Delayed Overshooting Puzzle: Does Systematic Monetary Policy Matter?*

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Abstract

We propose a novel identification strategy based on a combination of sign, zero, and policy coefficient restrictions to identify the exchange rate response to a US monetary policy shock. Our strategy crucially hinges upon imposing a sign on the policy response to exchange rate fluctuations, i.e., monetary policy tightens after a depreciation of the US dollar. We support this restriction with narrative evidence as well as empirical evidence from the extant literature. We find an unexpected increase in the policy rate to generate an immediate appreciation followed by a persistent depreciation. This evidence is consistent with the overshooting hypothesis. Importantly, we show that our identification strategy implies robust impulse responses across samples characterized by different monetary policy conducts. Differently, restrictions imposed only on impulse responses return evidence that is subsample specific and associate Volcker's regime with a delayed overshooting.

Keywords: Delayed overshooting, vector autoregressions, monetary policy rule, exchange rate dynamics, Volcker policy regime.

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

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1 Introduction

According to Dornbusch's (1976) exchange rate overshooting hypothesis, countries should experience an immediate appreciation of their currencies followed by a gradual depreciation in response to an unexpected monetary policy tightening by the domestic central bank. This prediction is due to a mechanism present in models featuring expectations over future realizations of the exchange rate: in presence of an excess return on domestic assets driven by a monetary policy tightening, no-arbitrage at an international level requires the exchange rate to strongly appreciate on-impact to allow for future, persistent depreciations.

While this mechanism is one of the building blocks of most open economy macroeconomic models, empirical investigations - typically conducted via vector autogregressions - have often rejected the overshooting hypothesis. Working with recursive identification, Eichenbaum and Evans (1995), Grilli and Roubini (1996), and Kim and Roubini (2000) find that the materialization of the peak response of the exchange rate can take between 2 and 3 years, an evidence termed "delayed overshooting puzzle" (DOP). This evidence is at the basis of theoretical research that has generated mechanisms able to replicate the DOP, e.g., models featuring information rigidities (Gourinchas and Tornell (2004), Müller, Wolf, and Hettig (2021)), dispersed information (Candian (2019)), or portfolio adjustment costs (Bacchetta and van Wincoop (2021)).

As stressed by Cushman and Zha (1997), Faust and Rogers (2003), Scholl and Uhlig (2008), and Bjørnland and Thorsrud (2015), appropriate identification of monetary policy shocks is crucial for correctly establishing if Dornbusch's hypothesis is indeed rejected by data or not. Scholl and Uhlig (2008) tackle this identification issue by working with sign restrictions à la Uhlig (2005) to pin down the exchange rate response to a monetary policy shock. They find evidence against the overshooting hypothesis. Kim, Moon, and Velasco (2017) go a step further and show that Scholl and Uhlig's (2008) findings are basically driven by observations related to the Volcker disinflation. Once such observations are omitted - i.e., if one focuses on post-Volcker observations -, evidence in favor of Dornbusch's hypothesis arises. They interpret this evidence as pointing to the importance of dealing with breaks in the Federal Reserve's policy conduct. The message arising from this recent literature is clear: Identification is crucially connected with monetary policy regimes.

This paper estimates the exchange rate response to a US monetary policy shock by putting *systematic* monetary policy in the spotlight.[1] We do so by extending the state-of-the-art set-identification strategy recently proposed by Arias, Caldara, and Rubio-Ramírez (2019) - which

[1]For an early exploration on the link between the systematic component of monetary policy and monetary policy shocks, see Leeper, Sims, and Zha (1996).

requires imposing signs on the systematic responses of the Federal Reserve to movements in inflation and real activity - to the open-economy context. On top of requiring a systematic policy response of the policy rate to movements in prices and industrial production (as Arias, Caldara, and Rubio-Ramírez (2019) do), we also require the description of the US monetary policy to feature a systematic increase (decrease) of the policy rate in response to a depreciation (appreciation) of the US dollar. This restriction is supported by narrative evidence, which covers different monetary policy regimes. It is also backed up by evidence on the systematic monetary policy response to exchange rate fluctuations by a variety of central banks around the world. On top of policy coefficient restrictions, which have recently been shown by Wolf (2020, 2022) to be extremely effective in recovering the true macroeconomic responses to a monetary policy shock, we also employ traditional restrictions on impulse responses à la Scholl and Uhlig (2008) and Kim, Moon, and Velasco (2017) to sharpen our econometric estimates.

Our main results are the following. First, we find robust evidence supporting the overshooting hypothesis, i.e., no trace of DOP is detected conditional on our identification strategy. Second, we show that our proposed restriction on the systematic policy response to exchange rate fluctuations is crucial for our identification scheme to imply an immediate appreciation of the US dollar to a US monetary policy shock. Dropping such a restriction leads our VAR estimates to imply estimated policy rules that admit a policy *tightening* in response to an exchange rate appreciation, a policy responses at odds with our narrative evidence. Third, our identification strategy supports the overshooting hypothesis across different subsamples, including the one associated with the Volcker regime. Differently, as pointed out by Kim, Moon, and Velasco (2017), a standard identification strategy based on IRF-restrictions would reject the overshooting hypothesis when handling samples that include the Volcker regime. After replicating Kim et al.'s (2017) results, we dig deeper to understand the drivers of this difference. We find that the standard IRF-based identification strategy retains a non-negligible share of rotations (structural models) that are associated with a *negative* response of the policy rate to an exchange rate depreciation. This last finding is not robust to moving to a sample that excludes the Volcker observations - the policy function coefficients implied restrictions imposed on impulse responses only imply a positive policy response to an exchange rate depreciation when the post-Volcker sample is employed. This last set of results offers an interpretation to the evidence documented by Kim, Moon, and Velasco (2017), which goes as follows. The Volcker regime was importantly characterized by a systematic monetary response to the exchange rate. If such a response is not considered among the set of restrictions imposed to achieve identification, spurious evidence in favor of a DOP in the '80s may arise. This result is connected with the huge monetary policy shocks due to Volcker's policy decisions in the late 1970s-early 1980s, which were mainly engineered to abruptly reduce inflation. Such shocks generate a negative conditional correlation between the exchange rate and the policy instrument. VARs that do not impose a positive sign on the systematic policy response to the exchange rate confound the positive systematic response of policymakers to unexpected depreciations with the negative response of the exchange rate to a policy shock. As long as monetary policy shocks are the stronger driver (between systematic monetary policy and monetary policy shocks) of the policy rate-exchange rate correlation, as it is likely to be the case in the Volcker regime, imposing a policy coefficient restriction on the policy response to exchange rate movements is likely necessary to correctly identify a monetary policy shock and its exchange rate effects.

