series, $\tilde{S}_t^A$ and $\tilde{S}_t^C$ (not orthogonalised to Greenbook forecasts), together with the responses to the factor ("level") shock from Barakchian and Crowe (2013) in red, estimated in a 3-variable system (identical responses are repeated across each row). The median and 90% confidence intervals (blue for our VAR and dashed red for BC) were obtained from bootstrapping each VAR model 500 times. Responses are to a one standard deviation positive shock to the anticipated policy rate.

BC make a convincing case that monetary policy in the U.S. has become more forward-looking after 1994.[26] However, we believe that also Fed communication and its reception by the markets have become more forward-looking during this time. Therefore, unlike BC we prefer

[26]They show that many widely used recursive identification schemes fail for samples starting in the late 1980s. We confirm this finding in Appendix C: A recursive identification as e.g. in Christiano et al. (1996) within a three-

not to apply an interpretation to a first factor over futures data, but instead to explicitly extract structural shocks.[27] Our distinction between action and communication shocks allows us to find that, in post-1994 data, it is not monetary policy surprise rate changes, but rather surprise central-bank communication that affects economic activity in the way we would expect from a "standard" monetary policy shock.

3.2 Baseline Results: Controlling for Internal Fed Forecasts

As discussed, each of the shocks above likely contains two elements: Surprise action or communication by the Fed, but also transmission of internal Fed information about the likely future course of the macroeconomy. Such an information-revelation channel might counteract the pure action or communication effect: A surprise hike in rates will likely dampen the economy, but could also signal a Fed outlook on the economy which is more expansionary than markets anticipated, and thus have stimulative effects.[28] To isolate our action and communication shocks from such information transmission, we show results from such shocks orthogonalised on internal Fed Greenbook data, i.e. the S_t^j shocks above.

Figure 5 shows that results are affected by this orthogonalisation. In fact, for the action shock, information revelation seems to explain most of the counter-intuitive expansionary effect on IP: After the purging, we only find a borderline significant positive (but no negative) effect on IP. Further, the contractionary effect of communication on IP is slightly dampened when controlling for Fed information, but remains significant and sizable with the expected sign. The price puzzle is not solved by controlling for information transmission, but is reduced to borderline insignificance for the communication shock.[29] Thus we find that our key result, the importance of FOMC communication about its near-future policy for the business cycle, is preserved even in the case that we control for potential contemporaneous information revelation on the part of the FOMC. This implies that Fed communication matters over and above

variable SVAR including log IP, log CPI, and the federal funds rate, delivers a significant positive response of both production and inflation to a surprise policy-rate hike for a sample starting in 1994.

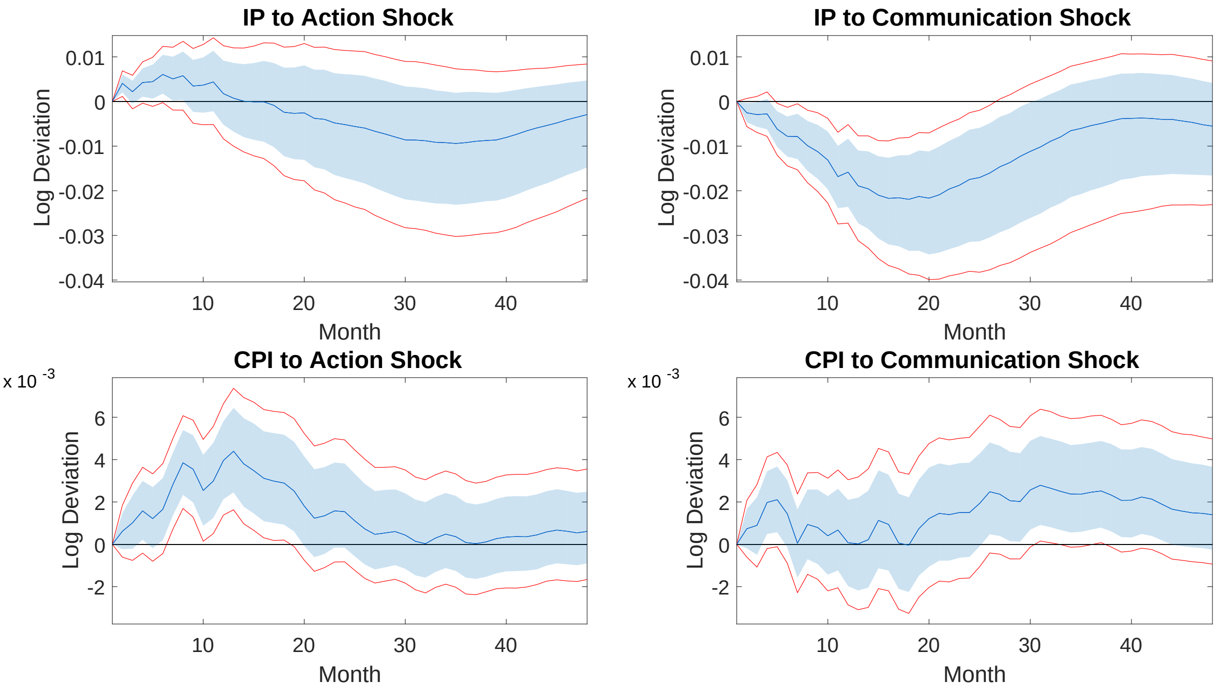
[27] BC choose to only use a first factor over the six futures maturities, reasoning that "[s]ince the transmission of monetary policy is generally thought to occur via the impact of short rate changes on longer term (real) rates, it is this portion of the new information on rates that corresponds most closely to the relevant policy shock." (p. 959). We argue that this interpretation may not be justified, since some maturities react more strongly and consistently during FOMC meetings for their factor; these are the ones at the upper end of the six-month spectrum. This is difficult to align with the "levels effect" interpretation of BC (supposedly analogous to the "target factor" in GSS). In fact, the correlation between the first factors in GSS and BC (for the overlapping sample) is 0.73 (it is 0.34 between the GSS path factor and BC), while the correlation of our action shock to the first GSS factor is 0.88. The correlation of our communication shock to the second GSS factor is 0.60, see also Appendix A. Thus, our action shock is more closely related to the GSS factors than the BC factor is to either.

[28] Again, see e.g. Romer and Romer (2004), Campbell et al. (2012), Nakamura and Steinsson (2018) or Jarocinski and Karadi (2018).

[29] We obtain similar results when using commodity prices as a control for central-bank information (see Appendix D).

the information-revelation channel.

Figure 5: The Effects of Shocks Orthogonal to Greenbook Forecasts



Notes: Impulse responses from our four-variable VAR, including $\log(\mathrm{IP}_t)$, $\log(\mathrm{CPI}_t)$ and the cumulated action and communication shock series (purged of Fed information), S_t^A and S_t^C. The median response and confidence intervals were obtained from 5,000 bootstrap draws of both the purging and the VAR regressions; the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are to a 10 basis point positive shock to the anticipated policy rate.

In magnitude the effects of our shocks are large relative to the literature. Ramey (2016) summarises existing estimates of the effects on industrial production of 100 basis-point increases in the federal funds rate, and the maximum reported decrease is typically less than 5% (from BC), and usually closer to 1% (Christiano et al., 1996, find 0.7% after 24 months). A 100 basis-point communication shock would deliver a negative 22% trough 18 months after the shock hits. However, a surprise of this size would exceed 25 standard deviations of our shocks (3.27 and 3.94 basis points for the purged action and communication shock respectively). Since our shock series are measures of purely unanticipated changes in the federal funds rate on FOMC meeting days, they are small relative to the shock series employed in existing research which does not use high-frequency identification. The stronger impact of our shock series relative to that of BC is interesting, and is partially explained by the fact that our communication shock has stronger negative effects than the action shock. To the extent the BC shock amalgamates both our shock series, the estimated effect they obtain should be smaller than the one of our communication shock.

Table 1: Forecast-Error Variance Decomposition at Business Cycle Frequencies

	Horizon (months)	IP_t	CPI_t	S_t^A	S_t^C
IP_t	12	0.68	0.09	0.01	0.21
	18	0.39	0.19	0.06	0.36
	24	0.23	0.26	0.11	0.40
	36	0.13	0.34	0.20	0.34
CPI_t	12	0.08	0.62	0.27	0.03
	18	0.10	0.49	0.38	0.02
	24	0.11	0.44	0.42	0.03
	36	0.08	0.39	0.43	0.10

Notes: Contribution of our shocks to a forecast-error variance decomposition of IP and CPI from our baseline four-variable purged VAR at the various horizons. The identified two (purged) shocks are S_t^A and S_t^C, while "IP" and "CPI" are not identified.

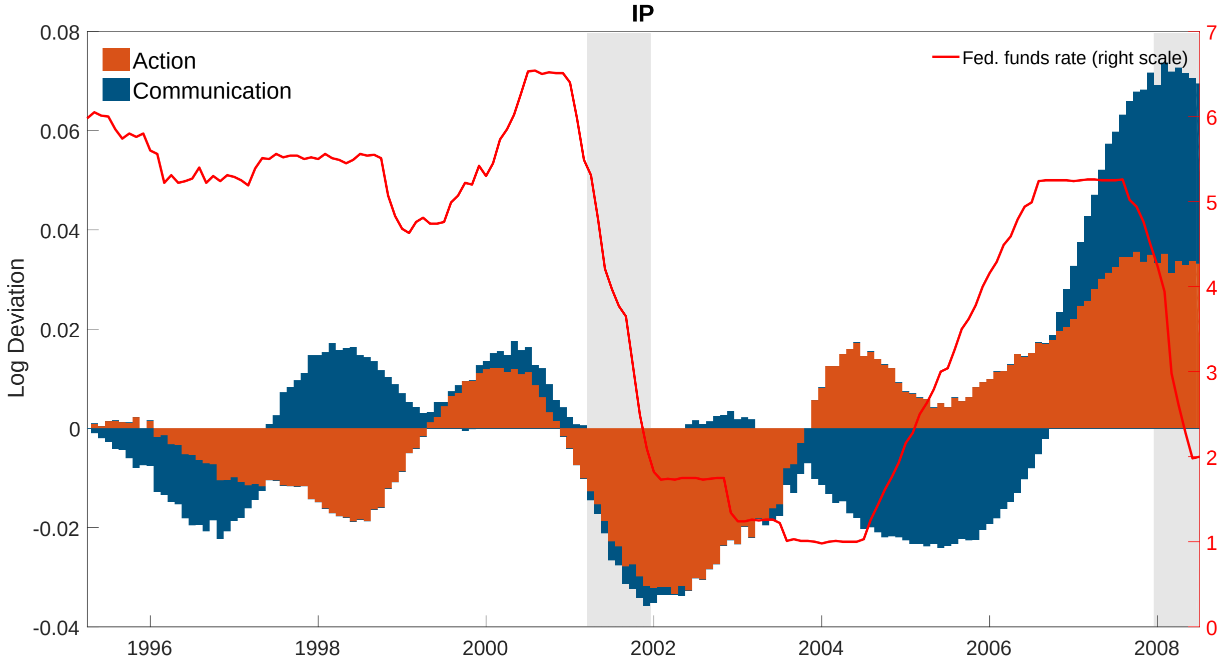
Forecast-Error Variance Decomposition. Table 1 depicts the shares of our purged shocks in a forecast-error variance decomposition of both macro variables at different horizons. The share of the communication shock is larger than that of the action shock for industrial production at all horizons. Central bank surprise communication seems to have larger effects on production than surprise actions, but the action shocks have large effects on the variability of inflation (although they affect it in a counter-intuitive direction).

