Macroeconometrics: Advanced Time-Series Analysis

Prof. Giovanni Ricco

A Solution to the Price Puzzle on US Data

A Structural VAR Approach

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December 23, 2025

Abstract

This paper revisits the price puzzle—the empirical finding that inflation increases after a contractionary monetary policy shock—in the United States. We first the puzzle in a standard Cholesky SVAR before 1979 and show its re-emergence after 2010. Following Castelnuovo and Surico (2010), we augment the VAR with inflation expectations from the Greenbook and impose sign restrictions à la Uhlig (2005). Expectations eliminate the puzzle in the post-1979 era, and sign restrictions further improve identification. The results confirm that missing information on inflation expectations is a key driver of the puzzle and that expectations-based identification is crucial in both the Great Inflation and the post-ZLB environment.

Contents

1 Introduction

The price puzzle, first documented in Sims (1980), refers to the surprising empirical fact that inflation tends to increase temporarily after a contractionary monetary policy (MP) shock identified using a recursive Cholesky VAR. This phenomenon is difficult to reconcile with standard macroeconomic theory: higher interest rates should reduce demand and inflation.

Two historical contexts are well known to exhibit this puzzle:

1. the period before Paul Volcker's disinflation (pre-1979),
2. the post-2008 era, where the zero lower bound (ZLB), large-scale asset purchases, and imperfect identification complicate VAR inference.

This paper revisits the puzzle using modern identification techniques. Relying on U.S. quarterly data for the output gap, inflation, and the federal funds rate (FFR), we document:

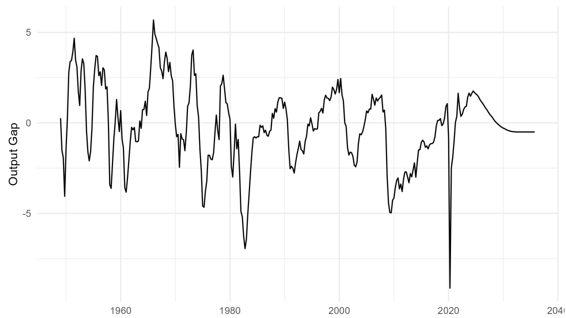
- a strong price puzzle before 1979,
- a re-emergence of the puzzle after 2010,
- that augmenting the VAR with Greenbook inflation expectations eliminates the puzzle,
- and that imposing simple sign restrictions stabilizes impulse responses.

Our findings extend the interpretation of Romer and Romer (2004), Castelnuovo and Surico (2010), and Galí (2015): *the price puzzle arises from the omission of the Fed's internal inflation forecasts.*

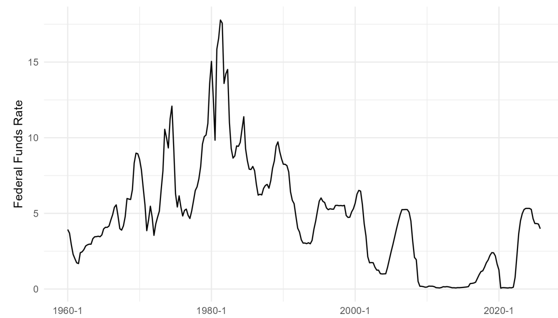
1.1 Data and break points

We construct a quarterly dataset (cf. Figure 1) combining:

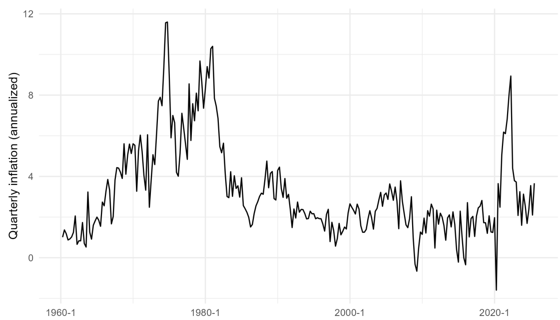
- the CBO[1] output gap,
- the GDP deflator[2],
- the federal funds rate (monthly FRED series aggregated to quarterly),
- https://www.philadelphiafed.org/surveys-and-data/real-time-data-research/greenbook (for the expectations-augmented VAR).



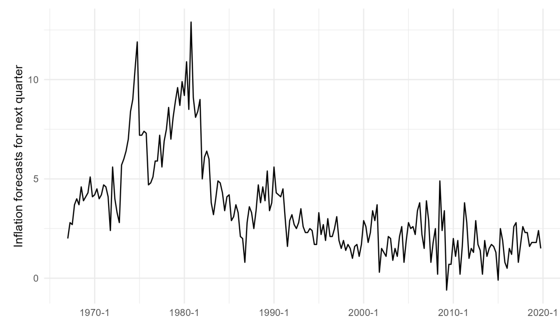
(a) Output gap



(b) Federal funds rate



(c) Inflation



(d) Inflation forecasts

Figure 1: Macroeconomic data set

These data are standard in the monetary VAR literature (e.g. Christiano et al. (1999); Stock and Watson (2001)). We run Chow tests to assess regime changes around Volcker's appointment in 1979. A break is detected around 1979Q4. We then consider a third sample starting after the 2008 crisis (Figure 2).

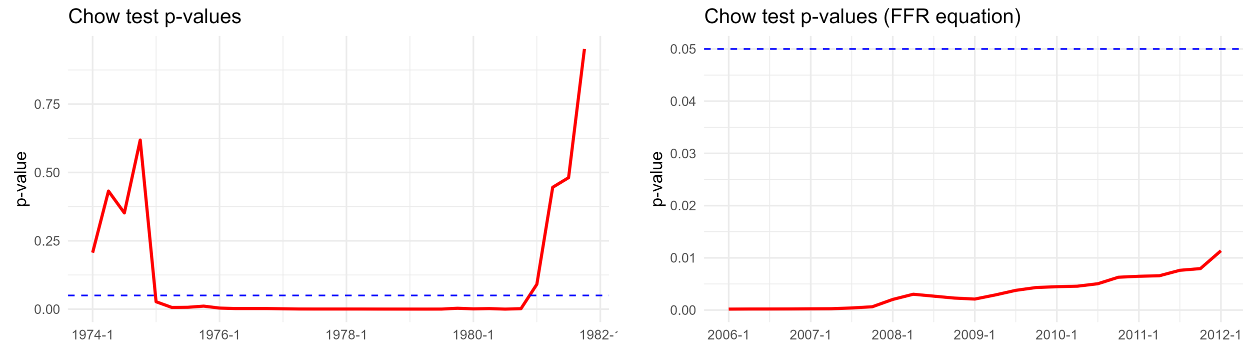
2 NK model predictions and VAR evidence

2.1 Theoretical response of inflation

We consider a standard linearised New Keynesian (NK) model in the spirit of Clarida et al. (2000) and Woodford (2003). The economy is described by a forward-looking IS curve, a New Keynesian Phillips Curve (NKPC) augmented with a cost-push shock, and a monetary policy rule with interest-rate smoothing. All shocks follow stationary AR(1) processes.