Our results are important from a policy and modeling standpoints. From a policy standpoint, our results stress that unexpected policy changes may indeed generate an immediate, large volatility in exchange rates. From a modeling perspective, our findings suggests to preserve mechanisms consistent with the exchange rate overshooting hypothesis, which is supported by the data. Importantly, our results are not at odds with the established stylized fact on the persistence of the swings in the real exchange rates (Chari, Kehoe, and McGrattan (2002)). As pointed out by Steinsson (2008), NK models featuring sticky prices can generate both a quick *conditional* response of the real exchange rate to a monetary policy shock - in line with the overshooting hypothesis - and a hump-shaped *unconditional* response of the exchange rate, this last one being generated by a combination of real shocks hitting the Phillips curve (productivity shocks, labor supply shocks, government spending shocks, shocks to the world demand for home produced goods, and cost-push shocks). In other words, our empirical findings are consistent with models featuring mechanisms that account for the slowly decaying exchange rate responses to macroeconomic shocks in general, e.g., financial shocks, which have recently been proposed as a possible explanation for a variety of open-economy puzzles (Itskhoki and Mukhin (2021)).

Our paper joins previous contributions that have proposed alternatives to recursive identification strategies to pin down the exchange rate response to a monetary policy shock. Bjørnland (2009) and Doko Tchatoka, Haque, and Terrell (2022) use a combination of short and long-run restrictions to study the exchange rate effects of monetary policy shocks in Australia, Canada, New Zealand, and Sweden. They find evidence supporting the overshooting hypothesis. Rüth (2020), Miranda-Agrippino and Rey (2020), Miranda-Agrippino and Ricco (2021), Degasperi, Hong, and Ricco (2021), and Rüth and Van der Veken (2022) work with instruments based on high-frequency information/financial data to pin down the exchange rate effects of unexpected variations in the policy rate.[2] They also find evidence supporting Dornbusch's (1976) overshoot-

[2] Rüth and Van der Veken (2022) also propose a comparison with the exchange rate responses arising from a battery of set-identified SVARs.

ing hypothesis. We complement these contributions by proposing an identification strategy that enables us to: i) focus on the systematic monetary policy component to achieve identification, something which we see as naturally connected with the narrative and empirical evidence on the attention posed by central banks to fluctuations in the exchange rates; ii) unveil the implications of different sets of restrictions for the description of the US systematic monetary policy across different retained models, which is useful to understand the different results obtained by papers dealing with standard IRF-restrictions only vs. those obtained with our novel identification strategy; iii) avoid the challenges one faces when dealing with long-run restrictions (Faust and Leeper (1997)); iv) circumvent the weak-instrument issue that can potentially affect IV-regressions, above all across different samples; v) naturally deal with model uncertainty. While the investigation in this paper focuses on US monetary policy shocks, our proposal to identify monetary policy shocks in an open-economy context can be easily applied to other countries' data.[3] Finally, Faust and Rogers (2003) investigate the exchange rate effects of monetary policy shocks by imposing a minimal set of sign restrictions on selected impulse responses. They find many rotations to be consistent with the DOP hypothesis, and notice that allowing for simultaneity among interest rates and exchange rates is the possible driver of this empirical finding. Our paper connects with theirs by exploring the role that the systematic policy response to exchange rates has for the DOP in different policy regimes.

The paper is structured as follows. Section 2 describes the data, introduces the VAR, and discusses the identification strategy. It also presents narrative and empirical evidence supporting the policy coefficient restriction involving the exchange rate. Section 3 documents our full-sample and Volcker-related results, and compare them to those obtained with the standard IRF-related restrictions. Section 4 concludes.

[3]While writing the first draft of this paper, a related paper by Groshenny and Javed (2022) came to our attention. They also achieve monetary policy shock identification by imposing restrictions on policy coefficients (including the one associated with the exchange rate). There are several differences between our paper and theirs, though. First, we deal with US monetary policy shocks, while they focus on selected small-open economies (Australia, Canada, Norway, and Sweden). A second, related point is that we work with different subsamples as in Kim, Moon, and Velasco (2017) and unveil the reasons behind the absence (presence) of a delayed overshooting puzzle - with a focus on the Volcker period - when imposing policy coefficient (standard IRF) restrictions. Third, they deal with quarterly data, while we work with a higher frequency (monthly), which is likely to provide is with a sharper information on the effects of monetary policy shocks. We see our paper and Groshenny and Javed's as complementary. For a paper on Australia dealing with the identification of monetary policy shocks with a combination of different restrictions that include also one on the exchange rate policy coefficient, see Read (2022).

2 Data, VAR, identification strategy

2.1 Data

We follow Kim, Moon, and Velasco (2017) and consider monthly data for the US economy and 14 of its trading partners, period: 1976M1-2007M7.[4] The beginning of the period is based on the idea of excluding the transitional early years of the floating exchange rate era (for a detailed account of those years, see Hansen and Hodrick (1983)). The end of the period is meant to avoid dealing with the acceleration of the financial crisis and the great recession, which would imply taking a position on how to separately identify conventional and unconventional monetary policy shocks. For the member countries of the European Monetary Union, data are available until 1998. For Germany, the sample is extended to 2007 by replacing the US-Germany exchange rate with the US-Euro one on the basis of the fixed Germany-Euro rate.

Macroeconomic indicators are aggregated across the 14 US trading partners by appealing to real GDP shares at purchasing power parity.[5] Two aggregates are considered. The first one - "AGG98" - employs all 14 trading partners prior to 1999. The "AGG" method extends the series until 2007 and is based on the non-EMU countries plus Germany, which is treated as representative of the EMU countries over the entire sample 1976-2007.

In line with Eichenbaum and Evans (1995), Scholl and Uhlig (2008), and Kim, Moon, and Velasco (2017), our baseline VAR models the following seven variables: US and foreign industrial production y and y*, US and foreign 3-month interest rates i and i*, the ratio of US nonborrowed to total reserves $nbrx$, US consumer price index (CPI) p, and the real exchange rate $rex = s + p*$ - p, where s is the US/RoW nominal exchange rate, and an increase in s represents a depreciation of the US dollar. In the VAR, all variables are modeled in logs, except for the interest rates, which are modeled in levels.

[4]The list of US trading partners - representing in this analysis the rest-of-the-world (RoW) - includes Austria, Belgium, Canada, Denmark, France, Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom.

[5]In detail, weights for each country are calculated by dividing the country's GDP by the total GDP at purchasing power parity values. Then, growth rates for each individual country are computed. Third, aggregate growth rates are computed by the weighted sum of the individual growth rates. Finally, levels are recovered by cumulating aggregate growth rates from the initial base year. Further details on this aggregation procedure can be found in Scholl and Uhlig (2008) and Kim, Moon, and Velasco (2017).