Historical Decomposition. We present the historical decomposition of IP with respect to the purged shocks in Figure 6.[30] The effects of communication seem to move in four cycles over the sample: two hawkish ones, 1995 to mid-1997 and 2001 to 2007, and two dovish ones, around mid-1997 to 2001 and 2007 to mid-2008.

The first expansionary episode (1998 to 2001) coincides with the last phase of the so-called "Greenspan put", i.e. the conjecture that the Fed systematically eased policy in reaction to deteriorating stock market conditions during the period. The second contractionary episode (2001 to 2006) was one of unstable growth and several corporate scandals involving American enterprises. Even though the Fed kept policy rates at low levels, markets seem to have generally expected more policy easing than was actually delivered between 2001 and 2004.

[30]Given the puzzling responses of prices, we choose to examine only variation in industrial production. However, we discuss the decomposition of CPI for the Eurodollar case below.

Figure 6: Historical Decomposition of $\log(\mathrm{IP}_t)$



Notes: Historical decomposition of $\log(\mathrm{IP}_t)$ in our four-variable VAR, including the variables $\log(\mathrm{IP}_t)$ and $\log(\mathrm{CPI}_t)$ and the cumulated purged action and communication shock series, S_t^A and S_t^C. The bar plots are stacked, so their height above (below) the zero-axis represents the cumulative historical contribution of our monetary shocks to industrial production above (below) its unconditional mean. We also display the federal funds rate (right-hand scale) for reference. Grey areas denote NBER recession periods.

Generally we find mixed evidence for the "monetary excesses" view of John Taylor, who argues that monetary policy had remained too lax for too long and contributed to an unsustainable housing boom in the U.S. during the period preceding the financial crisis (Taylor, 2009). Between 2002 and 2004, the effects of monetary surprises are predominantly contractionary in their contribution to fluctuations in industrial production. During the gradual increase of the federal funds rate from June 2004 onwards, the rate increases seem to have been of little surprise to markets (the action component is small), whereas the communication of the continued increases may have lowered market sentiment (as visible in the negative contribution of this shock over the period).[31] Only after 2006 there is some expansionary effect as markets seem to have expected more contractionary actions than were delivered. Finally, after the beginning of financial-market turmoil in August 2007, both actions and communication successfully helped to stabilise production until futures markets became stuck at their zero-lower bound in mid-2008.

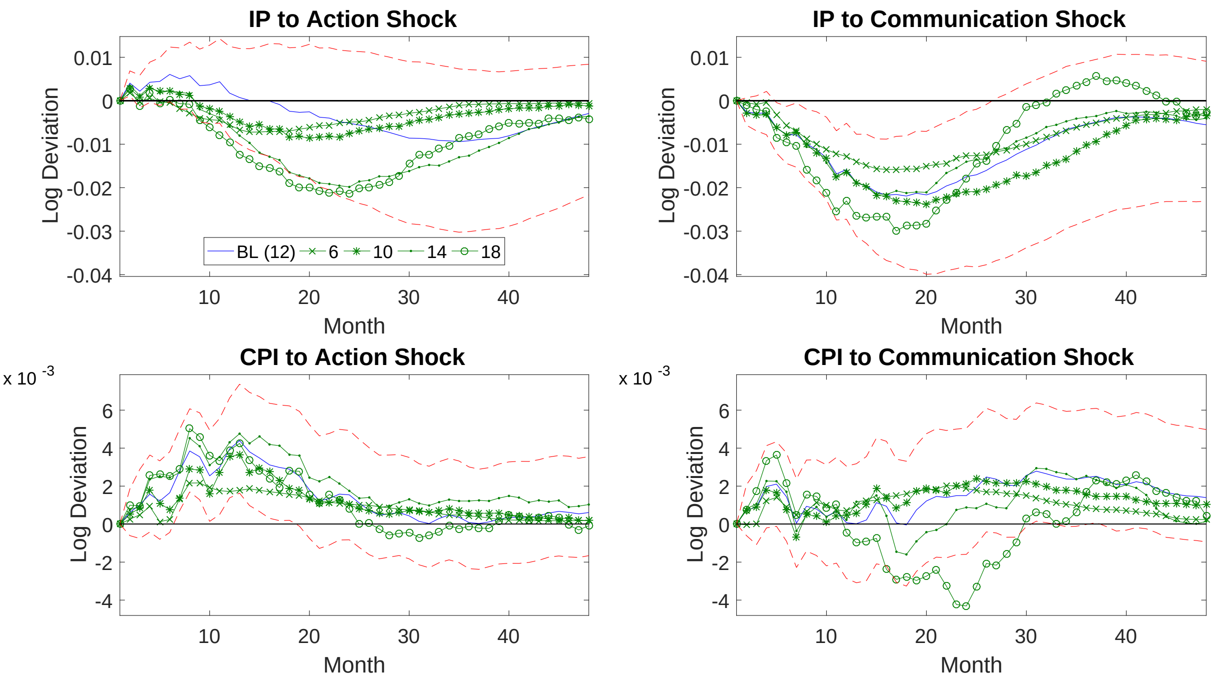
[31] The communication horizon of about six weeks might be too short to capture the "signaling" episode of 2003/04, in which the Fed communicated a slow return to higher rates in order to sustain the recovery even without lowering rates below the 100 basis-point threshold (see Woodford, 2005, pp. 29ff.). There is evidence for successful stabilisation by longer-term communication as captured by our Eurodollar-based shocks in Section 4.

To summarise, distinguishing between central-bank action and communication shocks adds detail to our understanding of the recent monetary policy history of the U.S., and our communication shock seems broadly in line with common narratives.

3.3 Robustness

Figure 7 contrasts the impulse responses of our baseline VAR to those of versions with 6 to 18 lags.[32] The responses always the fall into the 90% confidence bands of our 12-lag model except for the case of 18 lags, and even in this case dynamics remain very similar.

Figure 7: Robustness Check – Different lags



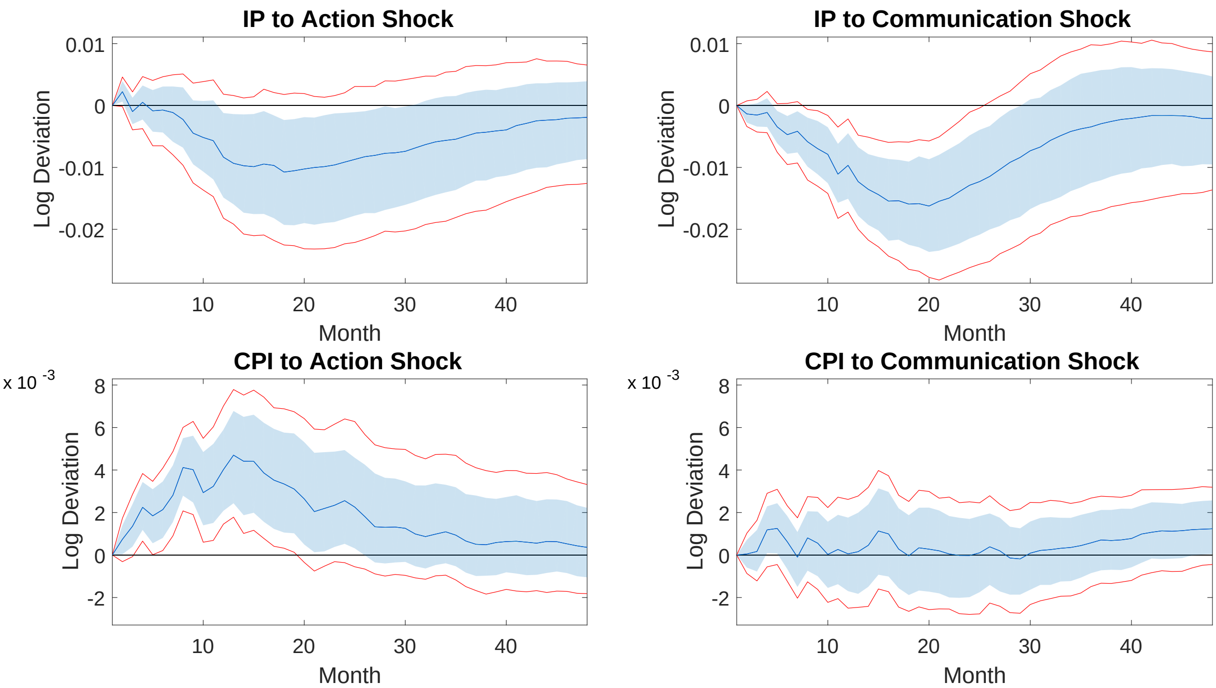
Notes: Impulse responses from our four-variable VAR, including $\log(\mathrm{IP}_t)$, $\log(\mathrm{CPI}_t)$ and the cumulated action and communication shock series (purged of Fed information), S_t^A and S_t^C, with twelve lags (median blue, 90% confidence band in red), as well as VARs with 6, 10, 14 and 18 lags (median responses in green). The median response and confidence intervals were obtained from 5,000 bootstraps of both the purging and the VAR regressions; the graph depicts the latter at the 90% significance level. Responses are to a 10 basis point positive shock to the anticipated policy rate.

