

Monetary Policy, Term Structure, and the Asymmetric Excess-Sensitivity Puzzle

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Abstract

Excess sensitivity, the significant response of long-term interest rates to monetary policy, is a well-known puzzle. This paper shows that excess sensitivity is more pronounced following monetary policy easing than tightening, a phenomenon we term the asymmetric excess-sensitivity puzzle. By contrast, no comparable asymmetry is observed around the release of other macroeconomic data. A model with an ambiguous signaling channel of monetary policy can account for these findings. The model predicts that monetary easing has stronger and excessive effects on long-term interest rates but weaker effects on real GDP than monetary tightening. We provide evidence that supports the proposed mechanism.

Keywords: Asymmetric Excess-sensitivity, Monetary Policy, Term Structure, Ambiguous Signaling Channel

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1 Introduction

Changes in the short-term interest rate surrounding Federal Open Market Committee (FOMC, hereafter) meetings reflect unexpected monetary surprises. That such surprises have significant effects on long-term interest rates—the *excess sensitivity*—is well established; see, for example, [Hanson and Stein \(2015\)](#) and [Nakamura and Steinsson \(2018\)](#). In standard New Keynesian (NK, hereafter) models, however, long-term yields should respond only modestly to short-term policy surprises, because they primarily reflect expected future fundamentals rather than transitory movements in the policy rate. Since the long-term rate is a weighted average of the current and expected future short-term rates, excess sensitivity is therefore at odds with the NK paradigm that money is neutral in the long run. The observed large movements in long-term yields thus represent an overreaction relative to model predictions, giving rise to the *excess sensitivity puzzle*.

This paper shows that excess sensitivity is asymmetric and depends on the sign of the monetary policy surprise. Excess sensitivity is substantially more pronounced following monetary easing (a negative surprise) than monetary tightening (a positive surprise), giving rise to an *asymmetric excess-sensitivity puzzle*. By contrast, no comparable asymmetry emerges when examining the correlation between long-term and short-term interest rates around the release of other macroeconomic data. Nor do surprises in other macroeconomic announcements generate asymmetric responses in long-term yields. Together, these findings pose an additional challenge for developing a coherent theoretical framework.

Understanding the source of the asymmetric excess-sensitivity puzzle is central to understanding the transmission of monetary policy. One might argue that excess sensitivity suggests monetary policy has greater power to affect real economic activity than implied by the standard model, since real long-term rates matter for investment decisions ([Stein 2013](#)). Hence, asymmetric excess sensitivity implies that monetary easing should more effectively stimulate real activity than monetary tightening. This conjecture, however, stands in contrast to a well-established empirical regularity: monetary tightening shocks affect real GDP and unemployment more strongly than do monetary easing shocks (see, e.g., [Tenreyro and Thwaites 2016](#); [Barnichon and Matthes 2018](#)). A natural question thus arises: What mechanism can reconcile these puzzling findings?

The paper proceeds by developing a theory that explains both the asymmetric excess-sensitivity puzzle and the asymmetric responses to monetary policy observed in the data. We develop a framework that extends the standard NK model by incorporating the sig-

nalizing channel of monetary policy (see, e.g., [Melosi 2017](#); [Zhang 2022](#)), whereby central bank actions signal long-term growth.¹ Importantly, Knightian uncertainty (i.e., ambiguity) and ambiguity-averse agents are introduced into the model. The private market faces Knightian uncertainty—that is, unknown odds—regarding the quality of monetary policy actions as signals. In this framework, agents react more strongly to bad news (unexpected monetary easing) than to good news (unexpected monetary tightening). The model predicts that monetary easing has larger effects on long-term interest rates but smaller effects on real GDP than monetary tightening. Note that while the signaling channel offsets the traditional channel of monetary policy on real economic activity, it does not overturn it.

We provide additional empirical evidence in support of the proposed transmission mechanism. The private market’s forecast of real GDP is revised *downward* in response to an *expansionary* monetary shock. This finding contradicts the prediction of the standard NK model but is consistent with the signaling channel of monetary policy. Importantly, the result is *sign-dependent*: the effects of a contractionary monetary shock on the market’s forecasts of real GDP are statistically insignificant, although the point estimates align with the standard NK model.

The signaling channel differs from the information effect of monetary policy emphasized by [Nakamura and Steinsson \(2018\)](#) and [Jarociński and Karadi \(2020\)](#). Whereas the latter refers to policy announcements that directly convey information about the unobserved state of the economy, the former arises from the market’s active learning: a change in the short-term interest rate *unrelated* to the state of the economy is partly interpreted as a change in that unobserved state.

The empirical evidence in this paper contributes to research on how monetary policy announcements affect the term structure of interest rates and private agents’ forecasts; see, for example, [Romer and Romer \(2000\)](#), [Gürkaynak et al. \(2005b\)](#), [Hanson and Stein \(2015\)](#), [Nakamura and Steinsson \(2018\)](#), [Gilchrist et al. \(2015\)](#), [Campbell et al. \(2012\)](#), [Hanson et al. \(2021\)](#), and [Zhang \(2022\)](#). This paper adds to this literature by documenting the sign dependence of the excess-sensitivity puzzle and the counterintuitive response of real GDP forecasts to monetary shocks. Existing explanations of excess sensitivity include, for example, [Hanson and Stein \(2015\)](#), [Nakamura and Steinsson \(2018\)](#), [Hanson et al. \(2021\)](#), and [Zhang \(2022\)](#). [Hanson et al. \(2021\)](#) show that long-term rates’ strong high-frequency

¹This signaling channel rests on the connection between long-term interest rates and *expectations* about long-run growth. Estimates of the natural rate of interest co-move with trend output growth ([Holston et al. 2017](#)), and interest rates contain predictive information about future real activity ([Ang et al. 2006](#)), providing empirical support for the signaling mechanism we emphasize.

reactions to policy surprises largely reflect temporary term-premium movements. In contrast, this paper focuses on shifts in long-term expectations driven by Knightian uncertainty faced by market participants. To the best of the author’s knowledge, it provides the first theory that rationalizes the *asymmetric* excess-sensitivity puzzle.

This paper also contributes to the literature on Knightian uncertainty and ambiguity aversion in business cycles; see, for example, Ilut (2012), Ilut and Schneider (2014), Ilut *et al.* (2018), Bhandari *et al.* (2019), Michelacci and Paciello (2019), Baqaee (2020), Masolo and Monti (2020), Ilut *et al.* (2020), Pei (2021), Kroner (2021), and Chen *et al.* (2024). Michelacci and Paciello (2019) study the ambiguous effects of policy announcements when agents face Knightian uncertainty about the monetary authority’s commitment. Masolo and Monti (2020) show that introducing Knightian uncertainty into the *first moment* of the policy rule can generate wedges among long-term inflation expectations, trend inflation, and the inflation target. This paper instead focuses on Knightian uncertainty about the *second moment*, the quality of information, as in Epstein and Schneider (2008) and Ilut *et al.* (2018). In a contemporaneous and independently developed paper, Kroner (2021) shows that more-uncertain firms behave “as if” more pessimistic, cutting investment more after expected tightenings and increasing it less after expected loosening. He demonstrates that this pattern is consistent with a New Keynesian model in which ambiguity-averse agents, learning about future policy, are uncertain about the informativeness of forward-guidance signals. In contrast, the ambiguity-averse agents in our framework learn about future economic growth from policy actions, and this mechanism generates the asymmetric excess-sensitivity puzzle we document in the data. Taken together, Kroner (2021) and our paper complement each other in highlighting the role of ambiguity aversion in generating the asymmetric propagation of monetary policy.

This paper is closely related to the literature on the signaling channel of monetary policy; see, for example, Cukierman and Meltzer (1986), Ellingsen and Soderstrom (2001), Erceg and Levin (2003), Kozicki and Tinsley (2005), Gürkaynak *et al.* (2005b), Baeriswyl and Cornand (2010), Tang (2015), Melosi (2017), Falck *et al.* (2017), and Zhang (2022). Melosi (2017) show that *firms’* learning from policy actions can rationalize the Great Inflation, while Zhang (2022) show that *households’* learning can account for the excess-sensitivity puzzle. Our contribution is to demonstrate that an *ambiguous* signaling channel can explain the *asymmetric* excess-sensitivity puzzle.

2 Empirical Facts

Section 2.1 presents the asymmetric impact of monetary surprises on the yield curve on FOMC announcement dates. Section 2.2 shows that such asymmetry is absent around announcements of other, non-FOMC, macroeconomic data releases. The details of the data used in this paper and their sources are provided in Appendix B.

2.1 Asymmetric Excess-Sensitivity Puzzle

The empirical specification extends the linear models studied in the existing literature (see, e.g., [Gürkaynak et al. 2005b](#), [Hanson and Stein 2015](#), and [Nakamura and Steinsson 2018](#)) to allow for asymmetric effects of changes in the short-term interest rate on long-term interest rates. Specifically, we estimate regressions of the following form:

$$\Delta_d Y_t^h = \alpha_1^h + \alpha_2^h I_{\Delta_d MP_t < 0} + \beta_1^h \Delta_d MP_t + \beta_2^h (\Delta_d MP_t \times I_{\Delta_d MP_t < 0}) + X_t + v_{h,t}. \quad (1)$$

Here, $\Delta_d Y_t^h$ denotes the daily change in the nominal yield, with the superscript h indicating yield maturity. $\Delta_d MP_t$ denotes the daily change in the monetary policy instrument: the two-year nominal yield surrounding FOMC policy announcement dates. Following [Gilchrist et al. \(2015\)](#), [Gertler and Karadi \(2015\)](#), and [Hanson and Stein \(2015\)](#), the two-year nominal yield is used as the policy instrument, a common practice that allows the sample to include periods in which the federal funds rate is constrained by the zero lower bound. Finally, $I_{\Delta_d MP_t < 0}$ is an indicator variable equal to 1 if $\Delta_d MP_t < 0$ and 0 otherwise.

β_1^h captures the effect of positive monetary surprises on the interest rate of maturity h . The identification assumption is that changes in the monetary instrument within a short window surrounding FOMC announcement dates reflect monetary actions. Following [Hanson and Stein \(2015\)](#), the baseline specification uses daily changes in the monetary instrument. Policy decisions are typically announced at 2:15 p.m., and the yield curve data are constructed from quotes taken at 3:00 p.m. Thus, the measure of monetary surprises effectively allows only 45 minutes for the market to react to FOMC announcements. An additional advantage of this choice is that all baseline data are publicly available.

A potential concern, however, is that the daily window may be too wide and may capture extraneous noise, as discussed in [Gürkaynak et al. \(2005a\)](#). To address this issue, we adopt an alternative identification strategy that uses high-frequency identified (HFI)

monetary surprises—constructed within a 30-minute window surrounding FOMC policy announcements, based on financial futures contracts—as instruments for $\Delta_d MP_t$.

A Fed policy announcement includes both policy actions and the Fed’s assessment of current and future economic conditions. To the extent that the central bank possesses private information about the state of the economy, monetary *surprises* may partly reflect this information rather than the policy action component: the confounding problem. To address this concern, we follow the identification strategy of [Romer and Romer \(2004\)](#) by controlling for the Fed’s information set. Specifically, we include the Greenbook forecasts in vector X_t , which contains the Fed’s internal forecasts of inflation, real output growth, the unemployment rate, and the change in forecasts since the previous meeting, as a proxy for the central bank’s information set, following [Romer and Romer \(2004\)](#)’s specification.²

The parameters of interest are α_2^h and β_2^h , which capture the additional effects, in absolute value, of negative monetary surprises relative to positive ones. The null hypothesis is that positive and negative monetary surprises affect long-term interest rates equally in absolute value; that is, $\alpha_2^h = 0$ and $\beta_2^h = 0$ for all h .

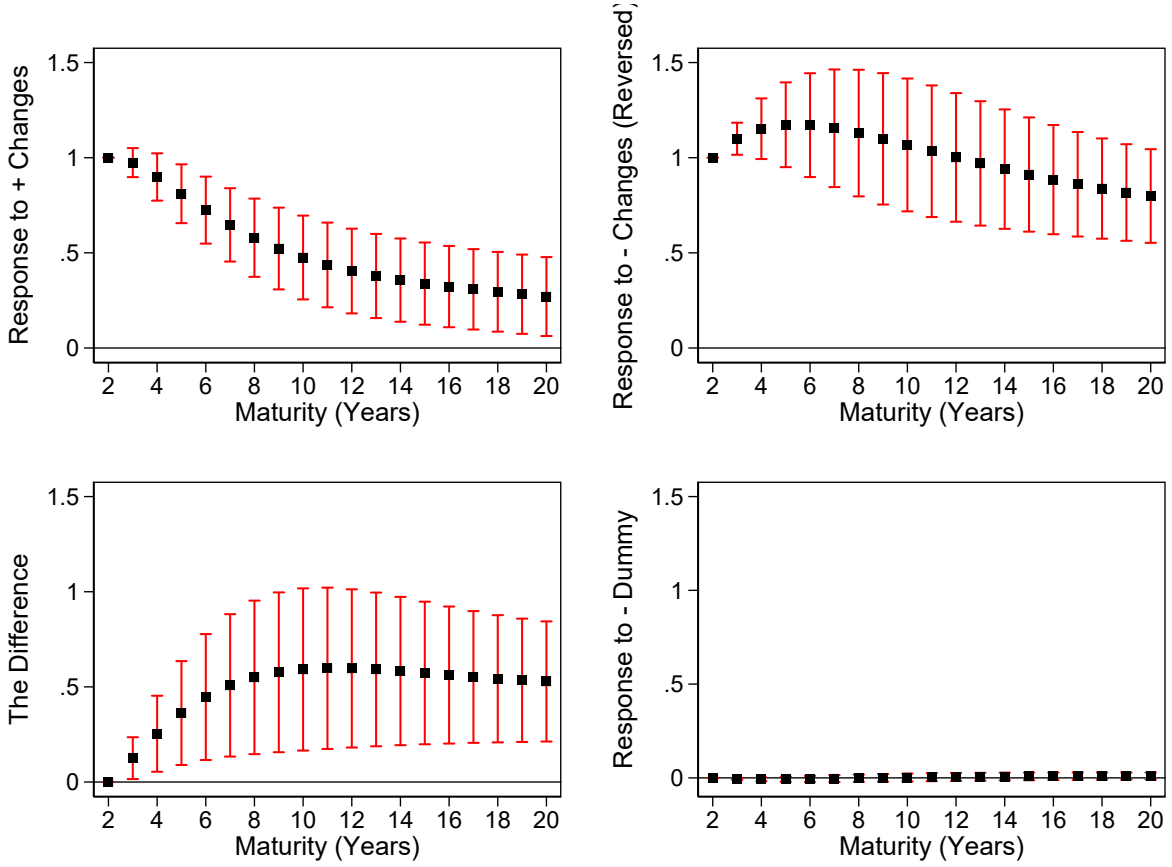
Equation (1) is estimated separately for each nominal yield of maturity h . In the baseline specification, the sample spans February 1994 to August 2018. The starting point is chosen to coincide with the FOMC’s adoption, on February 4, 1994, of the practice of immediately announcing its policy decisions.

The Asymmetric Excess-Sensitivity Puzzle Figure 1 plots the impact of monetary surprises on nominal yields. The square dots denote point estimates, and the lines represent 95 percent confidence intervals. The top-left panel shows $\hat{\beta}_1^h$, the effect of a positive monetary surprise (tightening) on long-term nominal interest rates. The top-right panel shows $\hat{\alpha}_2^h + \hat{\beta}_1^h + \hat{\beta}_2^h$, the *reversed* effect of a negative monetary surprise (easing). The estimates indicate that the 10-year nominal interest rate falls by about 1 percentage point in response to a monetary easing surprise that reduces the policy instrument by 1 percentage point (top-right panel), reflecting the well-documented excess sensitivity of long-term rates.

The novelty of this paper lies in showing that these effects are stronger for negative (expansionary) monetary shocks: as Figure 1 indicates, their impact on 20-year yields is more than twice that of positive (contractionary) shocks. The bottom-left panel plots $\hat{\alpha}_2^h + \hat{\beta}_2^h$, the difference (in absolute value) between the effects of a negative and a positive

²The main findings are robust to an empirical setting that does not control for Greenbook forecasts; see Figure A.6.

Figure 1: Asymmetric Excess-Sensitivity Puzzle

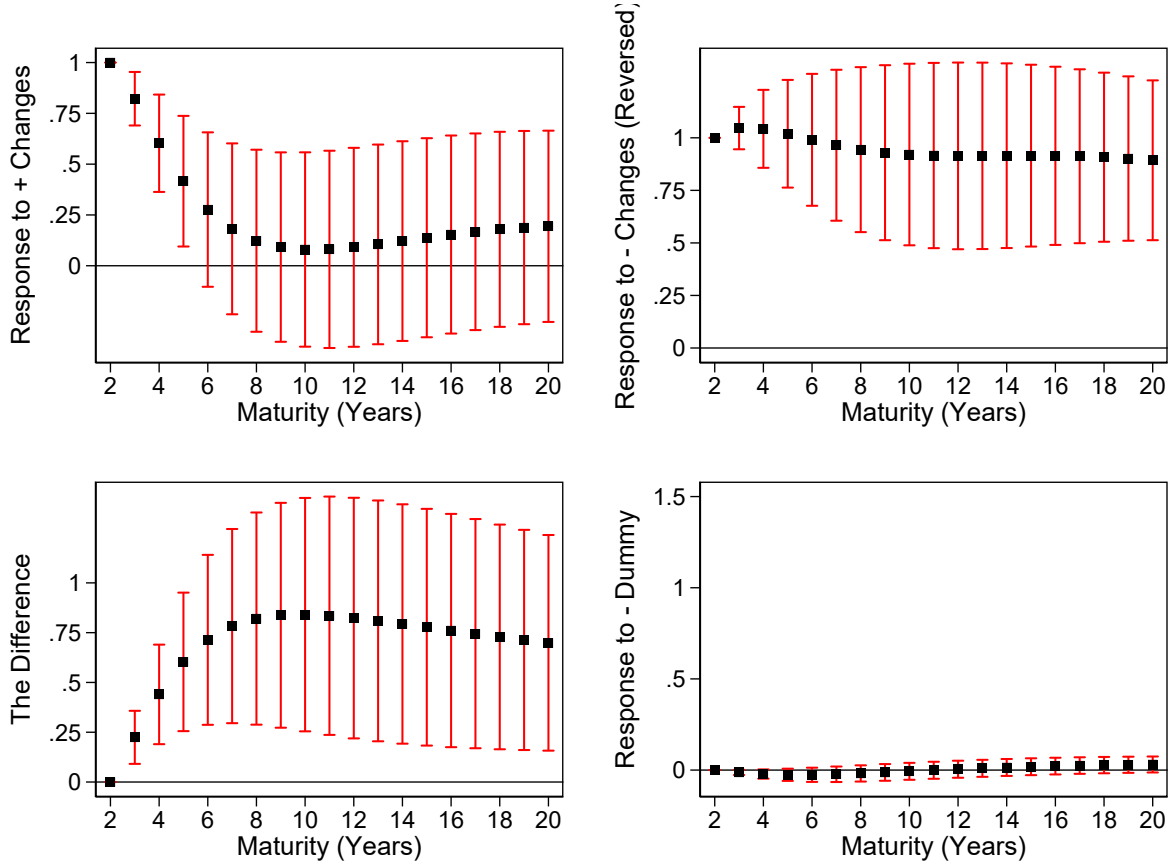


Note: This figure plots the impact of monetary surprises on nominal yields. The square dots in the top-left, top-right, bottom-left, and bottom-right panels represent the estimated coefficients $\hat{\beta}_1^h$, $\hat{\alpha}_2^h + \hat{\beta}_1^h + \hat{\beta}_2^h$, $\hat{\alpha}_2^h + \hat{\beta}_2^h$, and $\hat{\alpha}_2^h$, respectively. The lines indicate the 95 percent confidence intervals, constructed using standard errors robust to serial correlation and heteroskedasticity.

monetary shock, which is both statistically and economically significant. The bottom-right panel shows $\hat{\alpha}_2^h$, whose small magnitude implies that the difference primarily reflects $\hat{\beta}_2^h$.

