Reassessing International Effects of U.S. Monetary Policy Shocks*

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In light of recent evidence on the significant contribution of persistent monetary shocks to inflation dynamics in the U.S., we study their international transmission. In contrast to standard temporary nominal interest rate shocks, persistent shocks increase long-run inflation and the nominal rate while decreasing the real rate. We find that this leads to nonnegligible international spillovers and dollar depreciation. We further show that when it comes to understanding the international spillover effects of U.S. monetary policy, persistent monetary policy shocks rather than temporary nominal interest rate shocks have the potential to explain long-run comovements of macroeconomic variables across advanced countries.

JEL Codes: E12, F31, E52, E58.

1. Introduction

This paper studies the international transmission of U.S. monetary policy shocks, by considering two types of shocks—a standard temporary interest rate shock and a persistent inflation target shock. Traditionally, the effects of monetary policy are studied through temporary nominal interest rate shocks. Several key contributions, however, highlight the importance of persistent monetary policy shocks in understanding large and persistent swings in inflation in postwar data; that is, the low-frequency behavior of inflation or trend inflation (see Ireland 2007; Stock and Watson 2007; Cogley, Primiceri, and Sargent 2010; Del Negro, Giannoni, and Schorfheide 2015,

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among others). In closed-economy settings of the U.S. economy, a few recent contributions provide empirical evidence on the effects of an inflation target shock, which is one way to model persistent shifts in monetary policy (Mumtaz and Theodoridis 2018; Uribe 2022; Lukmanova and Rabitsch 2023).[1] A common conclusion in this literature is that a positive target shock tends to raise nominal interest rates together with inflation (and possibly output), inducing a positive comovement already in the short run or in the close aftermath of the shock.[2] There is also a vast empirical literature on the international transmission of U.S. monetary policy shocks (see, for example, Kim 2001; Canova 2005; Jacques and Rogers 2007; Bluedorn and Bowdler 2011; Dedola, Rivolta, and Stracca 2017, among many others). The general conclusion (across various time and country samples) is that there exist sizable international spillovers from the U.S. to other countries. However, most studies typically focus only on temporary monetary shocks, with the international transmission of persistent shocks remaining an underinvestigated topic.

Our paper contributes in this respect, proposing an empirical vector autoregression (VAR) modeling approach that explicitly distinguishes a standard temporary shock from a persistent monetary policy shock, studying their international transmission. In this, we build upon recent theoretical (Schmitt-Grohé and Uribe 2014, 2022; Cochrane 2016; DeMichelis and Iacoviello 2016) and empirical work (Mumtaz and Theodoridis 2018; Uribe 2022; Lukmanova and Rabitsch 2023) that argues that central banks affect inflation dynamics and the macroeconomy in these two ways. In addition to the conventional temporary shock to the nominal interest rate, we model the persistent monetary policy shock as a shock that shifts the inflation target. Adapting this setting to an international setup allows us to extend the analysis of the spillover effects of U.S. monetary shocks to long-natured policy shocks, and to disentangle the two types of monetary shocks. Our precise empirical setting is a simple extension of a baseline open-economy VAR model often used in

[1] Uribe (2022) studies an explicitly permanent interest rate shock, not an inflation target shock. However, as documented in Lukmanova and Rabitsch (2023), permanent interest rate shocks and highly persistent inflation target shocks affect the economy in qualitatively similar ways.