We also estimate separate three-variable VAR systems, loading in one shock at a time. We do this to respond to any concerns regarding the efficiency of our baseline VAR: In our four-variable system, the shocks are allowed to respond endogenously to each other, when in fact these interaction effects should be limited, given the shocks are externally identified and orthogonal to each other by construction. Figure 8 shows that results change slightly: IP now falls by around the same for the action as for the communication shock, however the

[32] We cannot use more lags (BC use 36) due to insufficient degrees of freedom for our four-variable VAR.

effect is borderline significant at best. The price puzzle still shows for the action, but not the communication shock. Overall, we therefore find our main results supported.

Figure 8: Robustness Check – Separate Three-Variable VAR Systems



Notes: Impulse responses from two three-variable VAR, including $\log(\mathrm{IP}_t)$, $\log(\mathrm{CPI}_t)$ and one of the cumulated action and communication shock series each, $\tilde{S}_t^A$ and $\tilde{S}_t^C$. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are to a 10 basis point positive shock to the anticipated policy rate.

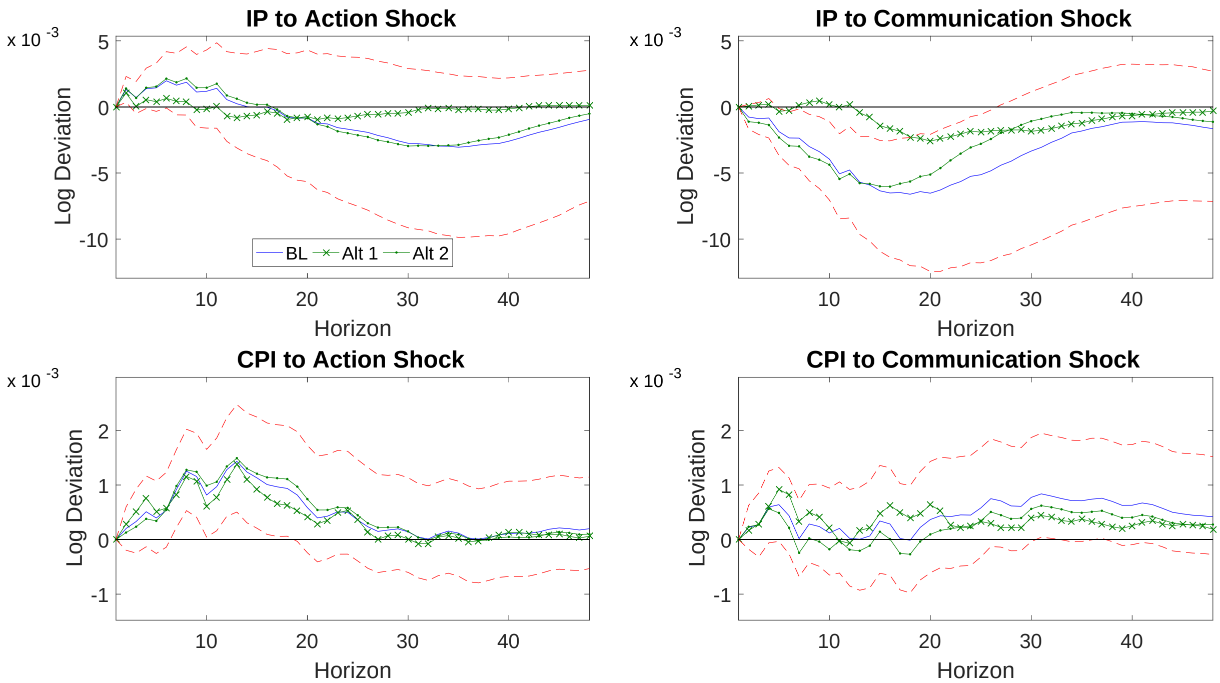
As a next check, we vary the weighting schemes employed in Equation (1), which is reproduced for convenience here:

$$\Delta\rho_{d,t}^0 = \frac{M_0 - (d_0 - 1)}{M_0 - (d_0 - 1) + M_1} \cdot \Delta\tilde{\rho}_{d,t}^0 + \frac{M_1}{M_0 - (d_0 - 1) + M_1} \cdot \Delta f_{d,t}^{(1)} \qquad (1)$$

In this baseline specification, we use the relative number of days for which the futures movement is valid, $\omega_\rho = \frac{M_0 - (d_0 - 1)}{M_0 - (d_0 - 1) + M_1}$ and $\omega_f = \frac{M_1}{M_0 - (d_0 - 1) + M_1}$, to weight the information from the movement in rates within the meeting month and the next month without a meeting (in case no meeting takes place in the next month). Here we investigate the effect of using two alternative weighting schemes:

- Alt 1: $\omega_p = 1, \omega_f = 0$, i.e. full weight on the next meeting month
- Alt 2: $\omega_p = 0, \omega_f = 1$, i.e. full weight on the month without a meeting (for all the meetings not followed by another meeting in the consecutive month)

Figure 9: Robustness Check – Different Weighting Schemes

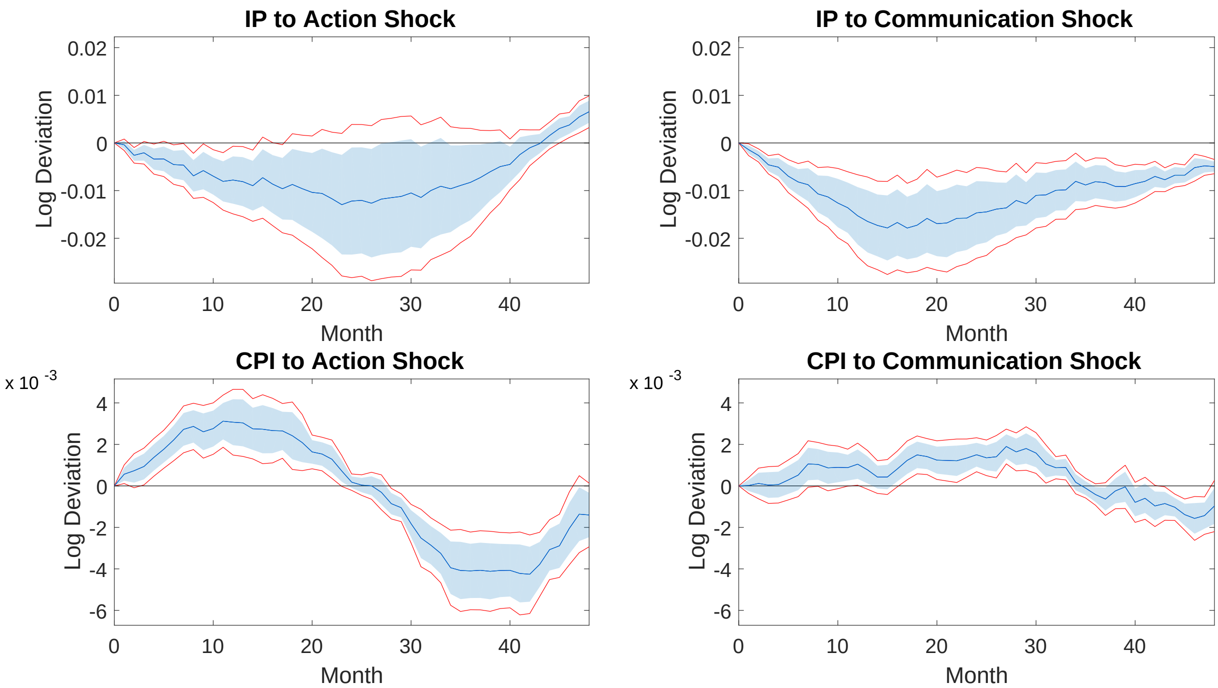


Notes: Impulse responses from our four-variable VAR, including $\log(\text{IP}_t)$, $\log(\text{CPI}_t)$ and the cumulated action and communication shock series (purged of Fed information), S_t^A and S_t^C, where different weighting schemes are employed in obtaining the $\Delta\rho_{d,t}^j$, see text for details. The median response and confidence intervals were obtained from 5,000 bootstraps of both the purging and the VAR regressions; the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are to a 10 basis point positive shock to the anticipated policy rate.

Not surprisingly, our baseline IRFs in blue in Figure 9 look closest to the case where we use consecutive non-meeting months wherever possible (Alt 2) – the reason is that meetings with no meeting in the next month tend to take place towards the end of the calendar month (so ω_p is close to 0 and ω_f close to 1). Instead, using only the information from months with meetings (Alt 1, which is closest to the setup in Gürkaynak, 2005) would not yield significant results for the communication shock on IP. The difference is likely due to the ability of our baseline approach to reduce noise by using all available information.

However, none of the results from the alternative specifications stray too far from our baseline results. Altogether, we find that a careful use of all available information as in our weighting scheme in Subsection 2.2 sharpens the identification of the quantitative effects of action and communication shocks, but that qualitative results are largely unaffected by alternative, potentially simpler weightings.

Figure 10: Robustness Check – Local Projection Approach



Notes: Impulse responses of $\log(\mathrm{IP}_t)$ and $\log(\mathrm{CPI}_t)$ to the purged movements $\Delta\rho_t^{p,0}$ and $\Delta\rho_t^{p,1}$ under the local projection approach. 90% and 75% confidence intervals were obtained using Newey-West standard errors. Responses are to a 10 basis point positive shock to the anticipated policy rate.

Furthermore, since our shocks are identified outside the VAR system, it is not necessary to "estimate all interactions between variables as part of a VAR. In fact, our analysis lends itself to the local projection approach of Jordà (2005). We run separate forecasting regressions of our shocks on our two macro variables of interest, while controlling for the contemporaneous values and lags of these macro variables. This approach avoids compounding any potential errors due to misspecification of the VAR (see Ramey, 2016). We project our variables of interest $\mathbf{Y}_{t+q} = [\log(IP_t), \log(CPI_t)]$ onto several controls as well as the the purged changed in expectations before ($\Delta\rho_t^{p,0}$) and after the next meeting ($\Delta\rho_t^{p,1}$), in order to obtain the response to action and communication shocks, respectively following Equation (5) and (6):

$$\mathbf{Y}_{t+q} = D_c^q + \sum_{l=0}^{2} D_{Y,l}^q \mathbf{Y}_{t-l} + D_A^q \Delta\rho_t^{p,0} + u_{t+q}^q, \qquad q = 0, 1, 2, ..., Q \tag{5}$$

$$\mathbf{Y}_{t+q} = G_c^q + \sum_{l=0}^{2} G_{Y,l}^q \mathbf{Y}_{t-l} + G_A^q \Delta\rho_t^{p,0} + G_C^q \Delta\rho_t^{p,1} + u_{t+q}^q, \quad q = 0, 1, 2, ..., Q, \tag{6}$$

where D_i^q and G_i^q are various coefficient matrices for horizons q up to Q, with D_c^q and G_c^q being deterministic regressors (a constant and a linear trend). We include two lags l and the contemporaneous value of the macro variables, IP_t and CPI_t, thus establishing recursiveness of our shocks to these variables. Further, we add the contemporaneous value of the earlier expectation revisions (the "action jumps"), $\Delta\rho_t^{p,0}$, when estimating the effect of the communication shock (jumps in $\Delta\rho_t^{p,1}$), thus assuming recursiveness of the shocks as in the VAR specification. The coefficients $\{D_A^q\}_1^Q$ and $\{G_C^q\}_1^Q$ at horizons 1 to $Q = 48$ then give the impulse of the action and the communication shock, respectively, on the log of IP and CPI. Confidence bands are computed using the heteroskedasticity and autocorrelation robust Newey and West (1987) standard errors.