[1] Congressional Budget Office

[2] Because the GDP deflator is older than consumer price indices, it is generally used as the main inflation indicator.



(a) Full sample (1961–2006) (b) Post-Volcker sample (1979–2019)

Figure 2: P-values of Chow tests for different breakpoints.

Dynamic IS equation.

$$x_t = \mathbb{E}_t[x_{t+1}] - \chi\,(i_t - \mathbb{E}_t[\pi_{t+1}]) + a_t, \tag{1}$$

where x_t denotes the output gap, i_t the nominal interest rate, π_t inflation, and a_t an aggregate demand (IS) shock.

New Keynesian Phillips Curve.

$$\pi_t = \beta\,\mathbb{E}_t[\pi_{t+1}] + \kappa\,(x_t - c_t)\,, \tag{2}$$

where β is the discount factor, κ the slope of the NKPC, and c_t a cost-push shock capturing exogenous variations in marginal costs.

Monetary policy rule.

$$i_t = \rho_R i_{t-1} + (1-\rho_R)\,(\phi_\pi \mathbb{E}_t[\pi_{t+1}] + \phi_x(x_t - c_t)) + b_t, \tag{3}$$

where b_t is an exogenous monetary policy shock and $\rho_R \in (0,1)$ captures interest-rate smoothing.

Shock processes.

$$a_t = \rho_a a_{t-1} + \varepsilon_t^a, \tag{4}$$

$$b_t = \rho_b b_{t-1} + \varepsilon_t^b, \tag{5}$$

$$c_t = \rho_c c_{t-1} + \varepsilon_t^c, \tag{6}$$

with $|\rho_a|, |\rho_b|, |\rho_c| < 1$.

Figure 3 reports the impulse responses generated by the structural NK model following a contractionary monetary policy shock ($\varepsilon_t^b > 0$). The model delivers the standard New Keynesian transmission mechanism: the policy rate increases persistently, the output gap declines on impact, and inflation falls gradually. Importantly, the model predicts no price puzzle: inflation does not rise following a monetary tightening.

2.2 VAR-based impulse responses and the price puzzle

To assess how these structural predictions translate into reduced-form evidence, we estimate a vector autoregression (VAR) on artificial macroeconomic time series simulated from the NK model. The VAR is estimated on noisy measures of the output gap, inflation, and the policy rate, and impulse responses are identified using a recursive (Cholesky) ordering in which the interest rate reacts contemporaneously to output and inflation.

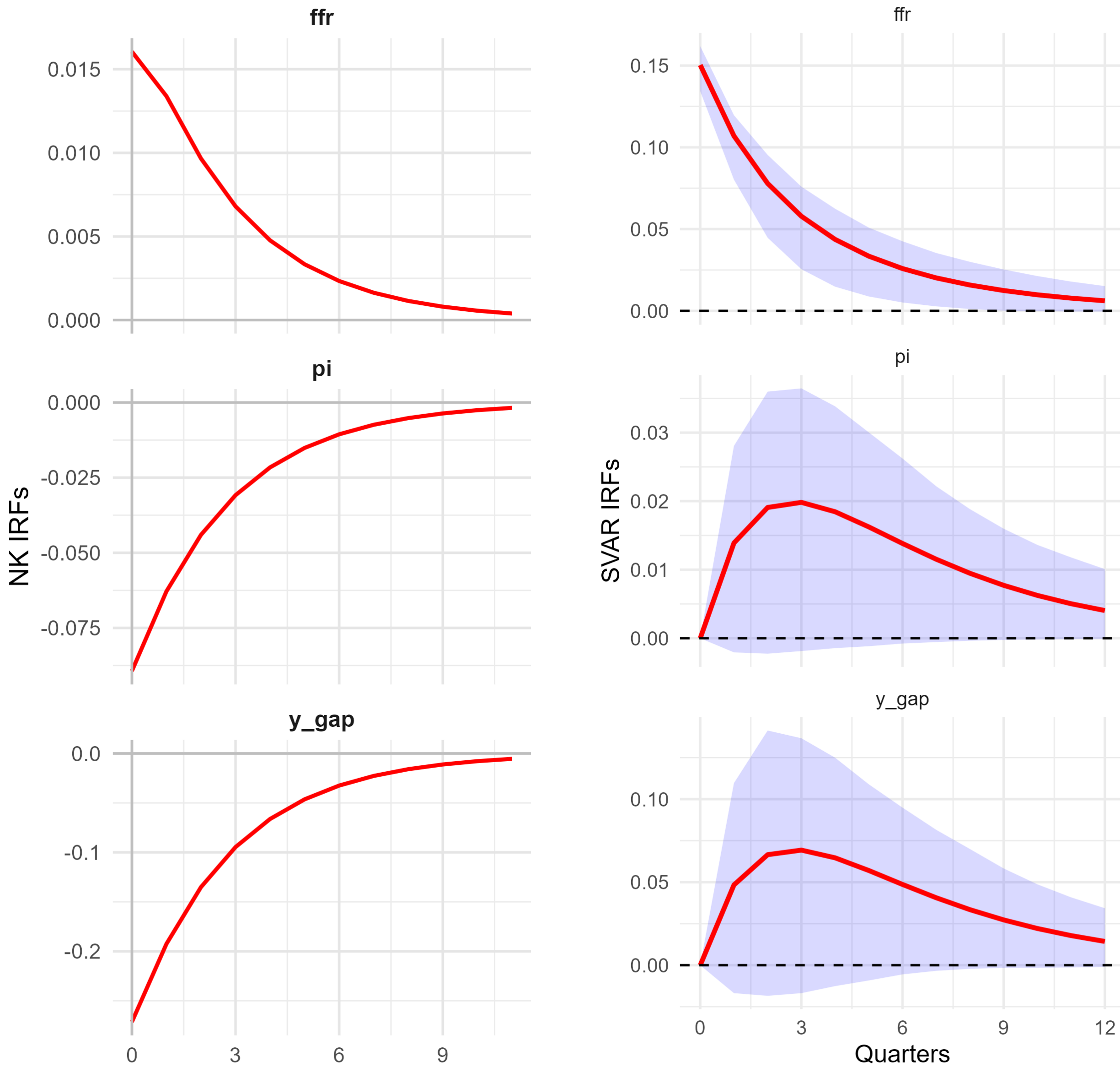
Figure 3 displays the VAR-based impulse responses to a monetary policy shock. In contrast with the structural NK model, the VAR exhibits a *price puzzle*: inflation rises temporarily following an increase in the policy rate, despite the true data-generating process implying the opposite response.