[2] This positive comovement is also at the heart of a recent discussion on the existence of a Neo-Fisher effect.

the literature. In particular, in our baseline setting we include major macroeconomic variables typically used in the literature (i.e., output growth, inflation, nominal interest rates) of the domestic economy (U.S.) and a foreign composite economy, consisting of eight major advanced economies,[3] and the (change in the) nominal exchange rate. In addition, to be able to identify U.S. inflation target shocks, we include a time series that serves as a proxy for the inflation target in addition to these conventional macroeconomic variables. In particular, we adopt the inflation target series (denoted "PTR") from the Federal Reserve Board's FRB/US model (cf. Brayton, Laubach, and Reifschneider 2014).[4,5]

For identification, we adopt the novel methodology of Baumeister and Hamilton (2015, 2018, 2019), following our related research work on inflation target shocks in a closed-economy setting (Lukmanova and Rabitsch 2023). Baumeister and Hamilton (2015, 2018, 2019) show how explicit prior information can be used about both contemporaneous structural coefficients and the impacts of shocks, proposing to incorporate prior beliefs about the magnitude and signs of equilibrium impacts in a nondogmatic way. Our goal of adopting this methodology is that it allows us to derive guidance about the implied structural VAR parameters from theoretical models; for parameters about which there is consensus, we can specify priors with higher prior precision (for example, effects of the temporary interest rate shock), but the framework also explicitly allows us to account for the uncertainty of our structural parameters where there is less consensus from theoretical models (such as the effects of persistent inflation target shocks).

Our results are as follows. Domestically, the two types of shock have been shown to lead to opposite effects. Our paper's

[3]We include Australia, Canada, Japan, New Zealand, Norway, Sweden, Switzerland, and the U.K.

[4]We do so because the PTR has the longest data availability. Alternatively, long-run inflation expectations of the Survey of Professional Forecasters are available from 1979 onward. Lukmanova and Rabitsch (2023) discuss a number of possible proxy measures for the U.S. inflation target.

[5]For other countries, we collect data on long-run inflation expectations from various national sources. Yet, because availability of these estimates for a number of countries is limited—the shortest sample starts in 1990:Q2—a foreign inflation target measure is not included in the VAR.

contribution is to document that the international spillovers also differ markedly. The conventional temporary monetary policy shock causes an increase in the nominal interest rate and, due to nominal rigidities, an increase in the real rate, and tends to lead to a contraction, decreasing inflation and output. We find that the contraction spills over to the foreign economy, where foreign output and inflation also decrease. The exchange rate appreciates. Yet, quantitatively, international spillovers are mild. In contrast, the transmission mechanism of a persistent inflation target shock is markedly different. Domestically, it implies an increase in inflation expectations. When households expect higher prices, the real rate drops, they start increasing current consumption, and output grows. To accommodate increased demand, producers increase prices, so that inflation goes up. As the economy is expanding, the central bank raises the nominal interest rate and we therefore observe a comovement between the nominal rate and inflation. Internationally, the U.S. inflation target increase leads to a U.S. depreciation, in line with related studies (cf. Mumtaz and Theodoridis 2018; Schmitt-Grohé and Uribe 2022, further discussed below), and raises not only domestic but also foreign inflation, as foreign countries import part of the higher inflation from the U.S. Given an insufficient response of foreign central banks, this leads to a rise in foreign countries' inflation expectations as well, also decreasing the foreign real rate. As a result, we observe expansionary effects abroad as well, and a dollar depreciation from U.S. inflation target shocks. After a few quarters, the foreign nominal interest rate responds to the changed macroeconomic environment, starting to rise in a similar fashion to that in the U.S. The behavior of real rates has also been identified as a main channel of international transmission of U.S. monetary policy in previous work (Kim 2001; Faust et al. 2003; Canova 2005; Ehrmann and Fratzscher 2009). As the U.S. real rate moves in opposite directions after each shock, disentangling the two shocks helps to uncover unbiased international effects of U.S. monetary policy.