Results are comparable to the ones from our VAR specification (Figure 10). The decline in IP is now borderline significant for the action shock, but slightly smaller than for the communication shock. We see a significant price puzzle for both shocks, which is however smaller in size for the communication shock.

To conclude, our main results, i.e. the stronger effect of communication on IP and the smaller associated price puzzle, are robust to various alternative specifications.

4 Covering the Zero-Lower Bound Episode

Following the start of the ZLB period during the financial crisis of 2008, the federal funds futures prices of our short-run maturities cease to move and our decomposition into action and communication shocks is no longer possible. However, Eurodollar futures contracts remained liquid during the ZLB period and can help us to analyse communication shocks.

Eurodollar contracts are defined over quarters and not months, so it is no longer possible to extract expectations regarding particular meetings for these contracts.[33] Neither are we able to clearly identify an "action shock" in this case, since the contemporaneous Eurodollar future reflects expectations regarding both the most recent meeting and all future meetings within one quarter. Furthermore, the underlying for the contracts is the 3-month LIBOR rate on dollar-denominated assets as opposed to the overnight federal funds rate, so the contracts are less tightly linked to the policy decisions of the FOMC. However, these contracts trade in highly liquid markets and the their pricing moves systematically on FOMC meeting days, implying that market participants were updating their expectations for future shorter-term interest rates in reaction to central-bank communication.

We propose a linear decomposition of the Eurodollar contracts similar to that used in our previous analysis. To capture longer-term communication as used for forward guidance, we employ contracts related to the Eurodollar rate one, two and three years out (ED4, ED8 and ED12). Including one maturity longer than the two years usually associated with Fed forward

[33] Eurodollar futures take as their underlying the 3-month LIBOR rate on time-deposits of U.S. dollar denominated assets held outside of the U.S. Unlike the federal funds futures contracts, these contracts are defined relative to the interest rate prevailing on the third Wednesday of the expiration month, and are available across quarterly horizons, for the next ten years.

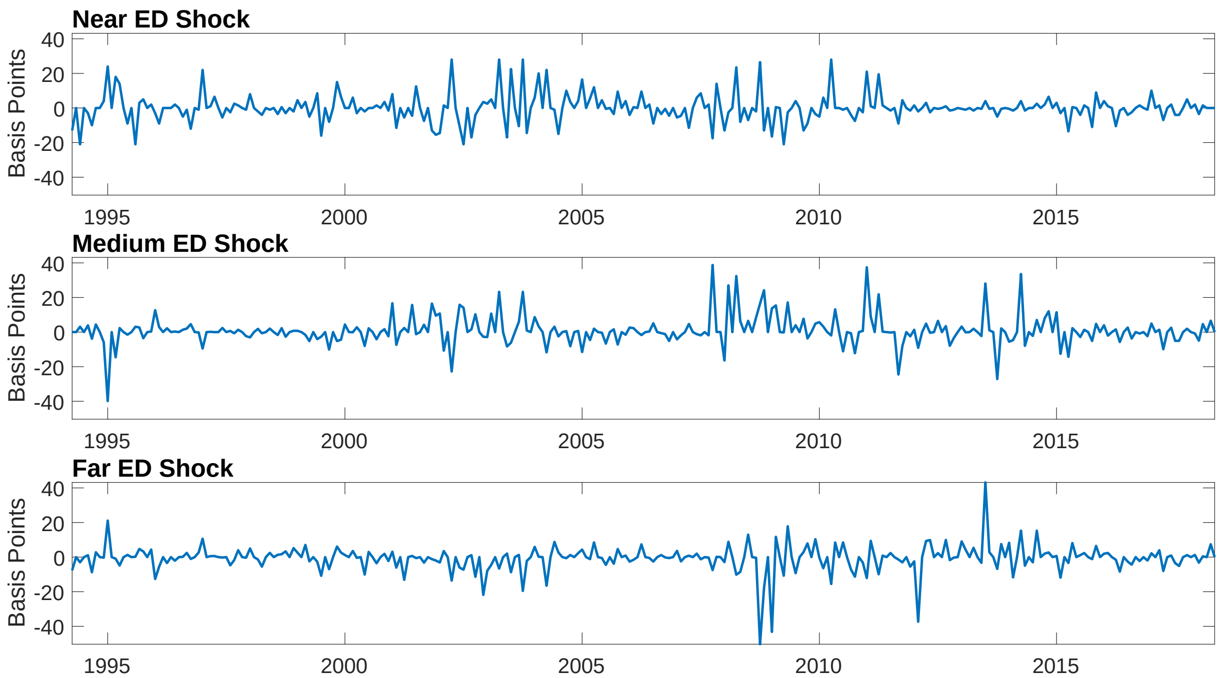
guidance (ED12) allows us to disentangle the effects of forward guidance from other communication about the longer-term outlook.[34]

Here, we use a recursive scheme directly on the selected futures maturities as follows:

$$\begin{bmatrix} \Delta \tilde{ED}^{(4)}_{d,t} \\ \Delta \tilde{ED}^{(8)}_{d,t} \\ \Delta \tilde{ED}^{(12)}_{d,t} \end{bmatrix} = \begin{bmatrix} k_{11} & 0 & 0 \\ k_{21} & k_{22} & 0 \\ k_{31} & k_{32} & k_{33} \end{bmatrix} \cdot \begin{bmatrix} \varepsilon^{NED}_{d,t} \\ \varepsilon^{MED}_{d,t} \\ \varepsilon^{FED}_{d,t} \end{bmatrix} = \mathbf{K} \cdot \mathbf{E}_{d,t}, \tag{7}$$

where $\Delta \tilde{ED}^{(h)}_{d,t}$ is the daily difference of the Eurodollar contract futures rates at horizon h on the FOMC meeting day indexed by day d and month t, not purged for central-bank information for now. We call these shocks "near ED shock", "medium ED shock", and "far ED shock". It is important to note that the near ED shock is quite different to the action shock discussed previously: Since it represents the combined effects of all FOMC communication regarding interest rates during the next year, it contains the effects of action and communication shock above, as well as other communication shocks.

Figure 11: Eurodollar Shock Series



Notes: The figure displays the three Eurodollar shocks S^j_t, $j \in \{NED, MED, FED\}$ – dubbed "near ED", "medium ED", and "far ED" shock, respectively.

The shock series are displayed in Figure 11, for our sample period covering March 1994

[34]Our results are robust to using the ED futures maturities ([ED4, ED8, ED18] and [ED4, ED6, ED8])—in the latter case, only ED8 gives a significant reaction to CPI. FEVD analysis underlines the stronger effect on CPI than IP of our ED communication shocks. For these results, see Appendix E.

to April 2018. A striking feature is the marked shift in volatility from the near ED shock to the longer-term ED shocks during the ZLB period: This suggests that before the Great Recession, markets were less likely to receive important surprise information about monetary policy more than one year into the future during FOMC meetings. However, with the onset of unconventional monetary policy, surprise information about the potential course of central bank decisions two or three years into the future became increasingly important. We can also see a period of larger volatility of the medium ED shock during the dot-com bust and prior to 2004, which does not translate equally into far ED shock volatility.[35]

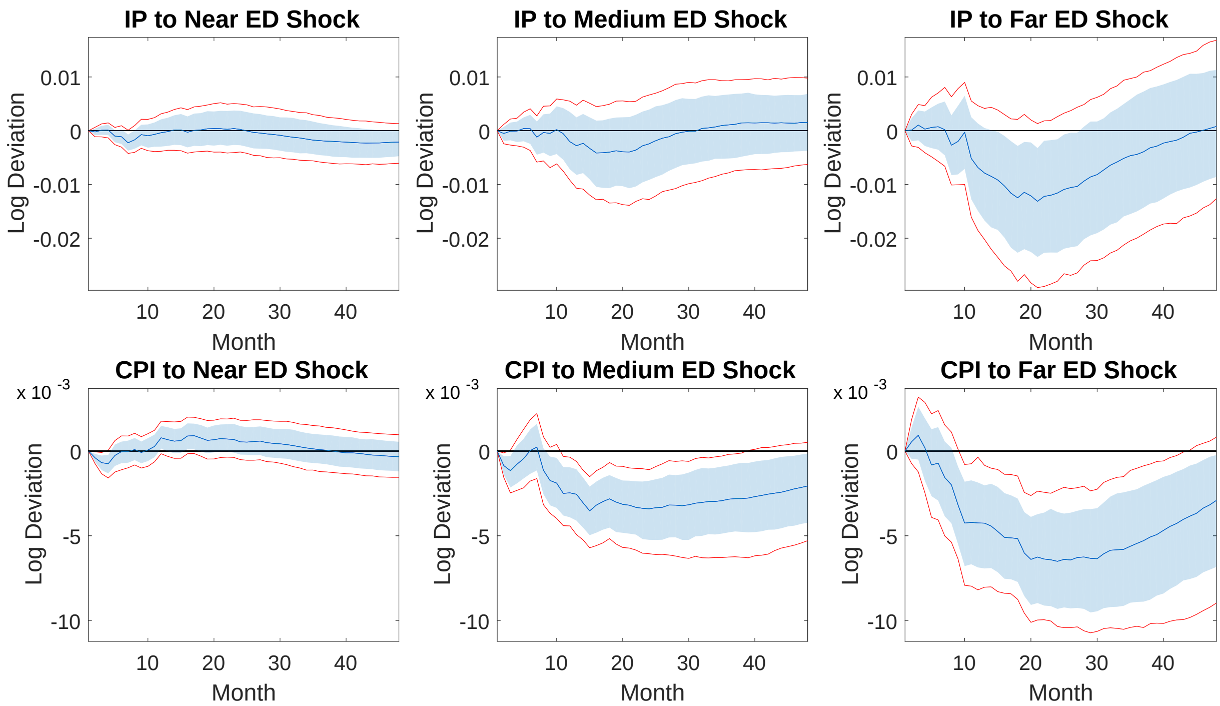
We follow the baseline VAR specification above, entering our three cumulated shock series at the end of a vector including log IP and CPI, with 12 lags. Again we avoid a two-step estimation by entering the movements $\Delta \tilde{ED}^{(4)}_{d,t}$, $\Delta \tilde{ED}^{(8)}_{d,t}$, and $\Delta \tilde{ED}^{(12)}_{d,t}$ directly into a recursive VAR. The impulse response functions are displayed in Figure 12. None of the Eurodollar shocks have significant effects on IP – the fact that responses are smaller and less significant than in our previous analysis may be due to Eurodollar futures being a noisier measure of monetary policy stance than federal funds futures. The near ED shock has no significant effect on prices except right after immediate impact; if anything, there is a borderline insignificant price puzzle in the medium term.

