University of Heidelberg

Department of Economics

Discussion Paper Series | No. 673

Shifts in Monetary Policy and Exchange Rate Dynamics: Is Dornbusch's Overshooting Hypothesis Intact, After All?

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November 2019

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November 11, 2019

Abstract

How do nominal exchange rates adjust after surprise contractions in monetary policy? While the seminal contribution by Dornbusch provides concise predictions—exchange rates appreciate, i.e., overshoot on impact before depreciating gradually—empirical support for his hypothesis is at best mixed. I argue that the failure to discover overshooting may result from assumptions researchers have imposed to recover structural VARs. Specifically, simultaneous feedback effects between interest rates and exchange rates, which are inherently forward-looking variables, are often excluded or modeled alongside with strong restrictions. In this paper, I identify U.S. monetary policy shocks using surprises in Federal funds futures around policy announcements as external instruments, which recent literature has established to represent the appropriate laboratory in settings encompassing macroeconomic and financial variables. Resulting adjustments of the dollar, conditional on shifts in policy, generally align with Dornbusch's predictions during the post-Bretton-Woods era, including Volcker's tenure as Fed Chair.

Keywords: Nominal exchange rate, monetary policy shock, external instrument, structural vector autoregression.
JEL codes: E44, E52, F31, F41.

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1 Introduction

What is the transmission mechanism of a monetary policy tightening in the open economy? In a nutshell, the answer to this question by Dornbusch (1976) reads as follows: (i) the central bank brings about a surprise hike of interest rates; by doing so, (ii) a positive interest differential relative to other countries arises, (iii) inducing exchange rates to appreciate instantaneously, followed by (iv) gradual depreciation. Building on a combination of uncovered interest parity, purchasing-power parity, and liquidity effects, the so-called '*exchange rate overshooting*' hypothesis ranges among the most important concepts in the history of international economics and finance (see Rogoff, 2002).[1] Paying tribute to Dornbusch's hypothesis, the literature has termed any empirical failure to discover overshooting in reference to his concept. Roughly speaking, departures are documented along three dimensions: qualitatively (*exchange rate puzzle*), quantitatively (*forward discount puzzle*), and in terms of timing (*delayed overshooting*). Using a Vector autoregressive (VAR) model that is identified by external instruments, I provide fresh causal evidence for U.S. monetary policy shocks during the post-Bretton-Woods era that aligns with Dornbusch (1976), along all three dimensions.

Since its first formulation, which closely coincides with the transition of several industrialized countries from fixed to flexible exchange rate regimes, Dornbusch's theory has been put to empirical tests largely within the VAR framework ever since.[2] While VARs have been shown to summarize and forecast macroeconomic and financial data quite well, drawing structural inference from them to make an economic interpretation feasible, requires further restrictions. By using different assumptions to solve the identification challenge, researchers have produced rather mixed results when it comes to the vital question on how monetary policy impacts exchange rates.

A large body of existing empirical evidence, initiated by Eichenbaum and Evans (1995) and Grilli and Roubini (1996), is based on recursive schemes that recover the structural form by translating reduced form VAR residuals into orthogonal innovations via a Cholesky-factorization of the variance-covariance matrix (see recently Hnatkovska et al., 2016). The economic reasoning for this strategy is the perception that macroeconomic variables display a contemporaneous zero-elasticity with

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[1] Obstfeld and Rogoff (1996) provide a textbook treatment of exchange rate overshooting.

[2] In the class of dynamic stochastic general equilibrium models, augmented to speak to open economy issues, there is a widespread account of UIP and overshooting (e.g., Kollmann, 2001); these models are frequently used to inform policy. Notwithstanding, there is a growing literature that considers departures from overshooting as stylized facts and formulates this notion in theoretical models (e.g., Bacchetta and van Wincoop, 2010; Burnside et al., 2011; Hettig et al., 2019).

respect to the policy instrument. Within the recursive setting, another restriction needs to be imposed: either the policy rate does not simultaneously affect exchange rates or it is not allowed to respond to the latter, on impact. As exchange rates are inherently-forward looking time-series that are determined in flexible and highly-liquid markets, modeling their interplay with interest rates in such a way appears to be controversial.[3] The so-identified shocks are in essence a mixture of policy shocks and endogenous responses to, e.g., exchange rates. Overall, recent literature cautions against the recursive approach in VARs that model both, macroeconomic and financial variables (Gertler and Karadi, 2015; Caldara and Herbst, 2019).

As an appealing alternative to allow for a meaningful contemporaneous interplay between exchange rates and interest rates, several studies abandon zero-restrictions by replacing them with sign-restrictions on impulse response functions that identify their VARs (see Faust and Rogers, 2003; Scholl and Uhlig, 2008; Kim et al., 2017; Schmitt-Grohé and Uribe, 2018). These approaches usually come out in favor of violations of overshooting or conditional UIP. Albeit relaxing the simultaneous link of financial variables in the VAR, sign-restrictions approaches need to resort to otherwise sharp assumptions about the qualitative repercussions of monetary policy shocks. Typically, these assumptions involve restrictions on the impulse responses of interest rates and prices, and often of economic activity or monetary aggregates, for a bandwidth of post-shock horizons.

Recent literature, yet, has established that our understanding of the monetary policy pass-through—if studied by sign-restricted VARs—may still be far from a consensus, even in closed economy settings. For instance, Baumeister and Hamilton (2015) critically assess how sign-restrictions are commonly implemented, and Baumeister and Hamilton (2018) demonstrate how doubts about identification assumptions should be accounted for; which, as they show, crucially affects the ramifications of monetary policy shocks. Building on methodological progress of Arias et al. (2018), Arias et al. (2019) impose sign- *and* zero-restrictions on the monetary policy rule in their VAR and challenge the seminal work of Uhlig (2005). In particular, they question his finding of an output expansion conditional on a tightening of policy; which, notably, can also be observed in the open economy setting of Kim et al. (2017), who follow Uhlig's lead. Put together, although sign-restrictions may constitute an attractive avenue to study exchange rate dynamics, against the back-

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[3] Bjørnland (2009) shows that shifting around zero-restrictions within a recursive VAR—by rotating exchange and interest rates—may still mask true underlying shocks. A similar reasoning applies to semi-structural VARs or local-projections that use narrative shocks and maintain the recursiveness assumption (Ramey, 2016). Related, Kim and Roubini (2000) find support for overshooting without relying on a full recursive scheme, yet, they still resort to zero-restrictions.

drop of the ongoing debate on how to properly impose such restrictions, alternative identification strategies may be desirable to complement these studies and to help expanding our knowledge about the open economy pass-through of monetary policy.

Another strand of research uses high-frequency financial markets data to study the effects of monetary policy actions, measured as surprise components in asset prices (see Kuttner, 2001; Gürkaynak et al., 2005; Hamilton, 2008). These event studies typically document large *contemporaneous* repercussions of monetary policy on financial variables. In this vein, Glick and Leduc (2018) study the effects of unconventional monetary policy on exchange rates and estimate large coefficients. Overall, these high-frequency approaches are silent on the ramifications of shocks over time, which are at the heart of the overshooting hypothesis.[4]

In this study, I combine the advantages of the high-frequency and VAR approaches, as in Gertler and Karadi (2015), by using the external instruments augmented VAR (SVAR-IV) framework of Stock and Watson (2012) and Mertens and Ravn (2013) to identify monetary policy shocks and to track their causal effect on foreign exchange rates. I employ financial markets data as 'proxies' for U.S. monetary policy innovations, which I measure as Federal funds futures surprises observed around Fed announcements. Contrasting the narrative identification approach of, e.g., Romer and Romer (2004), the SVAR-IV model perceives the instrument as a noisy signal of the true underlying shock and thus accounts for measurement error. Contrasting the zero- and sign-restricted identification schemes, information about shocks is directly derived from forecasts of market participants who rely on a plethora of sources to form expectations. Conditional on the instrument-selection, the SVAR-IV model does not necessitate assumptions about the structural form, i.e., the identifying restrictions are data-determined. Importantly, this strategy *allows for a full contemporaneous interplay between all variables in the system*. To draw inference, I rely on recent progress of Montiel Olea et al. (2018) to calculate asymptotically valid confidence sets and to test the strength of the instrument, which turns out to be 'strong' (see Caldara and Herbst, 2019, for a Bayesian treatment).