In an extension to our baseline empirical setup, we consider a VAR model augmented with additional time series on long-term interest rates, to investigate if highly persistent monetary policy shocks contribute to the comovement of long-term rates across countries. In the model version with long-term rates, a positive U.S. inflation target shock continues to lead to expansionary effects in the foreign economy and to higher foreign inflation expectations, but moreover leads to higher long-term interest rates. In contrast, there is no significant response of long-term interest rates to the nominal interest rate shock. This suggests that inflation target shocks have the potential to explain international comovement of long-term interest rates, as previously suggested by Chin et al. (2018), and, more generally, may have important implications for our understanding of bond term premia.[6,7]

In related work, Schmitt-Grohé and Uribe (2022) study the effects of U.S. permanent monetary policy shocks on the exchange rate of the dollar versus the pound or yen. They find a persistent dollar depreciation after a permanent monetary policy shock. They also discover that once the effects of permanent and transitory shocks are separated, there appears to be no exchange rate overshooting. We similarly do not find evidence of exchange rate overshooting in our work. Using a factor-augmented vector autoregression (FAVAR) model augmented with international data, Mumtaz and Theodoridis (2018) similarly suggest that persistent monetary shocks, such as inflation target shocks, may play a significant role in the international transmission of U.S. monetary policy, leading to an increase in foreign output, inflation, and short- and long-run interest rates, as well as a nominal depreciation of the U.S. dollar. Kim, Moon, and Velasco (2017) relate the exchange rate overshooting result to the monetary regime, documenting that the overshooting behavior is a consequence of a lack of monetary credibility during Volcker's chairmanship of the Federal Reserve: instead of treating monetary shocks toward the end of the 1970s to the beginning of the 1980s as nearly permanent—the Fed was committed to combating high inflation—these shocks were perceived as temporary, creating wrong expectations. In other words, Kim, Moon, and Velasco (2017) point to the fact that assessing the right magnitude of the persistence of monetary shocks is consequential for the response of exchange rates.

[6]Using an open-economy estimated DSGE model, Chin et al. (2018) show that an inflation target shock in the U.S. results in a shift in long-run inflation of its foreign partner, and may be responsible for international comovement in long-term interest rates. Our empirical VAR model with observable time series for long-run inflation expectations and long-term interest rates produces findings that are consistent with Chin et al. (2018).

[7]Bauer and Rudebusch (2019) also emphasize the low-frequency behavior of inflation as a key determinant in understanding the yield curve.

Inoue and Rossi (2019) emphasize that the effects of monetary policy depend on how it affects expectations. They show that when interest rates are constrained at zero (which applies to about one-third of observations), fluctuations in exchange rates are driven not only by short-term expectations (as is the case when interest rates are not constrained) but also by longer-term expectations (5, 10, and even 20 years ahead). Our methodological approach deviates from these references by directly looking at the observable time series on long-run inflation expectations and adopting a set of identifying restrictions that ensures the inflation target shock absorbs efforts of the Fed to change the long-run inflation expectations.

The remainder of the paper is organized as follows: in Section 2 we summarize the channels of international monetary transmission discussed in the related literature. Section 3 presents the baseline VAR model of the international economy, describes the data used in our estimations, and discusses the methodological approach. Section 4 lays out the results of the baseline model, while in Section 5 we consider an extension of our model adding the long-term interest rates. Finally, Section 6 concludes.

2. Hypotheses about International Monetary Transmission Channels and Related Literature

Our profession's understanding of the international transmission channels of monetary shocks starts with textbook macroeconomic models such as the Mundell-Fleming model, where the behavior of exchange rates plays a crucial role. Much of the theoretical and empirical literature focuses exclusively on short-natured monetary shocks, such as (temporary) shocks to the nominal interest rate. According to the existing empirical literature, a contractionary monetary policy shock in the U.S. leads to contractionary effects in foreign economies and an appreciation of the U.S. dollar (Eichenbaum and Evans 1995; Bluedorn and Bowdler 2011; Georgiadis and Mehl 2016; Dedola, Rivolta, and Stracca 2017; Inoue and Rossi 2019; Kose et al. 2019).[8]

[8]We provide a description of some closely related literature on international effects of the U.S. monetary policy, as well as exchange rate behavior, in Table A.1 (see Appendix A).