2.2 VAR

Following Arias, Caldara, and Rubio-Ramírez (2019), let us consider the following VAR representation:

$$\mathbf{y}_t'\mathbf{A}_0 = \sum_{l=1}^{v} \mathbf{y}_{t-l}'\mathbf{A}_l + \varepsilon_t' \tag{1}$$

In this representation, $\mathbf{y}_t$ is an n x 1 vector of endogenous variables, ε_t is an $n \times 1$ vector of structural shocks, $\mathbf{A}_0$ is an invertible $n \times n$ matrix of structural parameters, v is the number of lags of the VAR, l is the lag-indicator, and t is a time-index ranging from 1 to T, where T is the size of the considered sample. The vector ε_t, conditional on past information and initial conditions, is Gaussian with mean zero and covariance matrix $\mathbf{I}_n$ (the $n \times n$ identity matrix).

Post-multiplying the SVAR (1) by $\mathbf{A}_0^{-1}$, one can move to the reduced form representation:

$$\mathbf{y}_t' = \sum_{l=1}^{v} \mathbf{y}_{t-l}'\mathbf{A}_l\mathbf{A}_0^{-1} + \mathbf{u}_t' \tag{2}$$

where $\mathbf{B}_l = \mathbf{A}_l\mathbf{A}_0^{-1}$, $\mathbf{u}_t' = \varepsilon_t'\mathbf{A}_0^{-1}$, and $\mathrm{E}(\mathbf{u}_t\mathbf{u}_t') = \mathbf{\Sigma} = (\mathbf{A}_0\mathbf{A}_0')^{-1} = (\mathbf{A}_0\mathbf{Q}\mathbf{Q}'\mathbf{A}_0')^{-1}$, where $\mathbf{Q}$ is a conformable orthonormal matrix.

As is well known, there are uncountable rotations of the $\mathbf{A}_0$ matrix all equally consistent with the data but that offer different interpretations of the economy (e.g., the macroeconomic effects of a monetary policy shock). We then select out rotations (interpretations) that are economically unpalatable by imposing a set of identifying restrictions that include constraints on the systematic monetary policy response to macroeconomic fluctuations. Given that - without loss of generality - we place the policy rate on top of the vector $\mathbf{y}_t$, the monetary policy equation reads as follows:

$$\mathbf{y}_t'\mathbf{a}_{0,1} = \sum_{l=1}^{v} \mathbf{y}_{t-l}'\mathbf{a}_{l,1} + \varepsilon_{1t} \tag{3}$$

Our policy coefficient-restrictions focus on the contemporaneous responses of the Federal Reserve to macroeconomic fluctuations, which are captured by:

$$i_t = \psi_y y_t + \psi_p p_t + \psi_{\mathrm{rex}} rex_t + \psi_{y^*} y_t^* + \psi_{i^*} i_t^* + \psi_{\mathrm{nbrx}} nbrx_t + \sigma\varepsilon_t^{MP} \tag{4}$$

We now present and discuss our identification strategy.

2.3 Identification strategy

Our set-identification strategy is based on a combination of sign and zero restrictions. First and foremost, we exploit the proposal by Arias, Caldara, and Rubio-Ramírez (2019) and impose restrictions on the contemporaneous coefficients of the monetary policy function in the VAR. The idea is that of correctly specifying the systematic monetary policy response to changes in relevant macroeconomic indicators to get the effects of unexpected changes of the policy rate right. Arias, Caldara, and Rubio-Ramírez (2019) impose a positive systematic response of the Federal Reserve (i.e., an increase of the federal funds rate) to increases in price and industrial production. Moreover, they impose zero restrictions on the response of the policy rate to nonborrowed reserves. We borrow these restrictions, which are natural for a closed-economy context, and add extra policy coefficient-restrictions that we believe to be sensible when modeling the US economy as an open economy. In particular, we impose: i) a positive sign on the response of the policy rate to exchange rate fluctuations (i.e., a policy tightening in response to an exchange rate depreciation); ii) zero restrictions on the impact of foreign industrial production and the Rest-of-the-World (RoW) interest rate on the US systematic policy.[6] Restrictions ii) are justified by the Federal Reserve's natural main focus on domestic economic conditions. Restriction i) is instead meant to capture the attention that the Federal Reserve has paid over time to fluctuations in the exchange rate, justified by e.g. the imported inflation that such fluctuations may bring along. Going back to eq. (4), we impose a positive sign on ψ_y, ψ_p, and ψ_{rex}, and we also set to zero the coefficients ψ_{y^*}, ψ_{i^*}, and ψ_{nbrx}. Finally, we sharpen our set-identification by imposing traditional sign restrictions on the impulse responses to a US monetary policy shock. In particular, we impose a positive on-impact (i.e., contemporaneous) response of the policy rate and a negative on-impact response of prices, industrial production, and nonborrowed reserves over total reserves to an unexpected increase in the policy rate. These sign restrictions have often been used in the open-economy context to identify US monetary policy shocks (see, e.g., Scholl and Uhlig (2008), Kim, Moon, and Velasco (2017)).

The above described restriction on the policy coefficient is a crucial component of our identification strategy. Let us justify it further by offering narrative support and highlighting links with the extant empirical literature.

Narrative support. Our sample covers three different chairmen of the Federal Reserve, i.e., Paul Volcker, Alan Greenspan, and Ben Bernanke. Evidence of the attention posed by the three of them while being members of the Federal Open Market Committee or chairmen can be easily found in a variety of official documents and accounts for that historical period, an example being the quote reported in the Introduction of this paper. A few instances follow.

In 1979, US President Jimmy Carter nominated New York Federal Reserve President Paul Volcker to become the next chairman of the Federal Reserve. This nomination was done in an

[6] Our results remain materially unchanged when dropping these zero restrictions.

attempt to regain control of inflation, which was on an upward trajectory. At the same time, there was concern about the US dollar, which had lost 12 percent of its value against major foreign currencies since late 1976.[7] In the hearing before the Committee on Banking, Housing, and Urban Affairs of the US Senate (Ninety-Sixth Congress, First Session, July 30, 1979), the soon-to-be Federal Reserve chairman Paul Volcker stated:

> *"I have spoken out and I expect to continue to speak out on the need for stability, broadly conceived — thinking of it in terms of our domestic inflation, thinking of it in terms of the value of the dollar internationally. I speak out of a very strong conviction that this sense of stability is necessary in order to assure the prosperity and growth of our economy at home and to deal with those problems of unemployment, poverty and all the others. I don't think we can build on a sense of instability—accelerating inflation, instability of the dollar abroad —if we want to deal constructively with those problems of the domestic economy."*

Volcker was put under pressure by his peers right after his appointment. As reported by The Atlantic (October 30, 2018):

> *"Two months into his new job, Volcker attended a conference of central bankers in Belgrade and was shocked to find himself harangued by his peers. As he explains in his memoir, German Chancellor Helmut Schmidt, who was a friend, lectured Volcker for almost an hour "about waffling American policymakers who had let inflation run amok and undermined confidence in the dollar." A shaken Volcker cut his trip short, got his fellow Fed members on board, and called an unusual evening press conference. Most dramatically, he stressed that he was shifting his key policy tool to monetarism. As a hedge, he also raised the Fed's discount rate by a full point".*

Alan Greespan was also explicit on the need of tracking the stance of the US dollar and the influence that a depreciation of the US currency could have on the US monetary policy. In his remarks before the Banco de Mexico's 80th Anniversary International Conference (Mexico City, November 14, 2005), he stated:

> *"What could be the potential consequences should the dollar's status as the world's reserve currency significantly diminish, especially if foreign investors reduce their rate of accumulation of claims on U.S. residents? Most analysts would contend that U.S. interest rates were lowered by the world's accumulation of dollars. Accordingly, in the*

[7] For an account of that period, see https://www.federalreservehistory.org/essays/anti-inflation-measures.

event of a significant diminishing of the dollar's reserve currency status, U.S. interest rates would presumably rise."