Interpretation and implications

The emergence of a price puzzle in the VAR, despite its absence in the structural NK model, highlights that the puzzle is not a structural feature of monetary transmission but rather an identification problem. As originally argued by Sims (1992), a recursively identified VAR may fail to capture the full information set of the central bank. If the policy authority reacts to signals about future inflation that are omitted from the VAR—such as cost-push pressures or inflation expectations—the identified monetary policy shock combines an exogenous tightening with endogenous responses to anticipated inflationary developments.

This interpretation is consistent with the analysis of Castelnuovo (2012), who emphasizes the role of expectations and information effects in explaining price puzzles, and with Castelnuovo and Surico (2010), who show that the presence of a price puzzle depends crucially on the identification scheme and the monetary policy regime.

Resolving the price puzzle requires either enriching the information set of the VAR, adopting alternative identification strategies (such as sign restrictions), or using external instruments to better isolate exogenous monetary policy shocks.



(a) FFR shock in the New Keynesian model

(b) FFR shock in the SVAR (artificial data)

Figure 3: Impulse responses to a monetary policy shock in the NK model and the SVAR.

3 Baseline SVAR and the Price Puzzle

We estimate a three-variable SVAR including the output gap, inflation, and the FFR. The ordering

$$y_{gap} \to \pi \to ffr$$

reflects standard timing assumptions in the monetary VAR litterature. Its is economically motivated by information and adjustment frictions. Real activity, measured by the output gap, is assumed to respond sluggishly within the quarter to monetary policy shocks, while inflation reacts with an additional delay due to price rigidities. By contrast, the Federal Funds Rate is set by the monetary authority after observing contemporaneous developments in real activity and inflation. Hence, monetary policy may respond within the quarter to both variables, whereas output and prices only react to policy with a lag.

Structural shocks are identified through a Cholesky decomposition following Sims (1980). We compute bootstrap confidence bands and display impulse responses over a three-year horizon (12 quarters).

Baseline IRFs reveal markedly different transmission mechanisms across subsamples (Figure 4).

Pre-1979. Inflation exhibits a pronounced price puzzle. The inflation equation shows a large positive reaction to lagged FFR,

$$\widehat{\beta}_{ffr,t-1} = 0.53(***)$$

reflecting the pre-Volcker regime in which the Fed reacted weakly to inflation and primarily to real activity. The output gap has no significant effect on inflation. The VAR therefore confuses anticipatory policy with causal effects.

Post-1979. After Volcker, the puzzle disappears. Inflation no longer rises on impact. The FFR has no significant short-run effect,

$$\widehat{\beta}_{ffr,t-1} = -0.003(nosignificant)\widehat{\beta}_{ffr,t-2} = -0.13(nosignificant)\widehat{\beta}_{ffr,t-3} = 0.10(nosignificant)$$

but medium-term coefficients become negative. The Phillips curve reappears.

Post-2007. VAR coefficients become unstable, reflecting the ZLB and QE. The Cholesky identification becomes unreliable, generating a spurious price puzzle.

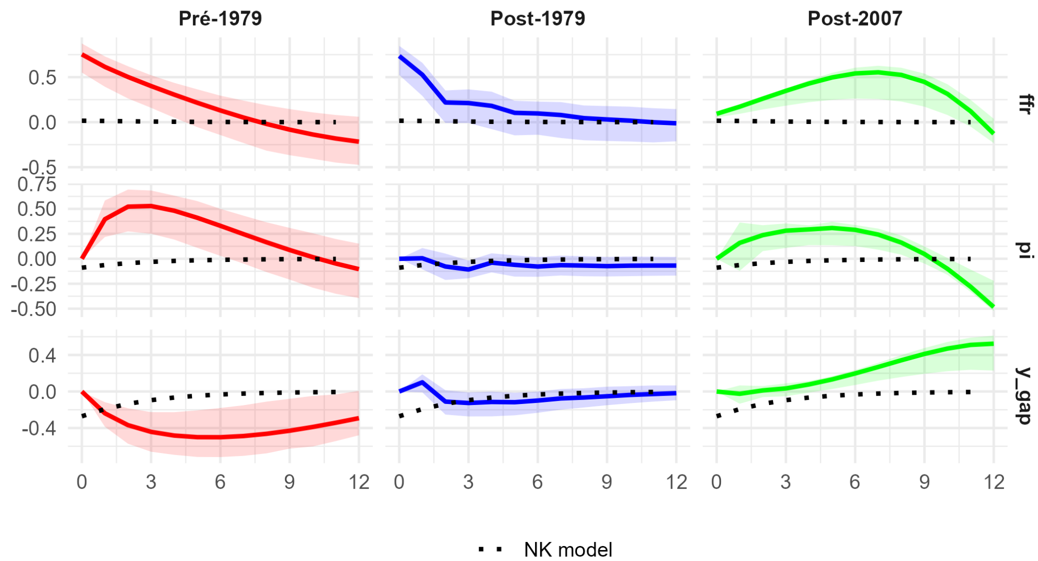


Figure 4: IRFs of the SVAR to a monetary policy (FFR) shock across subsamples.

4 Solving the Puzzle Before 1979

Before 1979, the Fed systematically raised interest rates in response to *expected* inflation. Since VARs omit expectations, the Cholesky shock contains anticipatory components. Thus inflation appears to rise *because* of a tightening when in reality the tightening occurred *because* inflation was expected to rise.

4.1 Orthogonal rotations and sign-restricted IRFs

Let the reduced-form VAR residuals satisfy

$$u_t = B\varepsilon_t, \qquad \mathbb{E}[u_t u_t'] = \Sigma.$$

A Cholesky factor P satisfies $PP' = \Sigma$, but the structural impact matrix is not unique: for any orthogonal matrix Q,

$$B = PQ, \qquad Q'Q = I,$$

yields identical reduced-form implications. This *rotational indeterminacy* forms the basis of sign-restricted identification. Rather than fixing a single structural decomposition—such as the Cholesky factor—we explore the entire class of admissible impact matrices $\{ PQ \}$ and retain only those rotations that are consistent with economic theory. For each candidate rotation, we compute impulse responses manually and select those satisfying a set of New Keynesian–inspired sign restrictions: the federal funds rate increases on impact, while the output gap declines after one quarter (see Figure 6). Inflation is deliberately left unrestricted, allowing the data to determine its response.