I estimate a VAR for the U.S. economy at the monthly frequency; the sample period starts with Volcker's tenure as Fed Chair in July 1979 and ends before the on-

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[4] In a high-frequency setting, Inoue and Rossi (2019) propose a novel identification for monetary policy shocks; the latter are understood as multidimensional objects operating via the entire yield curve. They maintain the recursiveness structure for yields and exchange rates to trace dynamic adjustments, and document evidence in favor of overshooting for selected policy actions. However, comparison with existing VARs is complicated as they (i) focus on the pass-through within one month and hence do not speak to horizons usually considered, (ii) do not inspect or control for macroeconomic aggregates, and (iii) study conceptually very different shocks.

set of the zero-lower-bound episode in September 2008. Identified via Federal funds futures surprises, a 25 basis point policy tightening delivers adjustment patterns, consistent with studies employing similar methods. Most notably, for a basket of the ten largest trade partners of the U.S., nominal exchange rates significantly appreciate on impact and reach their maximum reaction of one percent in the second month after the shock, before gradually depreciating. This finding corroborates the overshooting hypothesis and further emerges for bilateral exchange rates, for an even broader exchange rate index capturing 15 economies, and for real exchange rates. In addition, the causal evidence on overshooting extends to the Great Recession episode and persists when explicitly accounting for forward guidance or when using proxies that are purged from central bank information shocks. Consistent with the prevalence of overshooting, I document that UIP generally appears to hold as well, in a conditional sense. These results for the U.S. align with Bjørnland (2009), who reports similar evidence for small open economies using zero- and long-run VAR-restrictions.

The remainder of the paper is as follows: Section 2 outlines the empirical strategy, Section 3 presents the main findings, Section 4 discusses extensions of the model, Section 5 scrutinizes the findings along several dimensions, and Section 6 concludes.

2 Empirical framework

The econometric framework I employ to trace the dynamic causal effects of monetary policy shocks over time follows a long-standing tradition of VARs pioneered by Sims (1972, 1980). While there is no major dissent about the estimation of VARs, identifying shocks that make an economic interpretation feasible, i.e., in VAR jargon recovering the structural form, necessitates additional information. To tackle the identification challenge, a growing literature initiated by Stock and Watson (2012) and Mertens and Ravn (2013) employs information from outside of the VAR, i.e., external instruments, that correlate with the shocks of interest. I follow this line of research and use the SVAR-IV methodology to recover monetary policy surprises. Section 2.1 lays out the model framework and empirical specifications. Section 2.2 discusses my identification approach and pitfalls in existing identification strategies, meant to narrow down my contribution. Section 2.3 explains the method used to construct robust confidence intervals for the objects of interest.

2.1 Vector autoregressive framework

I postulate that the joint dynamics of U.S. macroeconomic aggregates and domestic as well as foreign financial variables can be cast in a finite-order linear VAR:

$$\mathbf{Y}_t = \sum_{j=1}^{p} \mathbf{A}_j \mathbf{Y}_{t-j} + \mathbf{u_t}. \tag{1}$$

$\mathbf{Y}_t$ represents a $n \times 1$ vector of observable time-series. Omitting a vector of intercepts without loss of generality, $\mathbf{A}_j$ are $n \times n$ matrices capturing the dynamic structure of the model, for $j = 1, \ldots, p$; p constitutes the number of lagged realizations of $\mathbf{Y}_t$ included as regressors. The vector $\mathbf{u}_t$ measures one-step ahead forecast errors of the model, which have a linear mapping with the structural shocks, ε_t, of the form:

$$\mathbf{u}_t = \mathbf{B}\varepsilon_t, \tag{2}$$

where $\mathbf{B}$ is an invertible matrix that contains the simultaneous causal effects of structural shocks on the observables. The variance-covariance matrix of $\mathbf{u}_t$ reads:

$$\mathbb{E}[\mathbf{u}_t \mathbf{u}_t'] = \mathbb{E}[\mathbf{B}\mathbf{B}'] = \mathbf{\Sigma}. \tag{3}$$

The vector of observables, $\mathbf{Y}_t$, includes seven variables measured at the monthly frequency. The selection of time-series posing the core block of the VAR follows Gertler and Karadi (2015), who emphasize that for a successful identification of monetary policy shocks in the U.S., the inclusion of a measure of financial tensions, such as corporate bond spreads, is crucial. Reinforcing this line of research, Caldara and Herbst (2019) show that U.S. monetary policy systematically and simultaneously reacts to corporate credit spreads and that the failure to account for this nexus induces a severe bias for impulse response functions. Accordingly, in addition to (i) the effective Federal funds rate, meant to represent an indicator of the monetary policy stance, (ii) industrial production, (iii) a measure of the price level, I include (iv) the excess bond premium, as proposed in Gilchrist and Zakrajšek (2012). The latter has been shown to outperform other spreads in its predictive power for economic activity and represents the portion of corporate relative to government bond yield spreads that is purged from fluctuations due to default risk.[5] Gertler and Karadi (2015)

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[5] Consistent with Gertler and Karadi (2015) and Caldara and Herbst (2019), I do not include monetary aggregates, but consider them in an extension. My measure of prices is the producer price index for finished goods, as in Romer and Romer (2004) and Caldara and Herbst (2019). The latter argue that producer prices are more informative for identifying the response of prices to shifts in monetary policy relative to the CPI. In addition, producer prices more closely resemble my indicator of economic activity, for which the monthly frequency of the VAR dictates the choice of industrial production, instead of GDP. My core results are robust to using the CPI level.

use the one-year government bond rate as policy indicator; as innovations to this series also capture shifts in expectations about the future path of the Federal funds rate, they can also speak to the effects of forward guidance, which is the focus of their paper. However, in my analysis, I want to assure comparability with the more conventional ‘money shock’ VARs that are usually put to the test of exchange rate overshooting. Therefore, I include the effective Federal Funds rate in the baseline model, instead.

To study exchange rate dynamics triggered by monetary policy innovations, I add three further variables to the system that are usually stressed in open economy models of the New Keynesian type and that are included in related empirical applications (e.g., Bjørnland, 2009): (v) short-term (3-months) interest rates in the U.S., (vi) short-term rates of a foreign country (block), and (vii) the spot nominal exchange rate of the U.S. dollar vis-à-vis another country (block). For the baseline model, I construct a GDP weighted index (in PPP terms) for the exchange and foreign short-term interest rates including the ten largest trade partners of the U.S., following the methodology proposed in Scholl and Uhlig (2008).[6] My results are very similar when using the trade-weighted nominal exchange rate index for the 15 largest trade partners of the U.S., for which I also explore data on real exchange rates, as provided by the Bank for International Settlements (Section 5). In addition, I present country-specific results for several bilateral exchange and interest rates (Section 4.3).