Could a weakening of the US dollar pose a problem in terms of inflation and, therefore, the US policy conduct? Ben Bernanke offered his view on this topic in his remarks on the economic outlook at the International Monetary Conference held in Barcelona on June 3, 2008:

> *"In collaboration with our colleagues at the Treasury, we continue to carefully monitor developments in foreign exchange markets. The challenges that our economy has faced over the past year or so have generated some downward pressures on the foreign exchange value of the dollar, which have contributed to the unwelcome rise in import prices and consumer price inflation. We are attentive to the implications of changes in the value of the dollar for inflation and inflation expectations and will continue to formulate policy to guard against risks to both parts of our dual mandate, including the risk of an erosion in longer-term inflation expectations."*

In our view, these quotes are consistent with our identification restriction that imposes a positive response of the policy rate to a US dollar depreciation. We corroborate further this modeling choice with a discussion of the extant literature on the empirical evidence of the systematic response of monetary policy to exchange rate fluctuations.

Exchange rates and Taylor rules: Empirical evidence. US monetary policy is often modeled with Taylor rules responding to inflation and real activity. The literature dealing with the systematic policy response of the Federal Reserve to exchange rates is scant, and results are mixed. Chadha, Sarno, and Valente (2005) estimate Taylor rules for the US economy and find evidence of a systematic response of the Federal Reserve to exchange rate fluctuations. This evidence is not limited to the US. Lubik and Schorfheide (2007) find evidence in favor of a systematic policy response to exchange rates for the Bank of Canada and the Bank of England, while Alstadheim, Bjørnland, and Maih (2021) find evidence if favor of policy response to exchange rates in Canada, Australia, and New Zealand.

It has to be noted that not all empirical estimates in the extant literature point to a systematic policy response to fluctuations in the exchange rate by the Federal Reserve or other central banks. For instance, Lubik and Schorfheide (2005) estimate a two-country forward-looking microfounded DSGE model with US and Euro area data and find evidence in favor of a systematic response for neither economy. Similar evidence for the Euro area is found by Adolfson, Laséen, Lindé, and Villani (2007). Is this evidence necessarily inconsistent with the presence of the exchange rate in the central bank's feedback function? To the extent that transmission lags are a real-world characteristic and are captured by VAR models, the presence of the exchange rate in the "contemporaneous-looking" policy equation of our VAR may very well proxy concerns for future inflation the Federal Reserve may have responded to, which are fully consistent with the quotes reported above. Hence, another interpretation of the sign on the exchange rate policy coefficient we work with is that of a sign regulating policymakers' response to expected inflation - for an elaboration on this point, see Taylor (2001).

Before turning to our empirical results, a consideration is in order. While the narrative accounts and the literature reported and cited above are meant to offer a rationale for imposing a systematic policy easing in response to a depreciation of the US dollar, nothing is imposed as regards: i) the magnitude of such a response (which can very well approach zero); ii) the stability of such a response over different periods. These considerations will become important later, when we analyze the Volcker vs. post-Volcker periods.

We now turn to our empirical results.

3 Results

3.1 Full sample analysis

Figure 1 plots the impulse responses obtained by implementing our identification strategy in our VAR analysis.[8] Let us focus on the response of the real exchange rate first. Such a response suggests an immediate appreciation followed by a gradual, persistent depreciation. This response is exactly what the Dornbusch (1976) model predicts, i.e., an immediate appreciation of the US dollar in response to a monetary policy shock (an unexpected tightening) followed by a persistent depreciation. Notably, this evidence is based on the same dataset and reduced-form VAR model employed by Kim, Moon, and Velasco (2017), who find a delayed response of the real exchange rate, i.e., a delayed overshooting puzzle. We elaborate later on the differences and implications between our identification strategy and theirs.

Back to Figure 1, we note standard responses of domestic variables in response to a US monetary policy shock, i.e., a temporary but persistent deflation and an delayed peak effect on industrial production, whose impulse response follows a well-known hump-shape. Nonborrowed reserves react negatively to an unexpected hike in the short-term interest rate, a response in line with the well-known liquidity effect. RoW's short-term interest rate displays a temporary increase, a response potentially consistent with the uncovered interest parity condition. World real activity's response is uncertain. A possible interpretation is that of confounding factors

[8]For the sake of brevity, we focus in the paper on the evidence obtained with the AGG dataset. Our results are fully confirmed when working with the AGG98 dataset - evidence available in our Appendix.

behind the response of world industrial production, with US domestic output and RoW's interest rate exerting contractionary pressures on the one hand, and the appreciation of the US dollar improving RoW's net exports and, therefore, the business cycle on the other hand.

Our identification strategy imposes signs on the policy response to prices, industrial production, and the real exchange rate, but it is silent on the magnitude of such coefficients. Table 1 collects the posterior median estimates and the 68% credible sets. The coefficients reported at the top of the Table - those related to the entire sample - put in evidence that there is a large mass of realizations of the policy coefficient related to exchange rate fluctuations that suggests a non-negligible attention posed by the Federal Reserve on fluctuations in the US dollar. But how crucial is the restriction $\psi_{rex} > 0$ for our results? Figure 2 shows the impulse responses we obtain if we drop such a restriction all else being equal. The response of the real exchange rate becomes very uncertain, and it is not possible to exclude a nil relative effect on the US dollar vs. other countries' currencies. Obviously, this result is not at all in line with Dornbusch's (1976) overshooting hypothesis, and it is at odds with most of the evidence in the extant literature on the significant effects exerted by monetary policy shocks on the exchange rate. This sensitivity check, joint with the narrative and empirical evidence discussed above, leads us to retain the restriction on the exchange rate.

