Monetary Policy and Exchange Rate Anomalies in Set-Identified SVARs: Revisited

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Abstract

Set-identified vector autoregressions typically document violations of uncovered interest rate parity (forward discount puzzle) and gradual appreciation-depreciation-cycles of exchange rates (delayed overshooting puzzle) following contractionary monetary policy shocks. We revisit both anomalies in a framework similar to Kim et al. (2017, JPE). We complement their identifying restrictions on how monetary policy affects the economy with restrictions on (i) how monetary policy reacts to the economy and (ii) historical monetary policy innovations. In this hybrid identification, no major forward discount premia emerge. Once we additionally impose that monetary policy propagates through domestic financial conditions, exchange rates also overshoot with less delay.

Keywords: Real exchange rate, monetary policy shock, credit spread, set-identification, structural vector autoregression.

JEL codes: C32, E44, E52, F31, F41.

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1 Introduction

The concept of exchange rate overshooting (Dornbusch, 1976) is considered to be a major cornerstone of international economics. Dornbusch formalizes that a tightening of monetary policy should *instantaneously* appreciate a country’s exchange rate, followed by a gradual depreciation. The empirical validity of his seminal model is, however, the subject of ongoing debate. In particular, structural vector autoregressions (SVARs) that are set-identified by sign-restrictions on impulse response functions (IRFs) typically report (i) *delayed* overshooting and (ii) deviations from uncovered interest rate parity (UIP), so-called forward discount premia (see, e.g., Scholl and Uhlig, 2008).

We revisit both open-economy anomalies within the class of set-identified, monetary policy SVARs. As an empirical laboratory, we center around the structural model of Kim et al. (2017). These authors recover exogenous surprises in the Fed’s policy stance in post-Bretton-Woods U.S. data. They assume that—conditional on a tightening of monetary policy—short-term interest rates do not fall, while prices and monetary aggregates do not rise (we refer to this identification as *sign-scheme*). Using the priors and algorithm of Arias et al. (2018), we successfully reproduce the IRFs of Kim et al. (2017), before refining their empirical strategy as follows.

As a first step, we augment their reduced-form VAR model with corporate credit spreads and equity prices. This modeling choice is motivated by recent evidence documenting (i) a strong impact of U.S. monetary policy on financial markets (Gertler and Karadi, 2015; Miranda-Agrippino and Rey, 2020) as well as (ii) a systematic reaction of the Fed to barometers of credit conditions (Caldara and Herbst, 2019). Failure to account for such monetary-financial-interactions may thwart identification, according to this line of research.
In a second step, we analyze whether the incorporation of new advances in the set-identification of monetary policy shocks—so far proposed for closed-economy models—can also update our conception of the open-economy dissemination of policy actions. In particular, we take up on recent contributions that caution against the sign-scheme arguing that traditional sign-restrictions “may not be enough to identify monetary policy shocks” (Arias et al., 2019).

We complement the sign-scheme by positing the following systematic behavior of the Fed: output and prices positively enter the SVAR-implied policy rule, while monetary aggregates do not (Arias et al., 2019).¹ In addition, we derive identifying information from a historical event: we narrow down the identified set by exploiting the sign and importance of the monetary policy shock that occurred in October 1979. In that month, the Volcker-reform marked a substantial deviation of the Fed from her historical conduct towards a more aggressive, anti-inflationary policy stance. We side with the view of Antolín-Díaz and Rubio-Ramírez (2018) in considering it “the clearest and most uncontroversial example of a monetary policy shock” due to “the forcefulness and the surprise character of the action and the dramatic break with established practice”.²

What do we learn from the above revisions to the set-identification of open-economy, monetary policy SVARs? By modeling credit spreads and equity prices, we continue to corroborate the puzzles of Kim et al. (2017): the real exchange rate overshoots with a delay of three years and UIP remains violated. Notably, the purely sign-identified SVAR does not suggest any meaningful pass-through of monetary policy to domestic financial markets. Complementing the sign-scheme with narrative information and

¹Wolf (2020) demonstrates that such restrictions are capable of purging monetary policy shocks from (linear combinations of) other masquerading innovations.

²Technically, we enforce that the Volcker-shock (i) represents a monetary contraction and (ii) has a larger contribution (in absolute terms) to the unexpected variation in short-term interest rates than all other shocks during October 1979 combined (see Antolín-Díaz and Rubio-Ramírez, 2018).
Taylor-rule restrictions unveils a sign-reversal in the transmission of monetary policy to economic conditions, i.e., the adverse monetary policy shock becomes recessionary.

Moreover, the refined, hybrid identification alters the international dissemination of exogenous interest hikes. The amplitude of the exchange rate reaction and deviations from UIP dwindle by approximately 50 percent, respectively; while forward discount premia are no longer statistically different from zero. Closely related, the domestic tightening of the policy stance now induces higher rather than lower policy rates abroad, which aligns with Kim and Roubini (2000) and Faust and Rogers (2003) or, more recently, Rogers et al. (2018) and Rüth (2020). The exchange rate IRF remains hump-shaped, though, and still reaches its maximum trend-deviation after three years.

Remarkably, within this hybrid set-identification, monetary policy still fails to propagate significantly through domestic financial conditions and systemically reacts to surging credit market tensions by raising policy rates; both inferences are at odds with the findings of, inter alia, Gertler and Karadi (2015) or Caldara and Herbst (2019). In our preferred structural model, we therefore impose that tighter policy at least does not increase the risk-bearing capacity of the financial system. This restriction is consistent with financial accelerator mechanisms and with the empirical strategy in Baumeister and Hamilton (2018). When we add this identifying information, departures from UIP become even smaller; moreover, the duration until the U.S. dollar experiences its maximum appreciation after the interest rate hike shrinks from more than three to less than two years. Finally, we demonstrate that the structural conclusions of our preferred set-identified SVAR generally align with those of a proxy-SVAR strategy.