In such a setting, several possible transmission channels are at work. One, an increase in the U.S. nominal rate leads to contractionary effects on the U.S. economy, lowering demand domestically as well as U.S. import demand, thus potentially contracting exports to the U.S. economy in the foreign economy via a trade channel. Two, the exchange rate appreciates in response to the U.S. monetary contraction, making home goods more expensive relative to foreign goods. In fact, in his seminal work, Dornbusch (1976) suggests that, in response to a monetary contraction, the level of appreciation in the short run is more pronounced than in the long run, known as exchange rate overshooting behavior. This behavior is consistent with a drop in the domestic price level that occurs in the long run to restore (long-run) equilibrium in goods markets—implied by purchasing power parity—in conjunction with an expected depreciation dictated by equilibrium in asset markets when the domestic over foreign interest rate differential is positive—implied by the uncovered interest rate parity condition. As a consequence of the dollar depreciation, which makes U.S. goods relatively cheaper, the foreign economy may thus benefit via an exchange rate channel, increasing its exports and contributing to an increase in foreign output. On the other hand, when imports from the U.S. prevail, U.S. goods become relatively more expensive due to dollar appreciation, which might lead to a decrease in purchasing power and a contraction of foreign demand. Three, a number of recent studies (Kim 2001; Faust et al. 2003; Canova 2005; Ehrmann and Fratzscher 2009) have also emphasized that spillovers to the foreign economy take place through shifts in the real interest rate, not exchange rates, and that the real rate channel constitutes an important international transmission channel.

Concerning the empirical evidence on the behavior of exchange rates, there is consensus in the empirical literature that contractionary monetary policy shocks lead to an appreciation of the country's nominal exchange rate (Clarida and Gali 1994; Eichenbaum and Evans 1995; Faust and Rogers 2003). However, a lot of the discussion on international effects of monetary policy shocks centers around the precise pattern of exchange rate responses, some confirming Dornbusch's result on exchange rate overshooting on impact (Kim 2001; Faust and Rogers 2003; Bjørnland 2008; Kim, Moon, and Velasco 2017), while others argue it might occur in a delayed fashion (Scholl and Uhlig 2008; Steinsson 2008). Inoue and Rossi (2019) show that the reaction of exchange rates depends on how the monetary shock is perceived: depending on whether the shock affects short-run or long-run inflation expectations, the effects on exchange rates might vary. Moreover, there is a large literature pointing toward persistent deviations from uncovered interest rate parity (UIP) in the data (Eichenbaum and Evans 1995; Faust and Rogers 2003; Faust et al. 2003). Other recent studies (Hettig, Müller, and Wolf 2019; Huber and Rabitsch 2019; Schmitt-Grohé and Uribe 2022) find no clear evidence for overshooting behavior. Most closely related, Schmitt-Grohé and Uribe (2022) study international effects of two types of monetary shocks, one permanent, one transitory, and conclude that no overshooting occurs.

The focus of our empirical analysis is on understanding the spillover effects on macroeconomic variables in the foreign country. As such, we study not only the effects on exchange rates, but track all key foreign macroeconomic variables, including economic activity in the foreign economy. In addition, our model allows for a distinction between two types of monetary shocks, an inflation target shock that affects long-run inflation expectations, and a nominal interest rate shock.[9] While there is little theoretical and empirical work on spillover effects in response to long-term natured monetary policy shocks, we expect similar mechanisms of a trade channel, an exchange rate channel, and a real rate channel to be relevant also for our shock to long-run inflation expectations. We expect the following effects of the inflation target shock and the nominal rate shock. The inflation target shock in the U.S. transmits via an increase in inflation expectations, which pushes down the real interest rate. As a result, agents increase consumption demand, causing an increase in