3.2 Is Volcker responsible for the delayed overshooting puzzle?

Kim, Moon, and Velasco (2017) document a novel empirical fact, i.e., they find the real exchange rate to display a delayed overshooting just during the Volcker era. This result is appealing, because it can be connected with the different systematic policy behavior often detected in US data when moving from a policy regime to another (see, e.g., Clarida, Galí, and Gertler (2000), Lubik and Schorfheide (2004), Boivin and Giannoni (2006), and Benati and Surico (2009)). Kim, Moon, and Velasco (2017) achieve identification of the US monetary policy shock by working with a standard identification strategy based on restrictions on impulse responses (IRF-restrictions only henceforth). The monetary policy shock is identified by imposing restrictions à la Uhlig (2005) on the responses of the policy rate (which has to go up) and prices, industrial production, and the nonborrowed/total reserves ratio (which all have to go down) over the first year after the shock.[9]

In the light of our discussion above on the attention paid by US policymakers to the fluctuations of the US dollar, it is of interest to unveil what the IRF-restrictions only strategy implies

[9]Following Kim, Moon, and Velasco (2017), these restrictions are imposed for horizons zero to eleven, i.e., one year. Differently, the restrictions of our proposed identification strategy are imposed just contemporaneously.

for the systematic policy response to exchange rate movements. Moreover, it is also of interest to check the solidity of our own findings - supportive of the overshooting hypothesis - to changes in the investigated samples associated with different policy regimes. We then estimate the very same reduced-form VAR over three different samples: full sample (1976M1-2007M7); Volcker sample (1979M8-1997M12); and post-Volcker sample (1998M1-2007M7). Given that the data, reduced-form VAR, and investigated samples are the same, differences in the impulse responses arising from the two different identification strategies employed here will naturally be driven by differences in the identification strategies at work.

Figure 3 plots the impulse responses of the exchange rate across the three different samples and over the two different identification strategies. The right column replicates the evidence documented by Kim, Moon, and Velasco (2017), i.e., samples containing Volcker-related observations are associated with evidence of a delayed overshooting puzzle, with the peak response of the exchange rate materializing after more than two years. Moving to the post-Volcker era, the response of the exchange rate is characterized by a strong, immediate appreciation of the exchange rate followed by a depreciation. Differently, our identification strategy points to a robust support of the overshooting hypothesis across the three investigated periods. Hence, a conclusion can be drawn here, i.e., these two different identification strategies imply a different description of the exchange rate dynamics after an unexpected increase in the US policy rate. Intriguingly, such a difference disappears when the post-Volcker era only is considered. In fact, the exchange rate impulse response produced via our proposed identification strategy is basically the same response estimated by Kim, Moon, and Velasco (2017).

As anticipated above, it is of interest to look at the estimates of the policy coefficients implied by the IRF-restrictions only identification strategy. Table 2 reports such coefficients. It is easy to notice that the two samples contaminated by the Volcker-related observations (entire period, Volcker era) are characterized by a negative median response to the real exchange rate, with a substantial mass in the negative territory as per the 68% credible set. This description of the US policy reaction function to exchange rate fluctuations is obviously in contrast with the narrative and empirical evidence discussed above.[10] Differently, the post-Volcker era is characterized by a positive median policy response to the exchange rate, with a negligible mass in the negative territory according to the 68% credible set. This finding offers a structural interpretation to the different evidence on the delayed overshooting puzzle (or the lack thereof) documented by Kim, Moon, and Velasco (2017) and our paper.

What is the contribution of a monetary policy shock for the volatility of the real exchange

[10]This evidence is robust to: i) setting to zero the policy coefficients that regulate the systematic response to foreign output, interest rate, and the nonborrowed/total reserves ratio; ii) imposing a negative sign to the on-impact response of industrial production to a monetary policy shock.

rate? According to our baseline model (which predicts an on-impact maximum response of the exchange rate), such a contribution is indeed regime-dependent, with a peak volatility within a six-month horizon equal to 13.5 percent for the full period, 8 percent for the Volcker period, and 22.3 percent post-Volcker. Interestingly, and conditional on the "short-run" (horizons ranging from 0 to six months), these figures are larger than those one obtains via Kim et al.'s (2017) identification strategies when Volcker's observations are accounted for - 6.3 percent (full sample) and 5 percent (Volcker period) -, while we get basically the same figure obtained with our baseline model for the post-Volcker sample (23 percent). This last finding confirms that the restriction on the systematic policy response to the exchange rate is less crucial when the Volcker observations are dropped. This evidence squares well the finding in Wolf (2020, 2022) on the identification via restrictions imposed on impulse responses being more challenging when the contribution of the shock one is after to the volatility of the variable of interest is lower. Finally, and in line with Kim et al.'s (2017) delayed-overshooting evidence, the peak contributions to the volatility of the real exchange rate by monetary policy shocks we obtain when replicating their results occur after about 5 years, and are estimated to be about 10 percent both for the Volcker-only sample and for the entire period.

Our results on the exchange rate response to a US monetary policy shock identified with our novel identification strategy are robust to the following changes of our baseline framework (evidence documented in our Appendix for brevity): i) forcing the response of foreign output to be negative on impact; ii) modeling prices and industrial production (both domestic and foreign) in growth rates; iii) adding the excess bond premium proposed (EBP) by Gilchrist and Zakrajšek (2012) to the vector and imposing a positive response of EBP to a monetary policy shock; iv) replacing the real exchange rate with its nominal counterpart. (Note: The correlation between the real and the nominal exchange rate in our sample is 0.77. When replacing the real exchange rate with its nominal counterpart, impulse responses remain basically the same (evidence available in our Appendix, which is under construction.) This last exercise enables us to verify if a conditional UIP is in place. This is what we scrutinize in the next Section.

4 Conditional UIP: Does it hold when policy coefficient restrictions are imposed?

Kim, Moon, and Velasco (2017) document the empirical failure of the UIP during the Volcker era but not post-Volcker conditional on their identification of US monetary policy shock. As documented in the previous Section, our identification of monetary policy shocks leads us to different impulse responses, above all during the Volcker regime. Does this imply a different conclusion regarding the existence in the data of a conditional UIP? We plan to address this question by investigating if different identification strategies lead to different empirical support for the conditional UIP. [to be continued]

5 Conclusions

This paper has proposed a novel identification strategy to pin down the response of the US real exchange rate to a monetary policy shock. Such a strategy involves restrictions on the policy coefficients and on the dynamic reaction of selected macroeconomic indicators to an unexpected hike in the policy rate. Among the restrictions imposed on policy coefficients, a crucial one is that requiring the Federal Reserve to implement a policy tightening following a depreciation of the US dollar. We offer narrative evidence supporting such a restriction and discuss the extant literature that has dealt with open economy models and policy rules featuring exchange rates. Then, we put our identification strategy at work and model a set of standard macroeconomic indicators with a Bayesian vector autoregressive framework.

Our main findings support Dornbusch's (1976) overshooting hypothesis, i.e., we document an immediate appreciation of the US dollar followed by a gradual, persistent depreciation. This finding is robust to the employment of different samples, including those affected by observations related to the Volcker disinflation. Differently, a more traditional identification strategy based on restrictions on impulse responses only returns evidence of a delayed overshooting puzzle when the Volcker regime is part of the analyzed samples. Digging deeper, we unveil that this latter evidence is due to the implications of this more traditional identification strategy for the policy coefficient capturing the systematic policy response to exchange rate movements, i.e., restrictions on the impulse responses do not necessarily imply a policy tightening in responses to a depreciation of the domestic currency. Wrapping up, our identification strategy returns a response of the exchange rate that is robust across different samples and supportive of the standard overshooting mechanism.