In an online appendix, we show that the results discussed in this section are robust to: (i) using real yields constructed from inflation-indexed bonds (Figure A.1); (ii) a horse-race regression that controls for state-dependent effects (Figure A.2); and (iii) using risk-neutral rates constructed by Kim and Wright (2005) (Figure A.3).

Figure 2: Asymmetric Excess-Sensitivity Puzzle: Using HFI Monetary Surprises as IV



Note: This figure plots the impact of monetary surprises on nominal yields. The square dots in the top-left, top-right, bottom-left, and bottom-right panels represent the estimated coefficients $\hat{\beta}_1^h$, $\hat{\alpha}_2^h + \hat{\beta}_1^h + \hat{\beta}_2^h$, $\hat{\alpha}_2^h + \hat{\beta}_2^h$, and $\hat{\alpha}_2^h$, respectively. The coefficients $\hat{\alpha}^h$ and $\hat{\beta}^h$ are estimated using HFI monetary surprises and their interactions with $I_{\Delta MP_t < 0}$ as instruments for the variables of interest, ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$. The lines indicate 95 percent confidence intervals, constructed using standard errors robust to serial correlation. The sample covers 1994Feb to 2018Aug. The first-stage F -statistics are 13.60 for ΔMP_t and 11.70 for $\Delta MP_t \times I_{\Delta MP_t < 0}$.

HFI Monetary Shocks Monetary surprises constructed from the daily window may capture other news released on FOMC announcement dates. To address this concern, we use HFI monetary surprises, measured within a 30-minute window around policy announcements, and their interactions with $I_{\Delta_d MP_t < 0}$ as instruments for the variables of interest, $\Delta_d MP_t$ and $\Delta_d MP_t \times I_{\Delta_d MP_t < 0}$.

Figure 2 shows that the asymmetric excess-sensitivity puzzle remains when HFI surprises are used as instruments, confirming the robustness of our findings to alternative

identification strategies.

Jarociński and Karadi (2020) decompose HFI monetary surprises into central bank information (provision) shocks and exogenous monetary policy shocks. The signaling channel of monetary policy that we emphasize operates conditional on exogenous monetary policy shocks, which are orthogonal to unobserved economic conditions. Figure A.4 in the online appendix shows that the asymmetric excess-sensitivity puzzle persists when Jarociński and Karadi (2020)’s exogenous monetary policy shocks are used as instruments. Bauer and Swanson (2023) further purify HFI monetary surprises by removing the Fed’s endogenous response to macroeconomic news. Figure A.5 in the online appendix shows that our baseline findings are robust to using HFI monetary surprises constructed following Bauer and Swanson (2023).

2.2 Other Macroeconomic Announcements

The asymmetric excess-sensitivity puzzle arises exclusively on FOMC announcement dates and not on other dates. To illustrate this, we estimate model (1) using dates t surrounding the release of *other* macroeconomic data.

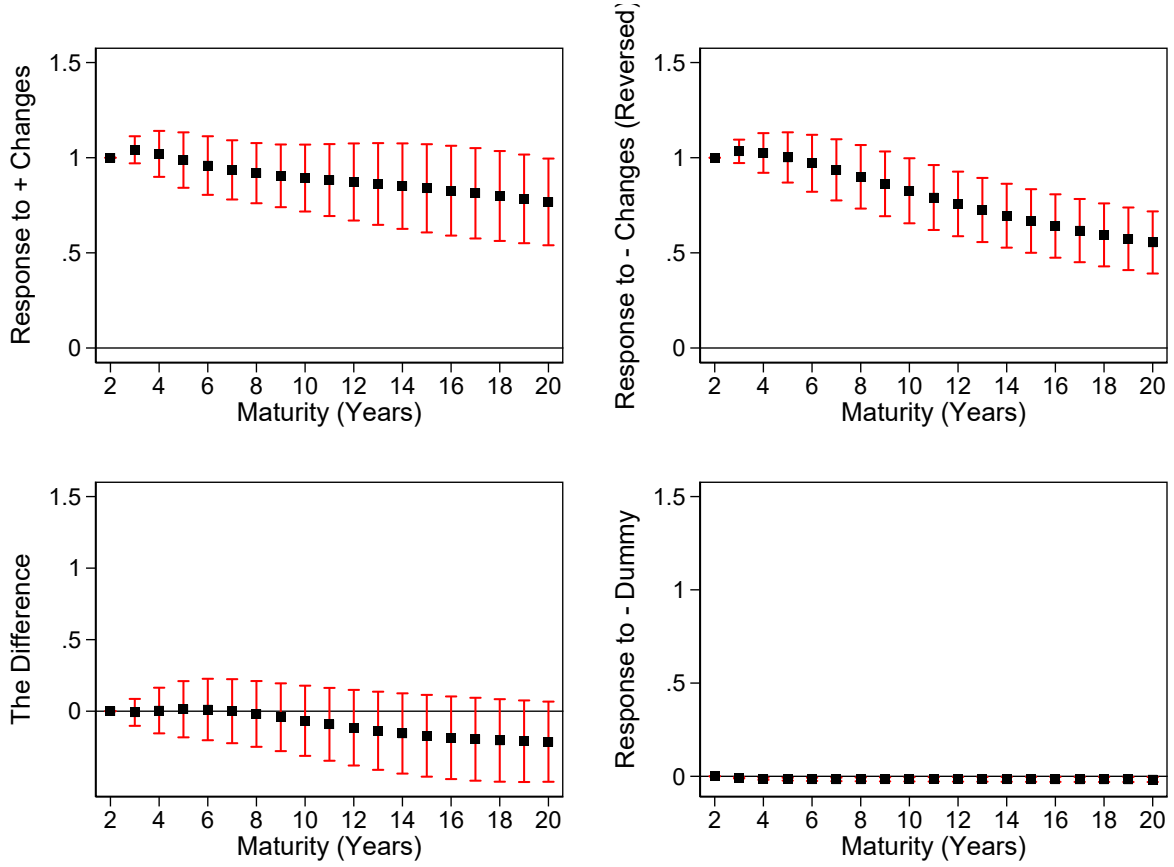
Figure 3 presents the results when focusing on dates with nominal GDP releases. As shown in the bottom-left panel, the estimated coefficient $\hat{\alpha}_2^h + \hat{\beta}_2^h$ is small in magnitude and statistically insignificant, indicating symmetric excess sensitivity. Similar patterns obtain for the release dates of other macroeconomic indicators, as shown in the online appendix A.2 (Figure A.7): conditional on macroeconomic announcement dates, short-term interest rates co-move with longer-term rates in a symmetric manner.³

Moreover, the symmetry effect also holds when we directly estimate the effects of macroeconomic announcement surprises on long-term nominal yields. Macroeconomic announcement surprises are defined as the difference between the released data and the market consensus expectation, where the consensus is measured as the average forecast of surveyed professional forecasters compiled by Bloomberg at the beginning of each month.

Figure A.8 in the online appendix A.2 shows that GDP announcement surprises have no asymmetric effects on long-term yields. This result extends to the majority of the 15 macroeconomic announcement surprises we consider (Figure A.9).

³There are a few exceptions. For certain macroeconomic announcements, we observe asymmetries of the opposite sign, albeit of small magnitude, relative to those on FOMC announcement dates. Explaining this heterogeneous relationship lies beyond the scope of this paper and is left for future research.

Figure 3: Symmetric Effects on Nominal GDP Release Dates



Note: This figure plots the impact of short-term interest rates on long-term rates by estimating model (1) using dates t surrounding nominal GDP releases. The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^h$, $\hat{\alpha}_2^h + \hat{\beta}_1^h + \hat{\beta}_2^h$, $\hat{\alpha}_2^h + \hat{\beta}_2^h$, and $\hat{\alpha}_2^h$, respectively. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity.

These findings suggest that the asymmetric excess-sensitivity puzzle is unique to monetary policy announcements.

3 The Ambiguous Signaling Channel of Monetary Policy

We extend a model with the signaling channel of monetary policy (Melosi 2017; Zhang 2022) to rationalize the empirical findings. Specifically, we build on Zhang (2022) by introducing two key features: households and firms face uncertainty about the volatility of monetary policy shocks, and agents are averse to ambiguity. Given the substantial

overlap with [Zhang \(2022\)](#), we relegate the full model to Appendix [C.1](#). Section [3.1](#) briefly highlights the key elements of the framework.

3.1 Key Features of the Model

Unobserved States and Monetary Policy Signal Firms and households share the same information set. They observe the growth rate of productivity (Δa_t):

$$\Delta a_t \equiv a_t - a_{t-1} = g_t + \epsilon_t^a, \quad \epsilon_t^a \sim N(0, \sigma_a^2),$$

but cannot determine whether movements in Δa_t reflect the persistent component (g_t) or the temporary component (ϵ_t^a). The persistent component follows:

$$g_t = \rho_g g_{t-1} + (1 - \rho_g) g^* + \epsilon_t^g, \quad \epsilon_t^g \sim N(0, \sigma_g^2).$$

The central bank observes all states of the economy, including g_t , and sets the interest rate according to a Taylor rule that tracks the efficient real interest rate (r_t^e) along with other targets:

$$\hat{i}_t = \rho_m \hat{i}_{t-1} + (1 - \rho_m) (r_t^e + \phi_\pi \hat{\pi}_t + \phi_y \hat{y}_t) + \epsilon_t^m, \quad \epsilon_t^m \sim N(0, \sigma_m^2).$$

The efficient real interest rate is proportional to g_t . Thus, the central bank's action $\hat{i}_t$ reveals private information about g_t . However, this signal is noisy because of unobservable monetary shocks ϵ_t^m , preventing the private sector from perfectly inferring the true state of the economy. The assumption that the central bank has superior information about g_t is made for tractability; what matters more generally is that the central bank has access to information that is valuable to market participants and that becomes partially revealed through its policy decisions ([Nakamura and Steinsson 2018](#)). Under this broader interpretation, the signaling channel we emphasize continues to operate.

Monetary Surprises and Belief Updating It is useful to interpret the monetary policy surprises used in the data through the lens of the model. For illustration, consider a simplified Taylor rule, $\hat{i}_t = g_t + \epsilon_t^m$. In this case, the monetary surprise, defined as $\hat{i}_t - E_{t-1} \hat{i}_t$, equals $\epsilon_t^g + \epsilon_t^m$ and consists of two components. First, an unanticipated increase in trend growth, ϵ_t^g , generates a positive monetary surprise. Alternatively, a positive surprise may arise purely from an exogenous monetary policy shock, ϵ_t^m . We assume that the central

bank does not (or cannot) communicate its knowledge of g_t . Instead, agents extract information from the policy action $\hat{i}_t$: the signaling channel of monetary policy. Agents update their beliefs using Bayes' rule. When a monetary tightening surprise originates from an exogenous monetary shock ϵ_t^m , the market partially interprets it as evidence that the trend growth of the economy is stronger than previously expected.

This signaling channel differs from the information channel discussed in the literature. The information channel refers to the central bank's direct communication or disclosure of information in policy announcements. In the language of our model, direct communication about ϵ_t^s can itself generate fluctuations in monetary surprises. Viewed in this way, the decomposition in [Jarociński and Karadi \(2020\)](#) separates monetary surprises into an information component, ϵ_t^s , and a monetary policy *shock*, ϵ_t^m .

The smaller the volatility of monetary policy shocks (i.e., the smaller σ_m), the more informative $\hat{i}_t$ is as a signal about g_t . Thus, the strength of the signaling channel depends on the perceived volatility of monetary policy shocks. Section 3.2 formally establishes this result using a simplified version of the model.

Ambiguous Monetary Policy Agents hold multiple priors about the quality of the monetary policy signal, σ_m ; that is, its precision is ambiguous. They know the true σ_m lies within a finite interval $[\underline{\sigma}_m, \bar{\sigma}_m]$. Ambiguity-averse agents evaluate outcomes using the worst-case value of σ_m within this set.

Given observed signals, agents choose the $\sigma_m \in [\underline{\sigma}_m, \bar{\sigma}_m]$ that generates the worst-case posterior belief. In our setting, this choice depends on the *sign* of the monetary surprise. Since household utility strictly increases in the unknown productivity trend g_t , the worst-case scenario corresponds to the σ_m that yields a lower posterior $g_{t|t}$. As a result, the perceived volatility of the monetary signal ($\tilde{\sigma}_m$) is kinked:

$$\tilde{\sigma}_m = \begin{cases} \bar{\sigma}_m, & \text{if monetary surprise} > 0, \\ \underline{\sigma}_m, & \text{if monetary surprise} < 0, \end{cases} \quad (2)$$

Intuitively, a negative (positive) surprise is partly perceived as bad (good) news. In the worst case, this corresponds, to a first-order approximation, to choosing a smaller (larger) σ_m , which generates a larger drop (smaller rise) in the expected trend.

3.2 Analytical Results Based on a Simplified Model

To clarify the mechanism behind the main findings in Section 4.2, we first analyze a version of the model without model uncertainty. Several simplifying assumptions are introduced to obtain analytical solutions. In particular, households and firms are assumed to rely solely on monetary policy ($\hat{i}_t$) when updating their beliefs about g_t . In addition, the monetary policy rule does not respond to endogenous variables. These assumptions simplify the belief-updating process and reduce the dimensionality of the state space. The resulting simplified model is characterized by the following equations:

$$\begin{aligned}\hat{y}_t &= \mathbb{E}_t \hat{y}_{t+1} - [\hat{i}_t - \mathbb{E} \hat{\pi}_{t+1} - \rho_g \mathbb{E}_t \hat{g}_t] \\ \hat{\pi}_t &= \beta \mathbb{E}_t \hat{\pi}_{t+1} + \kappa \hat{y}_t, \\ \hat{i}_t &= r_t^e + \epsilon_t^m, \epsilon_t^m \sim N(0, \sigma_m^2) \\ \hat{g}_t &= \rho_g \hat{g}_{t-1} + \epsilon_t^g, \epsilon_t^g \sim N(0, \sigma_g^2) \\ \hat{Y}_t^{(h)} &= \frac{1}{h} \mathbb{E} \sum_{j=1}^h \hat{i}_{t+j-1},\end{aligned}$$

where $\hat{Y}_t^{(h)}$ is the nominal yield with maturity h according to the expectation hypothesis that assumes that the long-term interest rate is the weighted average of the current and expected future short-term rates. $\hat{r}_t^e$ is the the efficient real interest rate, and $\hat{\pi}_t$ is the inflation rate. $\hat{y}_t$ is defined as $y_t - a_t$, the difference between log of production Y_t and log of stochastic productivity A_t , to obtain a stationary output measure. Note that the simplified monetary policy rule opens room for sunspot equilibria. In the following, We focus on the equilibrium driven by fundamental shocks. In the full model, the monetary policy rule ensures that the obtained solution is unique. Online Appendix C.3.2 solves for the impact effects of shocks in the simplified model.

Proposition 1 (Excess-sensitivity puzzle). *In the simplified model with a signaling channel of monetary policy, the sensitivity of the nominal yield of maturity h to a monetary policy shock increases in $\frac{\sigma_g}{\sigma_m}$ and declines with maturity h .*

Proof. See Appendix C.3.3. □

Proposition 1 shows that the sensitivity of long-term interest rates to monetary policy increases with the strength of the signaling channel and decreases with the maturity of the yield. A monetary tightening revises upward households' beliefs about the long-run

trend, raising expected future short-term rates. Because long-term yields are weighted averages of current and expected future rates, this mechanism generates excess sensitivity of long-term rates to monetary policy. A higher $\frac{\sigma_g}{\sigma_m}$ ratio implies a more precise policy signal, inducing agents to place greater weight on it. The signaling channel therefore strengthens, amplifying excess sensitivity. Moreover, because the stochastic trend decays over time, yields with longer maturities respond less to monetary shocks through the signaling channel.

Proposition 3 in online appendix C.3 provides additional results: (i) the signaling channel dampens the real effects of monetary policy; and (ii) it can overturn standard predictions, giving rise to output and price puzzles. Because the signaling channel reduces the impact of current policy shocks on real activity, it also attenuates the mechanism that generates the forward guidance puzzle in standard NK models. While the model is not designed to fully resolve the forward guidance puzzle, it moves in the right direction by weakening the excessive sensitivity of current variables to news about future policy.

4 Evaluating Model Predictions

The model introduced in Section 3 relies on the mechanism that monetary shocks have asymmetric effects on forecast revisions of future economic conditions, which in turn rationalizes the asymmetric excess-sensitivity puzzle. Before turning to the quantitative analysis (Section 4.2), Section 4.1 presents evidence supporting this mechanism.

4.1 Evidence Supporting the Model Mechanism

This empirical exercise examines the asymmetric effects of monetary shocks on revisions to real GDP forecasts. In particular, we estimate regressions of the form:

$$y_{t+j|t} - y_{t+j|t-1} = \alpha_1^j + \alpha_2^j I_{\Delta MP_t < 0} + \beta_1^j \Delta MP_t + \beta_2^j (\Delta MP_t \times I_{\Delta MP_t < 0}) + \gamma^j X_t + v_{j,t}, \quad (3)$$

where $y_{t+j|t}$ is the expected real GDP (in log) j quarters ahead. The Survey of Professional Forecasters (SPF) provides these variables. ΔMP_t is the quarterly change in the monetary policy instrument, and $I_{\Delta MP_t < 0}$ is an indicator equal to one when ΔMP_t is negative.

These quarterly changes ΔMP_t do not necessarily correspond to monetary shocks. To identify monetary shocks at a quarterly frequency, we use HFI monetary surprises purged of the Fed's information set, henceforth referred to as HFI monetary shocks (ms_t). As dis-

cussed above, HFI monetary *surprises* may reflect the Fed’s private information rather than the policy action component. To address this, HFI monetary *shocks* are constructed from the HFI surprises following the approach of [Romer and Romer \(2004\)](#) (see also [Miranda-Agrippino 2016](#), [Miranda-Agrippino and Ricco 2017](#), and [Zhang 2022](#)). Specifically, HFI monetary surprises are projected onto a proxy for the Fed’s information set: the Fed’s internal forecasts of inflation, real output growth, unemployment, and changes in these forecasts since the previous meeting. The residuals from this projection are the cleaned HFI monetary *shocks*.