Throughout the paper, I define spot exchange rates as the price of one unit of foreign currency in terms of U.S. dollars, in period t, following convention. Interest rates enter the VAR in percent. The remaining variables enter as log-levels (times 100), which allows for potential cointegration relationships in the system (Sims et al., 1990). As in Gertler and Karadi (2015), I estimate the VAR model with 12 lags on a data sample starting in July of 1979. This sample start coincides with the onset of Paul Volcker’s tenure as Fed Chair and further restricts the analysis to the post-Bretton-Woods era. For the baseline model, I cut the sample off in September 2008, when the effective Federal funds rate measured 1.8 percent, i.e., before the zero-lower-bound became binding. This dating of the pre-zero-lower-bound episode is also advocated for by Ramey and Zubairy (2018). In Section 4.2, I provide further insights on data samples including the Great Recession period and by accounting for forward guidance.

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[6] According to the International Trade Administration, the top ten U.S. trade partners ranked by export value of goods in 2017 consist of China, Canada, Mexico, Japan, Germany, South Korea, United Kingdom, France, India, and Italy. I consider these countries for the index-construction.

2.2 Identification

Identification via zero and/or sign restrictions A large body of existing empirical research analyzing the pass-through of monetary policy to exchange rates typically solves the identification challenge by imposing that matrix $\mathbf{B}$ is lower triangular, which is achieved by a Cholesky-factorization of the variance-covariance matrix, $\mathbf{\Sigma}$ (see, e.g., Eichenbaum and Evans (1995) and Grilli and Roubini (1996) for early contributions). Usually, researchers have implemented the recursive approach by ordering the monetary policy indicator after the macroeconomic variables in $\mathbf{Y}_t$, thereby imposing zero-restrictions on the contemporaneous elasticities of these variables to monetary policy innovations. In addition, the relative ordering of the policy indicator and the exchange rate, then, imposes further restrictions: either, policy rates are not allowed to react contemporaneously to fluctuations in the exchange rate, or alternatively, exchange rates are restricted not to adjust within the impact period to a monetary policy innovation. Since interest rates and exchange rates are priced in highly-liquid and competitive markets, and shock absorption for these variables is conceivable to take place on impact, such a setting appears to be debatable. Even if one takes the stance that U.S. monetary policy does not *directly* internalize exchange rate fluctuations within the impact-period, it is still likely that this inherently forward-looking variable contains information about or is correlated with other variables the Fed may implicitly target. Moreover, providing robustness by permuting the relative ordering of policy and exchange rates, as often done, does not alleviate these concerns. As Bjørnland (2009) documents, an apparently near zero covariance between exchange and interest rate residuals in such a scheme—i.e., the relative ordering does putatively not matter—could still severely mask an existing intrinsic contemporaneous relation between both variables; this is the case once the true exchange rate and monetary policy shocks have counteracting effects on the respective other variable. In this scenario, reshuffling of both financial variables within the recursive VAR, in essence, replaces one form of misspecification against another. Overall, recent literature strongly cautions against the use of recursive schemes for identification in the presence of financial variables (Gertler and Karadi, 2015; Caldara and Herbst, 2019).[7]

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[7] Similar caveats extend to semi-structural VARs or local projections that, e.g., use the Romer and Romer (2004) narrative policy shock series in a recursive setting to study exchange rate responses (see, e.g., Figure IV in Eichenbaum and Evans (1995) or recently Hettig et al. (2019)). Bjørnland (2009) allows for a meaningful contemporaneous relation of exchange and interest rates by imposing long-run VAR-restrictions. However, she maintains the recursiveness assumption for macroeconomic variables and restricts any contemporaneous feedback from foreign interest rates to zero. Inoue and Rossi (2019) also use a Cholesky-factorization imposing the yield curve not to respond contemporaneously to exchange rates, within an otherwise novel identification scheme.

As an attractive alternative to 'relax the dubious assumptions required by the recursive identification method' (Kim et al., 2017) and to allow for a contemporaneous interplay of financial variables in their VARs, recent contributions have followed the lead of, among others, Uhlig (2005) in replacing zero-restrictions against qualitative assumptions about the sign of impulse response functions. However, even when abstracting from open economy complications, the literature is still far from converging to a consensus view about the ramifications of monetary policy shocks, when the latter are recovered by sign-restrictions. In this vein, Baumeister and Hamilton (2015) criticize the way how sign-restrictions are commonly implemented and show that the influence of prior information used in existing—mostly Bayesian—approaches does not vanish asymptotically; Baumeister and Hamilton (2018) further elaborate on the reliability of prior information, and show how doubts about identifying assumptions—which are typically neglected—should be incorporated. Their approach of assigning priors on both, structural parameters and the impacts of shocks, suggests that inference about monetary policy innovations derived from conventional sign-restrictions strategies may have to be revised. In a similar vein, Arias et al. (2019) recover a SVAR by placing quantitative and qualitative restrictions on the interest equation, which characterizes the conduct of monetary policy, using methodological advancements of Arias et al. (2018). In a Bayesian framework, they document small posterior probability for the results on monetary policy shocks by Uhlig (2005); the latter study is frequently the point of departure for sign-restricted VARs studying exchange rates.

In open economy settings, Faust and Rogers (2003), Scholl and Uhlig (2008), Kim et al. (2017), and Schmitt-Grohé and Uribe (2018) achieve identification by means of sign-restrictions; the specific implementation steps such as the variables or the time-horizons being restricted differ across studies.[8] One common feature is that domestic prices are typically forced to behave in a textbook fashion, excluding the possibility of a price-puzzle, ex ante. By contrast, taking a Bayesian perspective, Arias et al. (2019) show that without further zero-restrictions, there exists non-negligible posterior probability mass for models featuring the price-puzzle. In addition, by achieving set-identification, sign-restrictions come with model uncertainty; thus, if we are interested in the *exact* timing of the peak-response of exchange rates, sharper

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[8] Schmitt-Grohé and Uribe (2018), in addition, identify a permanent monetary policy shock by imposing cointegration relationships in their VAR.

restrictions may be desirable (Bjørnland, 2009).[9]

To be clear, I view these approaches as appealing to allow for simultaneous interactions of financial variables in VARs. Yet, given the unsettled debate on how to properly impose sign-restrictions—see Baumeister and Hamilton (2019) and Kilian and Zhou (2019) for a controversy on the incorporation of, e.g., incomplete information in an oil market application—I view my identification strategy as complementary.

Identification via external instruments To translate the residuals from Equation (2) into economically interpretable shocks, i.e., to make a structural analysis feasible, I need to identify the relevant coefficients of matrix $\mathbf{B}$. My interest exclusively centers on the causal effects of exogenous monetary policy shocks; I do not aim to compute impulse responses for other shocks. As a consequence, I only need to identify a single column of $\mathbf{B}$. The indicator of the monetary policy stance, that is, the effective Federal funds rate, arbitrarily enters the VAR first in $\mathbf{Y}_t$; thus, it suffices to recover the parameters in the first column of $\mathbf{B}$. I proceed as follows: Suppose that $\mathbf{Z}_t$ is a vector of instrumental variables. ε_t^1 represents the shocks of interest where, in my application, this is the monetary policy shock. ε_t^2 captures the remaining structural shocks in the system. With $\mathbf{Z}_t$ at hand, I can recover the first column of $\mathbf{B}$ if the subsequent conditions are satisfied:

$$\mathbb{E}[\mathbf{Z}_t \varepsilon_t^{1\prime}] = \mathbf{\Psi} \tag{4}$$

$$\mathbb{E}[\mathbf{Z}_t \varepsilon_t^{2\prime}] = \mathbf{0} \tag{5}$$

where $\mathbf{\Psi}$ is non-singular. Equation (4) postulates that the external instrument contemporaneously correlates with the structural monetary policy shock—the so-called instrument relevance condition. Equation (5) requires that the instrument is contemporaneously uncorrelated with the remaining shocks in the system—the so-called exclusion restriction. Stock and Watson (2012) and Mertens and Ravn (2013) elaborate, how both Equations can be exploited to achieve identification. For implementation details about the SVAR-IV approach, I refer to these papers.