Our results are relevant for policymakers and modelers. Policy-wise, our results suggests that monetary policy shocks may indeed induce high short-run volatility in the exchange rate markets, a finding that supports research on the optimal monetary policy conduct in presence of external pressures. From a modeling standpoint, our results suggest that mechanisms generating expectations of a quick depreciation following an on-impact appreciation can still represent relevant references to build up empirically credible micro-founded open economy frameworks.

An extension of this analysis to the forward discount puzzle is in our agenda.

References

Adolfson, M., S. Laséen, J. Lindé, and M. Villani (2007): "Bayesian estimation of an open economy DSGE model with incomplete pass-through," *Journal of International Economics*, 72, 481–511.

Alstadheim, R., H. C. Bjørnland, and J. Maih (2021): "Do central banks respond to exchange rate movements? A Markov-switching structural investigation of commodity exporters and importers," *Energy Economics*, 96(105138).

Arias, J. E., D. Caldara, and J. Rubio-Ramírez (2019): "The Systematic Component of Monetary Policy in SVARs: An Agnostic Identification Procedure," *Journal of Monetary Economics*, 101, 1–13.

Bacchetta, P., and E. van Wincoop (2021): "Puzzling exchange rate dynamics and delayed portfolio adjustment," *Journal of International Economics*, 131(103460).

Benati, L., and P. Surico (2009): "VAR Analysis and the Great Moderation," *American Economic Review*, 99(4), 1636–1652.

Bjørnland, H. C. (2009): "Monetary policy and exchange rate overshooting: Dornbusch was right after all," *Journal of International Economics*, 79, 64–77.

Bjørnland, H. C., and L. A. Thorsrud (2015): Applied Time Series for Macroeconomics, Gyldendal Norsk Forlag.

Boivin, J., and M. Giannoni (2006): "Has Monetary Policy Become More Effective?," *Review of Economics and Statistics*, 88(3), 445–462.

Candian, G. (2019): "Information frictions and real exchange rate dynamics," *Journal of International Economics*, 116, 189–205.

Chadha, J. S., L. Sarno, and G. Valente (2005): "Monetary Policy Rules, Asset Prices, and Exchange Rates," *IMF Staff Papers*, 51(3), 529–552.

Chari, V., P. J. Kehoe, and E. R. McGrattan (2002): "Can Sticky Price Models Generate Volatile and Persistent Real Exchange Rates?," *Review of Economic Studies*, 69(3), 533–563.

Clarida, R., J. Galí, and M. Gertler (2000): "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory," *Quarterly Journal of Economics*, 115, 147–180.

Cushman, D. O., and T. Zha (1997): "Identifying Monetary Policy in a Small Open Economy under Flexible Exchange Rates," *Journal of Monetary Economics*, 110, 433–448.

Degasperi, R., S. S. Hong, and G. Ricco (2021): "The Global Trasnmission of US Monetary Policy," University of Warwick and OFCE-SciencesPo, mimeo.

Doko Tchatoka, F., Q. Haque, and M. Terrell (2022): "Monetary policy shocks and exchange rate dynamics in small open economies," University of Adelaide and Reserve Bank of Australia, mimeo.

Dornbusch, R. (1976): "Expectations and exchange rate dynamics," *Journal of Political Economy*, 84, 1161–1176.

Eichenbaum, M., and C. L. Evans (1995): "Some Empirical Evidence on the Effects of Shocks to Monetary Policy on Exchange Rates," *Quarterly Journal of Economics*, 110, 975–1009.

Faust, J., and E. M. Leeper (1997): "When Do Long-Run Identifying Restrictions Give Reliable Results?," *Journal of Business and Economic Statistics*, 15(3), 345–353.

Faust, J., and J. H. Rogers (2003): "Monetary Policy's Role in Exchange Rate Behavior," *Journal of Monetary Economics*, 50, 1403–1424.

Gilchrist, S., and E. Zakrajšek (2012): "Credit Spreads and Business Cycle Fluctuations," *American Economic Review*, 102(4), 1692–1720.

Gourinchas, P., and A. Tornell (2004): "Exchange rate puzzles and distorted beliefs," *Journalof International Economics*, 64(2), 303–333.

Grilli, V., and N. Roubini (1996): "Liquidity Models in Open Economies: Theory and Empirical Evidence," *European Economic Review*, 40, 847–859.

Groshenny, N., and N. Javed (2022): "The systematic component of monetary policy and the exchange rate puzzles: New evidence fromsmall open economy SVARs," University of Le Mans and University of Adelaide, mimeo.

Hansen, L. P., and R. J. Hodrick (1983): "Risk Averse Speculation in the Forward Foreign Exchange Market: An Econometric Analysis of Linear Models," in: Jacob A. Frenkel (Ed.): Exchange Rates and International Macroeconomics, University of Chicago Press, Chicago, 113–152.

Itskhoki, O., and D. Mukhin (2021): "Exchange Rate Disconnect in General Equilibrium," *Journal of Political Economy*, 129(8), 2183–2232.

Kim, S., and N. Roubini (2000): "Exchange Rate Anomalies in the Industrial Countries: A Solution with a Structural VAR Approach," *Journal of Monetary Economics*, 45, 561–586.

Kim, S.-H., S. Moon, and C. Velasco (2017): "Delayed Overshooting: Is It an '80s Puzzle?," *Journal of Political Economy*, 125(5), 1570–1598.

Leeper, E. M., C. A. Sims, and T. Zha (1996): "What Does Monetary Policy Do?," *Brookings Papers on Economic Activity*, 2, 1–63.

Lubik, T., and F. Schorfheide (2004): "Testing for Indeterminacy: An Application to U.S. Monetary Policy," *American Economic Review*, 94(1), 190–217.

Lubik, T., and F. Schorfheide (2005): "A Bayesian Look at New Open Economy Macroeconomics," in: Mark Gertler and Kenneth Rogoff (Eds.): NBER Macroeconomics Annual, University of Chicago Press, Chicago(20(5)), 313–366.

——— (2007): "Do central banks respond to exchange rate movements? A structural investigation," *Journal of Monetary Economics*, 54(4), 1069–1087.

Miranda-Agrippino, S., and H. Rey (2020): "US Monetary Policy and the Global Financial Cycle," *Review of Economic Studies*, 87(6), 2754–2776.

Miranda-Agrippino, S., and G. Ricco (2021): "The Transmission of Monetary Policy Shocks," *American Economic Journal: Macroeconomics*, 13(3), 74–107.

Müller, G. J., M. Wolf, and T. Hettig (2021): "Delayed Overshooting: The Case for Information Rigidities," University of T
bingen and University of St. Gallen, mimeo.

Read, M. (2022): "Estimating the Effects of Monetary Policy in Australia Using Sign-Restricted Structural Vector Autoregressions," Reserve Bank of Australia Discussion Paper, September.