Under these restrictions, the VAR no longer exhibits a price puzzle: output falls immediately following a contractionary monetary policy shock, and inflation declines gradually over time (Figure 5). This improvement reflects the removal of anticipatory components of monetary policy that contaminate recursive identification schemes, thereby yielding impulse responses more consistent with standard theoretical predictions.

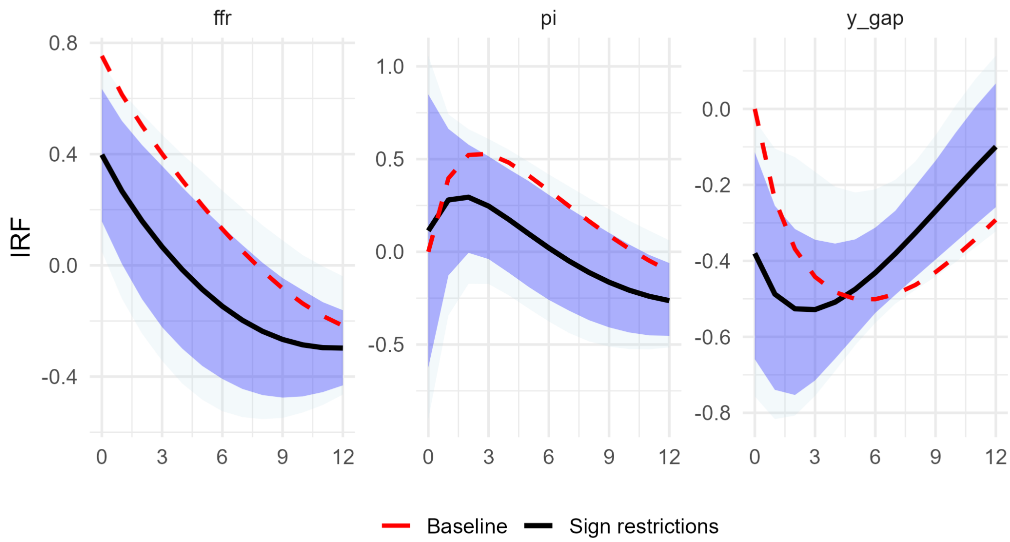


Figure 5: Sign-restricted IRFs.

Algorithmic procedure for sign-restricted identification

Step 1. Reduced-form VAR. Estimate the VAR(p)

$$y_t = c + A_1 y_{t-1} + \cdots + A_p y_{t-p} + u_t, \qquad \mathbb{E}[u_t u_t'] = \Sigma.$$

Define $Y_t = (y_t', y_{t-1}', \ldots, y_{t-p+1}')'$, so that $Y_t = A_{\text{big}} Y_{t-1} + U_t$, with

$$A_{\text{big}} = \begin{pmatrix} A_1 & \cdots & A_p & \\ I & \cdots & 0 & \\ & \ddots & & \\ 0 & \cdots & I & 0 \end{pmatrix}, \qquad \text{IRF}(h) = A_{\text{big}}^h B.$$

Step 2. Rotations of the impact matrix. Compute the Cholesky factor P such that $\Sigma = PP'$. Draw a large number of orthogonal matrices Q and form B = P Q. All such matrices satisfy $BB' = \Sigma$ and leave the reduced form unchanged.

Step 3. Candidate monetary shocks. For each rotation, compute IRFs using $B = PQ$. The monetary policy shock is identified with the column of B associated with the federal funds rate. This shock loads on all reduced-form innovations,

$$u_t = Be_{ffr} = (u_t^y, u_t^\pi, u_t^r)', \qquad \text{with signs and magnitudes depending on } Q$$

Step 4. Sign restrictions. Retain the rotation only if

$$\text{IRF}_{\text{ffr}}(0) > 0, \qquad \text{IRF}_{\text{y\_gap}}(0) < 0, \qquad \text{while leaving inflation unrestricted.}$$

Step 5. Inference. Repeat Steps 2–4 until enough admissible rotations are obtained. Construct pointwise 68% and 90% credible sets from the accepted impulse responses.

Most admissible rotations correspond to contractionary monetary policy shocks, raising the policy rate and reducing real activity on impact.

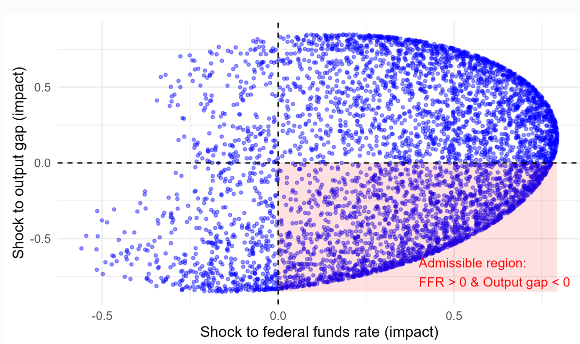


Figure 6: Impact responses for admissible rotations

4.2 Adding Greenbook expectations

Following Castelnuovo and Surico (2010), we augment the VAR with the Fed's internal inflation forecasts:

$$(green_t,\ y_{gap,t},\ \pi_t,\ ffr_t)'.$$

The Greenbook contains staff forecasts prepared before each FOMC meeting. These projections approximate the Fed's internal information set.

We construct $green_t$ by retrieving the *next-quarter* inflation forecast from the earliest Greenbook of each quarter or at the end of the last month. If no meeting occurs in the first month, we use the forecast from the last meeting of the previous quarter (cf. Figure **??**). We use the GDP deplator, compute its growth and annualized it. It looks like the correlation

We find strong correlations between realized inflation and Greenbook expectations, that indicates that Greenbook forecasts capture inflationary pressures in advance (cf. Figure **??**). $\text{Corr}(\pi_t, E_t[\pi_{t+1}]) = 0.86$, $\text{Corr}(\pi_t, E_{t-1}[\pi_t]) = 0.87$, and $\text{Corr}(\pi_t, E_{t-2}[\pi_{t-1}]) = 0.77$.