[9]In similar spirit, Schmitt-Grohé and Uribe (2022) contrast permanent and temporary interest rate shocks; however, their focus is mostly on implications for exchange rate behavior, not the size of spillovers on foreign activity. They estimate a five-variable VAR model, including U.S. output growth, U.S. inflation, U.S. nominal interest rate, exchange rate, and foreign nominal interest rate. The analysis is done for the U.K. and Japan.

output. With a demand increase, inflation jumps up. The simultaneous reaction of the nominal rate is small. A contractionary nominal interest rate shock leads to an increase in the nominal interest rate in the U.S. and to a decrease in U.S. output growth and inflation. The nature of this shock is well-known: in the U.S., a positive nominal interest rate shock leads to an increase in the nominal rate and, due to delayed response of prices, an increase in the real rate. This leads to a contraction of consumption and demand, leading to a decrease in output and inflation. As our types of monetary shocks affect the real interest rate in opposite ways and to a differing degree of persistence, we expect to also observe differences in international spillovers: the inflation target shock is very persistent, and it affects long-run inflation expectations and the real rate in the U.S. In fact, Inoue and Rossi (2019) show that monetary policy transmits to exchange rates via both the inflation expectations channel and the real rate channel, and the inflation target shock affects both.

3. Econometric Framework

This section introduces a structural vector autoregressive (VAR) model for our empirical analysis of the international transmission of U.S. monetary shocks. Our aim is to study the transmission mechanism and comovement properties of macroeconomic variables in response to a persistent monetary shock, the inflation target shock, in addition to the more widely studied temporary nominal interest rate shock. We are interested in the transmission of U.S. persistent monetary shocks to other advanced economies. We adopt the recent approach of Baumeister and Hamilton (2015, 2018, 2019) to obtain inference in structural VARs, applied on a VAR including main U.S. and foreign variables.

3.1 Data

We use data on the U.S. and eight foreign advanced economies: Australia, Canada, Japan, New Zealand, Norway, Sweden, Switzerland, and the U.K. Our main data sources are the OECD, the Federal Reserve Bank of St. Louis FRED II database, and the BIS. For the baseline specification, our estimations start in 1974:Q1 (this is dictated by data availability for all countries) and end in 2019:Q1. We consider a baseline setting of a bilateral VAR model of U.S. and foreign macroeconomic variables (output growth, inflation, and nominal interest rates), the nominal exchange rate, and a proxy variable for the U.S. inflation target. Foreign macroeconomic variables are constructed as trade-weighted averages (using trade weights of the BIS) over the eight advanced economies. Table 1 provides further details on data sources and transformations, and on time samples. A potential problem arises from the fact that the inflation target is unobserved. As a proxy for the implicit U.S. inflation target, we use time series on U.S. long-run inflation expectations that come from the Fed's FRB/US model, described in Brayton, Laubach, and Reifschneider (2014), the PTR (*p*erceived inflation *t*arget *r*ate) measure. This time series is available on a quarterly basis from 1962:Q1.[10] Thus, our vector of observed data includes the following eight variables:

$$\boldsymbol{y}_t = [\bar{\pi}_t, \Delta y_t, \pi_t, i_t, \Delta ex_t, \Delta y_t^*, \pi_t^*, i_t^*],$$

where $\bar{\pi}_t$ is the proxy for the domestic (U.S.) inflation target, $\Delta y_t(^*)$ is domestic (foreign) real output growth, $\pi_t(^*)$ is domestic (foreign) inflation, $i_t(^*)$ is the domestic (foreign) interest rate, and Δex_t is the change of the nominal effective exchange rate. U.S. variables are referred to as domestic variables; variables with an asterisk belong to foreign economies. The exchange rate is defined as the U.S. dollar price of a unit of foreign currency (EX_t = dollar/foreign currency), such that an increase in EX_t reflects a domestic (dollar) depreciation, and $\Delta ex_t := log(EX_t) - log(EX_{t-1})$.