Rüth, S. K. (2020): "Shifts in monetary policy and exchange rate dynamics: Is Dornbusch's overshooting hypothesis intact, after all?," *Journal of International Economics*, 126, 103344.

Rüth, S. K., and W. Van der Veken (2022): "Monetary Policy and Exchange Rate Anomalies in Set-Identified SVARs: Revisited," University of Erfurt and University of Ghent, mimeo.

Scholl, A., and H. Uhlig (2008): "New evidence on the puzzles: Results from agnostic identification on monetary policy and exchange rates," *Journal of International Economics*, 76, 1–13.

Steinsson, J. (2008): "The Dynamic Behavior of the Real Exchange Rate in Sticky Price Models," *American Economic Review*, 98(1), 519–533.

Taylor, J. B. (2001): "The Role of the Exchange Rate in Monetary-Policy Rules," *American Economic Review*, 91(2), 263–267.

Uhlig, H. (2005): "What Are the Effects of Monetary Policy? Results from an Agnostic Identification Procedure," *Journal of Monetary Economics*, 52, 381–419.

Wolf, C. K. (2020): "SVAR (Mis-)Identification and the Real Effects of Monetary Policy," *American Economic Journal: Macroeconomics*, 12(4), 1–32.

——— (2022): "What Can We Learn from Sign-Restricted VARs?," *American Economic Review Papers Proceedings*, 112, 471–475.

Entire period			
Coefficient	ψ_y	ψ_p	ψ_{rex}
Median	1.06	2.09	0.19
68% Prob. Interval	[0.55;2.25]	[0.86;4.95]	[0.05;0.68]
Volcker era			
Coefficient	ψ_y	ψ_p	ψ_{rex}
Median	1.10	2.03	0.21
68% Prob. Interval	[0.60;2.26]	[0.70;5.42]	[0.05;0.71]
Post-Volcker era			
Coefficient	ψ_y	ψ_p	ψ_{rex}
Median	0.69	0.88	0.13
68% Prob. Interval	[0.27;2.17]	[0.28;3.35]	[0.03;0.52]

Table 1: **Identification via policy coefficient-restrictions (this paper's identification strategy): Policy coefficients, estimates**. Identification strategy based on our proposed combination of restrictions imposed on policy coefficients and on-impact impulse responses, i.e., the requirement of positive (zero) contemporaneous policy coefficients related to prices, industrial production, and the exchange rate (foreign industrial production and foreign policy rate) in the VAR policy equation plus the requirement of an on-impact positive (negative) response of the policy rate (of prices, industrial production, and the nonborrowed/total reserves ratio) to a monetary policy shock. Samples: Entire period: 1976M1-2007M7; Volcker era: 1979M8-1987M12; post-Volcker era: 1988M1-2007M7.

Entire period						
Coefficient	ψ_y	ψ_p	ψ_{rex}	ψ_{y^*}	ψ_{i^*}	ψ_{nbrx}
Median	0.17	1.83	-0.03	0.18	1.01	0.03
68% Prob. Interval	[-1.14;1.45]	[-5.39;6.60]	[-0.43;0.32]	[-0.70;1.05]	[-3.62;5.02]	[-1.00;0.84]
Volcker era						
Coefficient	ψ_y	ψ_p	ψ_{rex}	ψ_{y^*}	ψ_{i^*}	ψ_{nbrx}
Median	-0.19	1.40	-0.09	0.10	-0.59	-0.13
68% Prob. Interval	[-1.66;1.83]	[-5.40;6.32]	[-0.53;0.37]	[-0.95;1.00]	[-4.72;4.54]	[-0.84;0.42]
Post-Volcker era						
Coefficient	ψ_y	ψ_p	ψ_{rex}	ψ_{y^*}	ψ_{i^*}	ψ_{nbrx}
Median	0.23	0.38	0.06	-0.09	0.94	0.18
68% Prob. Interval	[-0.01;0.61]	[0.10;1.11]	[-0.01;0.21]	[-0.38;0.04]	[0.26;1.99]	[0.04;0.55]

Table 2: **Identification via impulse response function-restrictions only: Policy coefficients, estimates**. Identification strategy based on the requirement of a positive (negative) response of the policy rate (of prices, industrial production, and the nonborrowed/total reserves ratio) to a monetary policy shock for the entire first year after the shock. Samples: Entire period: 1976M1-2007M7; Volcker era: 1979M8-1987M12; post-Volcker era: 1988M1-2007M7.

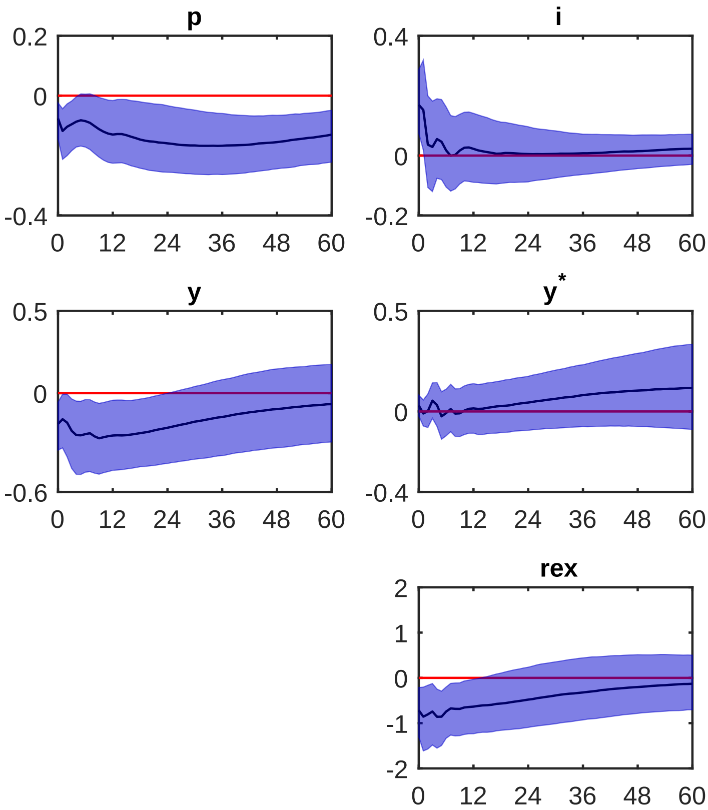

Figure 1: **Identification via policy coefficient-restrictions (this paper's identification strategy): Impulse responses**. Size of the shock: One-standard deviation. Identification strategy based on our proposed combination of restrictions imposed on policy coefficients and on-impact impulse responses, i.e., the requirement of positive (zero) contemporaneous policy coefficients related to prices, industrial production, and the exchange rate (foreign industrial production and foreign policy rate) in the VAR policy equation plus the requirement of an on-impact positive (negative) response of the policy rate (of prices, industrial production, and the nonborrowed/total reserves ratio) to a monetary policy shock.