Once Greenbook inflation expectations are included, the policy rate loses significance while expectations become the dominant driver of inflation, indicating that the puzzle originates from omitted anticipatory information rather than true monetary transmission.

$$\pi_t = 0.48\,\pi_{t-1} \;+\; \mathbf{0.53}\,ffr_{t-1} \;-\; 0.04\,y_{gap,t-1} \;+\; \varepsilon_t,$$

$$\pi_t = 0.39\,\pi_{t-1} \;-\; 0.04\,ffr_{t-1} \;+\; 0.12\,y_{gap,t-1} \;+\; 0.62\,green_{t-1} \;+\; \varepsilon_t.$$

Eventually, including $green_t$ drastically improves identification: anticipated movements in the FFR are removed, and the monetary shock becomes orthogonal to expected inflation. Inflation now responds negatively even before 1979.

This confirms the interpretation of Romer and Romer (2004): the price puzzle is an omitted-variable problem.

Combining Greenbook expectations with sign restrictions yields the cleanest results (Figure 10), but lead to very few admissible shocks. Once Greenbook forecasts are included in the 4-VAR, the set of rotations satisfying standard New Keynesian sign restrictions becomes extremely small (cf. Figure 11). In practice, very few orthogonal rotations simultaneously generate a positive impact response of the policy rate and a negative response of the output gap.

This finding is economically meaningful. Inflation expectations absorb most of the systematic variation in the federal funds rate that is correlated with real activity. As a result, what appears as a monetary policy shock in smaller VARs largely reflects anticipatory policy

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June 22, 1966

GROSS NATIONAL PRODUCT AND RELATED ITEMS
(Expenditures and income figures are billions of dollars,
seasonally adjusted annual rates)

	1964	1965	1965 II	1965 III	1965 IV	1966 Projected I	1966 Projected II	1966 Projected III
Gross National Product	628.7	676.3	668.8	681.5	697.2	713.9	725.0	739.0
Final sales	623.9	668.1	662.4	673.9	687.1	705.8	715.0	731.0
Personal consumption expenditures	398.9	428.7	424.5	432.5	441.0	451.8	456.4	465.7
Durable goods	58.7	65.0	63.5	65.4	66.4	68.7	65.9	67.5
Nondurable goods	177.5	189.0	187.9	190.5	195.0	200.1	203.8	207.5
Services	162.6	174.7	173.1	176.7	179.6	183.0	186.7	190.7
Gross private domestic investment	92.9	105.7	102.8	106.2	110.3	111.7	115.0	115.3
Residential construction	27.5	27.6	28.0	27.7	27.2	28.2	27.7	27.0
Business fixed investment	60.5	69.8	68.4	70.9	73.0	75.5	77.3	80.3
Changes in business inventories	4.8	8.2	6.4	7.6	10.1	8.1	10.0	8.0
Nonfarm	5.4	7.9	6.6	7.0	8.9	7.4	9.5	8.0
Net exports	8.6	7.1	8.0	7.4	6.9	6.4	5.7	5.7
Gov. purchases of goods and services	128.4	134.8	133.5	135.4	139.0	144.0	147.9	152.3
Federal	65.3	66.6	65.7	66.5	69.2	72.5	74.7	77.9
Defense	49.9	49.9	49.2	49.8	52.0	55.0	57.0	59.5
Other	15.4	16.7	16.5	16.7	17.2	17.5	17.7	18.4
State and local	63.1	68.2	67.8	68.9	69.8	71.5	73.2	74.4
Gross National Product in constant (1958) dollars	577.6	609.6	603.5	613.0	624.4	633.[illegible]	[illegible]	[illegible]
GNP Implicit deflator (1958=100)	108.9	110.9	110.8	111.2	111.7	112.[illegible]	113.5	114.5
Personal income	495.0	530.7	524.7	536.0	546.0	557.1	566.0	580.0
Wages and salaries	333.5	357.4	353.6	359.0	368.1	377.0	384.0	392.9
Transfer payments	36.6	39.2	37.5	41.2	39.7	41.7	41.8	45.7
Personal contributions for social insurance (deduction)	12.4	13.2	13.0	13.3	13.6	16.8	17.0	17.8
Disposable personal income	435.8	465.3	458.5	471.2	480.3	488.7	494.6	506.9
Personal saving	26.3	24.9	22.4	26.8	27.1	24.4	25.3	28.4
Saving rate (per cent)	6.0	5.4	4.9	5.7	5.6	5.0	5.1	5.5
Total labor force (millions)	77.0	78.4	78.1	78.5	79.0	79.4	79.7	80.1
Armed forces "	2.7	2.7	2.7	2.7	2.8	2.9	3.0	3.1
Civilian labor force "	74.2	75.6	75.4	75.8	76.2	76.5	76.7	77.0
Employed "	70.4	72.2	71.9	72.4	73.0	73.6	73.9	74.3
Unemployed "	3.9	3.5	3.6	3.4	3.2	2.9	2.8	2.7
Unemployment rate (per cent)	5.2	4.6	4.7	4.5	4.2	3.8	3.7	3.5