These HFI monetary shocks (ms_t) are used, together with their interaction with $I_{ms_t < 0}$, along with the third-order terms of them, are used as instrumental variables for ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$. The indicator $I_{ms_t < 0}$ equals one when the HFI monetary shock is negative and zero otherwise. Monetary shocks are aggregated to the quarterly frequency by summing all shocks occurring between two SPF survey dates. The vector X_t includes control variables: two lags of changes in the log form of CPI, changes in the first release of GDP, and the monetary policy shock as control variables. Without higher order terms as IV, results are similar qualitatively with a caveat of weak IV (see Figure [A.13](#)).

Figure [4](#) plots the estimation results: $\hat{\beta}_1^j$ in the top-left panel, $\hat{\alpha}_2^j + \hat{\beta}_1^j + \hat{\beta}_2^j$ in the top-right panel, $\hat{\alpha}_2^j + \hat{\beta}_2^j$ in the bottom-left panel, and $\hat{\alpha}_2^j$ in the bottom-right panel. These figures illustrate the effects of monetary tightening, the absolute effects of monetary easing, and the difference between the absolute effects of monetary policies of opposite signs. The shaded bands depict 95% confidence intervals.

The top-right panel of Figure [4](#) shows that, in response to an *expansionary* monetary shock (an interest rate cut) of one percent, agents revise their real GDP forecasts *downwards* by roughly one percent. This reaction is the opposite of what a standard NK model would predict. In contrast, the effects of *positive* monetary shocks on real GDP forecast revisions are insignificant (top-left panel), although the point estimates align with standard NK predictions. The difference between the absolute effects of monetary shocks of opposite signs is both economically and statistically significant (bottom-left panel).

Online Appendix [A.3](#) provides several robustness checks. The baseline results are not driven by boom–bust state dependence (Figure [A.10](#)), and they remain robust when using HFI monetary shocks constructed following [Bauer and Swanson \(2023\)](#) (Figure

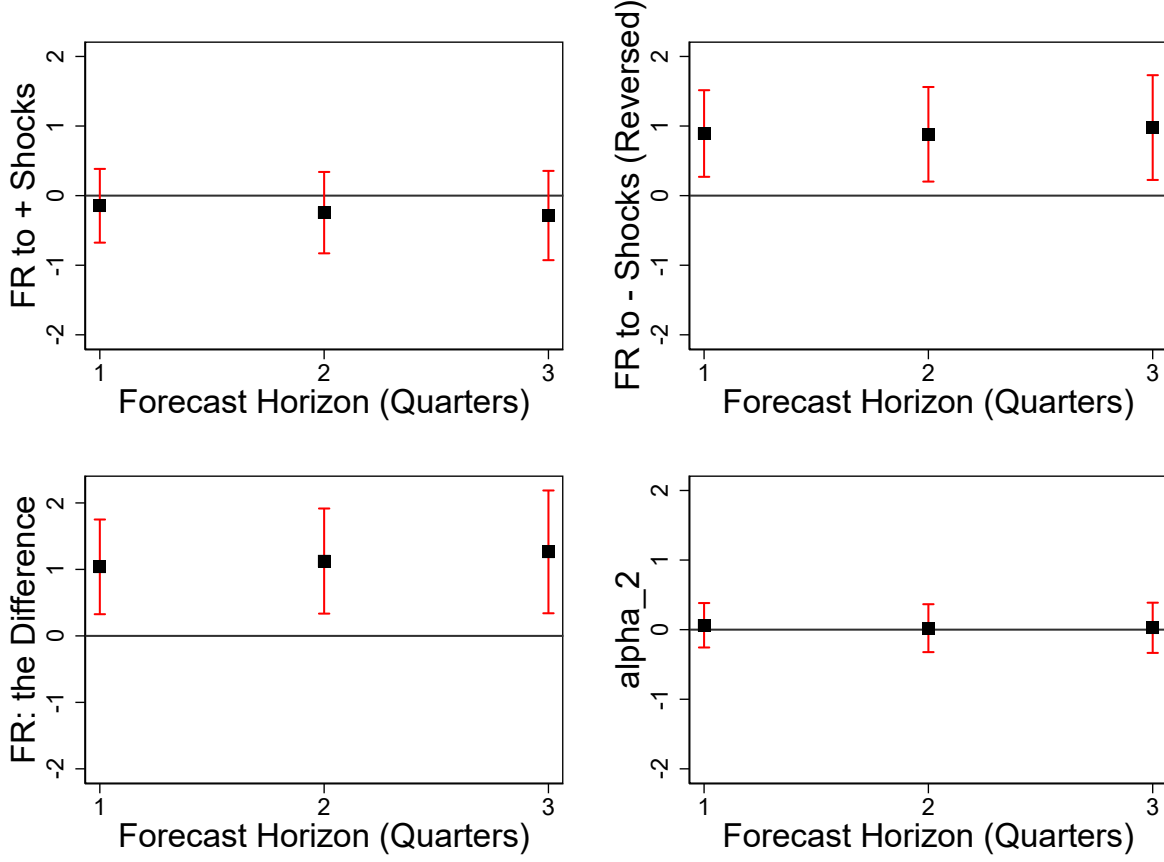


Figure 4: Impact Effect of Monetary Shocks on Real GDP Forecast Revisions.

Note: This figure plots the impact effects of monetary shocks on real GDP forecast revisions. The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^j$, $\hat{\alpha}_2^j + \hat{\beta}_1^j + \hat{\beta}_2^j$, $\hat{\alpha}_2^j + \hat{\beta}_2^j$, and $\hat{\alpha}_2^j$ respectively. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity. Sample: 1990Q3 to 2019Q2. The first stage F-statistics equal 45.65 and 77.33 for ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$, respectively.

A.11),⁴, when using exogenous monetary shocks constructed following Jarociński and Karadi (2020) (Figure A.12).

⁴Specifically, HFI monetary surprises are purged not only of the Fed's information set but also of recently released macroeconomic news. Note that Bauer and Swanson (2023) employ a monetary surprise constructed from a single financial futures contract as an instrument. In contrast, we use HFI monetary surprises constructed from multiple futures contracts to ensure first-stage relevance.

4.2 A Quantitative Exploration of the Model

We now present the quantitative predictions of the model. Appendix C.4 provides details on the model calibration. The key parameters governing the strength of the ambiguous signaling channel, such as $\bar{\sigma}_m$ and $\underline{\sigma}_m$, are calibrated to match the effects of monetary shocks on real GDP forecast revisions documented in Figure 4 and reproduced in Panel (a) of Figure 5.

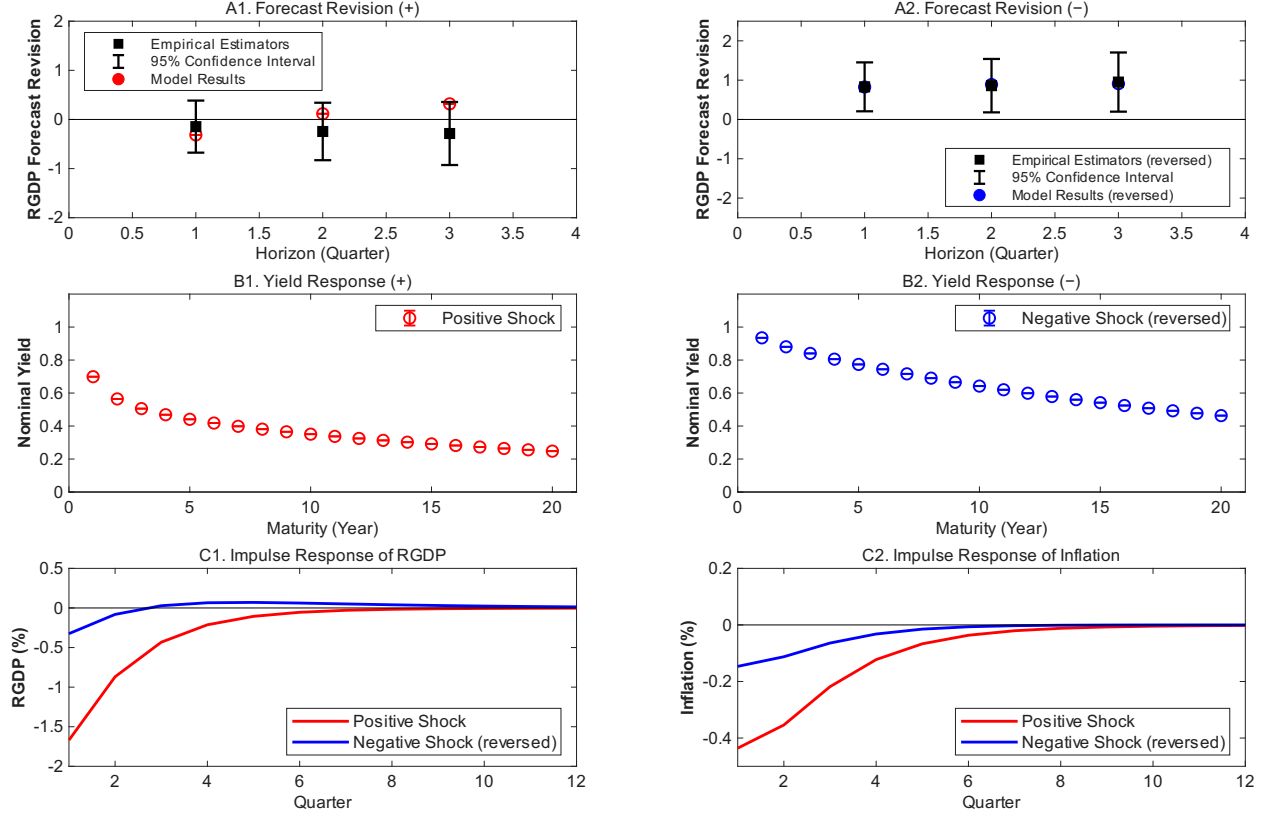


Figure 5: This figure plots the empirical and model's implied responses of real GDP forecast revisions at different horizons given a positive or negative monetary surprise (the top panels), nominal yield with different maturities given a positive or negative monetary surprise (middle panels), impulse responses of real GDP (bottom left panel) and impulse responses of inflation (bottom right panel) to monetary shocks. The red circles and red lines plots the responses to a positive monetary shock ($\epsilon_t^m > 0$), and the blue circles and blue lines depicts the reversed effects of negative monetary shock ($\epsilon_t^m < 0$). The black square dots in panel (a) indicate the estimated coefficients, while the black lines in panel (a) represent their 95% confidence intervals.

Asymmetric Excess-Sensitivity Puzzle The top panels of Figure 5 compare the empirical responses of real GDP forecast revisions with the model-implied responses at different horizons, and the middle panels show the corresponding yield-curve effects. Red circles

denote the model's response to a positive monetary shock ($\epsilon_t^m > 0$), blue circles the reversed effects of a negative shock ($\epsilon_t^m < 0$), and the black dots with confidence intervals reproduce the estimates from Figure 4.

The asymmetry is evident. The model closely matches the empirical pattern: negative shocks generate much larger forecast revisions than positive shocks. Because ambiguity-averse agents treat negative surprises as more informative about a possible deterioration in long-run growth (a lower perceived $\tilde{\sigma}_m$) and positive surprises as less informative (a higher perceived $\tilde{\sigma}_m$), the signaling channel is quantitatively much stronger for expansionary than for contractionary shocks. As a result, the signaling channel is stronger for easing than for tightening, producing larger downward revisions following expansionary shocks.

The middle panels show a similar asymmetry for the yield curve: negative shocks shift the curve more than positive shocks of equal size, consistent with Figure 1. Long-term rates respond through the signaling channel because a tightening raises beliefs about trend growth, increasing expected future rates. Since long-term yields average current and expected future rates, they display excess sensitivity to monetary policy. This effect diminishes with maturity as the stochastic trend converges to its steady-state value.

Asymmetric Effects of Monetary Policy on Economic Activity The bottom panels of Figure 5 plot the impulse responses of output and inflation to a positive monetary shock (red) and the *reversed* responses to a negative shock (blue). A tightening has stronger effects than an expansion, reflecting the ambiguous signaling channel of monetary policy. The signaling channel partly offsets the traditional transmission mechanism: while a monetary expansion stimulates consumption through the conventional channel, an unexpected rate cut also signals weaker economic conditions, reducing households' desire to consume. Because ambiguity-averse agents place less weight on policy signals that convey good news, the overall response is asymmetric.

Although the signaling channel dampens the conventional channel, it does not overturn it. Under our calibration, the conventional channel dominates, generating the counterintuitive combination of pessimistic long-term forecasts and an immediate rise in GDP following an interest rate cut. As agents gradually learn that the shock was an exogenous monetary policy shock rather than a negative trend shock, expectations adjust, and the responses of GDP and inflation converge back to zero. This prediction is consistent with Bundick and Smith (2020), who find that the signaling channel is dominated by the

conventional channel when considering realized economic outcomes. It is also consistent with our empirical finding, reported in Online Appendix A.3, that while monetary tightening shocks reduce stock prices and monetary easing shocks increase them, the effects of easing shocks are smaller.

5 Conclusion

The excess-sensitivity puzzle, which contrasts with the standard NK model, has attracted research that aims to rationalize it. This paper adds novel evidence, the asymmetric sensitivity puzzle, that creates challenges to developing a consistent theoretical model.

A theory to rationalize the asymmetric sensitivity puzzle based on the ambiguous signaling channel of monetary policy is then provided. The mechanism relies on the asymmetric information between the market and the monetary authority and, importantly, Knightian uncertainty and the ambiguity-averse preference.

The model's prediction is consistent with the existing evidence that monetary tightening is more effective than monetary easing in influencing real economic activities; see, for example, [Tenreyro and Thwaites \(2016\)](#) and [Barnichon and Matthes \(2018\)](#). Moreover, this study provides empirical evidence on the asymmetric response of the real GDP forecast to monetary shocks that support the mechanism proposed in this paper.

While we offer a model to rationalize the asymmetric excess-sensitivity puzzle and provide evidence supporting its mechanism, we do not view our framework as the unique explanation.⁵ Further work is needed to understand the sources of asymmetric excess sensitivity. For example, [Hanson *et al.* \(2021\)](#) show that temporary movements in the term premium can account for the strong high-frequency reactions of long-term rates to monetary policy surprises. Beyond documenting that the excess-sensitivity pattern remains when using the risk-neutral rates constructed by [Kim and Wright \(2005\)](#), our analysis largely abstracts from term-premium dynamics. Future research exploring whether asymmetric excess sensitivity reflects asymmetric movements in term premia would therefore be valuable.

Alternatively, models that generate asymmetric real effects of monetary policy might help rationalize asymmetric excess sensitivity. However, [Tenreyro and Thwaites \(2016\)](#), [Barnichon and Matthes \(2018\)](#), [Kroner \(2021\)](#), [Barnichon *et al.* \(2022\)](#), and [Debortoli *et al.*](#)

⁵Recent studies suggest that signaling effects are present but may not be dominant (e.g., [Andrade *et al.* 2019](#), [Lunsford 2020](#), and [Bauer and Swanson 2023](#)).

(2020) document that easing shocks typically have *smaller* effects on real activity than tightening shocks. Reconciling this empirical asymmetry in real outcomes with the *larger* response of long-term rates to easing shocks is challenging. The ambiguous signaling channel we emphasize provides one such candidate mechanism.

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Online Appendix to “Monetary Policy, Term Structure, and the Asymmetric Excess-Sensitivity Puzzle”

Jingyi Liang Donghai Zhang

A Additional Empirical Results

A.1 Asymmetric Excess-sensitivity: Additional Results

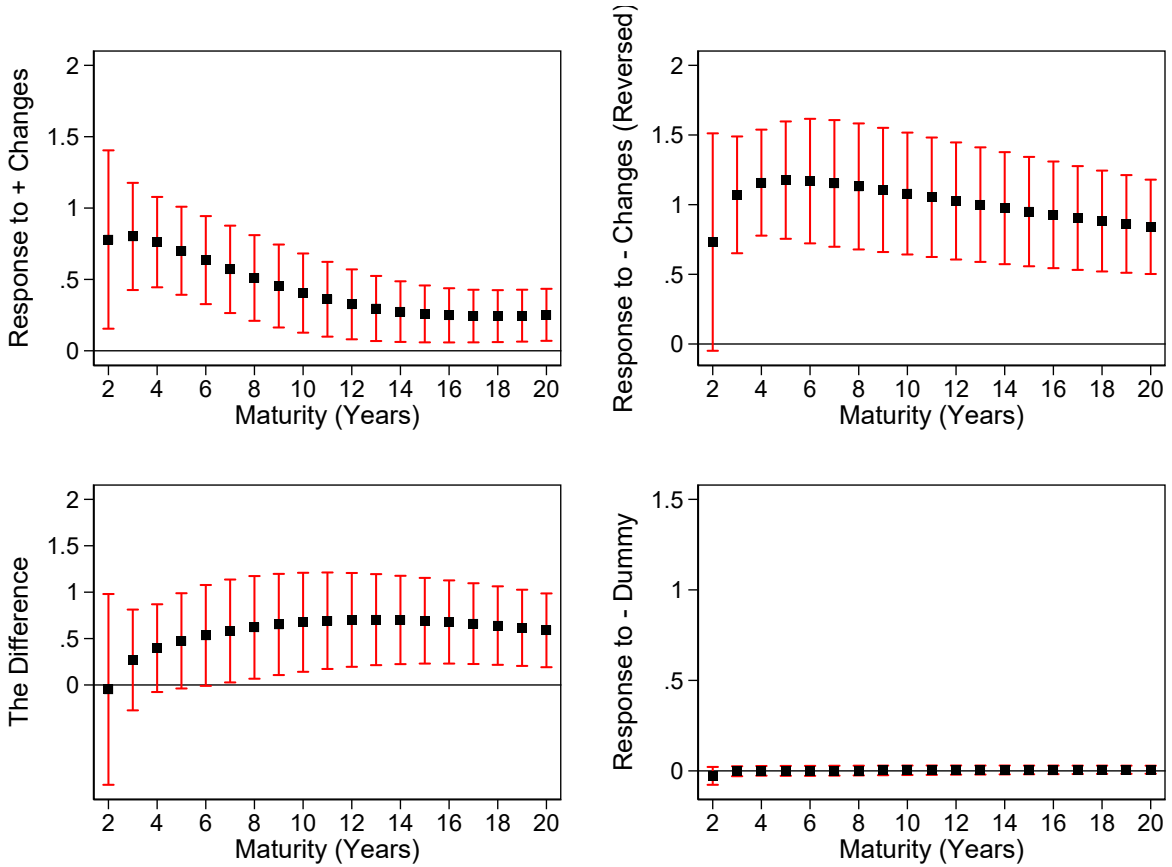


Figure A.1: Asymmetric Excess-Sensitivity Puzzle: Real Yields (TIPS)

Note: This figure plots the impact effects of monetary surprises on real yields. The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^h$, $\hat{\alpha}_2^h + \hat{\beta}_1^h + \hat{\beta}_2^h$, $\hat{\alpha}_2^h + \hat{\beta}_2^h$, and $\hat{\alpha}_2^h$, respectively. $\hat{\alpha}^h$ s and $\hat{\beta}^h$ s are estimated from separated regressions: $\Delta Y_t^h = \alpha_1^h + \alpha_2^h I_{\Delta MP_t < 0} + \beta_1^h \Delta MP_t + \beta_2^h \Delta MP_t \times I_{\Delta MP_t < 0} + X_t + v_{h,t}$. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity. Sample: 1994Feb to 2018Aug.