I use information from high-frequency financial markets data to construct the

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[9] At the same time, unidirectional sign-restrictions on interest rates and prices, combined with opposed restrictions on monetary aggregates may be 'too weak'. For instance, consider supply-side shifts that cause activity and prices to diverge and that are more strongly processed via output, relative to prices. Depending on the central bank's reaction function, the imposed restrictions may partly capture such shocks and an endogenous 'curbing the output boom'-motive of the central bank. Similarly, Barsky and Sims (2012) report dynamics for innovations in consumer confidence, which trigger increases in output *and* interest rates, despite a declining inflation rate.

external instrument. Specifically, I consider surprises in the current Federal funds futures rate on FOMC meeting dates. Respective futures contracts are traded at the Chicago Board of Trade. I measure each surprise within a 30-minutes announcement window (Gürkaynak et al., 2005). Gertler and Karadi (2015) use the three months ahead futures price, which could further capture revisions in expectations about the future policy course. Yet, as my focus is not on forward guidance and I aim for clear comparison with existing VARs on exchange rates, I choose the current month future and analyze three months contracts in extensions (Caldara and Herbst, 2019).[10]

Why should such surprise movements in high-frequency futures data serve as an external instrument? The answer is: because they plausibly meet the conditions from Equations (4) and (5). First, once a FOMC announcement about the policy conduct catches financial markets by surprise and induces a revision of market expectations, such an event conceptually relates to our notion of monetary policy deviating from its inferred rule; that is, it relates to the notion of a policy shock. We can thus think of these surprises as a signal—likely measured with noise—of the true unobservable structural shock, where both shocks are not required to correlate perfectly, as I argue below. Put differently, the instrument relevance condition plausibly applies. Second, if we are willing to accept the idea that incoming information about the state of the economy or the financial system on the FOMC meeting day itself do not influence the same-day policy decision and, more specifically, do not impact the external instrument measured during the tight announcement window, the exclusion restriction is likely to hold as well. That is, the instrument is plausibly orthogonal to the remaining shocks in the system, within period.

2.3 Inference in the SVAR-IV model

There is a recent debate on how to correctly perform inference about moments that are constructed using the variance-covariance matrix recovered from a VAR. In the SVAR-IV literature, there is a widespread application of wild-bootstrap procedures to perform this task. Brüggemann et al. (2016), however, show that so-produced confidence intervals are not asymptotically valid in general, and Caldara and Herbst (2019) provide a Bayesian alternative to the frequentist approach. Montiel Olea et al. (2018) propose novel theory on how to construct confidence intervals in SVAR-IV models. They recommend a method, which allows for a weak correlation between instrument and target shock, and which has the property to be asymptotically valid.

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[10] Data for the instrument is available from January 1991 onwards; the combination of this shorter sample—used for identification—with the longer sample—used to recover the reduced form VAR—increases efficiency and is also the route taken in, for instance, Gertler and Karadi (2015).

Specifically, the so-constructed confidence intervals are (i) robust to weak-instrument problems, and (ii) converge to the confidence intervals of standard inference if the instrument can be considered strong. I follow their lead for inference about impulse responses to monetary policy shocks and to test instrument-strength. I also explore results for confidence sets constructed via the Delta method, which likewise is asymptotically valid; conclusions derived from the Delta method are very similar.

3 The causal effect of monetary policy on exchange rates

In what follows, I trace the causal impact of shifts in U.S. monetary policy on the nominal exchange rate composite index for the ten largest trade partners of the U.S., over time, and along the lines of the SVAR-IV model sketched in Section 2. As a starting point, I formally test the strength of my interest futures instrument for the benchmark seven-variables VAR model in a more formal way.[11] In this vein, I calculate the heteroskedasticity-robust F-statistic from the first-stage regression of the reduced form VAR residuals on the instrument. As an alternative, I evaluate the Wald statistic for the Null that the instrument is irrelevant, i.e., $\mathbb{E}[\mathbf{Z}_t \varepsilon_t^{1\prime}] = 0$, as suggested in Montiel Olea et al. (2018); the 'center' of the latter statistic corresponds to the 'concentration' in linear IV settings.

The F-statistic is 21.86 and the Wald statistic indicates a value of 9.44. Both statistics safely cross the 5 percent critical value to reject the hypothesis of potentially weak instrument concerns, which amounts to 3.84. In addition, the F-statistic is more than double in size compared to the Stock and Yogo (2005) 'rule-of-thumb' threshold of $F > 10$, which assures approximately valid coverage of confidence intervals; the Wald statistic is slightly below this value. Overall, the instrument can be considered 'strong', notwithstanding that subsequent inference is valid, even if this was not the case.

Figure 1 plots impulse response functions of all variables in the SVAR-IV model to an adverse monetary policy shock that raises the Federal funds rate by 25 basis points, on impact. I normalize the shock size for comparability across specifications. The solid lines represent point estimates, and the dark to light shaded areas depict 50, 68, and 90 percent confidence intervals, respectively. By construction, the effective Federal funds rate jumps by 25 basis points once the shock hits the economy; it further contracts somewhat and peaks two months after the shock, before sluggishly returning to and eventually passing-through the conditional mean.