Furthermore, the medium and far ED shocks show significant contractions to CPI, of increasing strength. This would match the predictions of the New Keynesian literature regarding the effects of forward guidance at increasing horizons on inflation (Del Negro et al., 2016; McKay et al., 2016). However, we should be wary of interpreting the far ED shock as forward guidance: It represents any communication affecting expectations three years out, orthogonal to information on acts one or two years out, which is the common horizon of the Fed's forward guidance. Nevertheless, we reach the conclusion that communication surprises at longer horizons seem to have a stronger and more persistent effect on CPI than on industrial production for a sample including the recent ZLB episode. Figure 16 in Appendix E shows the responses when we purge for Fed information by regressing our shocks on the Greenbook forecasts (which restricts our sample to the end of 2012 due to the five-year lag in Greenbook publications). The results are essentially the same, except for the CPI reaction to the far ED shock, which becomes more erratic, likely because our sample ends before the normalisation of monetary policy. Overall, we conclude that it is revelations about the future policy course rather than of internal information that causes longer-term Fed communication to have an effect on inflation. This could be explained by the information revelation being closely linked

[35] 2004 is in fact an early example of forward guidance by the Fed: "[T]he Committee used a sequence of changes in the balance of risks and forward guidance language in the months leading up to the June 2004 tightening to signal that its assessment of the economy was evolving and that it was getting closer to raising its target for the federal funds rate." (Meade et al., 2015) The communication started in August 2003, in line with the upward movement of our shock series here: Markets seem to have changed their expectations about policy one and two years out, but not so much on additional policies three years out.

to the current state of the economy, rather than its medium-term course.

Figure 12: Responses of $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ to Eurodollar Shocks



Notes: Impulse responses from our five-variable VAR, including $\log(\text{IP}_t)$, $\log(\text{CPI}_t)$ and the three (non-purged) cumulated shock series $\Delta \tilde{ED}_t^{(j)}, j \in \{4, 8, 12\}$ – called near ED, medium ED and far ED shock, respectively. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are to a 10 basis point positive shock to the anticipated policy rate.

Historical decompositions of IP and CPI (see Figure 15 in Appendix E) show that from the onset of the crisis in early 2008 to around 2012, communication at all three horizons (1, 2 and 3 years) had a recessionary impact on IP. This could reflect that markets had expected stronger announcements than Fed statements like the one that the crisis was "likely to warrant exceptionally low levels of the federal funds rate for some time".[36] However, Eurodollar communication shocks nevertheless show a strong stabilising effect on inflation. This can perhaps be explained in terms of central-bank communication contributing to “anchored expectations”, thereby accounting for the “missing disinflation” even in the wake of a deep recession during this period (Bernanke, 2010).

Moreover, from the announcements of asset purchases and forward guidance in September 2012 onwards, all three ED shocks have an expansionary effect on IP and CPI, which is evidence for an important role of the Fed in accommodating the economy, despite the fact that its policy rate remained at the ZLB during the period. Indeed, the timing of these later expansionary

[36]See https://www.federalreserve.gov/faqs/what-is-forward-guidance-how-is-it-used-in-the-federal-reserve-monetary-policy.htm.

contributions almost exactly coheres with the timing of the FOMC's explicit forward guidance statements (2012-2015).[37] However, it is true that the strongest effects come from the far ED shock, which represents communication orthogonal to shocks regarding events one or two years out (the usual horizon for forward guidance). Thus, this shock might signal a shift in the monetary stance (e.g. by the announcements of QE3) rather than the forward guidance policies explicitly followed by the Fed during the period. For example, Swanson (2017) shows the importance of a third factor for longer-term yield movements during the ZLB period.[38] Overall, our analysis of Eurodollar futures supports our findings regarding the importance of central-bank communication for the macroeconomy, especially at longer horizons.

5 Conclusion

In this paper, we have investigated the effect of communication surprises during FOMC meetings on the macroeconomy, and contrasted them with surprises about actual policy decisions. To distinguish surprise action from surprise communication, we use a simple Cholesky decomposition of changes within certain maturity segments of federal funds futures contracts.

For our sample from 1994M3 to 2008M6, we find that communication surprises play a more important role in macroeconomic fluctuations than action shocks. Communication shocks lead to the expected contractionary reaction of industrial production, explain a larger share of variance in industrial production, and can be easily aligned with the recent history of U.S. monetary policy. These findings are robust to various changes in specification. Overall, our findings emphasise the crucial importance of central-bank communication, and of forward-looking information reception by market participants even before the explicit adoption of forward guidance as a policy tool by the Federal Reserve.

Using a complementary analysis based on Eurodollar futures, we find evidence for a stronger role of long-term communication by the FOMC during the zero-lower bound episode. This long-term communication helped in particular to stabilise inflation, with the size of its effect increasing in the horizon of the shocks. Overall, our analysis suggests that researchers ought to think of "monetary policy shocks", of the type extensively studied in the macroeconomic literature, in terms of central-bank communication rather than unanticipated rate changes.

[37] Additionally, the "signaling" episode of 2003/04 is reflected in a stabilising contribution of the medium ED shock to both IP and CPI.

[38] In Swanson's analysis, three instead of two factors as in GSS are found sufficient to describe the dynamics of underlying high-frequency changes in various returns on meeting days. The factors are then identified by rotating them such that the forward guidance and LSAP factor have no influence on yields of short-term assets, and by minimising the variance explained by the LSAP factor before the ZLB episode. While we find this method intuitive, we are not sure whether this identification would not also allow an alternative interpretation of the factors as action surprise, a pre-crisis communication component and a post-crisis communication component.

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Appendix

A Correlation with Other Shock Series

In order to better understand how our shock series relate to other high-frequency monetary shock series available in the literature, this section examines correlations with different measures. We always use the non-purged shocks for comparability.

Table 2: Correlation of Our Shocks with Other Monetary Policy Shocks

	Action Shock	Comm. Shock	# obs.
BC 1st Factor	0.74***	0.59***	115
BC 2nd Factor	0.53***	-0.61***	115
GSS Target Factor	0.88***	0.03	82
GSS Path Factor	-0.13	0.60***	82
RR Shock (original)	0.57***	-0.10	23
RR Shock (updated)	0.34***	0.05	111
NS Shock	0.66***	0.62***	68

Notes: Correlations to our non-purged shocks $\tilde{S}_t^A$ and $\tilde{S}_t^C$. BC: Barakchian and Crowe (2013); GSS: Gürkaynak et al. (2005); RR: Romer and Romer (2004); NS: Nakamura and Steinsson (2018). The updated RR series is from Wieland and Yang (2016).

We first examine the relation between our shock series and that of BC. From Table 2 we note that all our shocks are positively correlated with this shock, i.e. the first factor across maturities of contract. In fact, the action shock is most strongly correlated with the BC shock. This is somewhat surprising, since when we examine the impulse-response functions, we find that the communication shocks yield responses closest to those of the BC shock. With respect to the second factor extracted by BC from the futures jumps, we can see that only the action shock is positively correlated with the second factor. The communication shock instead is negatively correlated, so it is not true that our communication shock series merely reflect information captured by the second factor of BC. This is heartening, since we know from BC that the second factor explains only a small fraction of the variance of the federal funds futures contracts. We can conclude that our structural decomposition offers different kinds of information relative to the two factors of BC (although they restrict their analysis to the first factor).

When we examine the relation between our shocks and those of GSS we find largely expected results. Our action shock is strongly and significantly correlated with the GSS target shock. Our communication shock shows positive correlation with the GSS path factor, although it is smaller, at 0.60. Therefore our shocks should be understood to be closely related, but not reducible, to the factors of GSS.

We moreover find that the action shock is significantly correlated with the Romer and Romer (2004) shock, but the communication shocks are not. When we examine a longer period, using the series computed by Wieland and Yang (2016), we find similar results. Finally, both our shocks are positively correlated to that of Nakamura and Steinsson (2018). The fact that the correlation structure looks much like those of our shocks with that of the BC shock, with the greatest correlation for the action shock, is unsurprising since the Nakamura and Steinsson (2018) shock is also the first factor, although the bundle of futures jumps includes longer horizon Eurodollar contracts also.

B Testing our VAR for informational sufficiency

Here we outline our procedure to test our four-variable VAR for informational sufficiency as suggested in Forni and Gambetti (2014, FG in the following).

Preliminaries. We use our baseline VAR setting with $\boldsymbol{Y}_t = [\log(\text{IP}_t), \log(\text{CPI}_t), S_t^A, S_t^C]'$ as in Equation (4), with 12 lags and 2 deterministic regressors. For the principal components, we use the monthly "FRED-MD" data set by McCracken and Ng (2016). The data set comprises 128 monthly macro-financial time series and has been proposed specifically for the purpose of factor analysis. We obtain 10 principal components (PCs), as $P = 10$ is the maximum amount of PCs used by FG.