The article is structured as follows. Section 2 describes methodological aspects, Section 3 presents the empirical results, while Section 4 contains concluding remarks.
2 Methodology

In this section, we describe the modeling choices for the reduced-form VAR and summarize our hybrid set-identification strategy to recover the model’s structural form.

2.1 Model specification and estimation

Following Kim et al. (2017), we cast the dynamic interplay between U.S. industrial production, $y_t$, U.S. CPI, $p_t$, the ratio of non-borrowed to total reserves of U.S. depository institutions held with the Fed, $r_{rt}$, U.S. 3-month interest rates, $i_t$, industrial production abroad, $y_t^*$, 3-month interest rates abroad, $i_t^*$, and the real price of foreign currency in U.S. dollars, $q_t$, in a finite-order linear SVAR representation:

$$y_t' A_0 = \sum_{j=1}^{L} y_{t-j}' A_j + \epsilon_t.'$$

Motivated by recent evidence documenting a powerful leverage of monetary policy on credit costs (e.g., Gertler and Karadi, 2015) and asset prices (e.g., Miranda-Agrippino and Ricco, 2021), we expand the VAR by the Gilchrist and Zakrajšek (2012) excess bond premium, $ebp_t$, and the S&P 500 index, $sp_t$. $y_t$ is a vector capturing these nine observables and covering the post-Bretton-Woods era from January 1976 to July 2007. The invertible $9 \times 9$ matrix $A_0$ represents simultaneous interactions in the model, while the $A_j$’s capture dynamic relations. We set the lag-order to $L = 6$ and abstract from deterministic terms. $\epsilon_t$ contains structural innovations, with $\epsilon_t \sim N(0, I_9)$. A compact representation of (1) reads: $y_t' A_0 = x_t' \tilde{A} + \epsilon_t$, with $\tilde{A}' = [A_1' \ldots A_6']$ and $x_t' = [y_{t-1}' \ldots y_{t-6}']$. We estimate the model using a Bayesian approach. Specifically, a uniform-normal-inverse-Wishart distribution over the orthogonal reduced-form parameterization informs our priors, as in Arias et al. (2018).

Variables are in logs ($\times 100$), except $i_t$, $i_t^*$, and $ebp_t$, which enter in percent. The GDP-weighted basket of foreign country aggregates includes: AT, BE, CA, CH, DK, ES, FR, GE, IT, JP, NL, NO, SE, and UK. Data-construction, sample-choice, and the VAR’s lag-order follow Kim et al. (2017). While these authors stress instabilities across sub-samples, we restrict the analysis to their full sample since we intend to make a general point on identification in monetary policy SVARs, which are often estimated over even longer samples (Gertler and Karadi, 2015; Miranda-Agrippino and Ricco, 2021).
2.2 Hybrid set-identification of monetary policy shocks

The backbone of our identification consists of IRF-restrictions as in the sign-scheme of Scholl and Uhlig (2008). Conditional on an adverse monetary policy shock, that is, $\epsilon_1^t > 0$, we impose for $h = 0, \ldots, 11$ that $\frac{\partial i_{t+h}}{\partial \epsilon_1^t} \geq 0$, $\frac{\partial r_t}{\partial \epsilon_1^t} \leq 0$, and $\frac{\partial p_t}{\partial \epsilon_1^t} \leq 0$; where U.S. interest rates enter the VAR first. By collecting the structural coefficients, $\Theta = (A_0, \tilde{A})$, we sample candidate draws for IRFs of variable $i$ at horizon $h$, $\Phi_h(\Theta)$. We obtain admissible structural models by implementing restrictions as in Rubio-Ramírez et al. (2010), using auxiliary function $\Lambda(\Theta) = e_1^t F(\Theta)' S_1, \ldots, e_9^t F(\Theta)' S_9)' > 0$, where $e_i^t$ is the $i$-th column of $I_9$. $F(\Theta)$ contains IRFs stacked in columns. Specifically, we insert ones or minus ones in $S_i$ to impose positive ($i_t$) or negative ($r_t, p_t$) IRFs.

To further narrow down the set of structural models, we posit that (i) short-term interest rates reflect the policy instrument, and (ii) the latter positively responds to output and prices, while it does not internalize monetary aggregates (Arias et al., 2019). Technically, the restrictions on the systematic conduct of monetary policy imply setting $F(\Theta) = \Theta$, and putting in $S_i$ a one for $i_t$, a minus one for $y_t$ and $p_t$, and a zero for $r_t$. In addition, we shrink the set of structural models even further by imposing narrative restrictions (Antolín-Díaz and Rubio-Ramírez, 2018). Specifically, we impose that in October 1979 (period $t'$), the Volcker-reform (i) induced a contractionary monetary policy shock, and (ii) was the “overwhelming” source of exogenous variation in $i_{t'}$. Formally, the SVAR-shocks depend on the structural parameters as follows: $\epsilon_i'(\Theta) = y_i^t A_0 - x_i^t \tilde{A}$.