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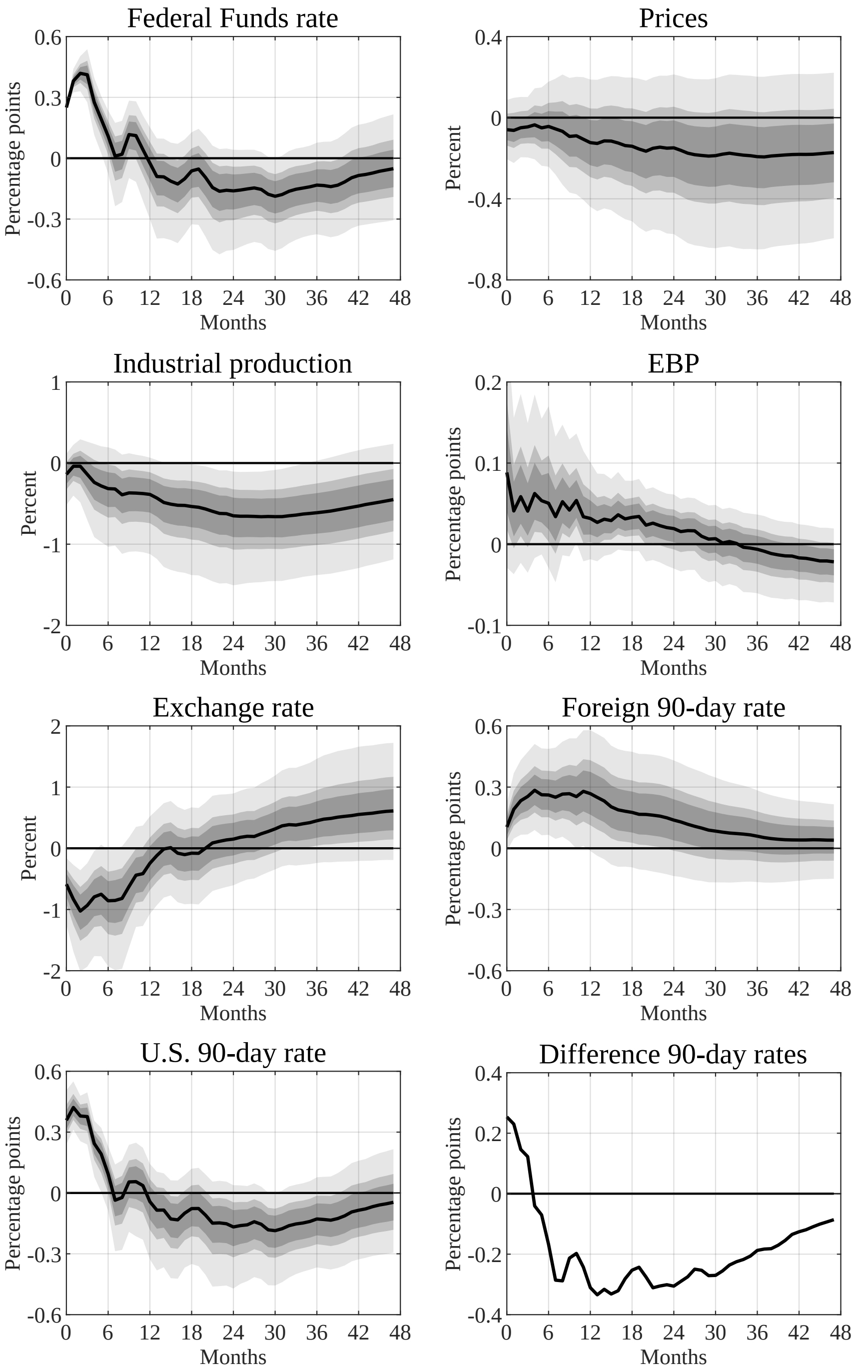
[11] For instance, Mertens and Ravn (2019) stress that instrument relevance rather than asymptotic validity of confidence sets is key when deriving inference from a SVAR-IV model.

Figure 1: Monetary policy shocks and exchange rates



Notes: The x-axis measures time in months. I plot dynamics obtained from the benchmark SVAR-IV model for a data sample covering 1979M7 to 2008M9. The solid line represents point estimates of the impulse response functions for 48 months. The dark to light shaded areas depict 50, 68, and 90 percent confidence intervals, constructed as in Montiel Olea et al. (2018). The solid line in the last panel reports the difference between the impulse response functions for domestic and foreign short-term interest rates, respectively.

The endogenous reversion of the policy rate after the exogenous shift in monetary policy in the medium run is well-documented and may be interpreted as a systematic accommodation in response to the policy tightening the Fed has created in the first place. The measure of economic activity, i.e., industrial production, behaves in the conventionally assumed way by revealing an inverted hump-shaped adjustment pattern. The impulse response troughs significantly between the second and third post-shock year, before slowly decaying. Prices react rather sticky and decline slowly over the forecast horizon, while the coefficients are estimated rather imprecisely.[12] The excess bond premium features the strongest shock absorption on impact, reaching almost ten basis points, and then monotonically declines; that is, giving rise to some financial accelerator mechanism. Apart from a slight upward shift, three-months interest rates in the U.S. practically emulate the Federal Funds rate impulse response. Overall, the closed economy part of the SVAR-IV model aligns well with papers using related methods and corroborates conventional wisdom about the consequences of a monetary policy tightening. Foreign 90-day interest rates—as measured by a weighted basket of ten trade partners—deviate significantly and persistently from the steady state after the U.S. monetary policy shock; reaching a peak of about 0.3 percentage points. On impact, the U.S. monetary policy shock induces a steepening of the yield curve's very short end that is approximately 25 basis points stronger in the U.S. relative to the foreign countries block. Over longer horizons, the 3-months cross-country interest differential flips sign (see last panel of Figure 1).

Most notably, the spot nominal exchange rate processes the monetary policy surprise immediately and in a highly statistically significant fashion; the impact response amounts to minus 0.6 percent. Resembling the initial behavior of the policy rate, the exchange rate reaches the maximum deviation from the conditional mean of approximately minus one percent already in the second month after the shock. Thereafter, the initial appreciation of the U.S. dollar is reverted by a gradual exchange rate depreciation.

I interpret the *maximum response of the exchange rate within the first post-shock quarter and the subsequent dynamic depreciation as support for the overshooting hypothesis*, as prominently formulated in Dornbusch (1976). While selected studies, using alternative identification schemes and model specifications, have interpreted

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[12] When I use the CPI as a measure of prices, instead, the impulse response function is estimated with less statistical uncertainty, yet, featuring some price-puzzle (Arias et al., 2019). This result obtains in a replication exercise, in which I estimate the original Gertler and Karadi (2015) model over my sample period, which excludes the Great Recession period, in contrast to their work.

similar findings accordingly, my results are remarkable as they arise in a sample that starts with the appointment of Volcker as Fed Chair. For instance, while Kim et al. (2017) generally do not recover dynamics conforming with overshooting or conditional UIP, they do document overshooting in the post-Volcker era, as an exception. Their evidence rejecting overshooting, yet, also comes with significant output 'puzzles', i.e., economic activity conditionally reveals the 'wrong' sign.[13] Their evidence favoring overshooting, yet, is limited to an episode that is notorious for producing puzzles when studying the monetary policy pass-through (Barakchian and Crowe, 2013) and for lacking robustness of results (Ramey, 2016). By contrast, my results confirm the notion of overshooting for the U.S., without producing puzzles and by relying on data that include Volcker's tenure as Fed Chair (see, e.g., Coibion (2012) or Arias et al. (2019) who also include the Volcker era).

4 Providing further insight into exchange rate overshooting

In what follows, I provide complementary evidence to inspect the mechanism of exchange rate overshooting in more detail: (i) I analyze the extent to which my results conform with the uncovered interest parity condition in a conditional and dynamic sense, (ii) I provide evidence for the Great Recession period and for the role of forward guidance, before (iii) exploring cross-country heterogeneity.

4.1 Uncovered interest parity and SVAR-IV monetary policy shocks

The SVAR-IV model evidence presented in the previous section suggests that Dornbusch (1976) exchange rate overshooting tends to *qualitatively* hold in post-Bretton-Woods U.S. data. A key theoretical assumption underlying the overshooting hypothesis is that exchange rate adjustments are determined, among others, by interest differentials across countries. Specifically, the uncovered interest parity (UIP) condition postulates that the decline in the interest rate differential between foreign and U.S. interest rates, i.e., $i_t^* - i_t$, has to be *quantitatively* offset by an expected depreciation of the dollar exchange rate, s_t, one period ahead, i.e., between period t and $t+1$. Deviations from uncovered interest parity give rise to ex-post excess returns, Λ_t, for investors who, at the same time, can benefit from higher interest rates *and* an exchange rate appreciation. I formulate the divergence in returns between holding foreign versus U.S. assets in terms of domestic currency as in Eichenbaum

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[13] Such behavior of output—which is also documented in Uhlig (2005), whose identification these authors use—has recently come under attack by Arias et al. (2019); they reveal more conventional output dynamics by imposing sign- and zero-restrictions on their VAR's interest equation.