A first step: F-test whether lagged PCs explain our shock series. In their simulation design, FG propose an F-test as an initial step to check whether principal components of a larger data set help explain their shock series. We follow this procedure, calculating the p-values of 12 F-tests, for both of our shocks S_t^A and S_t^C with their specifications:

$$\varepsilon_t^j = \sum_{i=1}^{P} \sum_{l=1}^{L} \phi_{il} f_{it-l} + v_t, \ \forall j = \{A, C\},$$

where we use the non-cumulated shock series ε_t^j, the lags $L = \{2, 4\}$ and number of PCs $P = \{1, 2, 4\}$, and where f_t are the estimated PCs.

The p-values for the test of the lagged PCs *not* explaining the shocks ($H_0 : \phi_{il} = 0 \, \forall \{i, l\}$) are reported in Table 3. For all of the tests, the null of no joint explanatory power of the lagged PCs cannot be rejected at the usual significance levels.

Table 3: p-values of an F-test whether lagged PCs help explain our shocks

	# lags	1 PC	2 PCs	4 PCs
ε_t^A	2	0.9443	0.9980	0.7197
	4	0.6434	0.9485	0.9258
ε_t^C	2	0.2593	0.5679	0.8837
	4	0.6095	0.8693	0.9502

The FG test for informational sufficiency. The FG test is a multivariate Granger-causality test checking whether PCs from a data set large enough to capture economic agents' expectations help predict variables in our VAR. If they do, then the econometrician's data set in the VAR (here, our four variables in $\boldsymbol{Y}_t$) is not informationally sufficient to capture the dynamics based on the economic agents' decisions. The major advantage of the FG fundamentalness test is that "rejection of PCs Granger-causing model variables" is not only a necessary condition for fundamentalness (as in other testing procedures), but also a sufficient one: If the state-space of the economy is captured by our PCs, then fundamentalness is *implied* by the failure to reject Granger-causality of the PCs (see FG for details and other tests available).

Technically, FG follow the multivariate test for Granger-causality in Gelper and Croux (2007, GC in the following), see FG p. 16. In particular, they use the "Regression" implementation, which GC show to have the largest power. The test proceeds as follows (compare GC pp. 3ff.): First, we set up an unrestricted or "full" model,

$$\boldsymbol{Y}_t = \phi_c + \sum_{l=1}^{L} \phi_l \boldsymbol{Y}_{t-l} + \sum_{l=1}^{L} \psi_l \mathrm{PC}_{t-l}(P) + \varepsilon_{f,t},$$

where $\mathrm{PC}_{t-l}(P)$ are the lth lags of P PCs (for the actual specification, see below). Also, set up a restricted model assuming the coefficients on the PCs are zero,

$$\boldsymbol{Y}_t = \phi_c + \sum_{l=1}^{L} \phi_l \boldsymbol{Y}_{t-l} + \varepsilon_{r,t}.$$

Now the idea is to compare forecast errors of both models: If the PCs matter in forecasting $\boldsymbol{Y}_t$, the forecasts should be significantly different for both models. So we split the sample into $T - H$ pseudo in-sample periods and H pseudo out-of-sample periods. Then we obtain the (recursive one-step-ahead) forecast error of both models for the H periods:

$$u_{f,t} = \boldsymbol{Y}_t - \hat{\boldsymbol{Y}}_{f,t}$$
$$u_{r,t} = \boldsymbol{Y}_t - \hat{\boldsymbol{Y}}_{r,t}$$

GC follow the univariate implementation of the test by Harvey et al. (1998) in defining no Granger causality as zero correlation between $u_{r,t}$ and $u_{r,t} - u_{f,t}$, i.e. whether

$$u_{r,t} = \lambda(u_{r,t} - u_{f,t}) + e_t \tag{8}$$

has $\lambda = 0$ (see GC p. 4). A likelihood ratio test with the statistic

$$\text{Reg} = H \left(\log(|u_r' u_r|) - \log(|\hat{e}'\hat{e}|) \right),$$

where $\hat{e}$ is the estimated residual from (8), will reject the null of no Granger causality ($H_0 : \lambda = 0$) if Reg is very large.[39]

As "the limiting distribution of the multivariate out-of-sample tests under the null hypothesis of no Granger causality is unknown" (GC, p. 16), we have to resort to a bootstrap procedure like GC: "The percentage of bootstrap statistics exceeding the test statistic computed from the observed time series is an approximation of the p-value." (GC, ibid.)

We choose the following setup for our testing procedure: Like FG, we let the Akaike Information Criterion (AIC) decide on the lag length of the VAR.[40] We include 2 deterministic regressors (constant and linear trend) as in our main VAR specification. Like FG, we report the p-values of the test for the number of factors included into the system $P = \{4, 6, 8, 10\}$, forecast horizons of $H = \{24, 48, 68\}$ and 500 bootstrap replications for the test statistics.[41] The corresponding p-values are summarised in Table 4 – the null of no Granger causality is never rejected at the 5%, and just once at the 10% significance level. We thus conclude that our four-variable VAR system is informationally sufficient.

Table 4: p-values of the Forni-Gambetti (2014) test for informational sufficiency

	$P=4$	$P=6$	$P=8$	$P=10$
$H=24$	0.3280	0.1180	0.4220	0.6740
$H=48$	0.3460	0.9940	0.8200	**0.060**
$H=68$	0.3760	0.8180	0.5800	0.5980

Notes: H_0 : no Granger causality (i.e. VAR is informationally sufficient); lags chosen by the Akaike Information Criterion.

[39] The p-value of the test would be given by the cdf of the statistic Reg at the χ^2 distribution with P times the number of lags ($P \cdot L$) degrees of freedom (the dofs are given by the difference in dofs of the full and restricted VAR). However, see the notes on the bootstrap below.

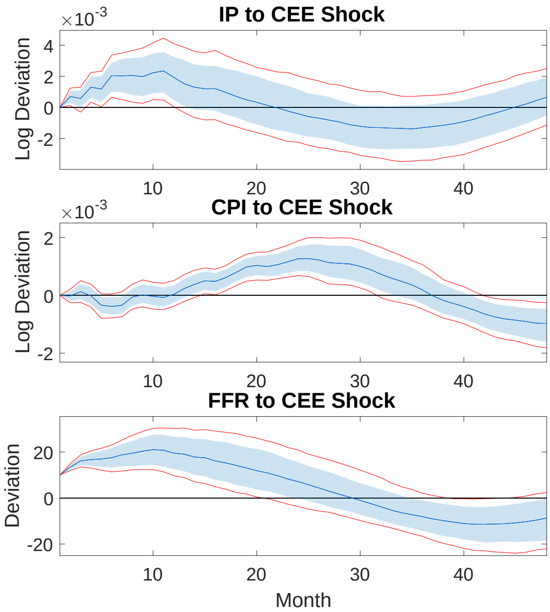
[40] The AIC consistently chooses one lag. If instead we want to use 12 lags for our VAR, we run into degree-of-freedom problems when including more than $P = 4$ factors or choosing a forecast horizon of $H > 24$. However, in a setting of $P = 4$ and $H = 24$ the test again fails to reject fundamentalness (the p-value is 0.5980).

[41] FG use $H = 80$ for their (simulated) VAR of 200 periods (footnote 6 on p. 131), and we scale down the maximal H in line with the smaller number of periods (172 for our analysis).

C Responses to Recursively Identified Shocks

When we use a simple recursive identification scheme with the ordering $Y_t = [\mathrm{IP}_t, \mathrm{CPI}_t, \mathrm{FFR}_t]'$, where FFR_t is the federal funds rate (Figure 13), we obtain the counter-intuitive responses reported in BC.

Figure 13: IRFs from a Recursively Identified Shock



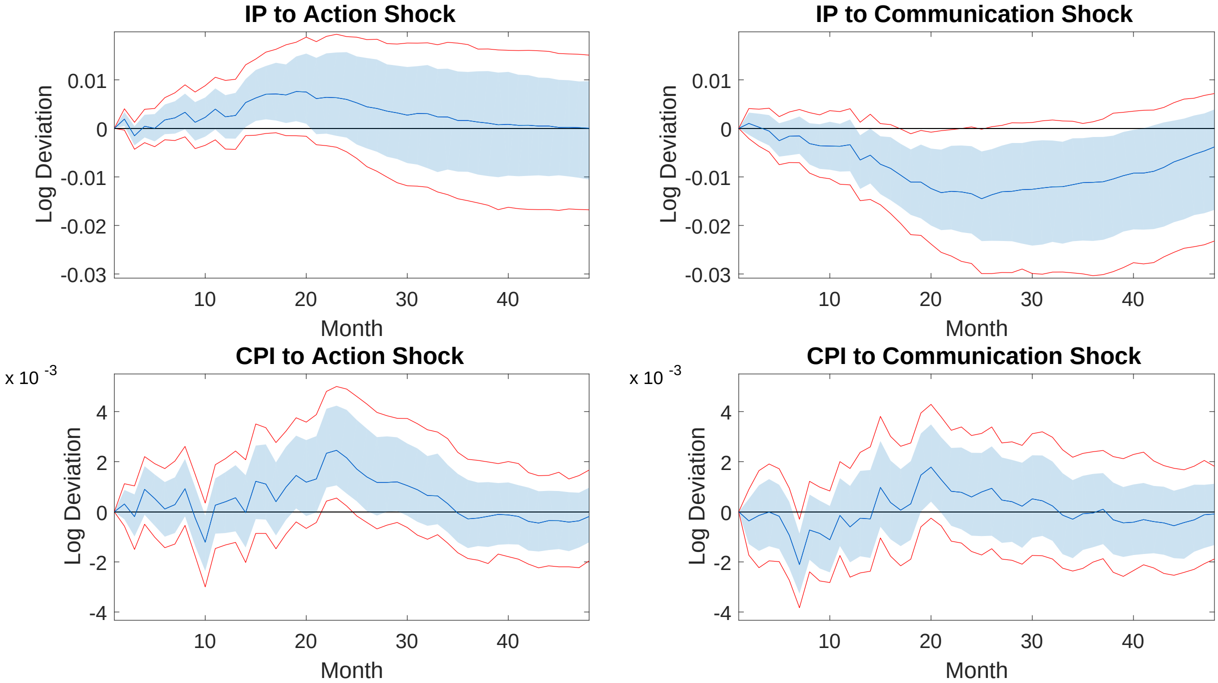
Notes: Responses of $\log(\mathrm{IP}_t)$, $\log(\mathrm{CPI}_t)$, and the Federal Funds Rate to a 10 basis point contractionary shock, identified via the lower triangular restriction of Christiano et al. (1996). The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels.