The cumulative contribution to historical fluctuations in time-series $i$ triggered by $\epsilon_i^t$ between $t$ and $t + h$ reads: $Y_{i,1,t,t+h}(\Theta, \epsilon_t, \ldots, \epsilon_{t+h}) = \sum_{j=0}^{h} e_{i,j}^t \Phi_j(\Theta) e_{1,9}^t e_{i,9}^t \epsilon_{t+h-j}$. In our application, restriction (i) involves $e_{i,9}^t \epsilon_{t'}(\Theta) > 0$, while restriction (ii) requires $Y_{1,1,t',t'}(\Theta, \epsilon_{t'}) > \sum_{k=2}^{9} |Y_{1,k,t',t'}(\Theta, \epsilon_{t'})|$.
3 Updating exchange rate anomalies in set-identified SVARs

This section contains causal time-series evidence meant to answer three questions. First, does the hybrid identification we propose alter our conception of the open-economy repercussions of monetary policy, relative to the sign-scheme? Second, do the set-identified SVARs imply meaningful monetary-financial-interactions at the national level; and, third, how do our inferences square with alternative identifications?

3.1 Evidence from a hybrid set-identification procedure

The red lines (with dots) in Figure 1 trace the causal implications of an exogenous tightening in the stance of U.S. monetary policy identified via the sign-scheme. We normalize the shock-size throughout the paper such as to raise the Fed’s policy instrument by 25 basis points on impact, for better comparability across specifications.

The key features of the SVAR in Kim et al. (2017) survive once we explicitly account for U.S. financial markets data in the model: in real terms, the U.S. dollar is initially sticky, then sluggishly appreciates for more than three years, before starting to revert toward its conditional mean. An inspection of cumulated excess returns resulting from a trading strategy against UIP likewise reveals consistent results: forward discount premia—formulated in annualized terms for a holding period of three months—adjust in a hump-shaped fashion and amount to almost 8 percentage points after 3 years.\footnote{The IRF is statistically different from zero from year one onward; we omit the corresponding probability bands to keep the illustration tractable. In the online appendix, we report IRFs and 68/90 percent posterior probability bands for each variable in each SVAR-specification along with other statistics of interest. Furthermore, we provide comprehensive evidence on how our results are affected by the individual identifying restrictions we impose, inter alia, by adding them step-by-step.}

In addition, we still observe an expansion of domestic output in our financial-markets-augmented model (see Uhlig, 2005). Finally, the purely sign-identified monetary policy disturbances cause a mild compression of credit spreads in the short run and do not significantly propagate via equity prices.
Figure 1: Set-identified monetary policy SVARs: narrowing down the identified set

Notes: We present point-wise medians (red/blue/black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs. The red lines with filled circles refer to the sign-scheme. The blue lines with diamonds refer to the hybrid model that adds narrative and Taylor-rule-type restrictions. The solid black lines refer to our preferred hybrid model that further includes a positive IRF-restriction for credit spreads. The panels in the last column report medians (filled circles), 68 percent (solid lines), and 90 percent (empty circles) posterior probability bands for the impact-IRF of the exchange rate (first row) and for the Volcker-shock (second row), across different set-identifications.

In the first row of Table 1, we provide the corresponding estimates of the Fed’s SVAR-implied reaction function. Overall, the uncertainty surrounding these coefficients is substantial. Focusing on the posterior medians, some interesting observations emerge, though. While the short-run reaction to the CPI fulfills the Taylor-principle, the long-run reaction does not; a finding that is inconsistent, inter alia, with evidence in Coibion and Gorodnichenko (2012).\footnote{We calculate the long-run reaction to the CPI, \( p_t \), as \( \psi_{p,lr} = \psi_{p,lr} \times (1 - \sum_{k=1}^{L} \rho_k)^{-1} \), where \( \psi_{p,lr} \) is the size of the short-run reaction. The maximum degree of interest rate smoothing is determined by \( L = 6 \), and \( \rho_k \) captures the estimated intensity of interest rate smoothing.} While being small in absolute terms, the Taylor-coefficients for output and the excess bond premium suggest some procyclical policy-conduct; that is, the Fed appears to accentuate business cycle fluctuations and to reinforce cyclical strains in the financial system, according to the sign-scheme.
Table 1: SVAR-implied reaction function of the Fed in different set-identifications

<table>
<thead>
<tr>
<th></th>
<th>$\psi_y$</th>
<th>$\psi_{p,sr}$</th>
<th>$\psi_{p,tr}$</th>
<th>$\psi_{ebp}$</th>
<th>$\psi_{sp}$</th>
<th>$\psi_{y^*}$</th>
<th>$\psi_{i^*}$</th>
<th>$\psi_q$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sign</strong></td>
<td>-0.05</td>
<td>1.75</td>
<td>0.53</td>
<td>0.03</td>
<td>0.01</td>
<td>0.23</td>
<td>0.67</td>
<td>-0.02</td>
</tr>
<tr>
<td></td>
<td>[-5.2, 5.5]</td>
<td>[17.5, 18.7]</td>
<td>[-0.6, 1.7]</td>
<td>[-11.9, 10.5]</td>
<td>[-0.9, 0.8]</td>
<td>[-3.2, 3.5]</td>
<td>[-14.3, 13.6]</td>
<td>[-1.2, 1.3]</td>
</tr>
<tr>
<td><strong>Both</strong></td>
<td>0.20</td>
<td>1.60</td>
<td>1.42</td>
<td>1.44</td>
<td>0.04</td>
<td>0.30</td>
<td>-0.72</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>[0.0, 0.6]</td>
<td>[0.7, 2.9]</td>
<td>[0.9, 2.6]</td>
<td>[0.1, 3.4]</td>
<td>[0.0, 0.2]</td>
<td>[-0.1, 0.7]</td>
<td>[-2.7, 0.6]</td>
<td>[-0.1, 0.2]</td>
</tr>
<tr>
<td><strong>Full</strong></td>
<td>0.24</td>
<td>1.41</td>
<td>1.61</td>
<td>-0.10</td>
<td>0.05</td>
<td>0.26</td>
<td>-0.81</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>[0.0, 0.5]</td>
<td>[0.6, 2.8]</td>
<td>[1.0, 2.2]</td>
<td>[-0.8, 0.5]</td>
<td>[0.0, 0.2]</td>
<td>[0.0, 0.6]</td>
<td>[-2.6, 0.3]</td>
<td>[-0.1, 0.2]</td>
</tr>
</tbody>
</table>