Figure 7: The Greenbook in June 1966

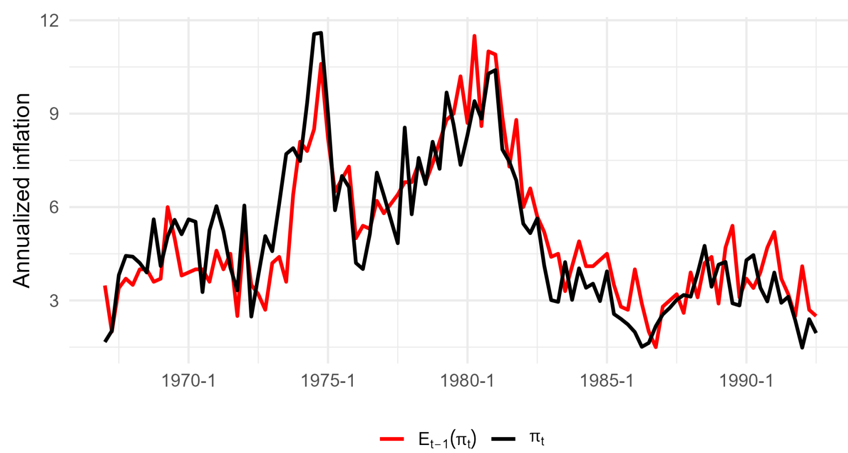

Figure 8: The Greenbook in June 1966

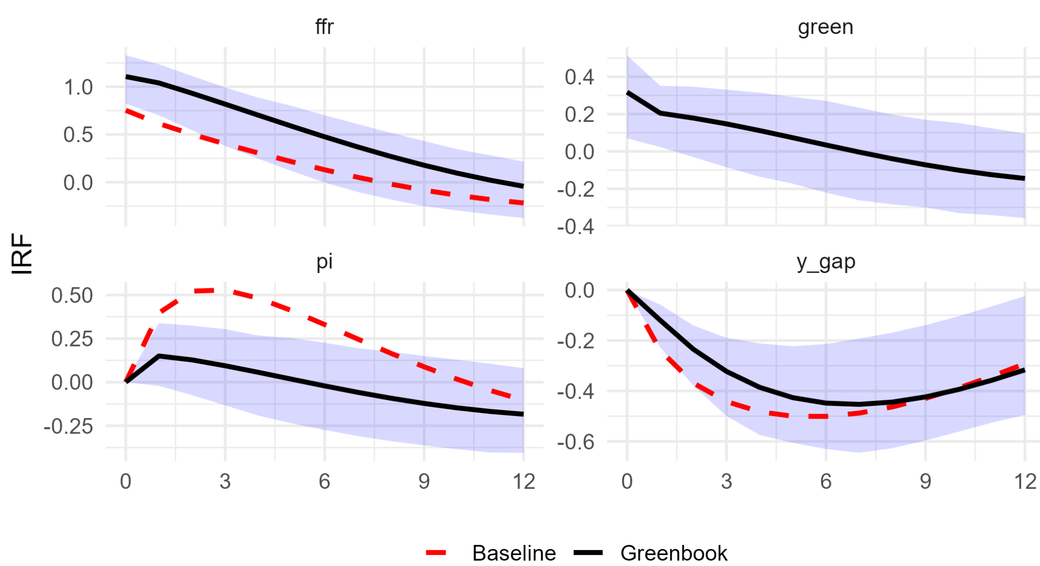

Figure 9: IRFs with Greenbook expectations.

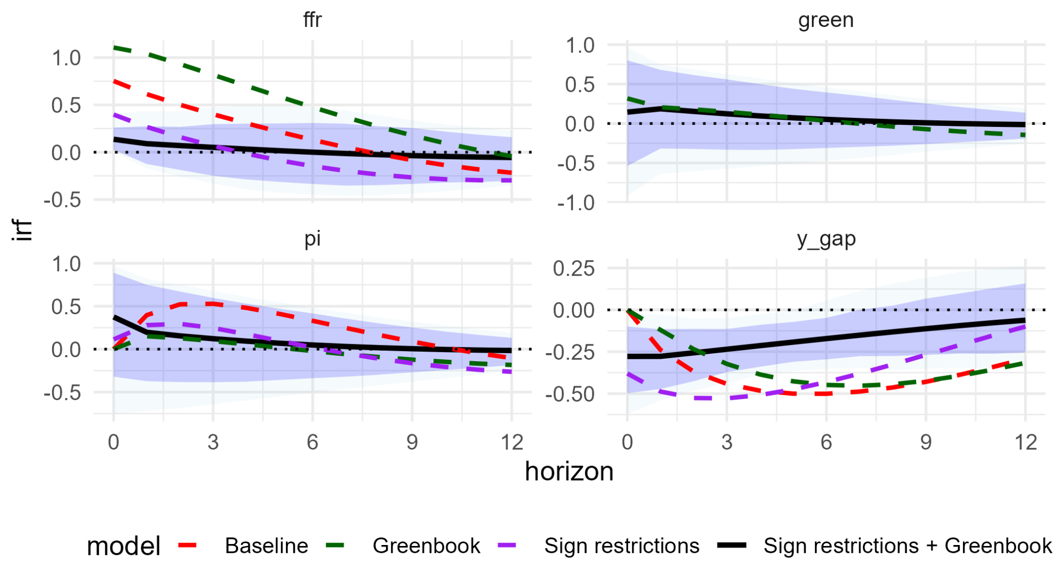

Figure 10: Baseline vs. Sign Restrictions vs. Greenbook vs. Both.

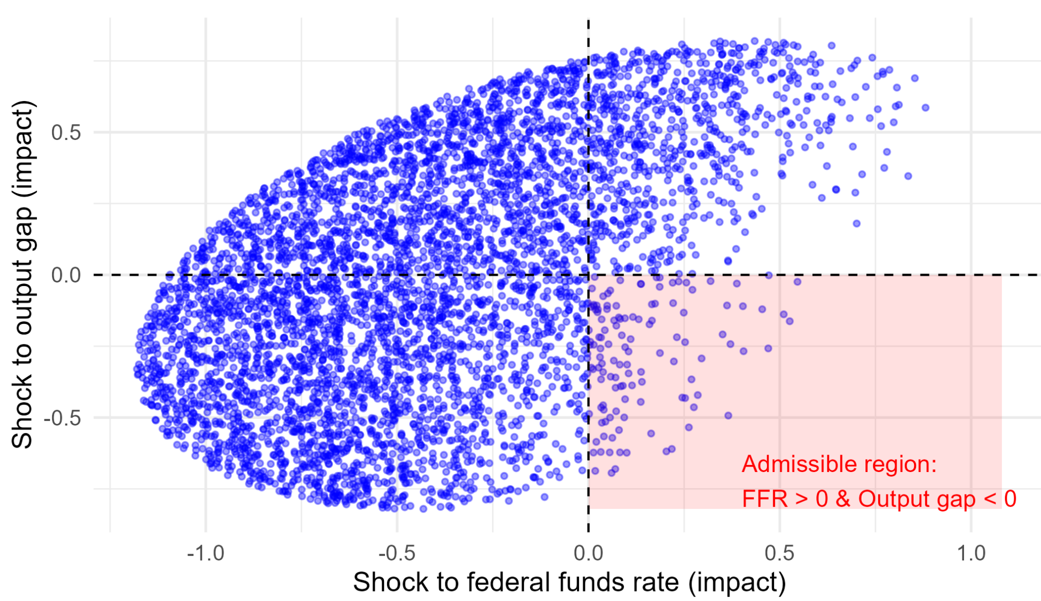

Figure 11: Interpretation of monetary shocks in the 4-VAR

responses to expected inflation rather than exogenous policy disturbances. Once this anticipatory component is purged, the remaining innovations to the policy rate are weakly linked to real activity and no longer resemble conventional contractionary monetary shocks.