D Commodity prices to control for inflation expectations

Christiano et al. (1996) suggest to include commodity prices, which are strong predictors of future inflation, into VARs to correct for forward-looking monetary policy. We thus include commodity prices (ordered first in the VAR) to see whether this is a viable alternative to orthogonalising shocks with respect to Greenbook data. Commodity prices have a notable effect: The reaction of IP to the action shock is no longer significantly positive and the price puzzle is reduced for this shock. Once more, only our communication shock shows a significant contraction on IP and no (highly) significant price puzzle. We thus find our main findings robust to using commodity prices instead of Greenbook forecasts.[42]

[42]Thapar (2008) argues that internal Fed Greenbook forecasts should strictly dominate commodity prices as a means to control for central-bank expectations and thus to resolve a price puzzle. We find that both methods resolve the price puzzle for our communication shock, but fail to do so for the action shock.

Figure 14: Impulse Responses of $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ in a VAR with Commodity Prices



Notes: Impulse responses from our five-variable VAR, including commodity prices $\log(\text{PCOMM}_t)$, $\log(\text{IP}_t)$, $\log(\text{CPI}_t)$ and the cumulated action and communication shock series not orthogonalised to Greenbook forecasts, $\tilde{S}_t^A$ and $\tilde{S}_t^C$. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are shown to a 10 basis point positive shock to the anticipated policy rate.

E Further Results from our Eurodollars Analysis

E.1 Forecast-Error Variance Decomposition

We examine forecast-error variance decompositions of the contribution of our Eurodollar-derived shocks to movements in macro variables, which are displayed for the 12, 18, 24 and 36 month horizons in Table 5. We chart economically significant differences between the contributions of shocks according to their horizon, with the further forward Eurodollar shocks typically having a larger contribution. In general, movements in the medium-term ED communication shock have a particularly strong forecasting power relative to the other two communication shocks.

Table 5: Forecast-Error Variance Decomposition at Business Cycle Frequency

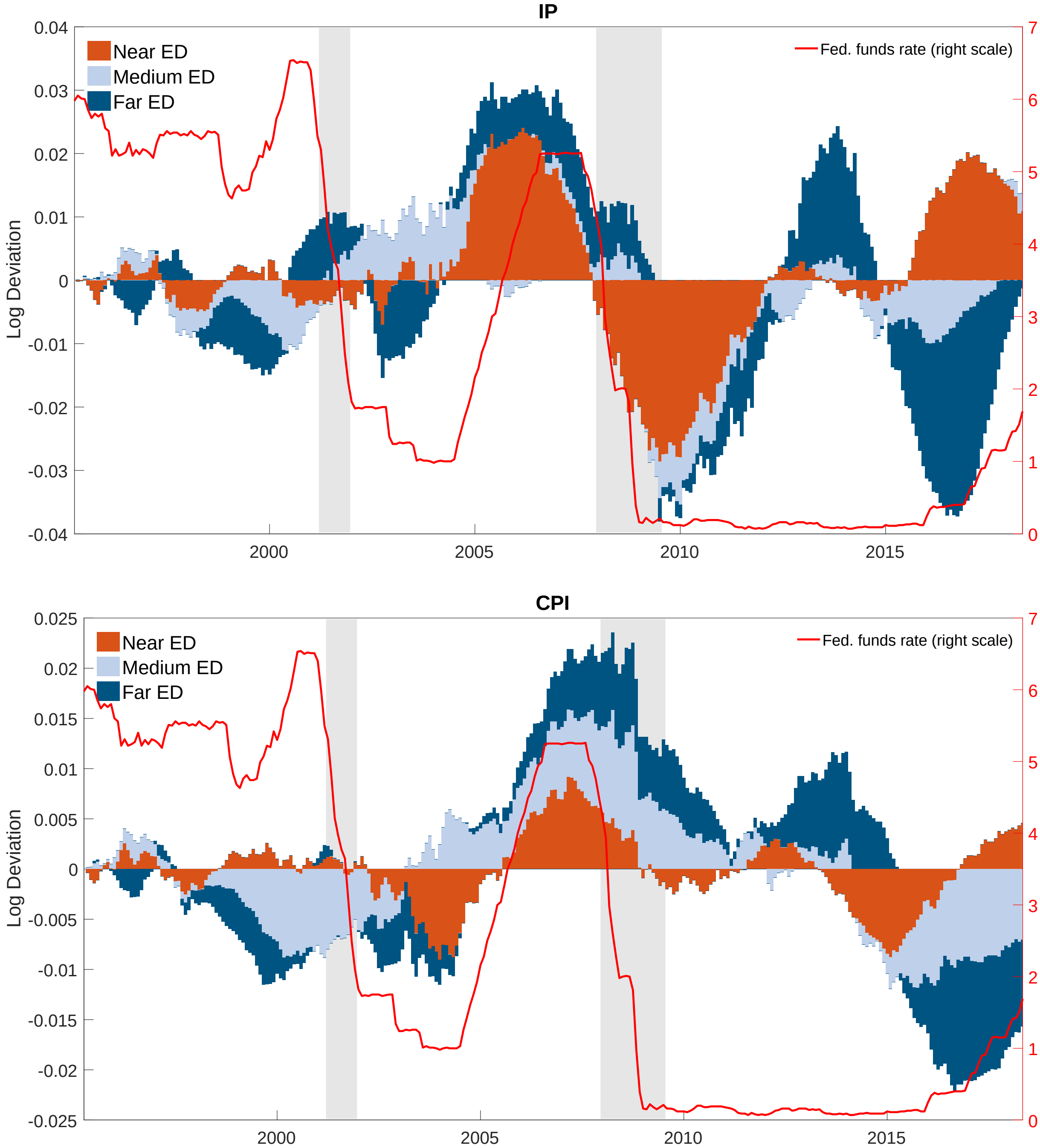
	Horizon (months)	IP	CPI	S_t^{NED}	S_t^{MED}	S_t^{FED}
IP_t	12	0.87	0.11	0.01	0.00	0.01
	18	0.71	0.25	0.00	0.01	0.03
	24	0.61	0.32	0.00	0.02	0.05
	36	0.54	0.35	0.01	0.02	0.08
CPI_t	12	0.06	0.83	0.02	0.04	0.05
	18	0.05	0.67	0.03	0.12	0.13
	24	0.04	0.51	0.05	0.18	0.21
	36	0.03	0.33	0.04	0.27	0.32

Notes: Contribution of our shocks to a forecast-error variance decomposition of IP and CPI at the 12, 18, 24 and 36 month horizons from our baseline five-variable Eurodollar VAR. The identified three (non-purged) shocks are $\tilde{ED}_t^j$, $j \in \{4, 8, 12\}$. "IP" and "CPI" shocks are not identified.

E.2 Historical Decompositions for the Eurodollar Specification

Here we show the results of historical decompositions of our ED futures analysis for both industrial production and prices, mentioned in Section 4 above (Figure 15).

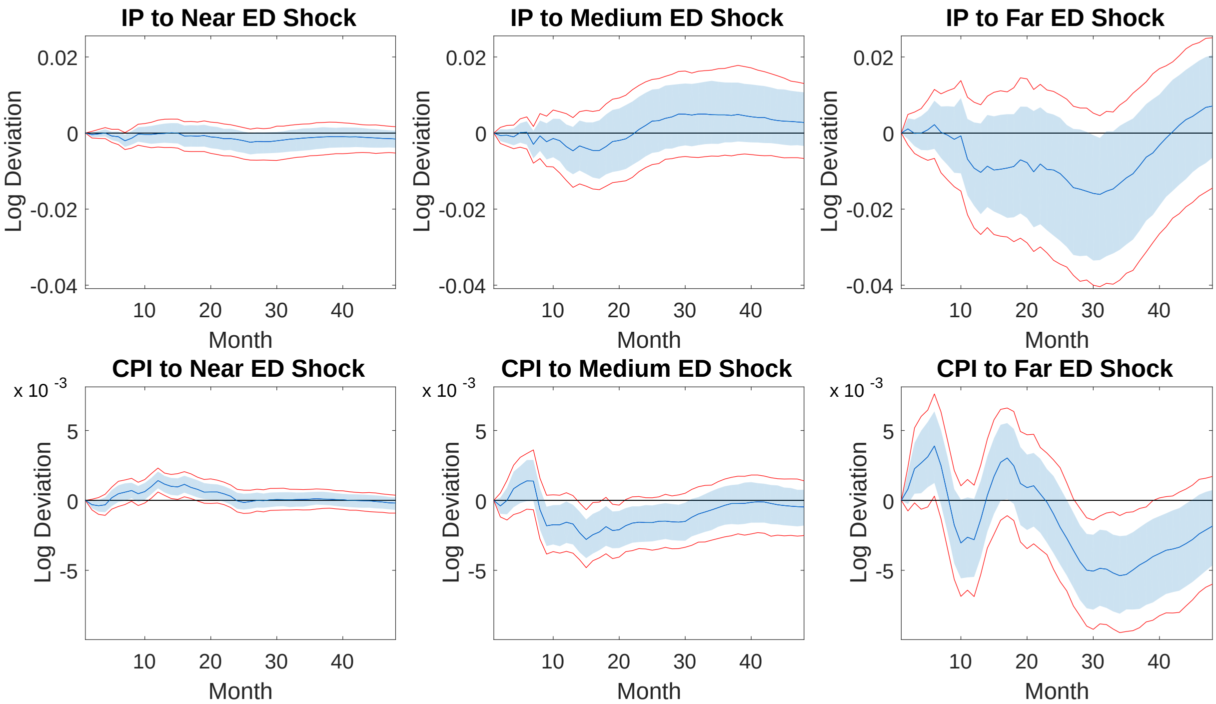
Figure 15: Historical Decomposition of $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ with Eurodollar Shocks



Notes: Historical decomposition of $\log(\text{CPI}_t)$ in our five-variable VAR, including the variables $\log(\text{IP}_t)$ and $\log(\text{CPI}_t)$ and three (non-purged) cumulated shock series $\Delta \tilde{ED}_t^{(j)}, j \in \{4, 8, 12\}$ – called near ED, medium ED and far ED shock respectively. The bar plots are stacked, so their height above the zero-axis represents the cumulative historical contribution of our monetary shocks to industrial production above its unconditional mean. Similarly for their height below the zero-axis. We also display the federal funds rate (using the right-hand scale) for reference. NBER recession periods are shown as grey areas.