Notes: The table reports estimates of point-wise medians along with 90 percent (numbers in square brackets) equal-tailed point-wise posterior probability bands for the Fed’s reaction to selected variables (columns), across set-identifications (rows). The first row refers to the **sign-scheme**, the second row refers to the hybrid model that adds narrative and Taylor-rule-type restrictions, while the third row refers to our preferred hybrid model that further includes a positive IRF-restriction for credit spreads.

The blue lines (with diamonds) in Figure 1 report the dynamic adjustments after the 25 basis point tightening of monetary policy once we add to the sign-scheme restrictions regarding (i) the systematic behavior of the Fed and (ii) the properties of the monetary policy shock in October 1979. Consistent with Antolín-Díaz and Rubio-Ramírez (2018) and Arias et al. (2019), our inference on domestic output is substantially revised by this identifying information. The exogenous shift in monetary policy toward a tighter stance now induces a slowdown in economic activity, rather than an expansion as in the purely sign-restricted case. Do these posterior revisions extend to the transmission of monetary policy via domestic financial markets? According to Figure 1, rather not. The adjustments of stock prices remain insignificant and closely track those from the sign-scheme, while, contemporaneously, credit spreads narrow even more; that is, albeit the adverse policy shock now comes with adverse consequences for the real economy, financial markets—perhaps surprisingly—withstanding these recessionary tendencies and do not appear to be a meaningful part of the propagation mechanism.

Narrowing down the set of structural models relative to the sign-scheme, however, noticeably affects the international dissemination of monetary policy. The magnitude of the exchange rate reaction is muted within the hybrid identification. Moreover, excess returns against UIP shrink roughly by half and can not be distinguished from
zero in a statistical sense, for many years (see appendix for probability bands). An important ingredient to the latter finding is the altered spillover from domestic to foreign short-term interest rates. The hybrid model, namely, produces a tightening of monetary policy abroad (e.g., Kim and Roubini, 2000; Faust and Rogers, 2003; Rogers et al., 2018). Notwithstanding these posterior revisions, the exchange rate response remains hump-shaped—thus giving rise to delayed overshooting.

Taken together, while the identifying restrictions that we add to the sign-scheme nudge the identified set closer toward the open-economy predictions of the Dornbusch (1976) model, we still view the resulting closed-economy inferences from the SVAR as somewhat controversial. Albeit the hybrid identification reveals conventional features of monetary policy when it comes to real concepts—i.e., tighter policy slows down economic activity and the systematic reaction to output is countercyclical—the domestic monetary-financial-interactions stand in conflict with a growing body of proxy-SVAR contributions. The latter typically come out in favor of (i) tighter financial market conditions after exogenous contractions in the monetary policy stance (Gertler and Karadi, 2015) and (ii) a stabilizing motive of the Fed when systematically responding to credit spreads (Caldara and Herbst, 2019). By contrast, the hybrid model—akin to the sign-scheme—suggests (i) narrowing credit spreads after a monetary policy contraction and (ii) a systematic rate hike of as much as 1.4 percentage points, conditional on a 1 percentage point widening of credit spreads (see Table 1, second row).

To address these irregularities, we advocate for the inclusion of one additional IRF-restriction meant to give rise to a meaningful leverage of monetary policy on domestic financial markets. Specifically, we impose: \( \frac{\partial \epsilon_{t+h}}{\partial \epsilon_t} \geq 0 \). In our preferred hybrid identification, we thus assume that contractionary monetary policy at least does
not increase the effective risk-bearing capacity of the financial system, as captured by the excess bond premium.\textsuperscript{6} Notably, while the IRF-restriction for credit spreads may be viewed as somewhat invasive, its application preserves a fundamental principle of the empirical strategy pursued in this paper: we exclusively include identifying information that directly involves the closed-economy block of the SVAR model. In doing so, we let the data determine any simultaneous or dynamic interactions of U.S. monetary policy with foreign exchange rate markets or with foreign monetary policy rates.\textsuperscript{7}

The inclusion of an IRF-restriction for the excess bond premium in our preferred set-identification updates our inferences as follows. The (enforced) short-run widening of spreads is accompanied by a significantly negative stock market reception of the adverse policy shock; while recessionary tendencies are reinforced. The maximum appreciation of the U.S. dollar drops from one percent to 0.6 percent. The exchange rate IRF remains hump-shaped, but peaks already after less than two years, rather than after more than three years; that is, the delay of exchange rate overshooting decreases substantially. In addition, the maximum deviation of cumulated forward discount premia from the UIP-implied path decreases from 3 to 1 percentage points. The estimated reaction function of monetary policy is rather insensitive to the inclusion of the IRF-restriction, with one notable exception: in our preferred model (third row of Table 1), the Fed lowers interest rates by 14 basis points, after a 1 percentage point surge of the excess bond premium. Interestingly, in none of our set-identification procedures does U.S. monetary policy systematically respond to developments in foreign exchange rate markets.