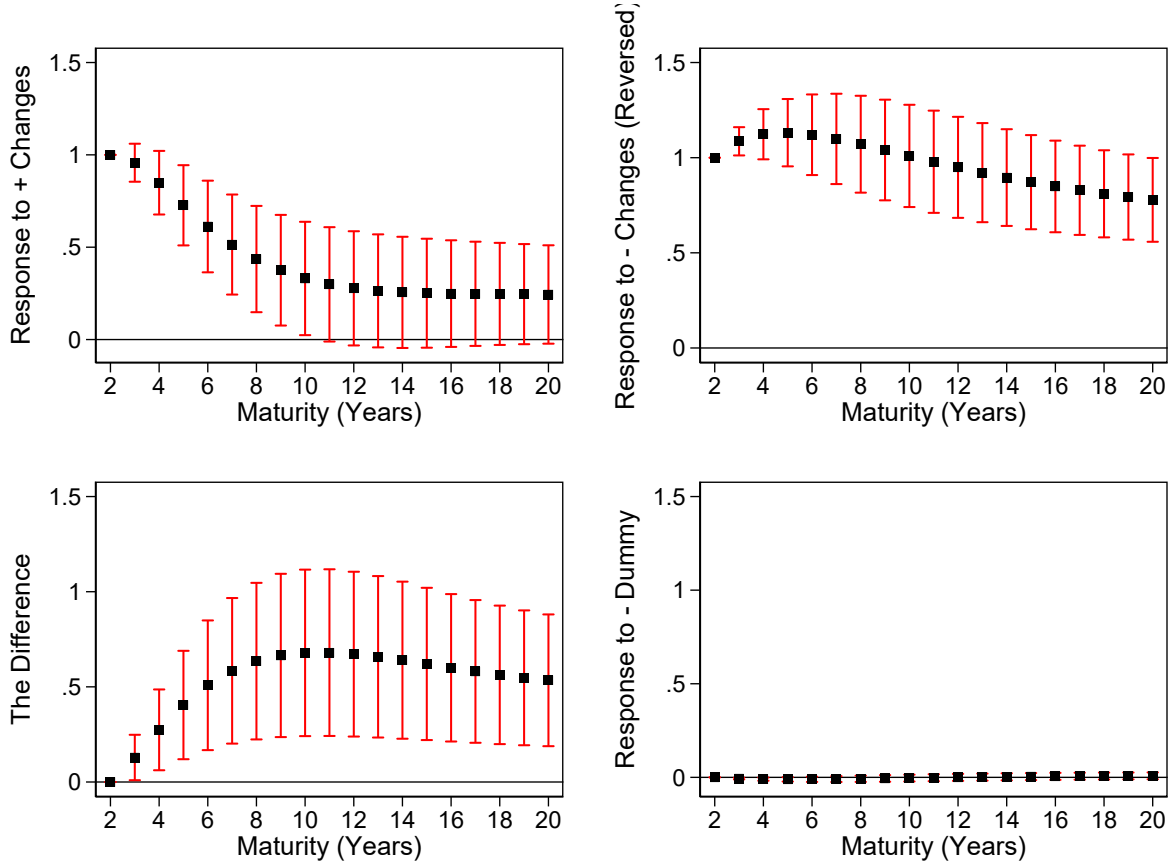


Figure A.2: Asymmetric Excess-Sensitivity Puzzle: Horse-Race with State-Dependence

Note: This figure plots the impact effects of monetary surprises on nominal yields. The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^h$, $\hat{\alpha}_2^h + \hat{\beta}_1^h + \hat{\beta}_2^h$, $\hat{\alpha}_2^h + \hat{\beta}_2^h$, and $\hat{\alpha}_2^h$, respectively. $\hat{\alpha}^h$ s and $\hat{\beta}^h$ s are estimated from separated regressions: $\Delta Y_t^h = \alpha_1^h + \alpha_2^h I_{\Delta MP_t < 0} + \beta_1^h \Delta MP_t + \beta_2^h \Delta MP_t \times I_{\Delta MP_t < 0} + X_t + v_{h,t}$. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity. Sample: 1994Feb to 2018Aug.

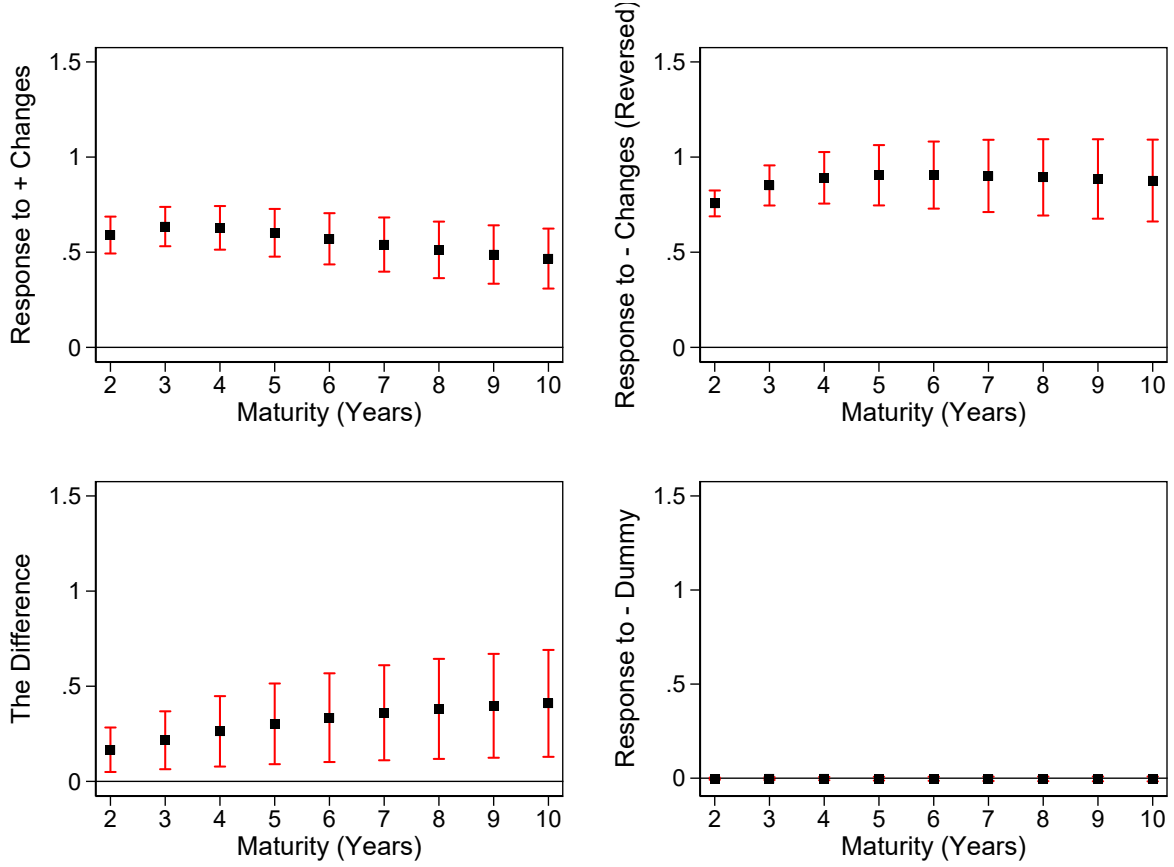


Figure A.3: Asymmetric Excess-Sensitivity Puzzle: Risk-Neutral Nominal Yields

Note: This figure plots the impact effects of monetary surprises on risk-neutral measures of nominal interest rates. The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^h$, $\hat{\alpha}_2^h + \hat{\beta}_1^h + \hat{\beta}_2^h$, $\hat{\alpha}_2^h + \hat{\beta}_2^h$, and $\hat{\alpha}_2^h$, respectively. $\hat{\alpha}^h$ s and $\hat{\beta}^h$ s are estimated from separated regressions: $\Delta Y_t^h = \alpha_1^h + \alpha_2^h I_{\Delta MP_t < 0} + \beta_1^h \Delta MP_t + \beta_2^h \Delta MP_t \times I_{\Delta MP_t < 0} + X_t + v_{h,t}$. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity. Sample: 1994Feb to 2018Aug.

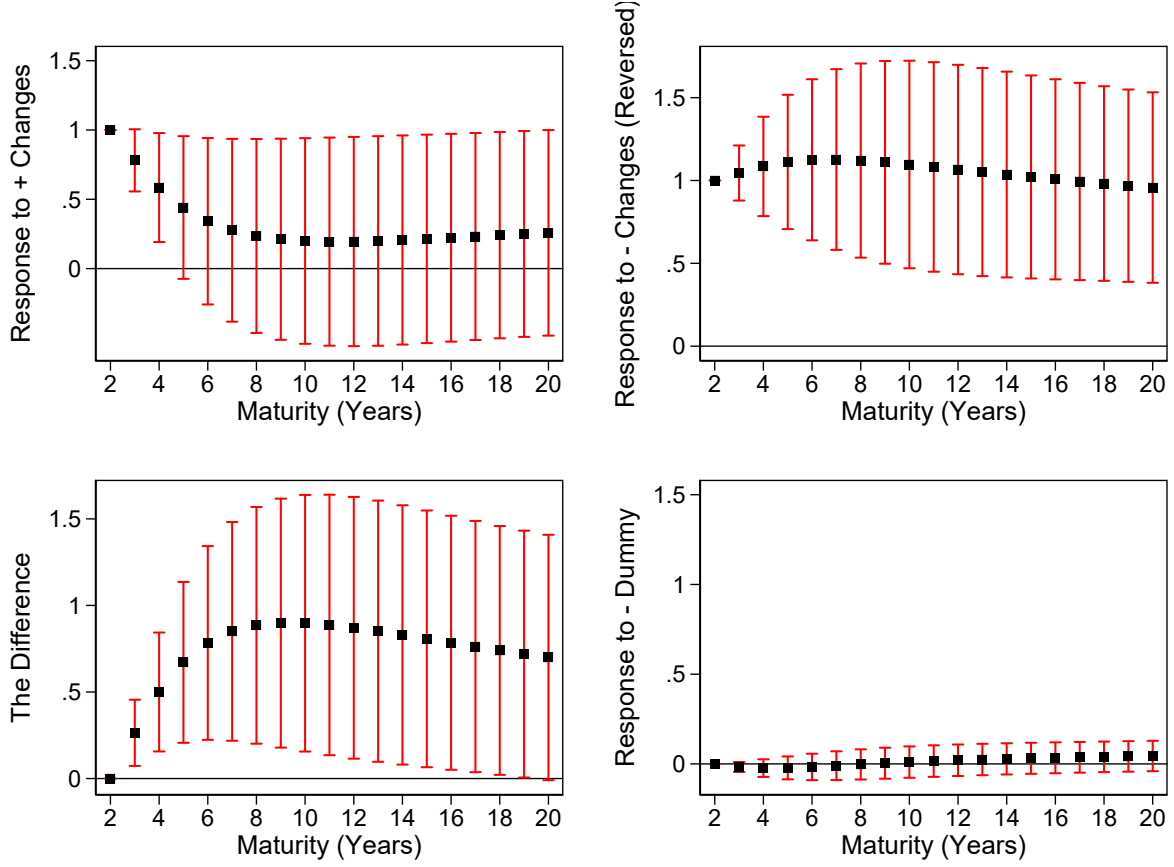


Figure A.4: Asymmetric Excess-Sensitivity Puzzle: Jarocinski-Karadi Shock as IV

Note: This figure plots the impact effects of monetary shocks on nominal yields. The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^h$, $\hat{\alpha}_2^h + \hat{\beta}_1^h + \hat{\beta}_2^h$, $\hat{\alpha}_2^h + \hat{\beta}_2^h$, and $\hat{\alpha}_2^h$, respectively. $\hat{\alpha}^h$ s and $\hat{\beta}^h$ s are estimated from separated regressions: $\Delta Y_t^h = \alpha_1^h + \alpha_2^h I_{\Delta MP_t < 0} + \beta_1^h \Delta MP_t + \beta_2^h \Delta MP_t \times I_{\Delta MP_t < 0} + X_t + v_{h,t}$ using the monetary policy shocks component of Jarocinski-Karadi shocks and those interacted with $I_{ms_t < 0}$ as instruments for the variable of interest ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation. Sample: 1994Feb to 2018Aug. The first stage F statistic equals to 25.58 and 13.93 for ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$.

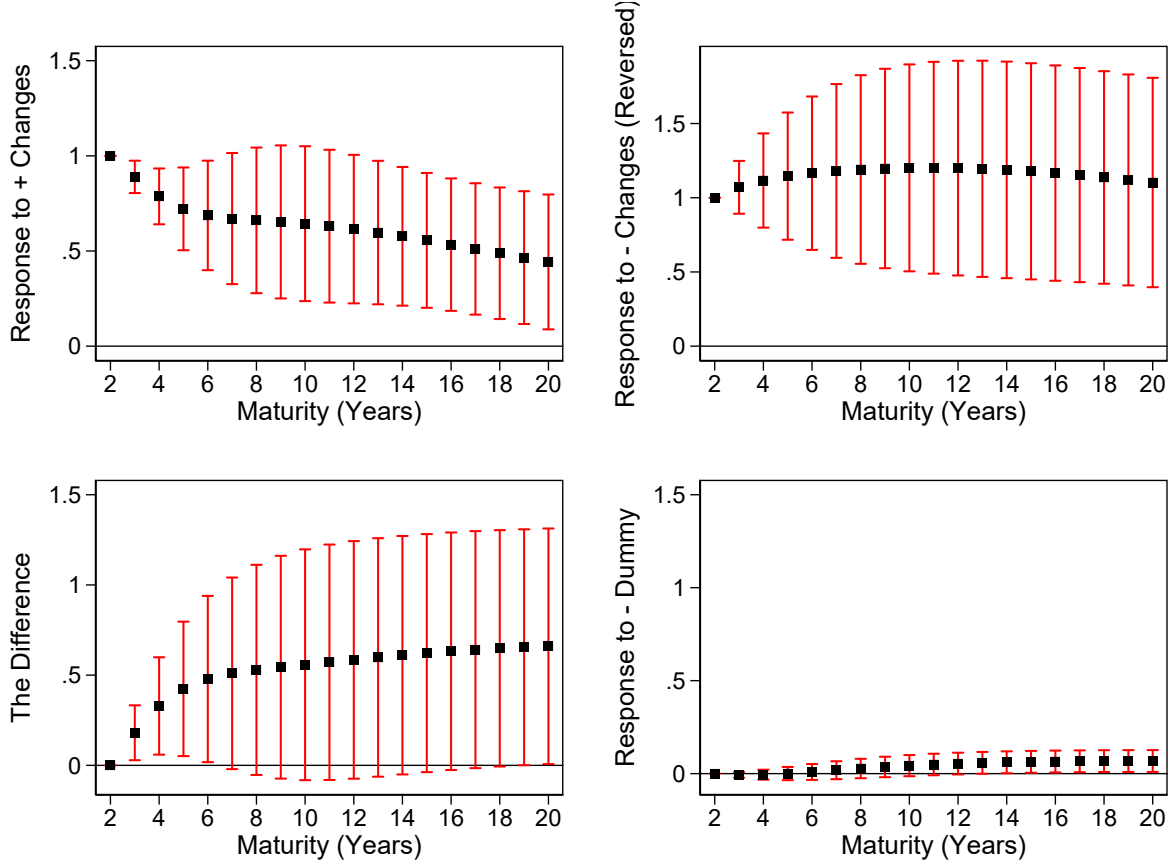


Figure A.5: Asymmetric Excess-Sensitivity Puzzle: Bauer-Swanson Shock as IV

Note: This figure plots the impact effects of monetary shocks on nominal yields. The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^h$, $\hat{\alpha}_2^h + \hat{\beta}_1^h + \hat{\beta}_2^h$, $\hat{\alpha}_2^h + \hat{\beta}_2^h$, and $\hat{\alpha}_2^h$, respectively. $\hat{\alpha}^h$ s and $\hat{\beta}^h$ s are estimated from separated regressions: $\Delta Y_t^h = \alpha_1^h + \alpha_2^h I_{\Delta MP_t < 0} + \beta_1^h \Delta MP_t + \beta_2^h \Delta MP_t \times I_{\Delta MP_t < 0} + X_t + v_{h,t}$ using the monetary policy shocks constructed by [Bauer and Swanson \(2023\)](#) and those interacted with $I_{ms_t < 0}$ as instruments for the variable of interest ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation. Sample: 1994Feb to 2018Aug. The first stage F statistic equals to 19.52 and 8.03 for ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$.

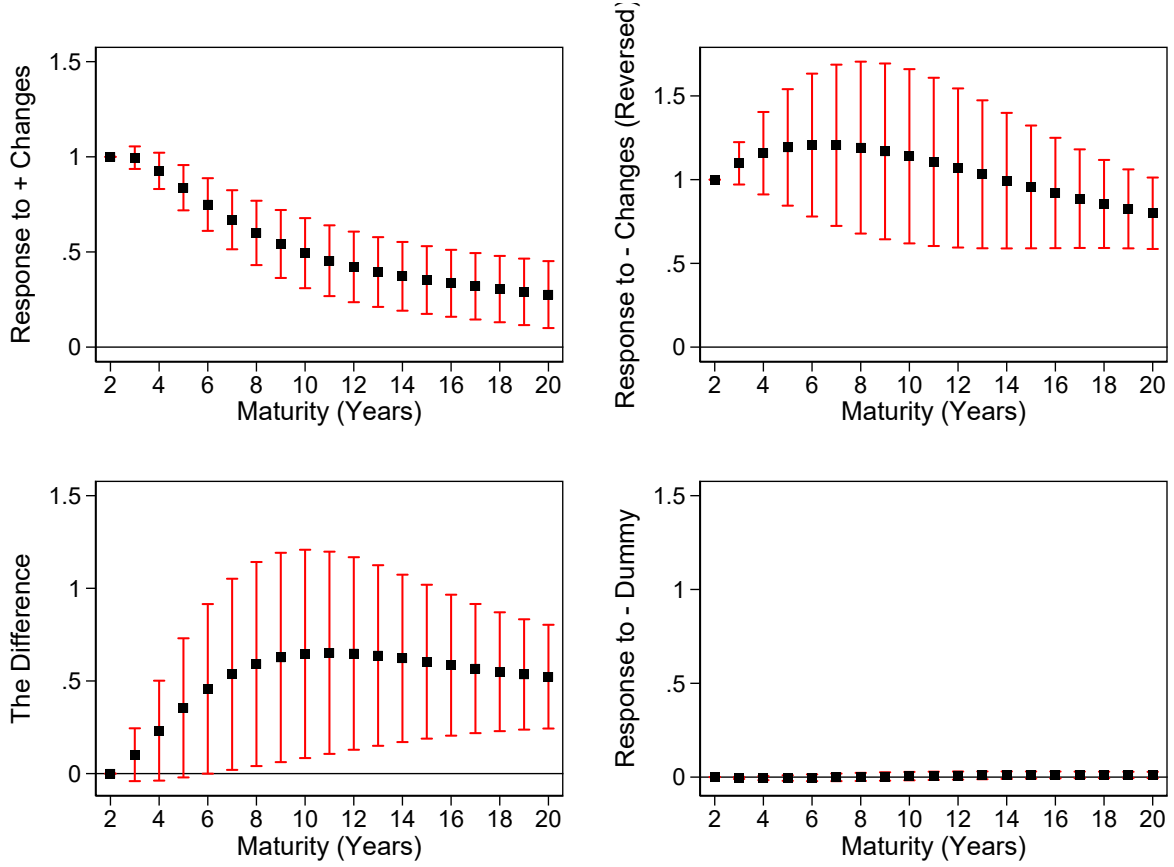


Figure A.6: Asymmetric Excess-Sensitivity Puzzle When Not Controlling for Greenbook Forecasts

Note: This figure plots the impact effects of monetary surprises on nominal yields without controlling for Greenbook forecasts. The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^h$, $\hat{\alpha}_2^h + \hat{\beta}_1^h + \hat{\beta}_2^h$, $\hat{\alpha}_2^h + \hat{\beta}_2^h$, and $\hat{\alpha}_2^h$, respectively. $\hat{\alpha}^h$ s and $\hat{\beta}^h$ s are estimated from separated regressions: $\Delta Y_t^h = \alpha_1^h + \alpha_2^h I_{\Delta MP_t < 0} + \beta_1^h \Delta MP_t + \beta_2^h \Delta MP_t \times I_{\Delta MP_t < 0} + v_{h,t}$. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity. Sample: 1994Feb to 2018Aug.