and Evans (1995) and Bjørnland (2009), which delivers the following definition:

$$\Lambda_t = i_t^* - i_t + 12 \times (\mathbb{E}\{s_{t+1}\} - s_t). \tag{6}$$

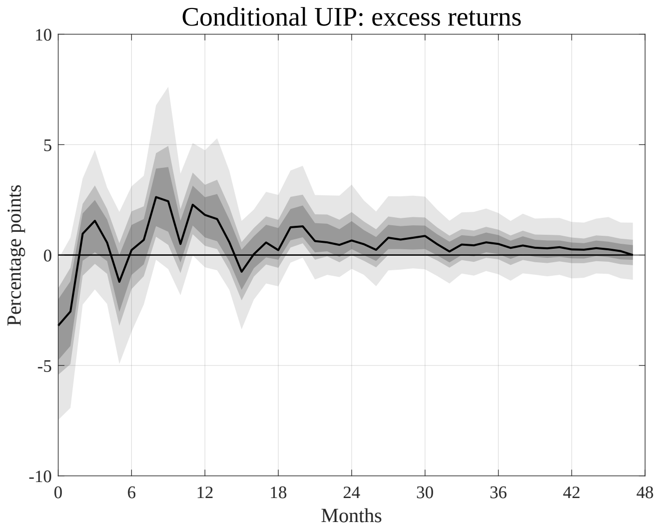
Interest rates enter the SVAR-IV model in annualized terms (in percent); i.e., for consistency, I multiply the exchange rate responses, which enter the model in monthly log-levels (times 100) by 12. $\mathbb{E}\{\cdot\}$ is the model-implied expected value. The variables on the right hand side of Equation (6) represent impulse responses after a monetary policy innovation, traced in the SVAR-IV model. As a consequence, the test of the uncovered interest parity condition must be interpreted in a conditional sense; that is, I exclusively test this hypothesis conditional on policy surprises, leaving unconditional UIP dynamics untested.

Under the null hypothesis of exchange rate adjustments fulfilling uncovered interest parity, the conditional expectation of excess returns should equal to zero, for all horizons considered. Formally, this implies:

$$\mathbb{E}\{\Lambda_{t+i}\} = 0, \ \forall \ i \geq 0. \tag{7}$$

Equation (7) provides a testable prediction; Figure 2 performs the according test and presents estimates of excess returns, together with confidence sets, over time.

Figure 2: Monetary policy shocks and uncovered interest parity



Notes: The x-axis measures time in months. I plot dynamics obtained from the benchmark SVAR-IV model for a data sample covering 1979M7 to 2008M9. The solid line represents point estimates of excess returns for 48 months. The dark to light shaded areas depict 50, 68, and 90 percent confidence intervals, constructed via the bootstrapping procedure proposed in Montiel Olea et al. (2018).

Overall, excess returns oscillate closely around zero for most months. On impact, there is a negative departure from zero, measuring minus 3.2 percentage points, which is consistent with the initial uptick in the first post-shock period documented for the reaction of the nominal exchange rate (see Figure 1). This estimate is only borderline significant. After the impact period, excess returns are statistically not distinguishable from zero, i.e., I generally document evidence in support of the uncovered interest parity, which further corroborates the observed dynamics of exchange rate overshooting. My finding deviates from conditional UIP dynamics presented in a broad recursive VAR literature, including Eichenbaum and Evans (1995), and also contrasts results obtained from the sign-restrictions approaches in, e.g., Scholl and Uhlig (2008). By contrast, Bjørnland (2009) documents results in favor of UIP for selected small open economies by applying a combination of zero-restrictions and long-run neutrality restrictions that help to identify her structural VAR.

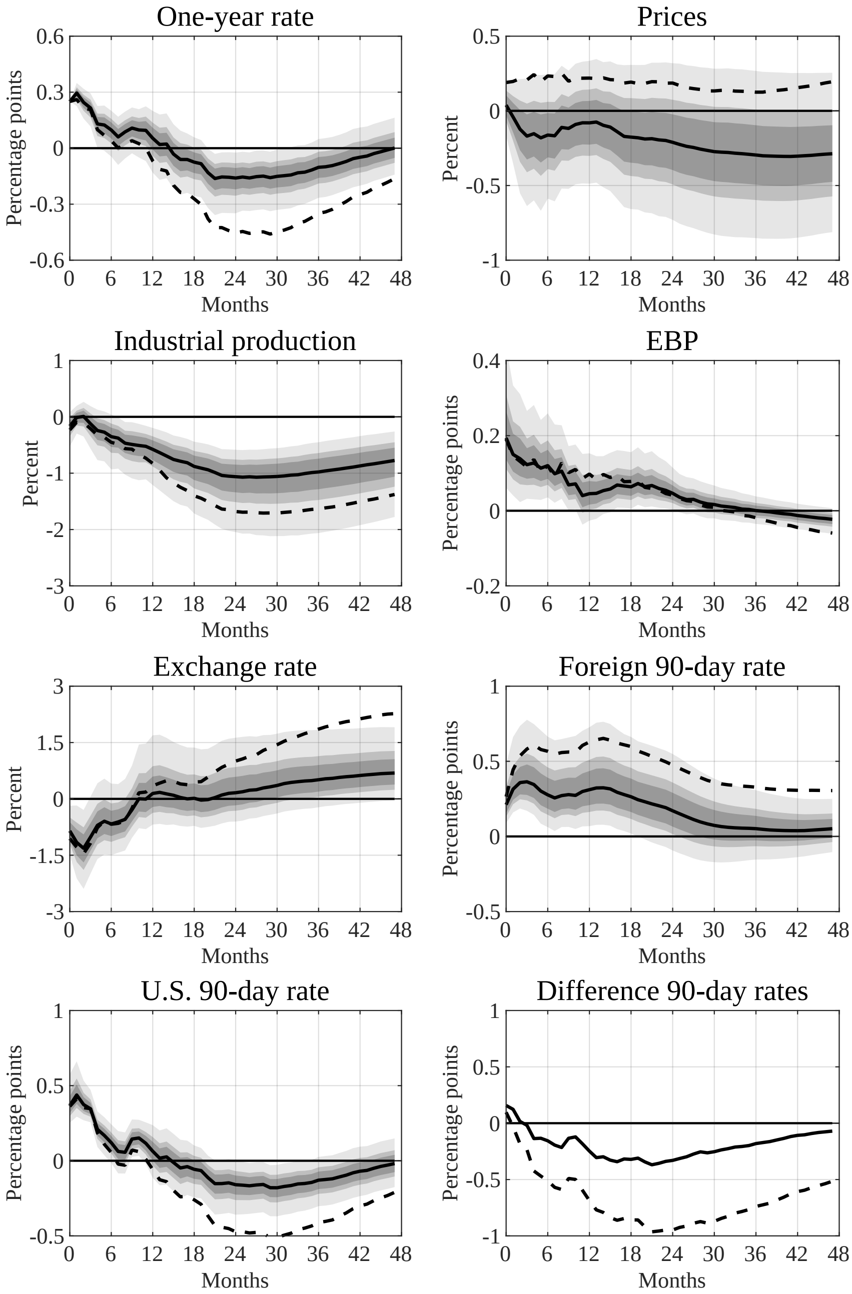
4.2 The Great Recession and the role of forward guidance