\textsuperscript{6}Similarly, Baumeister and Hamilton (2018) restrict Moody’s Baa spread to increase after a monetary policy contraction, which aligns with the literature on the credit channel of monetary policy (Bernanke and Gertler, 1995). While the specific modeling strategy of how tight policy translates into credit conditions differs across this literature, a common implication is a surge of credit spreads.

\textsuperscript{7}Recently, Yang et al. (2022) and Castelmuovo et al. (2022) study open-economy puzzles of monetary policy within set-identified VAR models by directly restricting, among others, (i) the impact of exogenous monetary policy shocks on exchange rates or (ii) the systematic reaction of monetary policy to fluctuations in the latter.
3.2 Alternative identifying assumptions and open-economy anomalies

Ultimately, we test the extent to which other restrictions to recover the structural VAR revise our inferences about the open-economy propagation of U.S. monetary policy.

First, we reduce the horizon over which we restrict IRFs in the set-identified structural models from one year to one quarter. This adjustment is motivated by recent high-frequency SVAR-identifications of monetary policy. For instance, while the sign-scheme imposes a liquidity effect over the course of one year, deviations of the monetary policy instrument from its conditional mean are often insignificant after few months in proxy-SVARs (see, e.g., Miranda-Agrippino and Ricco, 2021); Jarocinski and Karadi (2020) even report short-term interest rates turning insignificant straight after the impact period. We thus consider these stylized facts from the growing body of monetary policy proxy-SVARs as a justification to update the assumptions of the sign-scheme. Figure 2 (columns 1 to 3) illustrates that set-identified SVARs that feature shorter IRF-restrictions (black lines) come with smaller forward discount premia. Notably, deviations from UIP can no longer be distinguished from zero, even in the sign-scheme.

Second, in column 4 of Figure 2, we trace IRFs of our preferred set-identified model (blue dashed lines) and compare them to those of an exactly-identified proxy-SVAR model (black lines). To obtain IRFs in the latter case, we use the identical reduced-form VAR specification and Bayesian estimation environment as for the set-identified models, but we recover the VAR’s structural-form via the informationally robust external instrument of Miranda-Agrippino and Ricco (2021). Remarkably, the inferences we draw from both quite distinct identifications are overall consistent; in particular, when it comes to the absence of departures from UIP. While Rüth (2020) stresses differ-

\footnote{In the proxy-SVAR, the U.S. dollar overshoots on impact, while in the benchmark hybrid set-identification the dollar-appreciation is somewhat delayed, though.}
ences across proxy-identified and sign-restricted SVAR models, we thus contribute to the literature by aligning the two approaches via the proposed hybrid set-identification.

4 Conclusion

Taken together, our key insights are threefold. First, UIP may be intact even if foreign exchange rates overshoot somewhat sluggishly after exogenous shifts of monetary policy (see also Müller et al., 2022). We thus revise inferences of Scholl and Uhlig (2008) who reported that the “forward discount puzzle is robust even without delayed overshooting”. Second, without explicit restrictions, established set-identification strategies for monetary policy SVARs do not imply meaningful monetary-financial-interactions at the national level. Third, once we assume monetary policy to propagate via domestic financial markets, exchange rate anomalies generally become less pronounced—a result that is in line with recent external instruments augmented SVAR approaches.

Figure 2: Open-economy repercussions of monetary policy in alternative SVARs

Notes: We present point-wise medians (solid/dashed lines) and 90 percent (shaded regions/dotted lines) equal-tailed point-wise posterior probability bands for IRFs. Columns one to three demonstrate how inferences from the baseline sign-, both-, and full-scheme (blue dashed/dotted lines) change once we impose IRF-restrictions only for one quarter (solid black lines/shaded regions), instead of four quarters. The last column compares the baseline full-scheme (blue dashed/dotted lines) with a proxy-SVAR identification strategy (solid black lines/shaded regions), along the lines of Miranda-Agrippino and Ricco (2021).
References


Supplementary Appendix for:
“Monetary Policy and Exchange Rate Anomalies in Set-Identified SVARs: Revisited”

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Abstract

This appendix contains complementary information and additional empirical results for the paper: Rüth and Van der Veken (2022). Section 1 describes details on model specification, estimation, and inference. Section 2 provides the complete findings—i.e., impulse response functions, forecast-error-variance decompositions, estimates of the Fed’s reaction function, and other statistics of interest—for each time-series of the three set-identified SVARs of main interest: the sign-, both-, and full-scheme. In addition, the section comprises results for intermediate identification-steps, in which we add narrative restrictions (narrative-scheme) or restrictions on the Fed’s systematic policy conduct (Taylor-scheme) one-by-one to the sign-scheme. Section 3 presents evidence for alternative identification-strategies.

Keywords: Real exchange rate, monetary policy shock, credit spread, set-identification, structural vector autoregression.

JEL codes: C32, E44, E52, F31, F41.

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1 Methodological details

In this section, we provide complementary information on our empirical framework. First, we describe how we have chosen the reduced-form representation of the VAR. Second, we provide details on estimation and inference.

1.1 Specification of the reduced-form VAR

The point of departure for our empirical analysis is the following reduced-form VAR:

\[ y'_t = x'_t B + u'_t, \]

where \( y'_t \) includes a selection of \( n \) observable time-series with \( x'_t = [y'_{t-1} \ldots y'_{t-L}] \). We assume that the reduced-form coefficients in \( B \) and the reduced-form residuals in \( u'_t \) can be mapped with their structural VAR counterparts (as outlined in the paper) as follows: \( B = \tilde{A} A_0^{-1} \) and \( u'_t = \epsilon'_t A_0^{-1} \).