A.2 Other Macroeconomic Announcements

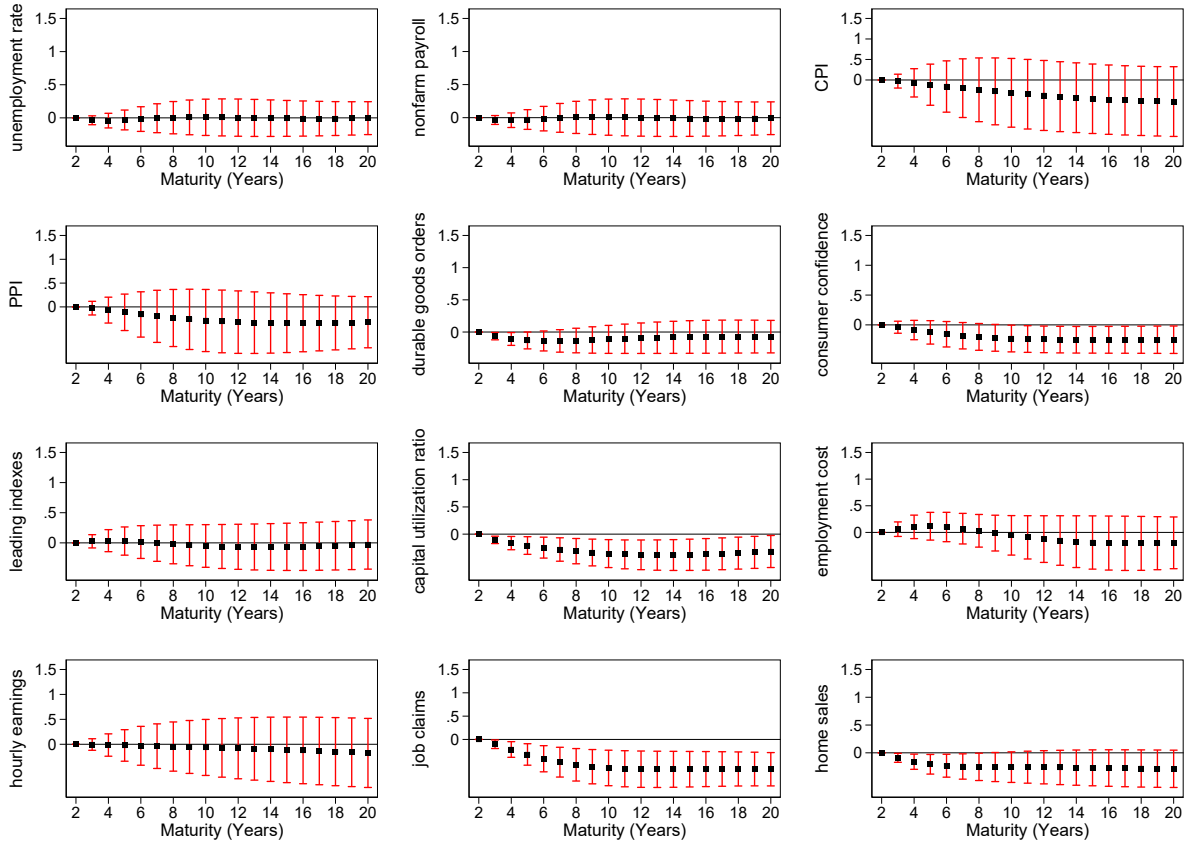


Figure A.7: Symmetric Excess-Sensitivity When Taking Non-FOMC Dates

Note: This figure plots the different impact effects between negative and positive short term yields changes on long term yields taking release dates of 12 kinds of macroeconomics indexes and all non-FOMC announcement dates. The square dots in each panel represent the estimated $\hat{\alpha}_2^h + \hat{\beta}_2^h$. $\hat{\alpha}_2^h$ and $\hat{\beta}_2^h$ s are estimated from separated regressions: $\Delta_d Y_t^h = \alpha_1^h + \alpha_2^h I_{\Delta_d MP_t < 0} + \beta_1^h \Delta_d MP_t + \beta_2^h (\Delta_d MP_t \times I_{\Delta_d MP_t < 0}) + X_t + v_{h,t}$, taking release dates of macroeconomics data of: unemployment rate, nonfarm payroll, CPI, PPI, durable goods orders, consumer confidence, leading indexes, capital utilization ratio, employment cost, hourly earnings, job claims, and home sales. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity. Sample: 1994Feb to 2018Aug.

Macroeconomic Announcement Surprises The symmetry also holds when we directly estimate the effects of macroeconomic announcement surprises on long-term nominal

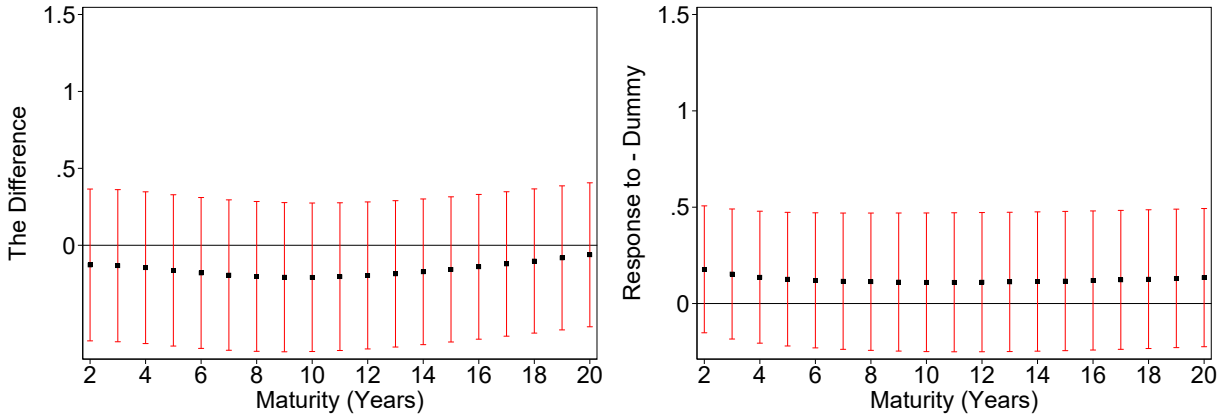
yields. Specifically, we estimate the following model (4):

$$\Delta_d Y_t^h = \alpha_1^h + \alpha_2^h I_{\Delta_d \text{Macro}_t < 0} + \beta_1^h \Delta_d \text{Macro}_t + \beta_2^h (\Delta_d \text{Macro}_t \times I_{\Delta_d \text{Macro}_t < 0}) + v_{h,t}. \quad (4)$$

Here, $\Delta_d \text{Macro}_t$ denotes the surprise component of the released macroeconomic data on the announcement date, and $I_{\Delta_d \text{Macro}_t < 0}$ is a dummy variable equal to 1 if the surprise is negative and 0 otherwise. The surprise component is defined as the difference between the released macroeconomic data and the market consensus expectation. The consensus expectation is constructed as the average forecast of surveyed professional forecasters, compiled by Bloomberg at the beginning of each month. We analyze 15 categories of macroeconomic indicators, with all surprises standardized, and estimate separate regressions for each category. The differential impact between a one-standard-deviation negative and positive surprise is given by $\alpha_2^h + \beta_2^h$.

Figures A.8 and A.9 show that $\hat{\alpha}_2^h + \hat{\beta}_2^h$ are generally small and statistically insignificant, indicating that surprises from macroeconomic data releases have no asymmetric effects on long-term yields.

Figure A.8: Symmetric Effect on Long-Term Yields When Taking Surprises of Nominal GDP as Independent Variable



Note: This figure plots the different impact effects between negative and positive nominal GDP news surprises on nominal yields. The square dots in the left and right panels represent the estimated $\hat{\alpha}_2^h + \hat{\beta}_2^h$ and $\hat{\alpha}_2^h$, respectively. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity.

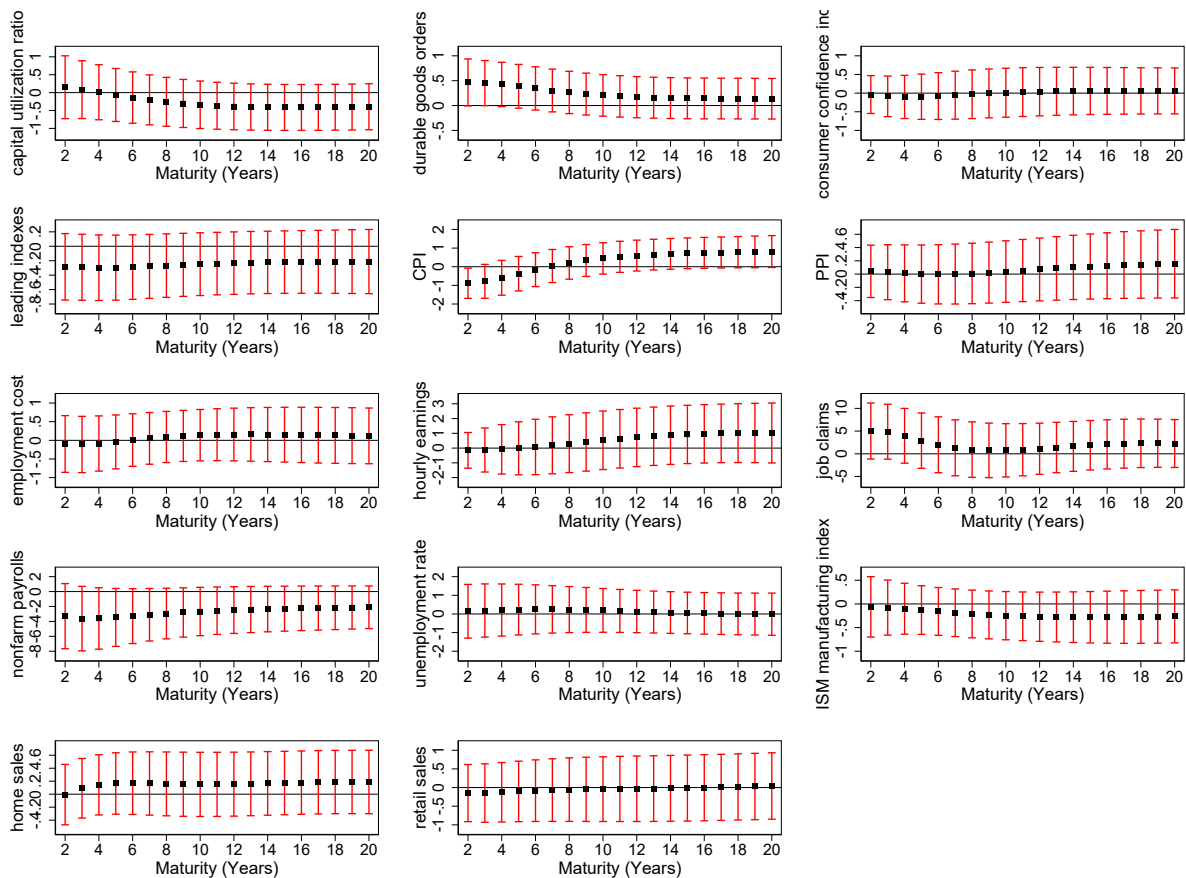


Figure A.9: Symmetric Effect on Long-Term Yields When Taking Macroeconomics Surprises as Independent Variable

Note: This figure plots the different impact effects between negative and positive macroeconomics news surprises on nominal yields. The square dots in each panel represent the estimated $\hat{\alpha}_2^h + \hat{\beta}_2^h$. There are 15 kinds of macroeconomics indexes analyzed: nominal GDP, capital utilization ratio, durable goods orders, consumer confidence, leading indexes, CPI, PPI, employment cost, hourly earnings, job claims, nonfarm payroll, unemployment rate, ISM manufacturing index, home sales, and retail sales. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity.

A.3 Forecast Revisions and Additional Results

Robustness Checks One might be concerned that state-dependence drives the sign-dependence results: negative shocks might occur more frequently in a recession, and shocks during recessions are propagated differently compared with a boom. Figure A.10 shows that this is not the case. The asymmetric results remain when a horse-race model that allows for state-dependence is estimated.

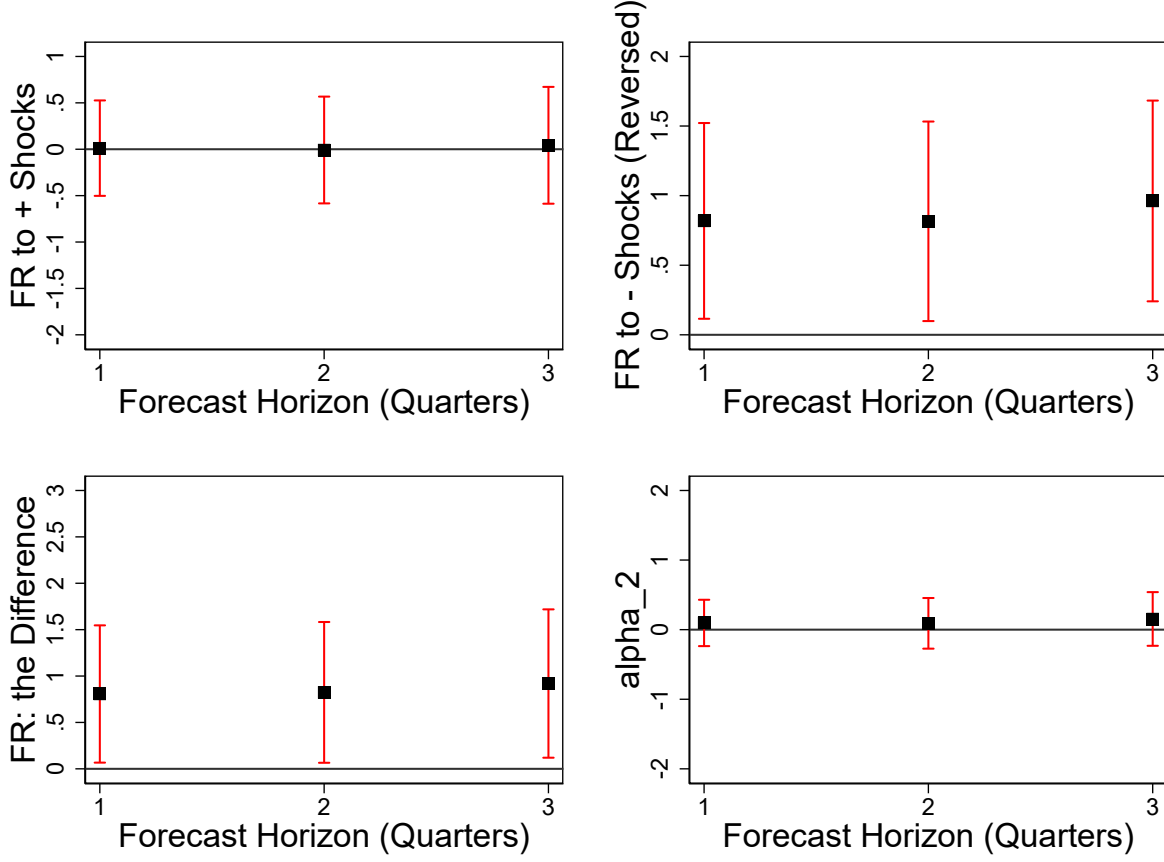


Figure A.10: Impact Effects of Monetary Shocks on Real GDP FR: Horse-Race with State-Dependence Sample

Note: This figure plots the impact effect of a HFI monetary shock on real GDP forecast revision controlling for state-dependence. The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^j$, $\hat{\alpha}_2^j + \hat{\beta}_1^j + \hat{\beta}_2^j$, $\hat{\alpha}_2^j + \hat{\beta}_2^j$, and $\hat{\alpha}_2^j$ respectively. $\hat{\alpha}^j$ s and $\hat{\beta}^j$ s are estimated from separated regressions: $y_{t+j|t} - y_{t+j|t-1} = \alpha_1^j + \alpha_2^j I_{\Delta MP_t < 0} + \beta_1^j \Delta MP_t + \beta_2^j \Delta MP_t \times I_{\Delta MP_t < 0} + \gamma^j X_t + v_{j,t}$, using a polynomial of HFI monetary shocks and monetary shocks interacting with $I_{ms_t < 0}$ as instruments for ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$. The forecast horizons are denoted in quarters, and $y_{t+j|t}$ denotes the forecast made at time t about the real GDP in quarter $t+j$. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity. Sample: 1990Q1 to 2019Q2. The first stage Sanderson-Windmeijer multivariate F-statistics equal 46.90 and 91.04 for ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$, respectively.