[10]For comparison, we show foreign inflation expectations in Figure C.1. A few observations stand out. First, foreign and U.S. inflation expectations are highly correlated, very persistent, and less volatile compared to actual inflation time series. Second, in the past 10 years, inflation expectations of all countries converge to values close to 2 percent. As we have many variables in our VAR but not a lot of data points, we have decided not to incorporate foreign long-run inflation expectations as an additional time series, as it would considerably shrink our sample size, being available only from 1990:Q1. Also, there is very little variation across all countries (U.S. included), thus the inclusion of foreign inflation expectations in addition to domestic brings little additional information.

Table 1. Data Description

Time Series	Database	Country	Time Span Available
U.S. Inflation Expectations, PTR	FRB/US model, Federal Reserve Board	US	1962:Q1–2019:Q1
Real Output Growth	OECD	AU, CA, JP, NZ, NO, SE, CH, UK, US	1962:Q1–2019:Q1
CPI-Based Inflation	OECD	AU, CA, JP, NZ, NO, SE, CH, UK, US	1962:Q1–2019:Q1
Short-Term Rate:			
- Three-Month Yield	FRED II, Federal Reserve Bank of St. Louis	NZ	1974:Q1–2019:Q1
- Interbank Rate		NO, US CH	1962:Q1–2019:Q1 1972:Q1–2019:Q1
- Three-Month Treasury Bill Rate		JP, SE, UK US	1960:Q2–2019:Q1 1947:Q2–2019:Q1
Long-Term Rate:			
- 10-Year Government Bond Yield	FRED II, Federal Reserve Bank of St.Louis	CA, CH, UK, US	1960:Q1–2019:Q1
		NZ AU NO SE JP	1970:Q1–2019:Q1 1969:Q3–2019:Q1 1985:Q1–2019:Q1 1987:Q1–2019:Q1 1989:Q1–2019:Q1
Trade Weights: - Weighting Matrix for Narrow Indices	BIS	AU, CA, JP, NZ, NO, SE, CH, UK, US	2017–19
Exchange Rate: - Nominal Effective Exchange Rate (NEER), Narrow Indices	BIS	AU, CA, JP, NZ, NO, SE, CH, UK, US	1964:Q1–2019:Q1

Note: This table contains the description of time series used for the analysis, their sources and time span.

3.2 The Model

Our baseline structural VAR model takes the following form:

$$\boldsymbol{A y_t} = \boldsymbol{B x_{t-1}} + \boldsymbol{u_t}, \boldsymbol{u_t} \sim \mathbb{N}(0, \boldsymbol{D}), \tag{1}$$

where $\boldsymbol{y}_t$ is the vector of observed variables at time t, vector $\boldsymbol{x'_{t-1}} = (\boldsymbol{y'_{t-1}}, \boldsymbol{y'_{t-2}}, \ldots, \boldsymbol{y'_{t-p}}, 1)'$ contains p lags of $\boldsymbol{y}$ and an intercept, $\boldsymbol{u_t}$, is the vector of structural shocks with covariance matrix $\boldsymbol{D}$. We specify our baseline model with two lags, i.e., $p = 2$.

A crucial challenge when working with VAR models arises from the need to identify structural shocks from the data. In particular, the data are loaded into the reduced-form VAR model:

$$\boldsymbol{y}_t = \boldsymbol{\Psi x}_{t-1} + \boldsymbol{\epsilon}_t, \boldsymbol{\epsilon}_t \sim \mathbb{N}(0, \boldsymbol{\Sigma}), \tag{2}$$