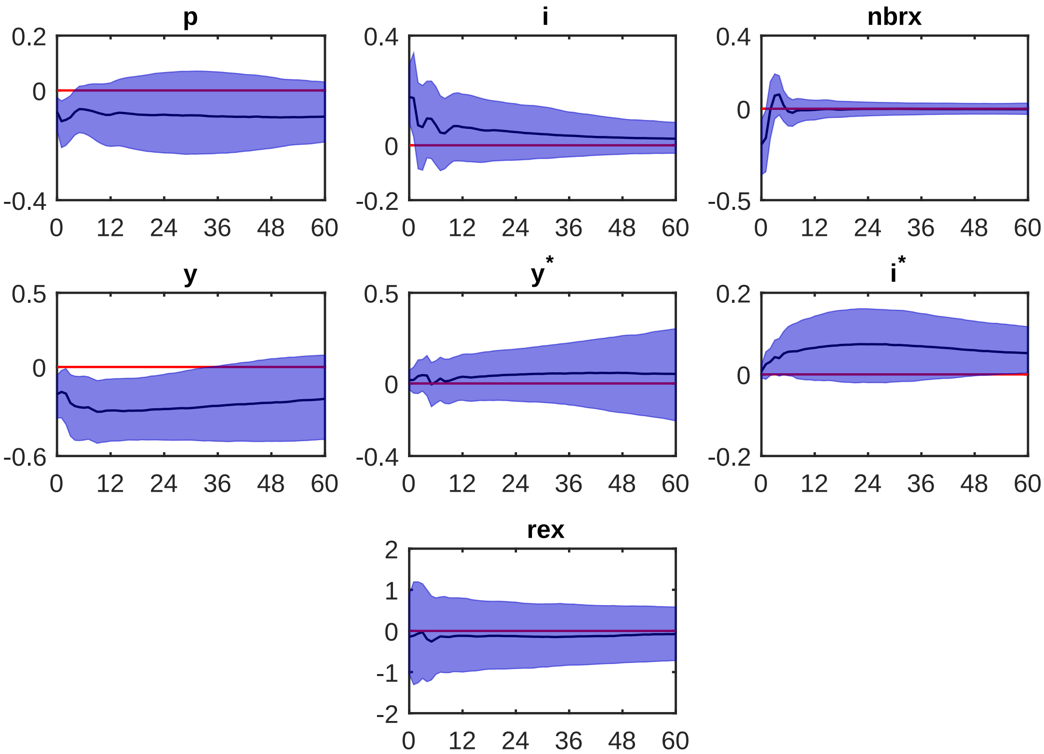

Figure 2: **Identification via policy coefficient-restrictions (this paper's identification strategy): Impulse responses, role of the policy coefficient-restriction on the exchange rate**. Identification strategy based on our proposed combination of restrictions imposed on policy coefficients and on-impact impulse responses, i.e., the requirement of positive (zero) contemporaneous policy coefficients related to prices and industrial production (foreign industrial production and foreign policy rate) in the VAR policy equation plus the requirement of an on-impact positive (negative) response of the policy rate (of prices, industrial production, and the nonborrowed/total reserves ratio) to a monetary policy shock. Policy restriction on the exchange rate (imposed in the baseline exercise) not imposed here.

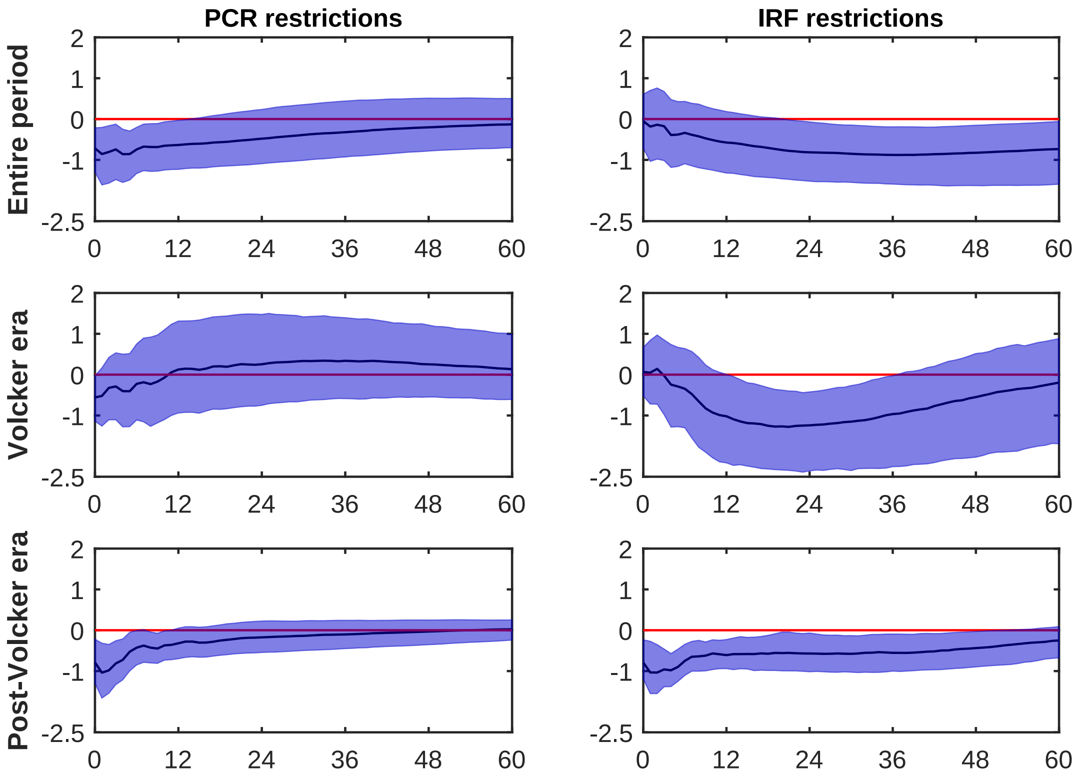

Figure 3: **Identification via policy coefficient-restrictions (this paper's identification strategy, which also includes restrictions on impulse responses) vs. via impulse response-constraints only: Impulse responses across different periods**. Impulse responses plotted above refer to the real exchange rate. Left column: Identification strategy based on our proposed combination of restrictions imposed on policy coefficients and on-impact impulse responses, i.e., the requirement of positive (zero) contemporaneous policy coefficients related to prices, industrial production, and the exchange rate (foreign industrial production and foreign policy rate) in the VAR policy equation plus the requirement of an on-impact positive (negative) response of the policy rate (of prices, industrial production, and the nonborrowed/total reserves ratio) to a monetary policy shock. Right column: Identification strategy based on restrictions over the first twelve horizons of the impulse responses of the policy rate (which has to go up), the price level (down), and the nonborrowed/total reserves ratio (down). Samples: Entire period: 1976M1-2007M7; Volcker era: 1979M8-1987M12; post-Volcker era: 1988M1-2007M7.