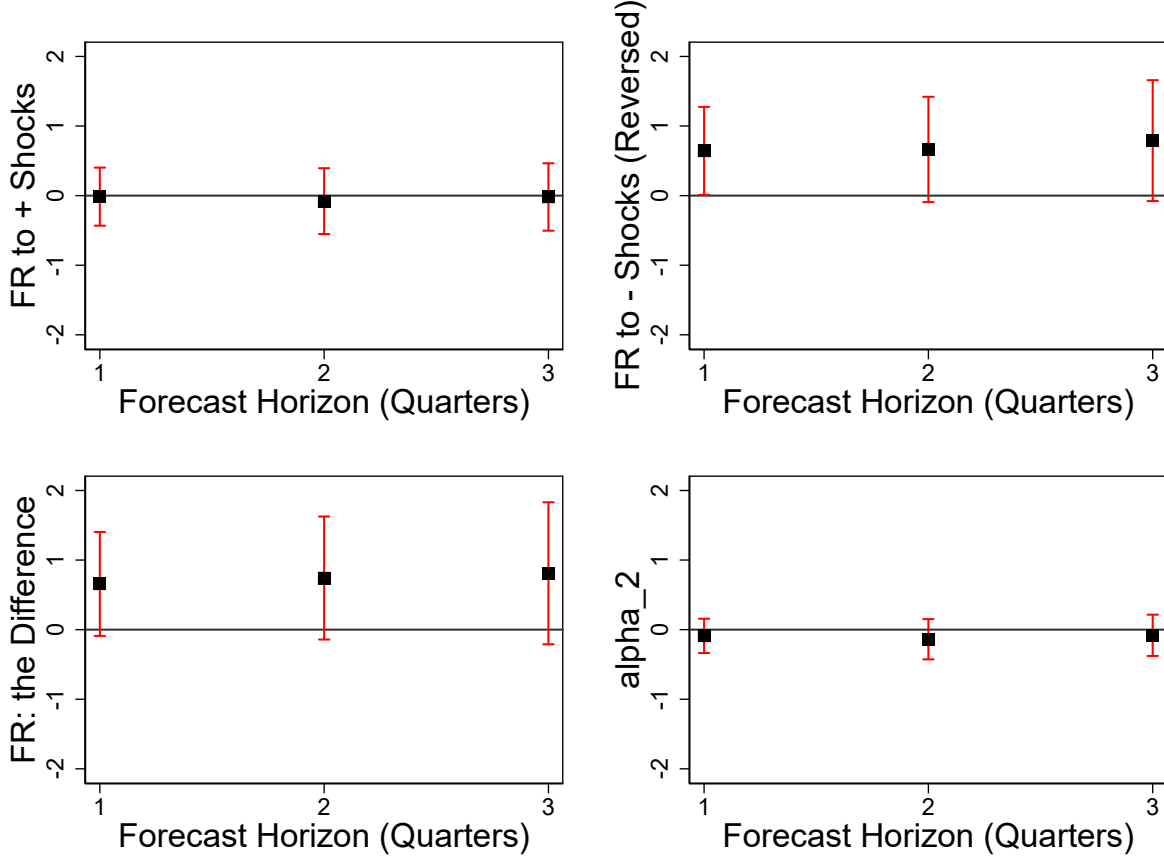


Figure A.11: Impact Effect of Monetary Shocks on Real GDP Forecast Revisions: Using Cleaned Bauer-Swanson HFI Monetary Shocks as IV

Note: This figure plots the impact effects of monetary shocks on real GDP forecast revisions when using cleaned HFI monetary shocks constructed following [Bauer and Swanson \(2023\)](#). The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^j$, $\hat{\alpha}_2^j + \hat{\beta}_1^j + \hat{\beta}_2^j$, $\hat{\alpha}_2^j + \hat{\beta}_2^j$, and $\hat{\alpha}_2^j$ respectively. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity. Sample: 1994Q2 to 2019Q3. The first stage F-statistics equal 15.77 and 37.70 for ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$, respectively.

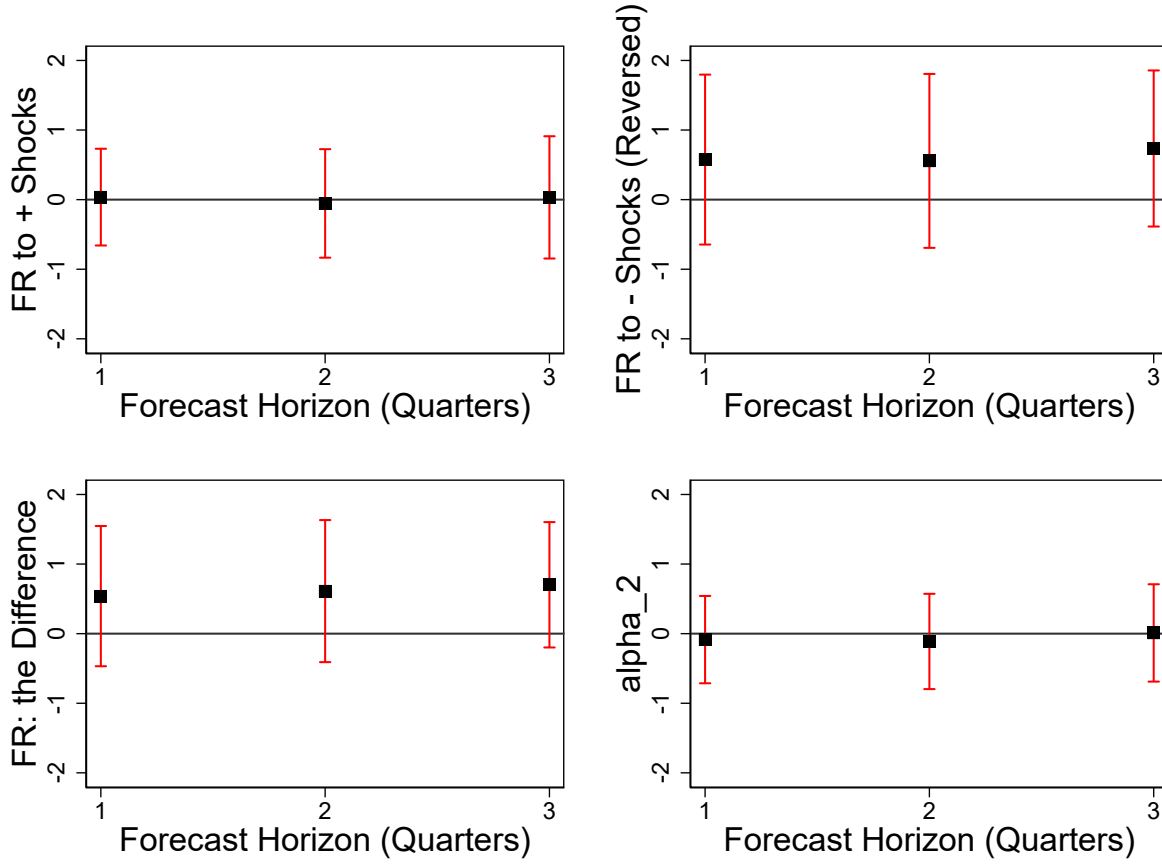


Figure A.12: Impact Effect of Monetary Shocks on Real GDP Forecast Revisions: Using Jarocinski-Karadi Shock as IV

Note: This figure plots the impact effects of monetary shocks on real GDP forecast revisions when using exogenous monetary policy shocks constructed following [Jarociński and Karadi \(2020\)](#). The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^j$, $\hat{\alpha}_2^j + \hat{\beta}_1^j + \hat{\beta}_2^j$, $\hat{\alpha}_2^j + \hat{\beta}_2^j$, and $\hat{\alpha}_2^j$ respectively. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity. Sample: 1990Q2 to 2019Q4. The first stage F-statistics equal 10.95 and 21.05 for ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$, respectively.

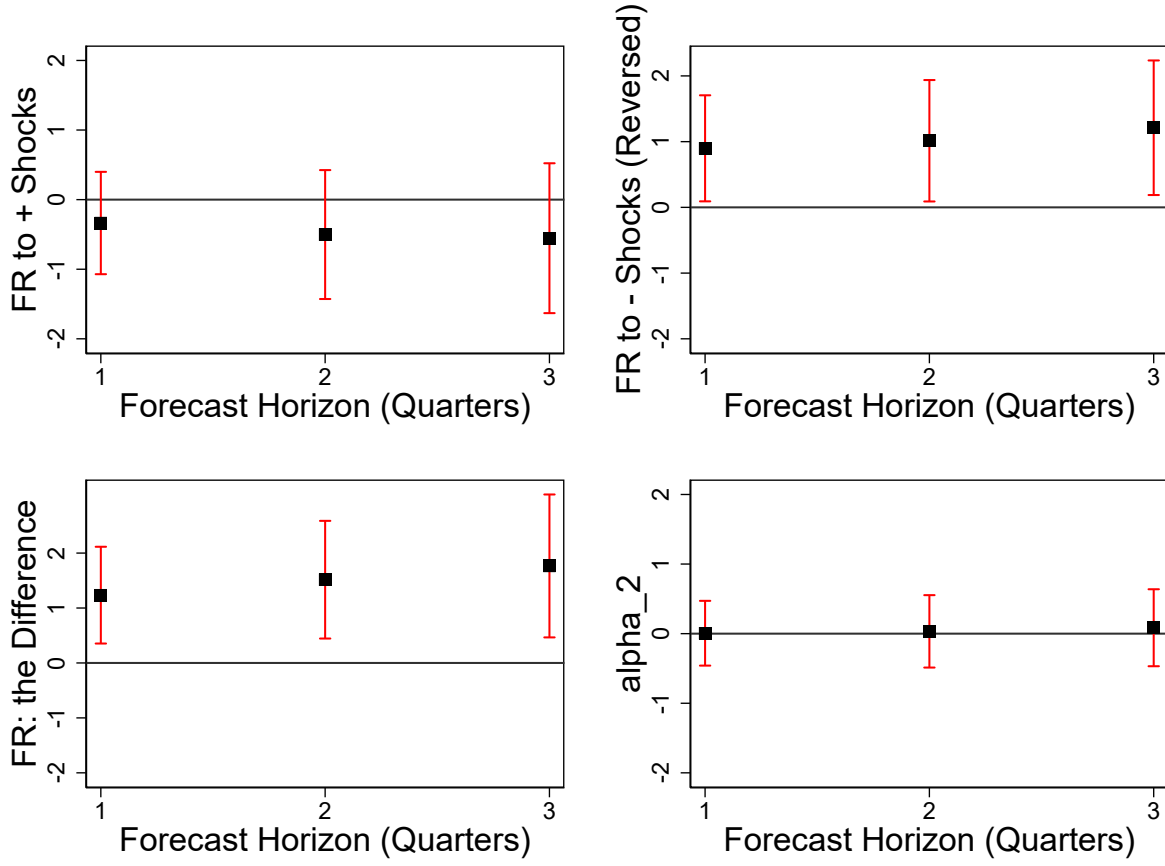


Figure A.13: Impact Effect of Monetary Shocks on Real GDP Forecast Revisions: no polynomials as instruments.

Note: This figure plots the impact effects of monetary shocks on real GDP forecast revisions when using cleaned HFI as instrument variables. The square dots in the top left, top right, bottom left, and bottom right panels represent the estimated $\hat{\beta}_1^j$, $\hat{\alpha}_2^j + \hat{\beta}_1^j + \hat{\beta}_2^j$, $\hat{\alpha}_2^j + \hat{\beta}_2^j$, and $\hat{\alpha}_2^j$ respectively. The lines represent the 95% confidence interval constructed using standard errors that are robust to serial correlation and heteroskedasticity. Sample: 1990Q3 to 2019Q2. The first stage F-statistics equal 4.19 and 6.81 for ΔMP_t and $\Delta MP_t \times I_{\Delta MP_t < 0}$, respectively.

Asymmetric Effects of Monetary Policy Shocks on the S&P 500. We examine the asymmetric response of stock prices to monetary policy shocks. Stock price changes are measured as the 30-minute return around FOMC policy announcements. To identify monetary policy shocks, we employ several instruments developed in the prior literature, all of which are constructed from high-frequency changes in financial market indicators within the same 30-minute announcement window. The results are reported in Table A.1. All monetary policy shock instruments are normalized to have unit standard deviation.

The estimates reveal a clear asymmetry: contractionary monetary policy has a larger impact on stock prices than expansionary policy. For example, using the cleaned Bauer–Swanson shock, a one–standard-deviation increase in the monetary policy instrument lowers stock prices by 28.7 basis points, whereas a one–standard-deviation decrease raises stock prices by only 18.4 basis points.

The signs of the effects are consistent with standard theory. However, the response to monetary easing is smaller. This pattern provides additional support for our proposed signaling channel: the signaling channel dampens the conventional effect of monetary policy, and because it is stronger under monetary easing, the impact of easing on stock prices is correspondingly weaker.

Table A.1: Asymmetric Response of Stock Price on Short-Term Rate Changes

Type of monetary policy shock instrument	Bauer-Swanson	HFI Monetary Surprise (MP1)	Jarociński-Karadi
Contractionary	-0.287 (0.058)	-0.354 (0.061)	-0.429 (0.048)
Expansionary	-0.184 (0.085)	-0.248 (0.074)	-0.385 (0.044)

Note: This table reports the asymmetric impact of contractionary versus expansionary monetary policy shocks on stock prices. The first row lists the type of monetary policy surprise used. The second row presents the estimated impact of a contractionary shock, followed by its standard error in the third row. The fourth row reports the estimated impact of an expansionary shock, with the corresponding standard error shown in the fifth row. Sample: 1994Feb to 2019Dec.

B Data: Description and Sources

In this appendix, we provide additional information on the data sources and the construction of our sample. We describe the sources for the daily, monthly, and quarterly data used in the analysis. Finally, we outline how we aggregate macroeconomic data, the corresponding expectations, and the monetary policy shocks.

B.1 Macro data description and sources

Our primary sources for daily, monthly, and quarterly macroeconomic data are the Federal Reserve Economic Data (FRED), the U.S. Bureau of Labor Statistics, and the Federal Reserve Bank of Philadelphia.

Table B.1: Macro data description and sources

Variable	Description	Source
Daily data		
NBER Recession Dates	An interpretation of US Business Cycle Expansions and Contractions data provided by The National Bureau of Economic Research (NBER)	FRED
Fed Funds Rate	The daily interest rate at which depository institutions trade federal funds with each other overnight.	FRED
3-month T-Bill Rate	dgs3mo	FRED
6-month T-Bill Rate	dgs6mo	FRED
1-Year T-Bill Rate	dgs1	FRED
2-Year T-Bill Rate	dgs2	FRED
5-Year T-Bill Rate	dgs5	FRED
10-Year T-Bill Rate	dgs10	FRED
Treasury Yield Curve	The U.S. Treasury Yield Curve from Gürkaynak <i>et al.</i> (2007)	FRED

TIPS Yield Curve	TIPS Yield Curve and Inflation Compensation from Gürkaynak et al. (2010)	FRED
risk neutral term structure	risk neutral term structure from Kim and Wright (2005)	FRED
FOMC dates	Dummy variable taht equals to one when FOMC announcements are made on that date	FRED
Monthly data		
Industrial Production	Industrial Production (IP) measures the real output of all relevant establishments located in the United States	FRED
Consumer Price Index	The Consumer Price Index for All Urban Consumers: All Items (CPIAUCSL) & Consumer Price Index for All Urban Consumers: All Items Less Food and Energy (CPILFESL)	U.S. Bureau of Labor Statistics, downloaded from FRED
Commodity Price Index	Producer Price Index by Commodity for Final Demand: Finished Goods & Producer Price Index by Commodity for Final Demand: Finished Goods Less Food and Energy	U.S. Bureau of Labor Statistics, downloaded from FRED
Unemployment Rate	Civilian Unemployment Rate (UNRATE), Percent, Seasonally Adjusted	U.S. Bureau of Labor Statistics, downloaded from FRED
Fed Funds Rate	The monthly average of daily interest rate at which depository institutions trade federal funds with each other overnight	FRED
3-month T-Bill Rate	dgs3mo	FRED

6-month T-Bill Rate	dgs6mo	FRED
M1	m1sl	FRED
Excess Bond Premium	ebp	FEDS Notes
Quarterly data		
nominal GDP	First, Second and Final Re-leases of GDP	Philadelphia Fed
CPI	First, Second and Final Re-leases of CPI	Philadelphia Fed
real GDP	First, Second and Final Re-leases of real GDP	Philadelphia Fed
GDP deflator	Corrected value for the median forecast of GDP deflator in SPF	Philadelphia Fed

B.2 Surprises of macro data

Macro data surprises are constructed as the average difference between the surveyed expected value of a given macroeconomic indicator and its realized release value. Expectations are obtained from the Economic Calendar forecasts available in the Bloomberg Terminal. These forecasts are typically compiled from surveys of professional economists and analysts conducted prior to the official data release. The average forecast therefore represents the market's expectation of each indicator. Table B.2 provides a summary of the macroeconomic surprises used in this paper.

Table B.2: Macro data description and sources

Variable	Description	Source
Surprises of nominal GDP	Differences between the released value and surveyed expected value of nominal GDP	Bloomberg Terminal
Surprises of capital utilization ratio	Differences between the released value and surveyed expected value of capital utilization ratio	Bloomberg Terminal

Surprises of durable goods orders	Differences between the released value and surveyed expected value of durable goods orders	Bloomberg Terminal
Surprises of consumer confidence index	Differences between the released value and surveyed expected value of consumer confidence index	Bloomberg Terminal
Surprises of leading indexes	Differences between the released value and surveyed expected value of leading indexes	Bloomberg Terminal
Surprises of CPI	Differences between the released value and surveyed expected value of CPI	Bloomberg Terminal
Surprises of PPI	Differences between the released value and surveyed expected value of PPI	Bloomberg Terminal
Surprises of employment cost	Differences between the released value and surveyed expected value of employment cost	Bloomberg Terminal
Surprises of hourly earnings	Differences between the released value and surveyed expected value of hourly earnings	Bloomberg Terminal
Surprises of job claims	Differences between the released value and surveyed expected value of job claims	Bloomberg Terminal
Surprises of nonfarm payroll	Differences between the released value and surveyed expected value of nonfarm payroll	Bloomberg Terminal

Surprises of unemployment rate	Differences between the released value and surveyed expected value of unemployment rate	Bloomberg Terminal
Surprises of ISM manufacturing index	Differences between the released value and surveyed expected value of ISM manufacturing index	Bloomberg Terminal
Surprises of home sales	Differences between the released value and surveyed expected value of home sales	Bloomberg Terminal
Surprises of retail sales	Differences between the released value and surveyed expected value of retail sales	Bloomberg Terminal
Greenbook forecasts	Greenbook forecasts data from Philadelphia Fed's Tealbook (formerly Greenbook) Data Set	Philadelphia Fed

B.3 Monetary policy surprise

In addition, we employ a set of external instruments constructed in prior research to examine the robustness of our empirical findings. Most monetary policy surprises are available at the daily frequency, while some are provided at the quarterly frequency. For instruments reported at higher frequencies, quarterly values are obtained by aggregating the shocks within each quarter, following the irregular-frequency aggregation methodology of [Ramey \(2016\)](#). All instruments are sourced directly from the authors' websites or data repositories associated with the referenced papers.

Table B.3: Monetary policy surprise description and sources

Variable	Description	Source
Daily HFI Monetary Surprise	High frequency identification of monetary policy surprise, constructed by Gürkaynak et al. (2022)	Gürkaynak's website

Nakamura and Steinsson's Monetary Surprise monetary surprise	Monetary policy surprise constructed by Nakamura and Steinsson (2016)	original dataset is available at Nakamura's website, updated by Jacobson <i>et al.</i> (2024)
Bauer-Swanson's monetary surprise	Monetary policy surprise constructed by Bauer and Swanson (2023)	Bauer's personal website
Jarocinski-Karadi's monetary surprise	Monetary policy surprise constructed by Jarociński and Karadi (2020)	Jarocinski's personal website
Quarterly Irregular HFI surprises	quarterly HFI surprises calculated by hand in the spirit of Ramey (2016)	Aggregate the daily HFI monetary Surprise by hand

C Model Appendix

C.1 The Description of the Full Model

A model with the signaling channel of monetary policy (Melosi 2017 and Zhang 2022) is extended by introducing the following features. First, the volatilities of shocks are uncertain to the market. Second, agents are averse to ambiguity. In the baseline model, monetary policy as a signal is ambiguous: the volatility of monetary shocks is unknown. However, private agents know that it lies within $[\bar{\sigma}_m^2, \underline{\sigma}_m^2]$. The main theoretical findings carry over to cases in which the volatilities of level or trend productivity shocks are unknown. The ambiguity in these shocks leads to an ambiguous Kalman gain in agents' belief updating equation. The latter is crucial for rationalizing the asymmetric excess-sensitivity puzzle.