where $\boldsymbol{\Psi} = \boldsymbol{A}^{-1}\boldsymbol{B}$ and $\boldsymbol{\epsilon}_t = \boldsymbol{A}^{-1}\boldsymbol{u}_t$ is the vector of reduced-form innovations, which are some linear combination of the structural shocks, $\boldsymbol{u_t}$, with covariance matrix $\boldsymbol{\Sigma}$. In order to draw conclusions on the causal effects of the monetary shocks on other variables in the system, we need to identify structural shocks, $\boldsymbol{u}_t$; thus, we need to know $\boldsymbol{A}$ and $\boldsymbol{D}$. The problem is that estimating the reduced-form VAR gives us $\boldsymbol{\Psi}$ and $\boldsymbol{\Sigma}$, which is not enough to know $\boldsymbol{A}$ and $\boldsymbol{D}$. The identification of the recent methodology of Baumeister and Hamilton (2018, 2019), which we follow, entails the prior choice on both contemporaneous structural coefficients (the coefficients of the $\boldsymbol{A}$-matrix) and the impacts of shocks (prior information on elements of the $\boldsymbol{H}$-matrix, which is defined below as an adjugate matrix of $\boldsymbol{A}$), proposing to incorporate prior beliefs about the magnitude and signs of equilibrium impacts in a nondogmatic way. Unlike the sign restrictions literature (cf. Uhlig 2005; Scholl and Uhlig 2008), which aims to identify structural shocks by relying on theory predictions about the signs of the responses of identified shocks, the identification of Baumeister and Hamilton (2018) (BH2018 henceforth) entails specific prior distribution choices, making explicit the identification assumptions and allowing for uncertainty over them. Since the related theoretical literature does not provide us with consistent predictions about the expected effects of the inflation target shock, especially not in the international environment, we believe incorporating uncertainty over the identifying assumptions is crucial for our analysis to yield reliable results.

All elements of the $\boldsymbol{A}$-matrix are distributed according to a t-distribution with some prior parameters, where we specify prior means according to predictions from economic theory. In particular, in our model the $\boldsymbol{A}$-matrix takes the following general form:

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} & a_{17} & a_{18} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} & a_{27} & a_{28} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} & a_{37} & a_{38} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46} & a_{47} & a_{48} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56} & a_{57} & a_{58} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} & a_{67} & a_{68} \\ a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & a_{76} & a_{77} & a_{78} \\ a_{81} & a_{82} & a_{83} & a_{84} & a_{85} & a_{86} & a_{87} & a_{88} \end{bmatrix}$$

and with $\boldsymbol{A}^{-1} = \frac{1}{det(\boldsymbol{A})}\boldsymbol{H}$, where $\boldsymbol{H}$ is the adjugate matrix of $\boldsymbol{A}$. We then check the signs of the resulting impulse responses by computing the prior and posterior probabilities that the response of a specified structural shock on the indicated variable is positive after the shock. If necessary, we impose additional restrictions on the sign of impulse responses by imposing structure on the elements of the $\boldsymbol{H}$-matrix using an asymmetric t-distribution as proposed in BH2018.

We begin by discussing our prior choices on the elements of the $\boldsymbol{A}$-matrix. For the prior means of the a coefficients highlighted in blue, which correspond to the contemporaneous relations between $\Delta y_t, \pi_t, i_t$ (or $\Delta y_t^*, \pi_t^*, i_t^*$, respectively), we adopt the values used by BH2018 based on a simple three-equation (closed-economy) New Keynesian (NK) model to pin them down (for both the domestic and the foreign economy). These capture the supply relation (based on a Phillips curve), the demand relation (IS curve), and an interest rate rule of a small-scale theoretical model. This model is summarized by Equations (4)–(6) below. For coefficients a_{11} to a_{14}, a_{21}, a_{31}, and a_{41}, highlighted above in green, we follow our closed-economy paper on inflation target shocks, Lukmanova and Rabitsch (2023), where we adapted the three-equation NK model of BH2018 to a four-equation model accounting for the presence of a time-varying inflation target, $\widehat{\pi}_t$, given by Equation (3) of the system below:

$$\widehat{\pi}_t = \rho_{\widehat{\pi}}\widehat{\pi}_{t-1} + \varepsilon_{\widehat{\pi},t} \tag{3}$$

$$\widehat{Y}_t = \alpha^S \widehat{\pi}_t + u_t^S \tag{4}$$

$$\widehat{Y}_t = \beta^D \widehat{\pi}_t + \gamma^D \widehat{R}_t + u_t^D \tag{5}$$

$$\widehat{R}_t = \rho_R \widehat{R}_{t-1} + (1-\rho_R)\left[\rho_\pi(\widehat{\pi}_t - \widehat{\pi}_t^*) + \rho_Y(\widehat{Y}_t)\right] + \varepsilon_{R,t}. \tag{6}$$