Researchers employing the traditional ‘money shock' VARs—identified by sign- or zero-restrictions—that document evidence mostly in favor of delayed or non-existing overshooting typically consider shocks within samples that abstract from the Great Recession episode and thereby do not explore an era of, among others, unprecedented conduct of forward guidance by the Fed. By contrast, my identification strategy can be extended to the analysis of these phenomena in a straight-forward way. In that respect, Gertler and Karadi (2015) show that using a monetary policy interest rate indicator with a somewhat extended maturity, combined with a corresponding longer-maturity interest future as an external instrument, is a powerful strategy to capture the role of forward guidance during the Great Recession episode, in a SVAR-IV setting. Following their specifications, (i) I replace the Federal funds rate in the benchmark model against the one-year Treasury rate, which still exhibits some distance to the zero-lower-bound, (ii) I use surprises in the three-months ahead futures rate instead of the current month Federal funds futures rate as an external instrument, and (iii) I shift the end of, both, the estimation and identification samples to June 2012 as in their paper. Importantly, this strategy is not an isolated experiment to study the mechanism through which a forward guidance action affects exchange rates (see, e.g., Galí, 2019); rather, it is a test of how the econometric inclusion of forward guidance *on top* of conventional monetary policy shocks influences my results during and before the onset of the Great Recession. The so-identified interest tightenings can thus be considered as constituting a composite of multidimensional underlying monetary policy surprises.

To set the stage, I evaluate the diagnostic checks proposed in Section 3 to test the strength of this alternative external instrument in the modified seven-variables SVAR-IV model, first, for the benchmark data sample and, second, for the extended sample. The heteroskedasticity-robust F-statistic is 6.03 and the Wald statistic amounts to 5.67 in the benchmark sample; the corresponding figures for the extended sample are 10.99 and 9.50, respectively. Interestingly, when including forward guidance shocks and further modeling the policy indicator as the one-year Treasury rate, the strength of the instrument declines substantially relative to the benchmark case in pre-Great-Recession data; the F-statistic drops by more than 70 percent and the Wald statistic decreases by roughly 40 percent. A possible interpretation of this finding is that during this period of mostly conventional policy conduct, forward guidance is not the driving source behind policy innovations conveyed through Fed announcements. By contrast, very short-run interest rates, such as the effective Federal funds rate, and the corresponding futures surprises, are more powerful to indicate the surprise components of monetary policy. This conclusion changes, though, when including the zero-lower-bound episode. For this sample, the role of forward guidance in transmitting monetary impulses to the broader economy and to the financial system becomes more prominent; both diagnostics are in the neighborhood of the Stock and Yogo (2005) threshold for strong instruments, i.e., communication about the future course of monetary policy becomes a crucial source of financial market surprises induced by the Fed. How do these combinations of conventional monetary policy shocks and communication about the future path of, among others, short-term interest rates propagate to exchange rates?

Figure 3 traces the dynamics of the 'forward-guidance-augmented' SVAR-IV model over time and for two samples; one including and the other one excluding Great Recession data. When cutting the sample off before the onset of the zero-lower-bound episode, the repercussions of the policy tightening become generally more pronounced relative to the benchmark case (dashed line). However, (i) prices display the 'wrong' sign, (ii) the Federal funds rate 'overshoots' into negative territory approximately double in size relative to the initial tightening, and (iii) foreign short-term interest rates reveal a maximum shock absorption of approximately 0.7 percentage points after a year, which is quantitatively more pronounced relative to the U.S. counterpart.

Figure 3: Monetary policy shocks, the Great Recession, and forward guidance



Notes: The x-axis measures time in months. I plot dynamics from SVAR-IV models using the one-year rate as policy indicator and respective futures surprises as instrument. The solid line represents the point estimates of the impulse responses for a data sample covering 1979M7 to 2012M6. The dark to light shaded areas depict 50, 68, and 90 percent confidence intervals, constructed as in Montiel Olea et al. (2018). The solid line in the last panel reports the difference between the impulse responses for domestic and foreign short-term rates. The dashed lines represent estimates for the benchmark sample.

All of these three findings may indicate some problems of the augmented instrument setting in proxying for a policy shock in the pre-crisis era, corroborating the choice of my benchmark specification for conventional times. The inspection of the full sample results, by contrast, pretty much aligns with the dynamics obtained from the benchmark model (solid line with confidence intervals); that is, the joint inclusion of forward guidance shocks and of the Great Recession episode leaves the transmission mechanism of monetary policy largely unaffected.

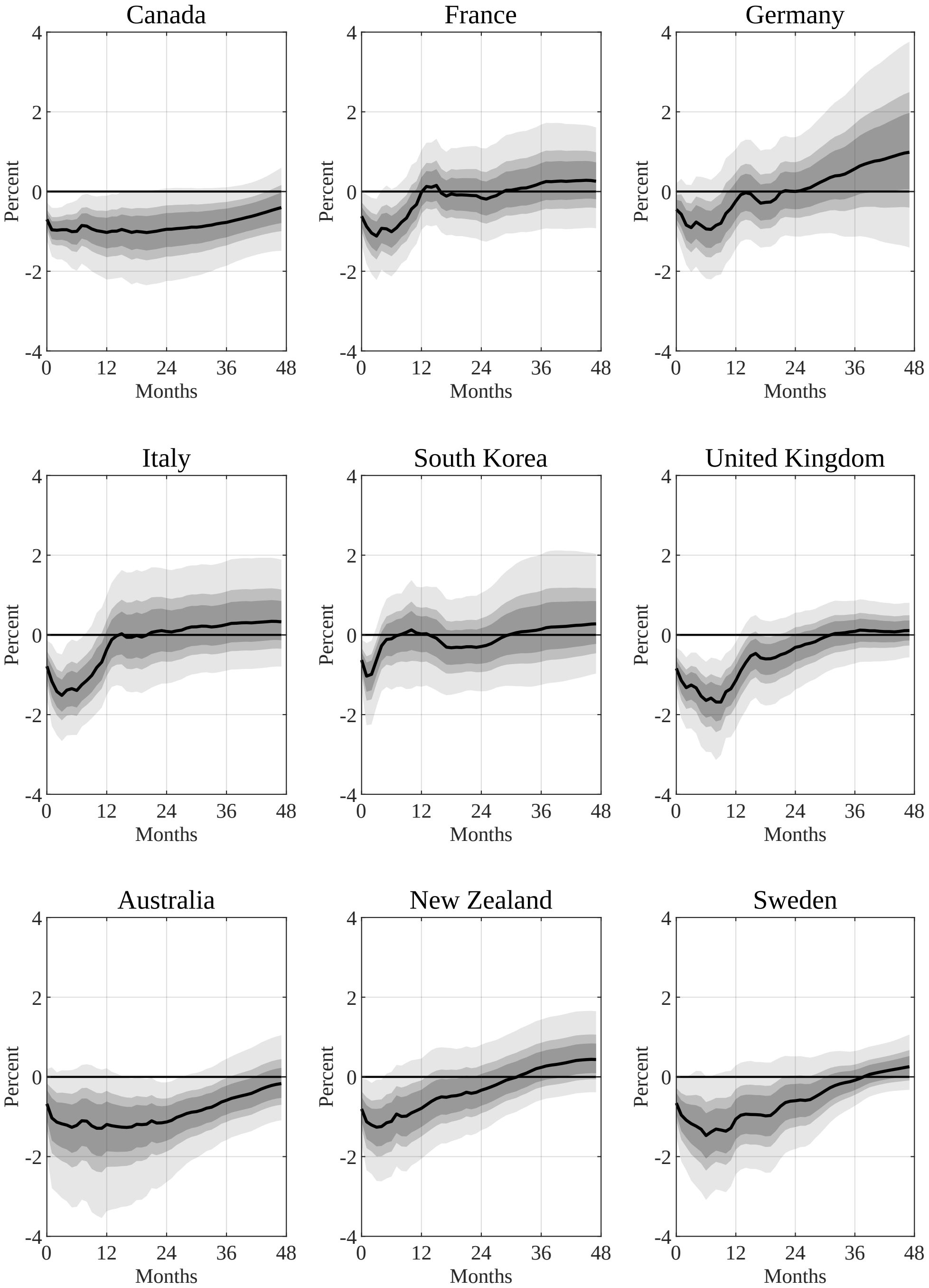
Most notably, both forward-guidance-augmented models imply a short-run exchange rate appreciation followed by a subsequent depreciation, i.e., giving rise to non-delayed overshooting of exchange rates. As a novel finding, thus, I infer that exchange rate dynamics are consistent with Dornbusch (1976)-overshooting, even when conditioning on more comprehensive monetary policy surprises that also feature the role of forward guidance and when exploring data during the Great Recession.