Since the main intention of our paper is to refine the structural part of set-identified, open-economy, monetary policy SVAR-models, we build on an established reduced-form VAR framework. In that respect, the modeling choices proposed in Kim et al. (2017) may be viewed as fairly representative for this strand of literature. Their specification is along the lines of Scholl and Uhlig (2008), who themselves build on the specifications of Eichenbaum and Evans (1995) and Faust and Rogers (2003). As the backbone of our empirical analysis, we thus employ the reduced-form model-environment of Kim et al. (2017), which constitutes a clean starting point to discuss the marginal effects of different identification-assumptions on inference from this VAR model.

Accordingly, the selection of the core variables entering our model is as follows. We include the U.S. consumer price index (CPI), \( p_t \), the ratio of non-borrowed to total reserves of U.S. depository institutions held with the Federal Reserve, \( rr_t \), and U.S. 3-month interest rates, \( i_t \). These three variables are necessary for the implementation of the sign-scheme; that is, these variables’ impulse response functions are subject to qualitative restrictions. In addition, U.S. industrial production, \( y_t \), and its counterpart abroad, \( y^*_t \), enter the model to explore the extent of domestic and foreign non-neutrality of monetary policy. To study the emergence of delayed exchange rate overshooting, the model features the real price of foreign currency in U.S. dollars, \( q_t \). Ultimately, to calculate potential deviations from uncovered interest rate parity, we further include foreign 3-month interest rates, \( i^*_t \).
We augment the reduced-form model of Kim et al. (2017) along one dimension. A recent literature using proxy-SVARs to identify monetary policy shocks forcefully demonstrates (i) that monetary policy meaningfully propagates via credit spreads and equity prices, and (ii) that monetary policy SVARs that do not account for such monetary-financial interactions are likely to be misspecified (see Gertler and Karadi, 2015; Caldara and Herbst, 2019; Miranda-Agrippino and Rey, 2020; Miranda-Agrippino and Ricco, 2021). Therefore, we add two variables to $y_t'$ that are meant to capture overall domestic financial market conditions and to test for the presence of financial accelerator effects (Bernanke et al., 1999). First, we include the excess bond premium, as proposed by Gilchrist and Zakrajšek (2012). These authors compile secondary-market, individual corporate bond prices and calculate a measure of corporate bond credit spreads that has strong predictive properties for economic activity. The excess bond premium measures movements in this spread that can be attributed to time-varying strains in the financial sector that are not just reflective of movements in expected default risks. Second, we include the Standard and Poor’s 500 stock market index, which captures the domestic propagation of monetary policy via equity prices.

Interest rates and interest rate spreads enter the VAR in percent, while the remaining variables are specified as natural logarithms $\times 100$. Foreign-country aggregates (denoted with superscript *) are GDP-weighted baskets of the following economies: Australia, Belgium, Canada, Denmark, France, Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom. The construction and transformation of the monthly time-series, the VAR’s lag-order ($L = 6$), and the sample period ranging from January 1976 to July 2007 follow Kim et al. (2017).

We refrain from further extending the sample to include more recent data, at least, for the following two reasons. First, not only Kim et al. (2017), but also Antolín-Díaz and Rubio-Ramírez (2018) and Arias et al. (2019) confine their samples to end in 2007; that is, for comparability with our most important reference papers, we end our analysis in 2007. Second, the Federal Reserve has engaged in, e.g., large-scale asset purchases and forward guidance operations since the Great Recession. The sign-scheme, which represents the core of our set-identification strategy, however, was developed to capture “conventional” monetary policy innovations to short-term policy rates. Thus, it may not convincingly isolate innovations in the Fed’s overall policy stance during the episode of “unconventional” policy conduct.
1.2 Estimation and inference

Estimation and inference in our paper is within the Bayesian paradigm. Following Arias et al. (2018), we perform independent draws from conjugate uniform-normal-inverse-Wishart posterior distributions over the orthogonal reduced-form parameters of the VAR model (see also Uhlig, 2005) and translate the drawn parameters into structural coefficients. The priors we use are identical to Arias et al. (2018); we refer to their study for technical details.

To recover the VAR’s structural form, we impose, among others, qualitative restrictions on the signs of impulse response functions (IRFs), as in Kim et al. (2017); we refer to this strategy as sign-scheme. The algorithm of Arias et al. (2018) further allows to simultaneously employ sign- and zero-restrictions on IRFs and on structural coefficients to identify a VAR model; thus we can also use it to complement the sign-scheme with restrictions on the systematic conduct of monetary policy, as in Arias et al. (2019). To add narrative restrictions on the distribution of historical shocks—which implies truncating the support of the VAR’s likelihood function—we adopt the implementation-strategy in Antolín-Díaz and Rubio-Ramírez (2018). Again, we refer to their paper for information on technical details.

Throughout, we are only interested in identifying a monetary policy shock, while leaving the remaining shocks in the system unidentified; that is, we only partially identify the SVAR. Since each combination of identifying-restrictions that we use features less than \( n - 1 \) exact (zero)-restrictions, the resulting SVAR-models are only set-identified (Rubio-Ramírez et al., 2010). The statistics we present for these set-identified models in the paper are based on at least 1,000 unique draws.