Hence, the scarcity of admissible rotations should not be interpreted as a failure of sign-restriction methods. Instead, it indicates that truly exogenous monetary policy shocks are quantitatively small once the central bank's information set is properly accounted for.

5 The Price Puzzle Across Monetary Policy Regimes

This section compares impulse responses to a contractionary monetary policy shock across two post-Volcker subsamples. We focus on the role played by Greenbook inflation expectations and sign restrictions in shaping VAR-based inference once monetary policy becomes more forward-looking.

5.1 End of the Great Inflation: 1979–2007

Figure 12 reports impulse responses for the period from the end of 1979 to 2007Q1. Three identification strategies are compared: a baseline recursive SVAR, an expectations-augmented VAR including Greenbook forecasts, and a sign-restricted SVAR.

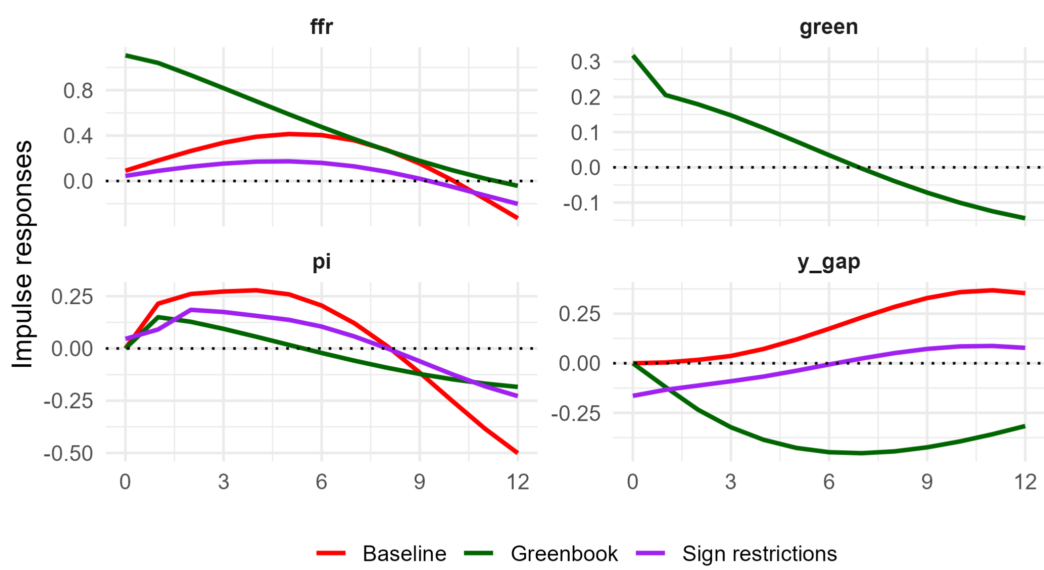

Figure 12: Impulse responses to a monetary policy shock, 1979–2007.

Several results stand out. First, the baseline VAR no longer exhibits a strong price puzzle. Inflation does not rise persistently following a monetary tightening, consistent with the post-

Volcker anchoring of inflation expectations and the restoration of monetary credibility. This finding echoes the consensus that the price puzzle is primarily a feature of the pre-1979 regime.

Second, augmenting the VAR with Greenbook inflation expectations slightly alters the magnitude and persistence of the responses but does not fundamentally change their qualitative shape. Inflation responses remain muted and generally non-positive, while the output gap declines following a policy tightening. This suggests that, during the Great Moderation, recursive identification already captures most of the relevant information driving monetary policy decisions.

Third, sign restrictions further stabilize impulse responses. By imposing a positive response of the policy rate and a negative response of real activity, the sign-restricted SVAR delivers smooth and theory-consistent dynamics. However, the incremental gain relative to the expectations-augmented VAR is limited, reflecting the fact that monetary policy shocks are already reasonably well identified in this regime.

Overall, Figure 12 illustrates a regime in which the policy rate is a credible and active instrument, inflation expectations are anchored, and standard VAR identification performs relatively well.

5.2 The ZLB and the Breakdown of Interest-Rate Identification: 2009–2019

Figure 13 reports the same set of impulse responses for the post-crisis period, from 2009 to 2019.

In sharp contrast with the previous regime, all identification strategies now struggle to deliver economically meaningful impulse responses. The baseline VAR exhibits a renewed price puzzle: inflation responds weakly or even positively to a contractionary policy shock. Output responses are small and imprecisely estimated.

Importantly, adding Greenbook inflation expectations no longer resolves the puzzle. While expectations absorb a substantial share of inflation dynamics, the remaining variation in the Federal Funds Rate carries little information about the stance of monetary policy. As a result, the identified interest-rate shock largely reflects endogenous noise rather than exogenous policy actions.

Sign restrictions also fail to restore a clear contractionary pattern. Although they discipline the short-run responses of the policy rate and output, inflation responses remain weak and unstable. This failure reflects a fundamental change in the monetary transmission mechanism: at the zero lower bound, the Federal Funds Rate ceases to be the marginal policy

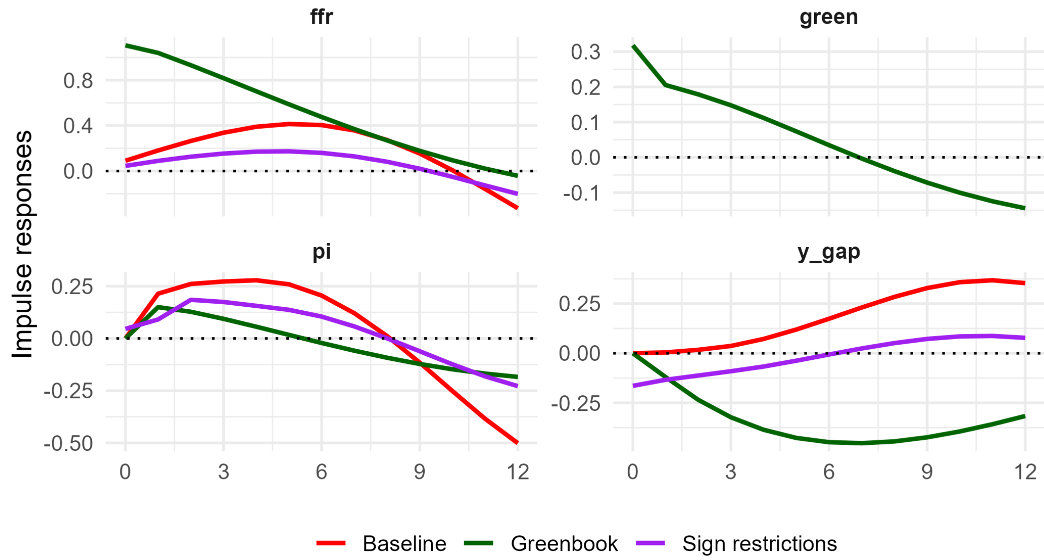

Figure 13: Impulse responses to a monetary policy shock, 2009–2019.

instrument.