E.3 Results for purged ED shocks (until end-2012)

Figure 16: Responses of $\log(\mathrm{IP}_t)$ and $\log(\mathrm{CPI}_t)$ to Eurodollar Shocks



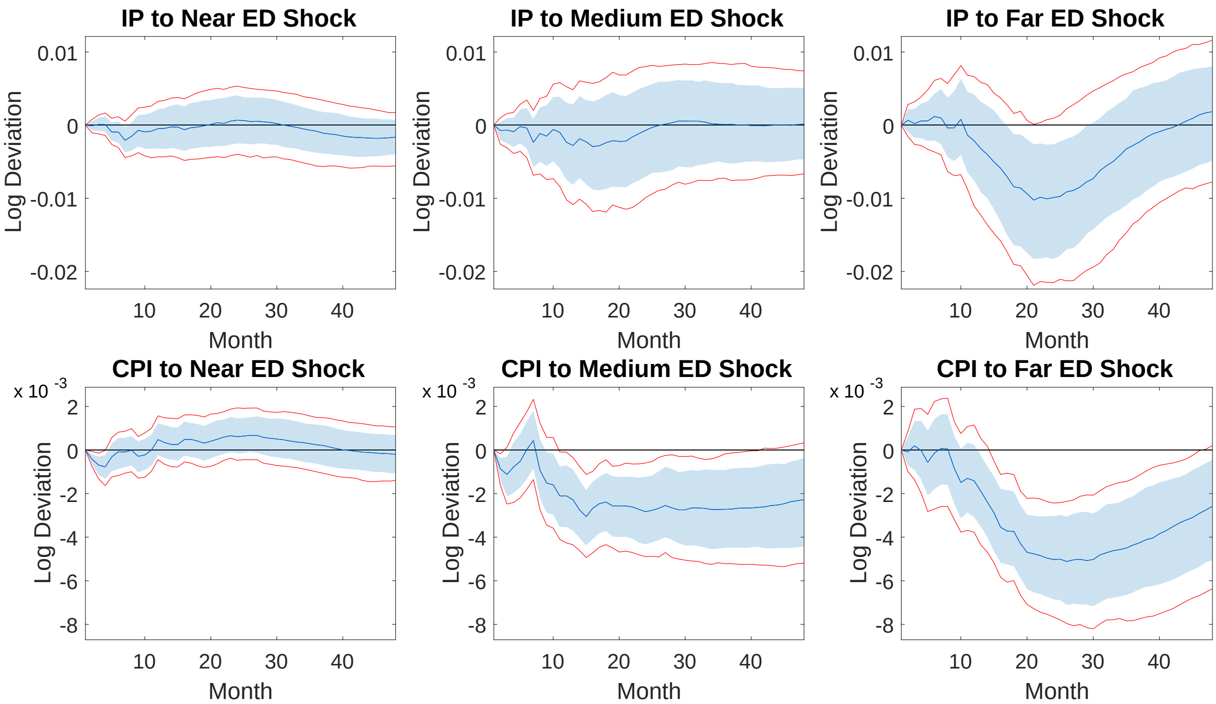
Notes: Impulse responses from our five-variable VAR, including $\log(\mathrm{IP}_t)$, $\log(\mathrm{CPI}_t)$ and the three cumulated shock series $\Delta ED_t^{(j)}$, $j \in \{4, 8, 12\}$ – called near ED, medium ED and far ED shock, respectively, purged for Fed information. The median response and confidence intervals were obtained from bootstrapping the VAR 500 times, the graph depicts the latter at 90% (red) and 75% (blue shadow) significance levels. Responses are to a 10 basis point positive shock to the anticipated policy rate.

E.4 Robustness Checks for the Eurodollar Specification

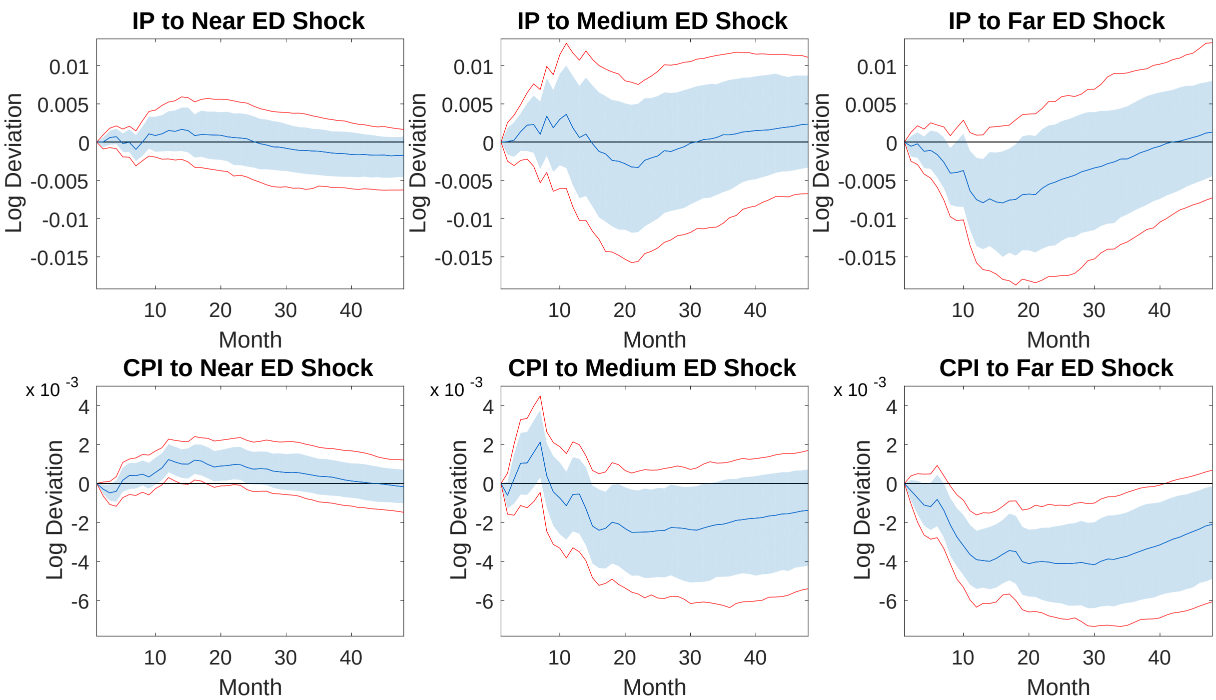
We assess the robustness of our results to different selections of Eurodollar contracts, namely $[ED4,\ ED8,\ ED18]$ and $[ED4,\ ED6,\ ED8]$. We display the IRFs in Figure 17. Results are qualitatively unaffected by our choices.

Figure 17: Responses of $\log(\mathrm{IP}_t)$ and $\log(\mathrm{CPI}_t)$ to Eurodollar Shocks

Contracts 4, 8, 18:



Contracts 4, 6, 8:



Notes: See Figure 12 in the main text.

F Details on FOMC meeting days

Here we report some details on which FOMC announcements we do not consider to be scheduled (and therefore do not use in our analysis). We also compare these to the Appendix 2 of the working paper version of GSS, Gürkaynak et al. (2004, GSSWP in the following), which contains a detailed summary (up to May 2004).

4/18/1994. Unscheduled conference call; from the minutes from March 22, 1994: "It was agreed that the next meeting of the Committee would be held on Tuesday, May 17, 1994."[43] GSSWP lists this date as an "intermeeting move".

10/15/1998. Unscheduled conference call. From the meeting statement of the previous meeting on Sept. 29th, it is not fully clear whether the meeting was scheduled: "In a telephone conference held on October 15, 1998, the Committee members discussed recent economic and financial developments and their implications for monetary policy. (...) At the conclusion of this discussion, the Chairman indicated that he would instruct the Federal Reserve Bank of New York to lower the intended federal funds rate by 25 basis points, consistent with the Committee's directive issued at the meeting on September 29, 1998. It was agreed that the next meeting of the Committee would be held on Tuesday, November 17, 1998."[44] However, we choose not to consider this date as GSSWP declare it an "intermeeting move".

1/3/2001. Unscheduled conference call. From the December 19th (2000) FOMC minutes: "This meeting adjourned at 1:35 p.m. with the understanding that the next regularly scheduled meeting of the Committee would be held on Tuesday-Wednesday, January 30-31, 2001."[45]

4/18/2001. Unscheduled conference call. From the March 20th FOMC minutes: "It was agreed that the next meeting of the Committee would be held on Tuesday, May 15, 2001."[46] GSSWP: "intermeeting move".

9/17/2001. Unscheduled conference call. From the August 21st FOMC minutes: "It was agreed that the next meeting of the Committee would be held on Tuesday, October 2, 2001." GSSWP: "intermeeting move".[47]

[43] https://www.federalreserve.gov/fomc/MINUTES/1994/19940322min.htm
[44] https://www.federalreserve.gov/monetarypolicy/fomchistorical1998.htm
[45] https://www.federalreserve.gov/fomc/minutes/20001219.htm
[46] https://www.federalreserve.gov/fomc/minutes/20010320.htm
[47] https://www.federalreserve.gov/fomc/minutes/20010821.htm

8/10/2007 and 8/17/2007. Both dates were unscheduled conference calls. From the August 7th FOMC minutes: "It was agreed that the next meeting of the Committee would be held on Tuesday, September 18, 2007."[48]

1/9/2008 and 1/22/2008. Unscheduled conference call on the 9th and 22nd, but meeting on the 30th was scheduled. From the Dec. 11th, 2007 FOMC minutes: "It was agreed that the next meeting of the Committee would be held on Tuesday-Wednesday, January 29-30, 2008."[49]

3/11/2008. Meeting on the 18th, unscheduled conference call on the 11th. From the Jan. 30th FOMC minutes: "It was agreed that the next meeting of the Committee would be held on Tuesday, March 18, 2008."[50]

10/08/2008. Meeting on the 29th, unscheduled conference call on the 7th. From the Sept. 16th FOMC minutes: "It was agreed that the next meeting of the Committee would be held on Tuesday-Wednesday, October 28-29, 2008."[51]

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[48] https://www.federalreserve.gov/fomc/minutes/20070807.htm
[49] https://www.federalreserve.gov/monetarypolicy/fomcminutes20071211.htm
[50] https://www.federalreserve.gov/monetarypolicy/fomcminutes20080130.htm
[51] https://www.federalreserve.gov/monetarypolicy/fomcminutes20080916.htm

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