2 Complete results for the main set-identified SVARs

In this section, we provide the complete empirical results for the main set-identified SVAR models proposed in Section 3.1 of the paper. Figure A.1 presents statistics for our preferred hybrid identification-strategy, the full-scheme, which combines (i) IRF-restrictions as in Kim et al. (2017), (ii) restrictions on the Fed’s reaction function, (iii) restrictions on the properties of the Volcker-shock, and (iv) an IRF-restriction on the excess bond premium. Figures A.2 to A.5 provide the corresponding results for set-identified SVAR models that add the identifying restrictions of the full-scheme step-by-step.
In this vein, Figure A.2 presents results for the *sign-scheme*. Based on the *sign-scheme*, Figure A.3 adds restrictions on the Fed’s systematic policy conduct (*Taylor-scheme*), while Figure A.4, instead, adds restrictions on the properties of the monetary policy shock in October 1979 (*narrative-scheme*). In Figure A.5, we combine the *sign-, Taylor-, and narrative-scheme* to a structural model that we call *both-scheme*. Table A.1 provides estimates of the SVAR-implied Taylor-rules that correspond to Figures A.1 to A.5. Finally, Figure A.6 fleshes out the differences and commonalities between the inferences from our preferred hybrid SVAR and those from the pure *sign-, Taylor-, and narrative-schemes* even further. In particular, the figure focusses on the same statistics as in Figure 1 of the manuscript, but reports the corresponding results from the individual identifications in relative terms to the *full-scheme*.

### 3 Alternative identifying restrictions

In this section, we first provide complementary empirical findings for set-identified SVAR models that impose sign-restrictions on IRFs for only one quarter rather than for four quarters. Figures A.7 to A.11 present the corresponding results revealing that deviations from uncovered interest parity become quantitatively smaller (and throughout insignificant), compared to identification-schemes that restrict IRFs for four quarters (see Figures A.1 to A.5).

Second, we contrast the evidence on set-identified SVARs with exactly-identified proxy-SVAR models (see Stock and Watson, 2012; Mertens and Ravn, 2013). Recovering the structural form of a proxy-SVAR requires identifying information from an external instrument that (i) correlates with the unobserved monetary policy shock, but (ii) is contemporaneously uncorrelated with the remaining, unidentified shocks in the VAR-system. Miranda-Agrippino and Ricco (2021) propose such an instrument which they construct using high-frequency financial markets data. Specifically, and elaborating on Gertler and Karadi (2015), their external instrument is the result of a projection of market-based price revisions in Federal funds rate futures contracts—observed around monetary policy announcements—on their own lags and on a set of Greenbook forecasts. According to Miranda-Agrippino and Ricco (2021), the residual from this regression can be viewed as an instrument that is plausibly purged from information rigidities; where the latter may compound the true policy shocks of interest with so-called central bank information shocks. We use their proxy-series and implement the external instruments identification along the lines of Miranda-Agrippino and
Rey (2020). For this proxy-SVAR identification-strategy, we use the same specification and Bayesian estimation for the reduced-form VAR as in the case of the set-identified models.

Figure A.12 presents the complete results for the proxy-SVAR model presented in the last column of Figure 2 in the paper; Figure A.13 performs the same proxy-SVAR identification of the monetary policy shock, but omits the ratio of non-borrowed to total reserves of U.S. depository institutions held with the Federal Reserve, $rr_t$, in the VAR’s reduced-form. We also provide this modified SVAR-model to better compare the results with prominent proxy-SVAR studies that typically abstract from monetary aggregates (see, inter alia, Gertler and Karadi, 2015; Caldara and Herbst, 2019).

Overall, the inferences we draw from the proxy-SVARs are broadly consistent with our preferred set-identified SVAR model from Figure A.1 (the full-scheme). While Rüth (2020) stresses differences across proxy-identified and sign-restricted SVAR models, we thus contribute to the literature by aligning the two approaches via the proposed hybrid set-identification. Nevertheless, three qualitative differences between the proxy-SVARs and the set-identified models we consider emerge. First, while the IRFs from the sign-scheme are estimated with higher uncertainty compared to the proxy-SVARs, the full-scheme (Figure A.1) allows for even sharper inference relative to the latter. Second, the exchange rate overshoots instantaneously in the proxy-SVAR models. By contrast, the full-scheme comes with an insignificant exchange rate appreciation on impact thus revealing some delayed overshooting. Third, the full-scheme suggests a slowdown of economic activity abroad, which aligns with recent evidence in, e.g., Breitenlechner et al. (2022), while the proxy-SVARs reveal a significant expansion of foreign industrial production.

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1When we omit monetary aggregates in the estimation—as is typically done in proxy-SVAR approaches—the exchange rate even starts to monotonically depreciate right after an initial appreciation (see Figure A.13).
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<td>[0.1; 0.2]</td>
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**Notes:** The table reports estimates of point-wise medians along with 90 percent (numbers in square brackets) equal-tailed point-wise posterior probability bands for the Fed’s reaction to each variable in the SVAR model (columns), across identifications (rows). The first row refers to the sign-scheme. The second row refers to the identification in which we add restrictions on the SVAR-implied reaction function to the sign-scheme (referred to as: Taylor-scheme). The third row refers to the identification in which we add restrictions on the distribution of the monetary policy shock during October 1979 to the sign-scheme (referred to as: narrative-scheme). The fourth row refers to the hybrid model that adds narrative and Taylor-rule-type restrictions to the sign-scheme, while the fifth row refers to our preferred hybrid model that further includes a positive IRF-restriction for the excess bond premium.
Figure A.1: Monetary policy shock: set-identified via the full-scheme

Notes: We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. The last panel reports medians (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the distribution of the Volcker-shock (first entry) and the impact-IRF of the real exchange rate (second entry).
Figure A.2: Monetary policy shock: set-identified via the *sign-scheme*

![Graphs showing interest rate, foreign interest rate, exchange rate, and CPI IRFs, and industrial production, foreign production, excess bond premium, stock prices, CPI FEVDs, industrial production FEVDs, foreign production FEVDs, excess bond premium FEVDs, and stock prices FEVDs.](image)