Household The period utility function of a representative household is: The setting of a representative household's period utility function and budget constraint is shown in the appendix.

$$U_t = \log C_t - \frac{N_t^{1+\varphi}}{1+\varphi}$$

where N_t is the labor supply, and C_t denotes the aggregate consumption defined as

$$C_t \equiv \left(\int_0^1 C_{j,t}^{(\gamma-1)/\gamma} dj \right)^{\gamma/(\gamma-1)}.$$

There is a continuous supply of consumption goods $[0,1]$. $C_{j,t}$ denotes the consumption of the variety j . γ denotes the elasticity of substitution among goods of a different variety. The household faces a budget constraint of the following form:

$$P_t C_t + Q_t B_{t+1} \leq B_t + W_t N_t + T_t$$

where $P_t \equiv \left(\int_0^1 P_{j,t}^{1-\gamma} dj \right)^{1/(1-\gamma)}$ denotes the aggregate price, Q_t is the price of a one period bond that pays B_{t+1} in the subsequent period, and $W_t N_t$ and T_t collect the wage income and the lump-sum transfer, including firms' profits, respectively.

Agents have multiple priors about the standard deviation of monetary policy shocks σ_m . This type of Knightian uncertainty is axiomatized by [Gilboa and Schmeidler \(1989\)](#) and [Epstein and Schneider \(2003\)](#). Agents believe that σ_m can potentially be time varying because of ambiguity. Let σ_m^t denote the perceived standard deviation in monetary shocks up to time t . $\Gamma^t = \underbrace{\{\Gamma \times \dots \times \Gamma\}}_{t \text{ times}}$ with $\Gamma = [\underline{\sigma}_m, \bar{\sigma}_m]$. A representative household $j \in [0,1]$

that is averse to ambiguity solves the following optimization problem:

$$\max_{C_{j,t}, N_t} \min_{\sigma_m^t \in \Gamma^t} \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j U_{t+j},$$

subject to the budget constraint. Ambiguity averse agents behave according to their worst-case belief, denoted as $\tilde{\mathbb{E}}_t$. Therefore, the household's optimization problem can be simplified as

$$\max_{C_t, N_t} \tilde{\mathbb{E}}_t \sum_{j=0}^{\infty} \beta^j U_{t+j},$$

and the choice of prior σ_m^t that enters in belief $\tilde{\mathbb{E}}_t$ remains to be determined. The discus-

sion on belief updating is postponed to Section C.1.

Solving the household's optimization problem leads to the following two optimality conditions:

$$Q_t = \beta \tilde{\mathbb{E}}_t \left\{ \frac{\Lambda_{t+1}}{\Lambda_t} \frac{P_t}{P_{t+1}} \right\}, \quad (5)$$

$$C_{j,t} = \left(\frac{P_{j,t}}{P_t} \right)^{-\gamma} C_t, \quad (6)$$

where $\Lambda_t \equiv U_{c,t}$ denotes the marginal utility of consumption. Those two conditions correspond to the consumption Euler equation and the demand curve faced by a firm j , respectively.

Firms A continuum of firms is indexed by $j \in [0,1]$. A firm j produces good $C(j)$ and sells it in a monopolistic competitive market. The production technology is common among firms:

$$Y_{t,j} = A_t N_{t,j},$$

where A_t denotes the stochastic productivity. Let a_t denote the $\log(A_t)$. The productivity growth rate is composed of temporary ϵ_t^a and persistent g_t components:

$$\Delta a_t \equiv a_t - a_{t-1} = g_t + \epsilon_t^a$$

with $\epsilon_t^a \sim N(0, \sigma_a^2)$. Moreover, the persistent component g_t evolves as follows:

$$g_t = \rho_g g_{t-1} + (1 - \rho_g) g^* + \epsilon_t^g$$

with $\epsilon_t^g \sim N(0, \sigma_g^2)$.

Firms are price setters in the monopolistic competitive market. However, firms set prices subject to nominal rigidities. A firm j can optimally reset its price according to its will at probability $1 - \theta$. At probability θ , a firm's price is set according to the following indexation rule:

$$P_{j,t} = P_{j,t-1} \pi_{t-1}^\omega \pi^{1-\omega},$$

where π_t and π denote the current inflation and the steady state inflation, respectively.

The parameter ω characterizes the degree of price indexation in the economy.

The fraction θ of firms with the freedom to adjust their prices freely prices to maximize their discounted profits. Formally,

$$\max_{P_{j,t}} \tilde{\mathbb{E}} \left[\sum_{k=0}^{\infty} \theta^k \beta^k \frac{\Lambda_{t+k}}{\Lambda_t} (P_{j,t} \Pi_{t,t+k} - MC_t) Y_{j,t+k} \right],$$

subject to constraint:

$$Y_{j,t+k} = \left(\frac{P_{j,t+k} \Pi_{t,t+k}}{P_{t+k}} \right)^{-\gamma} Y_{t+k}, \quad (7)$$

where MC_t denotes marginal costs and $\Pi_{t,t+k} \equiv \prod_{s=1}^k (\pi_{t+s-1}^\omega \pi^{(1-\omega)})$. The constraint (7) is a result of the household's optimal expenditure allocation decision (6) and the price indexation rule previously introduced. Note that firms are owned by the household; therefore, they share the same information set and worst-case beliefs $\tilde{\mathbb{E}}$.

Log-linearized equilibrium conditions Log-linearizing the Euler equation around the steady state results in the following dynamic IS equation:⁶

$$\hat{y}_t = \tilde{\mathbb{E}}_t \hat{y}_{t+1} - [\hat{i}_t - \tilde{\mathbb{E}}_t \hat{\pi}_{t+1} - \rho_g \tilde{\mathbb{E}}_t \hat{g}_t]. \quad (8)$$

Note that non-stationary variables are rescaled by level productivity A_t . A variable with a hat denotes its deviation from its steady state.

Solving firms' problems and log-linearizing the solution leads to the following New Keynesian Phillips curve:

$$\hat{\pi}_t = \frac{\beta}{1 + \omega\beta} \tilde{\mathbb{E}}_t \hat{\pi}_{t+1} + \frac{\omega}{1 + \omega\beta} \hat{\pi}_{t-1} + \kappa \hat{y}_t, \quad (9)$$

where $k \equiv \frac{(1-\theta\beta)(1-\theta)}{\theta(1+\omega\beta)}(\varphi + 1)$.

⁶Ilut and Schneider (2014) log-linearize their model around the worst-case steady state. In this paper, information is perfect in the steady state. Knightian uncertainty about signal qualities does not distort the steady state. Moreover, the only source of ambiguity is the volatility of monetary shocks, and it is shown later that the presence of ambiguous monetary policy signals dampens the effects of monetary shocks. In other words, the economy fluctuates closer around the steady-state than a model without Knightian uncertainty.

Monetary policy The central bank conducts policy according to the Taylor rule:

$$\hat{i}_t = \rho_m \hat{i}_{t-1} + (1 - \rho_m)(\hat{r}_t^e + \phi_\pi \hat{\pi}_t + \phi_y \hat{y}_t) + \epsilon_t^m, \quad (10)$$

where $\hat{i}_t$ denotes the nominal interest rate associated with the price of the bond (Q_t). ϵ_t^m , which is randomly drawn from a normal distribution $N(0, \sigma_m^2)$, captures exogenous monetary shocks. Importantly, the Taylor rule keeps track of the efficient real interest rate $\hat{r}_t^e$, which is defined as the prevailing real interest rate in the absence of frictions (Wicksell 1989). In the current framework, $\hat{r}_t^e$ is the real interest rate if the market were perfectly competitive and if the private market had full information. Formally, $\hat{r}_t^e$ can be derived as the real interest rate under the social planner's allocation in a frictionless market. The resulting expression for $\hat{r}_t^e$ is:

$$\hat{r}_t^e = E^{full}(g_{t+1}) = \rho_g g_t, \quad (11)$$

where E^{full} denotes the expectation under full information. The Taylor rule can be rewritten as:

$$\hat{i}_t = \rho_m \hat{i}_{t-1} + (1 - \rho_m)(\rho_g g_t + \phi_\pi \hat{\pi}_t + \phi_y \hat{y}_t) + \epsilon_t^m. \quad (12)$$

Woodford (2001) showed that such a Taylor rule is optimal compared with other forms of the Taylor rule. Cúrdia *et al.* (2015) presented empirical evidence showed that an interest rate rule that tracks efficient real interest rate fits the U.S.'s data more than does other Taylor rules.

Note that by substituting $\hat{r}_t^e$ by $E^{full}(g_{t+1}) = \rho_g g_t$ in the Taylor rule, an implicit assumption is made that the central bank perfectly observes the true state of the economy. This simplifying assumption facilitates the illustration, and is equivalent to an alternative assumption that introduces information frictions to the central bank: $E^{cb}(\hat{r}_t^e) = \rho_g g_t + e_t$. In this case, one can interpret the noise shocks faced by the central bank as monetary shocks.

In the model, the expectation hypothesis holds. Long-term nominal interest rates are determined by an affine term structure model implied by the model; see, for example, Bekaert *et al.* (2010), Nimark (2008), and Zhang (2022) for derivations. Appendix C.2 presents the relevant equations.

Information Structure All agents know the model structure. However, some *state variables* are not observable, and some *parameters* of the model are not known with certainty.

Firms and households share the same information set. They observe the growth rate of productivity Δa_t but cannot determine whether a change in Δa_t is the result of the permanent (g_t) or the temporary ϵ_t^a component.

Private agents observe the policy action $\hat{i}_t$. The Taylor rule makes it straightforward to see that $\hat{i}_t$ contains information about the unobserved state g_t . However, this information is noisy because of the existence of unobservable monetary shocks ϵ_t^m that prevent the private market from fully backing up the true state of the economy.

In addition, the private market is assumed to observe a signal s_t about g_t :

$$s_t = g_t + \epsilon_t^s, \quad (13)$$

with $\epsilon_t^s \sim N(0, \sigma_s^2)$. s_t is introduced for calibration. The model can be calibrated to different degrees of information frictions by assigning different values to σ_s^2 without changing the volatility of other shocks in the economy.

Private agents also know the variables that are direct results of their actions: $\hat{\pi}_t$ and $\hat{y}_t$. $\hat{\pi}_t$ and $\hat{y}_t$ are shown to *solely* depend on the household and firms' beliefs about the state of the economy. Therefore, $\hat{\pi}_t$ and $\hat{y}_t$ do not provide information to the private market more than what they already knew.

To summarize, the unobserved states are g_t , ϵ_t^a , and ϵ_t^m . The relevant signals about these unobserved states are collected in $\Omega_t = \{s_t, \hat{i}_t, \Delta a_t\}$.

As previously anticipated in the description of the household's utility function, agents have multiple priors about the quality of the monetary policy signal σ_m . In other words, the precision of monetary policy signals is ambiguous. However, the private agents know that the true σ_m lies in a *known* finite interval: $[\underline{\sigma}_m, \bar{\sigma}_m]$.

Because of ambiguity, an ambiguity averse agent picks one $\sigma_m \in [\underline{\sigma}_m, \bar{\sigma}_m]$ at a time associated with the worst-case scenario.

Belief updating and model solution The fact that the monetary signal is ambiguous complicates agents' belief updating. Given signals, agents choose a $\sigma_m \in [\underline{\sigma}_m, \bar{\sigma}_m]$, which leads to the worst-case belief. In the setup of this paper, the choice of σ_m depends on the *sign* of the monetary surprise. The household's utility strictly increases in the unknown productivity trend g_t . Thus the worst-case scenario for private agents facing an ambiguous monetary signal is the σ_m that leads to a lower posterior $g_{t|t}$. Hence, the perceived

volatility of the monetary signal ($\tilde{\sigma}_m$) is kinked:

$$\tilde{\sigma}_m = \begin{cases} \bar{\sigma}_m, & \text{if monetary surprise} > 0 \\ \underline{\sigma}_m, & \text{if monetary surprise} < 0 \end{cases}. \quad (14)$$

Intuitively, a negative (positive) surprise is partially perceived as a bad (good) news shock. Thus, the worst case, up to the first order, is associated with a smaller (bigger) σ_m , leading to a larger (smaller) drop (rise) in the expected trend.⁷

The equation (14) results in a kinked belief updating equation:

$$\tilde{\mathbb{E}}_t(\cdot) = \begin{cases} \mathbb{E}(\cdot | \Omega_t, \bar{\sigma}_m), & \text{if monetary surprise} > 0 \\ \mathbb{E}(\cdot | \Omega_t, \underline{\sigma}_m), & \text{if monetary surprise} < 0 \end{cases}. \quad (15)$$

Given ambiguous monetary signals, the model dynamics change depending on the type and sign of the shocks. In the following, the dynamics of the economy in response to monetary shocks—the central focus of the paper—is discussed. The results can be easily generalized to other shocks.

Consider the case $\epsilon_t^m > 0$, in which a positive monetary shock (contractionary) that results in a positive monetary surprise at time t —partially perceived as a good news shock. Thus, agents revise upwards their beliefs about g_t . However, because they are max-minimizers, they choose to distrust the monetary signal and update their beliefs using the prior of the monetary signal associated with the worst-case scenario, that is, $\sigma_m = \bar{\sigma}_m$. This belief updating about g_t is rational but mistaken. Agents have become overly optimistic at time t . In the next and all the subsequent periods, overly optimistic agents are surprised by negative monetary surprises and slowly realize that no shock to g occurred at time t . Negative monetary surprises accompany this correction process starting at $t + 1$. Such negative monetary surprises are linked to a worst-case scenario $\sigma_m = \underline{\sigma}_m$. In summary, in this case, the model solution is summarized in the first half of Proposition 2.

⁷A positive monetary surprise is unambiguously associated with a worst-case scenario $\bar{\sigma}_m$. A more volatile monetary shock is associated with the lowest expected growth of the economy and the highest business cycle fluctuations that are detrimental to welfare. A negative monetary surprise is associated with a worst-case scenario $\underline{\sigma}_m$ provided that $\bar{\sigma}_m$ is not too big and that the cost of the business cycle is small (relative to the welfare loss resulting from a drop in the trend). The former is verified in our numerical exercise, and the latter is well-known: the cost of the business cycle is second order.

Similar reasoning applies to the case with a negative $\epsilon_t^m < 0$, which results in a negative monetary surprise at time t and subsequent positive monetary surprises. In this case, the model solution is summarized in the second half of Proposition 2.

Proposition 2. *If $\epsilon_t^m > 0$, then the model solution is as follows:*

$$X_{t+j} = \begin{cases} \bar{A}X_{t+j-1} + \bar{B}U_{t+j}, & \text{for } j = 0 \\ \underline{A}X_{t+j-1} + \underline{B}U_{t+j}, & \text{for } j > 0 \end{cases}, \quad (16)$$

$$X_{t+j}^f = \begin{cases} \bar{F}X_{t+j}, & \text{for } j = 0 \\ \underline{F}X_{t+j}, & \text{for } j > 0 \end{cases}. \quad (17)$$

where $\bar{A}$, $\bar{B}$, and $\bar{F}$ are parameters associated with $\bar{\sigma}_m$ and $\underline{A}$, $\underline{B}$ and $\underline{F}$ are parameters associated with $\underline{\sigma}_m$. The agent chooses to commit on her choices of $\sigma_{m,t}$ made in the past.

If $\epsilon_t^m < 0$, then the model solution of is as follows:

$$X_{t+j} = \begin{cases} \underline{A}X_{t+j-1} + \underline{B}U_{t+j}, & \text{for } j = 0 \\ \bar{A}X_{t+j-1} + \bar{B}U_{t+j}, & \text{for } j > 0 \end{cases}, \quad (18)$$

$$X_{t+j}^f = \begin{cases} \underline{F}X_{t+j}, & \text{for } j = 0 \\ \bar{F}X_{t+j}, & \text{for } j > 0 \end{cases}. \quad (19)$$

Proof. The online appendix attached to [Zhang \(2022\)](#) shows the solution of the model for a given σ_m . What remains to be shown is the choice of σ_m and its associated state-space representation of the model given the sign of shocks.

At time t a positive monetary shock leads to a positive monetary surprise, thus the agent updates $g_{t|t}$ upwards as little as possible using $\sigma_{m,t} = \bar{\sigma}_m$. Note that $E_t(i_{t+1})$ is positively related to $g_{t|t}$ with a coefficient θ_g .

At time $t + 1$, the misinterpretation committed at time t leads to a negative monetary surprise $-\theta_g g_{t|t}$, thus the agent updates $g_{t+1|t+1}$ downwards. The exact amount of forecast revision depends on her choice of $\sigma_{m,t}$ and $\sigma_{m,t+1}$. It is apparent that $\sigma_{m,t+1} = \underline{\sigma}_m$ leading to a maximum downward revision of $g_{t+1|t+1}$ (worse case) independently on the choice of $\sigma_{m,t}$.

The $\sigma_{m,t}$ chosen at $t + 1$ remains the same as before, i.e. $\bar{\sigma}_m$. To see this, by contradiction assume that the agent revises her choice of $\sigma_{m,t}$ downward such that $g_{t|t+1} - g_{t|t} = \Delta$. As a result, $g_{t+1|t+1}$ would be $(1 - (k_{t,t} - k_{t,t+1})\theta_g)\Delta$ higher than the one associated with $\sigma_{m,t} =$

$\bar{\sigma}_m$, thus this is not the worse case – contradicts the agent is a max-minimizer. Note that we have used the fact that under the worse case choice of $\sigma_{m,t}$ the belief updating equation is $g_{t+1|t+1}^* = g_{t|t} - k_{t,t}\theta_g g_{t|t}$ and under the alternative case $g_{t+1|t+1} = g_{t|t+1} - k_{t,t+1}\theta_g g_{t|t+1}$, with $(k_{t,t} - k_{t,t+1}) < 0$.

Similarly, at time $t + j$ for $j > 1$, the agent keeps being shocked by negative monetary surprise until she fully learned the truth, i.e there was merely a pure monetary shock at t . And the worse case belief is associated with $\underbrace{\{\bar{\sigma}_m, \dots, \bar{\sigma}_m\}}_{j \text{ times}}$.