The persistence of the price puzzle in Figure 13 should therefore not be interpreted as an identification failure in the usual sense. Rather, it signals that interest-rate-based SVARs are ill-suited to environments in which monetary policy operates through unconventional tools such as quantitative easing and forward guidance.

Regime-dependent interpretation

Taken together, Figures 12 and 13 highlight the fundamentally regime-dependent nature of VAR-based monetary policy analysis. Expectations-augmented identification and sign restrictions successfully resolve the price puzzle when the policy rate is an active and credible instrument. However, once the policy rate is constrained and supplanted by balance-sheet policies, these methods lose their effectiveness.

The re-emergence of the price puzzle after 2009 does not contradict the New Keynesian framework. Instead, it reflects the disappearance of the short-term interest rate as a sufficient statistic for monetary policy.

6 Conclusion

We revisit the price puzzle through the lens of identification, information sets, and monetary policy regimes. Our results confirm that it is not a structural feature of the U.S. economy.

In a baseline recursive VAR, a contractionary monetary policy shock appears to raise inflation on impact. This result is spurious. The puzzle emerges because the VAR omits a key state variable: the Federal Reserve's expectations of future inflation. When inflation is expected to rise, the Fed tightens policy preemptively. A VAR that ignores expectations misinterprets this systematic response as a causal effect of interest-rate shocks on inflation.

Augmenting the VAR with inflation forecasts substantially alters the identified monetary shocks by purging anticipatory policy responses. When combined with sign restrictions consistent with New Keynesian theory—namely, a positive response of the policy rate and a negative response of the output gap—the price puzzle disappears. Importantly, this correction does not require monetary policy to be fully credible or strongly anti-inflationary.

Before 1979, correcting for expectations does not generate a strong disinflationary response, but rather a near-zero inflation effect. This result is economically meaningful. In the pre-Volcker regime, monetary policy reacted weakly to inflation, while inflation dynamics were largely driven by cost-push shocks and poorly anchored expectations. Removing anticipatory components therefore eliminates a spurious positive response without uncovering a powerful disinflationary transmission mechanism.

In the post-Volcker period, inflation expectations became better anchored and policy credibility increased. In this regime, recursive VARs already perform reasonably well, and the additional gains from expectations-based identification are limited. After 2009, the zero lower bound and the shift toward unconventional monetary policies fundamentally weaken interest-rate-based identification, even in expectations-augmented VARs.

Three lessons emerge: (i) monetary policy is inherently forward-looking, and ignoring policymakers' expectations leads to severe identification biases, (ii) the validity of VAR-based identification is regime-dependent: what works under one policy framework may fail under another and (iii) the price puzzle should be interpreted as an identification problem rather than as evidence against standard macroeconomic theory.

More broadly, our findings echo Sims' critique of structural inference in VARs. VARs are reduced-form objects whose interpretation is not invariant to policy regimes and that are ill-suited to capturing rational expectations and information effects. The price puzzle thus illustrates both the usefulness and the limits of VARs in regime-dependent and information-rich monetary environments, rather than a failure of the New Keynesian framework itself.

A Estimated VARs (pre-1979)

This appendix reports the estimated reduced-form VARs used in the pre-1979 analysis. All models are estimated with one lag selected by the Schwarz criterion and include a constant.

Baseline VAR(1): $(y_{gap,t}, \pi_t, ffr_t)'$

$$y_{gap,t} = 1.00\, y_{gap,t-1} + 0.16\, \pi_{t-1} - 0.32\, ffr_{t-1} + 1.05 + u_t^y, \tag{7}$$

$$\pi_t = -0.04\, y_{gap,t-1} + 0.48\, \pi_{t-1} + 0.53\, ffr_{t-1} - 0.48 + u_t^\pi, \tag{8}$$

$$ffr_t = 0.19\, y_{gap,t-1} + 0.12\, \pi_{t-1} + 0.82\, ffr_{t-1} + 0.52 + u_t^r. \tag{9}$$

$$\widehat{\Sigma}_u^{(3)} = \begin{pmatrix} 0.72 & 0.07 & 0.14 \\ 0.07 & 1.38 & 0.30 \\ 0.14 & 0.30 & 0.63 \end{pmatrix}.$$

Expectations-augmented VAR(1): $(green_t, y_{gap,t}, \pi_t, ffr_t)'$

$$green_t = 0.58\, green_{t-1} + 0.06\, y_{gap,t-1} + 0.31\, \pi_{t-1} + 0.02\, ffr_{t-1} + 0.44 + u_t^g, \tag{10}$$

$$y_{gap,t} = 0.07\, green_{t-1} + 0.88\, y_{gap,t-1} - 0.06\, \pi_{t-1} - 0.13\, ffr_{t-1} + 0.90 + u_t^y, \tag{11}$$

$$\pi_t = 0.62\, green_{t-1} + 0.12\, y_{gap,t-1} + 0.39\, \pi_{t-1} - 0.04\, ffr_{t-1} + 0.30 + u_t^\pi, \tag{12}$$

$$ffr_t = 0.22\, green_{t-1} + 0.13\, y_{gap,t-1} - 0.07\, \pi_{t-1} + 0.88\, ffr_{t-1} + 0.24 + u_t^r. \tag{13}$$

$$\widehat{\Sigma}_u^{(4)} = \begin{pmatrix} 0.68 & -0.04 & 0.37 & 0.05 \\ -0.04 & 1.05 & 0.13 & 0.41 \\ 0.37 & 0.13 & 1.40 & 0.42 \\ 0.05 & 0.41 & 0.42 & 1.15 \end{pmatrix}.$$

Two differences are noteworthy. First, in the baseline VAR, inflation reacts positively and sizably to lagged interest rates, a reduced-form feature behind the price puzzle. Second, augmenting the VAR with inflation expectations substantially reduces the residual covariance between inflation and the policy rate (from 0.30 to 0.13), while expectations load strongly in the inflation equation and enter the policy-rate equation. This is consistent with the view that the baseline monetary policy shock is contaminated by anticipatory policy responses to expected inflation.

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