Notes: We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the *full-scheme* as dashed lines. The last panel reports medians (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the distributions of the Volcker-shock (entries 1 and 2) and the impact-IRF of the real exchange rate (entries 3 and 4).
Figure A.3: Monetary policy shock: set-identified via the *Taylor-scheme*

\[ \text{Interest rate (IRF)} \]
\[ \text{For. interest rate (IRF)} \]
\[ \text{Exchange rate (IRF)} \]
\[ \text{CPI (IRF)} \]
\[ \text{Industrial production (IRF)} \]
\[ \text{Foreign ind. prod. (IRF)} \]
\[ \text{Excess bond premium (IRF)} \]
\[ \text{Stock prices (IRF)} \]
\[ \text{Nonborr. res. ratio (IRF)} \]
\[ \text{Interest rate (FEVD)} \]
\[ \text{For. interest rate (FEVD)} \]
\[ \text{Exchange rate (FEVD)} \]
\[ \text{CPI (FEVD)} \]
\[ \text{Industrial production (FEVD)} \]
\[ \text{Foreign ind. prod. (FEVD)} \]
\[ \text{Excess bond premium (FEVD)} \]
\[ \text{Stock prices (FEVD)} \]
\[ \text{Nonborr. res. ratio (FEVD)} \]
\[ \text{Cum. UIP deviations} \]
\[ \text{Summary statistics} \]

Notes: We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the *full-scheme* as dashed lines. The last panel reports medians (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the distributions of the Volcker-shock (entries 1 and 2) and the impact-IRF of the real exchange rate (entries 3 and 4).
Figure A.4: Monetary policy shock: set-identified via the narrative-scheme

Notes: We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the full-scheme as dashed lines. The last panel reports medians (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the distributions of the Volcker-shock (entries 1 and 2) and the impact-IRF of the real exchange rate (entries 3 and 4).
Figure A.5: Monetary policy shock: set-identified via the both-scheme

Notes: We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the full-scheme as dashed lines. The last panel reports medians (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the distributions of the Volcker-shock (entries 1 and 2) and the impact-IRF of the real exchange rate (entries 3 and 4).
Figure A.6: Difference between individual identification-strategies and the full-scheme.

Notes: The first four columns of the figure compare the IRFs from the sign-, Taylor-, and narrative-scheme with our preferred full-scheme; in particular, the black zero-lines refer to the point-wise medians of the full-scheme, while the red/blue/pink lines show the respective difference from the point-wise medians of the IRFs from the alternative identifications. Similarly, the box plots in the last column show how the posterior distributions of the sign-, Taylor- and narrative-scheme differ from the point-wise medians of the full-scheme posterior distributions.
Figure A.7: *Full-scheme* with IRFs restricted for one quarter

![Graphs of various economic indicators showing interest rate (IRF), foreign interest rate (IRF), exchange rate (IRF), CPI (IRF), industrial production (IRF), foreign industrial production (IRF), excess bond premium (IRF), and stock prices (IRF), as well as their corresponding FEVDs.](image)

**Notes:** We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the *full-scheme* as dashed lines. The last panel reports medians (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the distributions of the Volcker-shock (entries 1 and 2) and the impact-IRF of the real exchange rate (entries 3 and 4).
Figure A.8: *Sign-scheme* with IRFs restricted for one quarter

![Graphs showing IRFs and FEVDs for various economic indicators](image)

**Notes:** We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the *full-scheme* as dashed lines. The last panel reports medians (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the distributions of the Volcker-shock (entries 1 and 2) and the impact-IRF of the real exchange rate (entries 3 and 4).
Figure A.9: *Taylor-scheme* with IRFs restricted for one quarter

![Graphs showing interest rate (IRF), for. interest rate (IRF), exchange rate (IRF), CPI (IRF), industrial production (IRF), foreign ind. prod. (IRF), excess bond premium (IRF), stock prices (IRF), interest rate (FEVD), for. interest rate (FEVD), exchange rate (FEVD), CPI (FEVD), industrial production (FEVD), foreign ind. prod. (FEVD), excess bond premium (FEVD), stock prices (FEVD), nonborr. res. ratio (FEVD), and summary statistics.]

*Notes:* We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the *full-scheme* as dashed lines. The last panel reports medians (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the distributions of the Volcker-shock (entries 1 and 2) and the impact-IRF of the real exchange rate (entries 3 and 4).
Figure A.10: Narrative-scheme with IRFs restricted for one quarter

Notes: We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the full-scheme as dashed lines. The last panel reports medians (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the distributions of the Volcker-shock (entries 1 and 2) and the impact-IRF of the real exchange rate (entries 3 and 4).
Figure A.11: Both-scheme with IRFs restricted for one quarter

Notes: We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the full-scheme as dashed lines. The last panel reports medians (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the distributions of the Volcker-shock (entries 1 and 2) and the impact-IRF of the real exchange rate (entries 3 and 4).
Notes: We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the full-scheme as dashed lines. The last panel reports the median (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the impact-IRF distribution of the real exchange rate.
Figure A.13: Monetary policy shock: proxy-SVAR without monetary aggregates

Notes: We present point-wise medians (black lines) and 68/90 percent (dark/light shaded areas) equal-tailed point-wise posterior probability bands for IRFs and forecast-error-variance decompositions (FEVDs), conditional on a contractionary 25 basis point monetary policy shock. For comparison, we add the point-wise medians of the full-scheme as dashed lines. The last panel reports the median (large empty circles) and 68/90 percent (solid lines/small circles) posterior probability bands of the impact-IRF distribution of the real exchange rate.