4.3 Cross-country exchange rate pass-through

To further scrutinize my findings, I zoom-in how bilateral exchange rates propagate the U.S. monetary policy shock, i.e., I explore potential cross-country heterogeneity. To this end, I rotate into the VAR an individual country's exchange rate and short-term interest rate, which replace the corresponding foreign country baskets in the VAR, one at a time for each country. As case studies, I consider the following economies out of the pool of the largest trade partners: Canada, France, Germany, Italy, South Korea, and the United Kingdom. In addition, I add three countries that my baseline composite-index does not comprise: Australia, New Zealand, and Sweden.

Figure 4 traces the impulse responses from these nine individual-countries SVAR-IV models; I only report the spot nominal exchange rate responses. Several common features stand out for the exchange rate reactions across countries: all impulse responses indicate a short-run appreciation, followed by a subsequent depreciation. The point estimates are generally significant at short horizons, while after a year this is typically not the case anymore. That is, there is no indication of delayed and significant overshooting taking place two or three years after the U.S. monetary policy tightening, as documented in several preceding contributions.

Figure 4: Monetary policy shocks and bilateral exchange rates of selected countries



Notes: The x-axis measures time in months. I plot dynamics obtained from country-specific SVAR-IV models, each estimated on a data sample covering 1979M7 to 2008M9. The solid line represents the point estimates of the impulse response functions for a horizon of 48 months. The dark to light shaded areas depict 50, 68, and 90 percent confidence intervals, constructed as in Montiel Olea et al. (2018).

Yet, also some heterogeneity emerges from the cross-country comparison: while the exchange rates of Canada, France, Germany, Italy, South Korea, Australia, and New Zealand reveal the quantitatively strongest appreciation within the first post-shock quarter, a bit of a delayed response arises for the United Kingdom and Sweden. However, these countries' phase shift of the impulse responses is limited to few months; the peak response can be located roughly after two quarters. Bjørnland (2009), for instance, interprets similarly shifted impulse responses still to be broadly in line with non-delayed overshooting. While the exchange rates of most countries revert quite rapidly after troughing, the depreciation in Canada and Australia is rather sluggish. These countries' exchange rates plateau for several months at the initial appreciation level. The maximum shock procession, yet, takes place almost immediately. In terms of magnitude, results are fairly homogenous. By closer inspection, Germany is an outlier on the side of a rather muted response, while the exchange rate appreciation of Italy and the United Kingdom appears to range among the strongest for the sample of economies considered. Put together, the cross-country inspection of nine selected countries corroborates the results I obtain from a broad exchange rate basket.

5 Robustness of findings

In this section, I confront my baseline results with a battery of sensitivity checks. First, I re-estimate the SVAR-IV model by using different lag-orders, p. The benchmark results were derived from the commonly used lag length for VARs using monthly data, $p = 12$. Alternatively, I reduce the lag length to 9 and increase it to 15. Second, I also include a monetary aggregate as an additional variable in the model. Specifically, I consider the ratio of non-borrowed to total reserves of depository institutions held with the Fed.[14] Third, I scrutinize the role and potential contamination of my results with respect to central bank information shocks. To do so, I use a monetary policy shock series that is orthogonalized from such information effects, as proposed in Jarocinski and Karadi (2019), as an alternative external instrument in the benchmark SVAR-IV model. The purged monetary policy shocks are based on longer-maturity futures contracts and thus also capture the effects of forward guidance, which somewhat complicates comparison, though. Fourth, I test whether exchange rate overshooting also emerges when studying the causal consequences of the monetary policy shock on an even broader trade-weighted exchange

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[14] As non-borrowed reserves turned negative in the course of 2008—since borrowing via liquidity facilities provided by the Fed exceeded total reserves—I restrict the sample to July 2007.

rate basket comprising 15 trade partners of the U.S., as provided by the Bank for International Settlements. The latter institution, in addition, provides a corresponding measure for the trade-weighted *real* effective exchange rate, which I also consider in an alternative VAR specification. Fifth, I use the Delta method of Montiel Olea et al. (2018) to draw inference on impulse response functions.

Overall, my main result of non-delayed exchange rate overshooting conditional on monetary policy innovations proves to be insensitive to these tests. In particular, the results from the broad trade-weighted exchange rate baskets—measured either in nominal or real terms—reveal that adjustment patterns are driven by nominal rather than real exchange rates. The impulse responses of both measures are barely distinguishable. A notable finding is provided by the monetary-aggregate-augmented VAR model. Albeit that exchange rate dynamics are qualitatively unaffected, yet, estimated with somewhat less precision, the reaction of macroeconomic variables appears to be more sensitive to the inclusion of such an aggregate. In this setting, namely, an output puzzle in the very short run emerges, i.e., industrial production expands rather than contracts at short horizons. The modification in the lag order or the inclusion of the Jarocinski and Karadi (2019) shocks, likewise, do not affect the observation of exchange rate overshooting. When drawing inference from the SVAR-IV model by constructing confidence intervals via the Delta method I reach practically identical conclusions, as well. Results from the robustness checks of this section are available upon request.

6 Conclusion

In this paper, I revisit the exchange rate overshooting hypothesis, formulated in Dornbusch (1976). By using high-frequency data on Federal funds futures surprises—measured around Fed announcements on FOMC meeting days—as external instruments, I trace the causal ramifications of monetary policy shocks for the U.S. dollar exchange rate. From a methodological perspective, I rely on recent progress made on testing instrument relevance and on drawing asymptotically valid inference in a SVAR-IV setting; for preceding studies that analyze the monetary policy pass-through using similar methods, this is typically not the case.

I provide results that are in favor of overshooting in the post-Bretton-Woods era and that extend to the Great Recession episode. A key feature in my analysis is that I allow for simultaneous interactions between interest and exchange rates in the VAR, without resorting to zero-, sign- or long-run restrictions in the model. Information about the structural form of the VAR comes from the external instrument, which is explicitly allowed to constitute a noisy signal of the true underlying monetary policy shock. Within my VAR framework, I document another empirical regularity, which further corroborates my findings: conditional on a monetary policy tightening, uncovered interest parity appears to hold, i.e., contradicting the notion of ‘money on the table’ for investors. Put together, the exchange rate adjustment patterns I provide caution against a premature rejection of exchange rate overshooting in post-Bretton-Woods U.S. data and constitute a caveat not to let the conditional puzzles documented in a vast empirical literature converge into a consensus view.

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