The same arguments hold for a negative monetary shock in Proposition 2. The choice of $\sigma_{m,t}$ made at time t is not revised at future periods. $\square$

C.2 Term structure

The long term interest rates are characterized by the following equations

$$Y_t^{(1)} \equiv i_t = M_I X_t \quad (20)$$

$$Y_t^{(n)} = -\frac{1}{n} \log(P_t^{(n)}) \quad (21)$$

$$P_t^{(n+1)} = E_t(M_{t+1} P_{t+1}^{(n)}) \quad (22)$$

$$M_{t+1}^{(n)} = \beta \frac{\Lambda_{t+1} P_t}{\Lambda_t P_{t+1}}. \quad (23)$$

Those equations correspond to the monetary policy rule, the long-term interest rate of the different maturities, the no arbitrage condition, and the stochastic discount fact, respectively.

Solving the affine term structure model leads to the following solution of long-term interest rate as functions of state variable X_t :

$$\begin{bmatrix} i_t \\ Y_t^{(2)} \\ \cdot \\ \cdot \\ Y_t^{(n)} \end{bmatrix} = \begin{bmatrix} -A_1 \\ -\frac{1}{2}A_2 \\ \cdot \\ \cdot \\ -\frac{1}{n}A_n \end{bmatrix} + \begin{bmatrix} -B_1 \\ -\frac{1}{2}B_2 \\ \cdot \\ \cdot \\ -\frac{1}{n}B_n \end{bmatrix} X_t \quad (24)$$

where i_t^n denotes the yield with maturity n at time t . A_n and B_n are derived recursively as in Zhang (2022).

C.3 The Simplified Model

C.3.1 The Simplified Model: Additional Results

Briefly, the simplified model features the following equations:

$$\begin{aligned}\hat{y}_t &= \mathbb{E}_t \hat{y}_{t+1} - [\hat{i}_t - \mathbb{E} \hat{\pi}_{t+1} - \rho_g \mathbb{E}_t \hat{g}_t] \\ \hat{\pi}_t &= \beta \mathbb{E}_t \hat{\pi}_{t+1} + \kappa \hat{y}_t, \\ \hat{i}_t &= r_t^e + \epsilon_t^m, \epsilon_t^m \sim N(0, \sigma_m^2) \\ \hat{g}_t &= \rho_g \hat{g}_{t-1} + \epsilon_t^g, \epsilon_t^g \sim N(0, \sigma_g^2) \\ \hat{Y}_t^{(h)} &= \frac{1}{h} \mathbb{E} \sum_{j=1}^h \hat{i}_{t+j-1},\end{aligned}$$

where $\hat{Y}_t^{(h)}$ is the nominal yield with maturity h according to the expectation hypothesis that assumes that the long-term interest rate is the weighted average of the current and expected future short-term rates. $\hat{r}_t^e$ is the the efficient real interest rate, and $\hat{\pi}_t$ is the inflation rate. Recall that $\hat{y}_t$ is defined as $y_t - a_t$, the difference between log of production Y_t and log of stochastic productivity A_t , to obtain a stationary output measure. In the following, the solution for y_t is presented. Note that the simplified monetary policy rule opens room for sunspot equilibria. In the following, We focus on the equilibrium driven by fundamental shocks. In the full model, the monetary policy rule ensures that the obtained solution is unique.

Appendix C.3.2 solves for the impact effects of shocks in the simplified model. In particular, the impact effects of monetary policy shocks (ϵ_t^m) are

$$y_t = -\Omega_y \epsilon_t^m, \quad \hat{\pi}_t = -\kappa \Omega_y \epsilon_t^m, \quad Y_t^{(h)} = \Omega_{Y^{(h)}} \epsilon_t^m,$$

where, $\Omega_y \equiv \frac{\sigma_m^2 - \rho_g P_g}{P_g \rho_g^2 + \sigma_m^2}$, $G \equiv \frac{P_g^2}{P_g^2 + \sigma_m^2 / \rho_g^2}$, $\Omega_{Y^{(h)}} \equiv \frac{1}{h} \left(\rho_g \frac{1 - \rho_g^h}{1 - \rho_g} G \right)$, and P_g is the solution to the Riccati equation defined in Appendix C.3.2.

Proposition 3. *The following results hold in the simplified model with the signaling channel of monetary policy.*

1. **The strength of the signaling channel.** First consider the case $\sigma_m^2 > \rho_g P_g$. In this case, $\Omega_y > 0$ and the degree of money non-neutrality (Ω_y) is decreasing in $\frac{\sigma_g}{\sigma_m}$. The result is driven by the signaling effect of monetary policy: $\frac{\partial \mathbb{E}_{g_t}}{\partial \epsilon_t^m}$ increases in $\frac{\sigma_g}{\sigma_m}$. In the limiting case without

the signaling channel of monetary policy, money non-neutrality achieves its maximum at $\Omega_y = 1$.

2. **The output and price puzzles of monetary policy.** Second, consider the case $\sigma_m^2 < \rho_g P_g$, which corresponds to the case of a strong signaling channel. In this case, $\Omega_y < 0$: monetary tightening ($\epsilon_t^m > 0$) increases y_t —the output puzzle of monetary policy. Similarly, the price puzzle arises ($\frac{\partial \pi_t}{\partial \epsilon_t^m} > 0$). The output and inflation puzzle increase in $\frac{\sigma_g}{\sigma_m}$. In the limiting case, when σ_m converges to zero, the signaling channel is maximized, and $\Omega_y = -1/\rho_g$.

Proof. See Appendix C.3.3. □

Two additional results emerge in the simplified model and are shown in Proposition 3. First, the strength of the signaling channel and, thus, the aggregate monetary non-neutrality depends on $\frac{\sigma_g}{\sigma_m}$. A higher ratio implies a more precise policy signal, leading agents to place greater weight on it. That is, the monetary policy signaling channel is strengthened and dampens the effects of the monetary policy. To see this, consider an expansionary monetary policy shock. An unexpected short-rate cut boosts consumption but also lowers forecasts of the natural rate, which reflects long-term growth, prompts pessimistic belief updates that reduce current consumption, thereby dampening policy effects through the signaling channel. More volatile policy shocks weaken the signaling channel and raise non-neutrality; when $\frac{\sigma_g}{\sigma_m} = 0$, the signaling channel vanishes and non-neutrality is maximal.

Second, a strong signaling channel *can* overturn conventional effects, producing output and price puzzles: tightening can raise GDP and inflation. The output and price puzzles have appeared in numerous empirical studies. For example, Ramey (2016) documented the output and price puzzles in the data for a variety of samples and model specifications. This paper provides a rationale for these puzzles, and the simplified model characterizes the condition for the emergence of these counterintuitive results.

C.3.2 Solution

This appendix solves the simplified model characterized by the following equations:

$$\hat{y}_t = \mathbb{E}_t \hat{y}_{t+1} - [\hat{i}_t - \mathbb{E}_t \hat{\pi}_{t+1} - \rho_g \mathbb{E}_t \hat{g}_t] \quad (25)$$

$$\hat{\pi}_t = \beta \mathbb{E}_t \hat{\pi}_{t+1} + \kappa \hat{y}_t, \quad (26)$$

$$\hat{i}_t = \rho_g \hat{g}_t + \epsilon_t^m, \epsilon_t^m \sim N(0, \sigma_m^2) \quad (27)$$

$$\hat{g}_t = \rho_g \hat{g}_{t-1} + \epsilon_t^g, \epsilon_t^g \sim N(0, \sigma_g^2) \quad (28)$$

Agents do not observe $\hat{g}$. The only signal about $\hat{g}$ is $\hat{i}_t$. Moreover, the long-term interest rates are: $\hat{Y}_t^{(h)} = \frac{1}{h} \mathbb{E} \sum_{j=1}^h \hat{i}_{t+j-1}$.

We solve the simple model by first conjecturing a solution then verify it.

Step 1: Conjecture the following solution

$$\hat{y}_t = \theta_1^y \hat{g}_t + \theta_2^y \epsilon_t^m \quad (29)$$

$$\hat{\pi}_t = \theta_1^\pi \hat{g}_t + \theta_2^\pi \epsilon_t^m \quad (30)$$

$$\hat{i}_t = \theta_1^r \hat{g}_t + \theta_2^r \epsilon_t^m \quad (31)$$

$$\mathbb{E}_t \hat{g}_t = K_1 \hat{g}_t + K_2 \epsilon_t^m. \quad (32)$$

The current section focuses on the *impact effects* of shocks that hit the economy in a steady state. This explains that prior expectation about $\hat{g}_t$ does not enter in (32).

The conjectured solution implies that

$$\mathbb{E}_t \hat{y}_{t+1} = \theta_1^y \rho_g \hat{g}_t \quad (33)$$

$$\mathbb{E}_t \hat{\pi}_{t+1} = \theta_1^\pi \rho_g \hat{g}_t \quad (34)$$

Step 2: Plug the conjectured solution into the model equations. First, the Dynamic IS equation can be rewritten as

$$\theta_1^y \hat{g}_t + \theta_2^y \epsilon_t^m = \theta_1^y \rho_g \hat{g}_t - (\theta_1^r \hat{g}_t + \theta_2^r \epsilon_t^m) + \theta_1^\pi \rho_g \hat{g}_t + (1 + \rho_g)(K_1 \hat{g}_t + K_2 \epsilon_t^m).$$

For the solution to be valid, the following equations have to hold:

$$\theta_1^y = \theta_1^y \rho_g - \theta_1^r + \theta_1^\pi \rho_g + (1 + \rho_g) K_1 \quad (35)$$

$$\theta_2^y = -\theta_2^r + (1 + \rho_g) K_2. \quad (36)$$

Second, the NKPC can be rewritten as

$$\theta_1^\pi \hat{g}_t + \theta_2^\pi \epsilon_t^m = \beta \theta_1^\pi \rho_g \hat{g}_t + \kappa (\theta_1^y \hat{g}_t + \theta_2^y \epsilon_t^m)$$

For the solution to be valid, the following equations have to hold

$$\theta_1^\pi = \beta \theta_1^\pi \rho_g + \kappa \theta_1^y \quad (37)$$

$$\theta_2^\pi = \kappa \theta_2^y \quad (38)$$

Third, the Taylor rule can be rewritten as

$$\theta_1^r \hat{g}_t + \theta_2^r \epsilon_t^m = \rho_g \hat{g}_t + \epsilon_t^m$$

For the solution to be valid, the following equations have to hold

$$\theta_1^r = \rho_g \quad (39)$$

$$\theta_2^r = 1. \quad (40)$$

Step 3: Plug the conjectured solution to the belief updating equation. The simplified model assumes that agents only observe $\hat{i}_t$ as the signal about g_t . The conjectured solution for $\hat{i}_t$ can be rewritten as

$$\frac{\hat{i}_t}{\theta_1^r} = \hat{g}_t + \frac{\theta_2^r}{\theta_1^r} \epsilon_t^m \quad (41)$$

Agents update their beliefs according to the Bayes' rule:

$$\mathbb{E}_t \hat{g}_t = G \frac{\hat{i}_t}{\theta_1^r} = G \frac{\theta_1^r \hat{g}_t + \theta_2^r \epsilon_t^m}{\theta_1^r} \quad (42)$$

where, $G \equiv \frac{P_g^2}{P_g^2 + \frac{\theta_2^r}{\theta_1^r} \sigma_m^2}$ and P_g is the solution to the Riccati equation

$$P_g = \rho_g^2 P_g - \frac{\rho_g^2 P_g^2}{P_g + \frac{\theta_2^r}{\theta_1^r} \sigma_m^2} + \sigma_g^2 \quad (43)$$

Combining this with the initial guess implies that the following equations have to hold

$$G = K_1 \quad (44)$$

$$G \frac{\theta_2^r}{\theta_1^r} = K_2 \quad (45)$$

To sum up, we have listed 8 linear equations for the 8 unknown parameters in the conjectured solution. The system of linear equations can be solved analytically to obtain:

$$\hat{y}_t = -\frac{\sigma_m^2 - \rho_g P_g}{P_g \rho_g^2 + \sigma_m^2} = -\frac{\rho_g \frac{P_g}{\sigma_m^2}}{\frac{P_g}{\sigma_m^2} \rho_g^2 + 1} \quad (46)$$

$$\hat{\pi}_t = -\frac{\kappa(\sigma_m^2 - \rho_g P_g)}{P_g \rho_g^2 + \sigma_m^2} \quad (47)$$

To summarize, the effects of monetary shocks are:

$$\hat{y}_t = -\Omega_y \epsilon_t^m, \quad \hat{\pi}_t = -\kappa \Omega_y \epsilon_t^m, \quad Y_t^{(h)} = \Omega_{Y^{(h)}} \epsilon_t^m,$$

where, $\Omega_y \equiv \frac{\sigma_m^2 - \rho_g P_g}{P_g \rho_g^2 + \sigma_m^2}$, $G \equiv \frac{P_g^2}{P_g^2 + \sigma_m^2 / \rho_g^2}$, $\Omega_{Y^{(h)}} \equiv \frac{1}{h} \left(\rho_g \frac{1 - \rho_g^h}{1 - \rho_g} G \right)$ and P_g is the solution to the Riccati equation $P_g = \rho_g^2 P_g - \frac{\rho_g^2 P_g^2}{P_g + \sigma_m^2 / \rho_g^2} + \sigma_g^2$.

C.3.3 Proof of Propositions 1 and 3

Proof. First, we prove that $\frac{P_g}{\sigma_m^2}$ increases in $\frac{\sigma_g}{\sigma_m}$. Rewrite the Riccati equation (43):

$$\frac{P_g}{\sigma_m^2} = \rho_g^2 \frac{P_g}{\sigma_m^2} - \frac{\rho_g^2}{\sigma_m^2 / P_g + (\frac{\theta_2^r}{\theta_1^r})^2 (\frac{\sigma_m^2}{P_g^2})^2} + \frac{\sigma_g^2}{\sigma_m^2}$$

Define $z \equiv \frac{P_g}{\sigma_m^2}$, then

$$\begin{aligned} z &= \rho_g^2 z - \frac{\rho_g^2}{1/z + (\frac{\theta_1^r}{\theta_1^r})^2 (\frac{1}{P_g z})^2} + \frac{\sigma_g^2}{\sigma_m^2} \\ (1 - \rho_g^2)z &= -\frac{\rho_g^2 z^2}{z + (\frac{1}{\rho_g P_g})^2} + \frac{\sigma_g^2}{\sigma_m^2} \\ z^2 + z\left(\frac{1}{\rho_g^2 P_g^2} - \frac{1}{P_g^2} - \frac{\sigma_g^2}{\sigma_m^2}\right) - \frac{\sigma_g^2}{\sigma_m^2 \rho_g^2 P_g^2} &= 0 \end{aligned}$$

Define $\Gamma \equiv z^2 + z\left(\frac{1}{\rho_g^2 P_g^2} - \frac{1}{P_g^2} - \frac{\sigma_g^2}{\sigma_m^2}\right) - \frac{\sigma_g^2}{\sigma_m^2 \rho_g^2 P_g^2}$, define $ns \equiv \frac{\sigma_g^2}{\sigma_m^2}$ applying implicit function theory:

$$z'(ns) = -\frac{\frac{\partial \Gamma}{\partial ns}}{\frac{\partial \Gamma}{\partial z}} = -\frac{-z - \frac{1}{\rho_g^2 P_g^2}}{2z + \frac{1}{P_g^2} \left(\frac{1}{\rho_g^2} - 1\right) - \frac{\sigma_g^2}{\sigma_m^2}} \quad (48)$$

The last inequality holds because $z \geq \frac{\sigma_g^2}{\sigma_m^2}$.

$\frac{\partial \Omega_y}{\partial \frac{P_g}{\sigma_m^2}} < 0$, together with $\frac{\partial \frac{P_g}{\sigma_m^2}}{\partial \frac{\sigma_g}{\sigma_m}} > 0$ proved above, lead to the first and the second results of the Proposition 3.

Given that $\frac{P_g}{\sigma_m^2}$ increases in $\frac{\sigma_g}{\sigma_m}$, it is straight forward to show $\Omega_{Y(h)}$ increases in $\frac{\sigma_g}{\sigma_m}$. Moreover, $\frac{\partial \Omega_{Y(h)}}{\partial \rho_g} > 0$ and $\frac{\partial \Omega_{Y(h)}}{\partial h} < 0$ can be easily confirmed by taking the corresponding derivatives. $\square$

C.4 The Full Model: Calibration

The standard parameters are fixed at values (see Panel A in Table C.1) that are widely adopted in the literature; see, for example, Galí (2008). The model is calibrated to quarterly data. The discount factor β equals 0.99 to reflect an annual interest rate of 4%. The degree of nominal rigidity ($\theta = 0.75$) corresponds to an average price duration of one year. The degree of price indexation ($\omega = 0.3$) is set to match the NKPC coefficient on the lagged inflation estimated by Galí and Gertler (1999). φ equals 0.5, corresponding to the inverse Frisch labor elasticity of 2. The elasticity of substitution across goods ($\epsilon = 6$) indicates a steady-state markup of 20%. The Taylor rule coefficients are within the range of

empirical estimates found in the literature. For the baseline analysis, the standard deviation of ϵ_t^a is set to $\sigma_a = 0.02$. The standard deviation of ϵ_t^g is set to one-fifth of σ_a , or 0.004, and the persistence of g_t equals to 0.98. Both values are consistent with the empirical estimates uncovered in the literature; see, for example, [Justiniano *et al.* \(2010\)](#), [Herbst and Schorfheide \(2015\)](#) and [Zhang \(2022\)](#). These values are widely adopted in the literature on long-run risk ([Bansal and Yaron 2004](#)).

The key parameters that determine the strength of the ambiguous signaling channel— σ_s , $\bar{\sigma}_m$, and $\underline{\sigma}_m$ —are calibrated to match the effects of monetary shocks on real GDP forecast revisions documented in Figure 4. Panel B in Table C.1 reports the calibrated parameters. A high σ_s value indicates that the precision of the private signal s_t is low. However, the market's private knowledge of g_t is bounded from below, because Δa_t is another signal that the household and firms observe. The two parameters that characterize the asymmetric effects of monetary shocks on forecast revisions are $\bar{\sigma}_m$ and $\underline{\sigma}_m$. The calibrated parameters suggest that the private market believes that the standard deviation of monetary shocks can be any number in the interval $[0.003, 0.007]$. This interval is within the range of empirical estimates documented in the literature on the contribution of monetary shocks to business cycle fluctuations. The Table C.1 show that the degree of parameter uncertainty characterized by this interval is sufficient to generate significant asymmetries.

Panel A: Fixed Parameters

Parameter	Description	Value
β	Discount factor	0.99
θ	Nominal rigidity	0.75
ω	Degree of price indexation	0.3
φ	Labor dis-utility parameter	0.5
γ	Elasticity of substitution	6
ρ_m	Taylor Coefficient on i_{t-1}	0.75
ϕ_π	Taylor Coefficient on inflation	1.5
ϕ_y	Taylor Coefficient on output	0.125
σ_a	Standard deviation of ϵ_t^a	0.02
σ_g	Standard deviation of ϵ_t^g	0.004
ρ_g	Persistence of g_t	0.98

Panel B: Calibrated Parameters

Parameter	Description	Value
σ_s	Standard deviation of ϵ_t^s	0.568
$\bar{\sigma}_m$	Upper bound $\bar{\sigma}_m$	0.003
$\underline{\sigma}_m$	Lower bound $\underline{\sigma}_m$	0.005

Table C.1: Model Calibration