To summarize, we thus adopt the choice for the prior parameters for the t-distribution of the elements of the $\boldsymbol{A}$-matrix pertaining to the standard three-equation NK model from BH2018. We use them not only for the choice of prior means for a-elements of the home (U.S.) economy, but also for the foreign economy (lower right block of blue-highlighted coefficients (a_{66} to a_{68}, a_{76} to a_{78}, and a_{86} to a_{88})). Additionally, we augment the domestic country's setting with a time-varying inflation target, following Lukmanova and Rabitsch (2023). The prior means of all remaining elements of the $\boldsymbol{A}$-matrix in these equations equal to zero. Finally, this leaves specifying the coefficients of the $\boldsymbol{A}$-matrix of the equations pertaining to the exchange rate, coefficients a_{51} to a_{58}. Our choice to follow closely the prior choices of BH2018 implies that we only obtain guidance for the choices of prior means of closed-economy relations. To establish prior choices for the coefficients of the exchange rate equations, we continue to let theoretical relationships guide us. In particular, suppose, as would be obtained by many open-economy macroeconomics models, that the exchange rate is determined by an uncovered interest rate parity (UIP) equation that relates the expected change in the exchange rate to the domestic to foreign interest rate differential:

$$E_t\left(ex_{t+1} - ex_t\right) = i_t - i_t^*. \tag{7}$$

Assuming, similar to how BH2018 do for a number of macro variables, that the law of motion for the exchange rate is governed by a simply (persistent) autoregressive process, e.g. $ex_{t+1} = \rho_{ex} ex_t + \varepsilon_{ex,t}$, we can derive the future expected change in the exchange rate, given by $E_t\left(ex_{t+1} - ex_t\right) = \left(\rho_{ex} - 1\right) ex_t$. Using this assumption together with the above UIP relation then allows us to choose coefficients $a_{54} = 1$, $a_{55} = 1 - \rho_{ex}$, and $a_{58} = -1$. We set $\rho_{ex} = 0.95$. Finally, we set the prior means of all other a-coefficients equal to zero. The resulting matrix containing prior means of the elements of the $\boldsymbol{A}$-matrix is the following:

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} & a_{17} & a_{18} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} & a_{27} & a_{28} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} & a_{37} & a_{38} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46} & a_{47} & a_{48} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56} & a_{57} & a_{58} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} & a_{67} & a_{68} \\ a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & a_{76} & a_{77} & a_{78} \\ a_{81} & a_{82} & a_{83} & a_{84} & a_{85} & a_{86} & a_{87} & a_{88} \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & -0.75 & 1 & 0 & 0 & 0 & 0 \\ 0.75 & -0.25 & -0.75 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0.05 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 1 & -2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & -0.75 & 1 \\ 0 & 0 & 0 & 0 & 0 & -0.25 & -0.75 & 1 \end{bmatrix}$$

Together with prior means, we need to specify the standard deviation of the t-distributions of the a_{ij} elements, σ_{ij}, reflecting how confident or uncertain we are about the above specified prior means. We specify prior scales that reflect somewhat more confidence on the a-coefficients highlighted in blue, setting them equal to 0.3. With respect to the inflation target process, we remain quite uninformative about the way it interacts with the other variables in the VAR system, following the logic outlined in the closed-economy setting in Lukmanova and Rabitsch (2023). This is because the inflation target shock is our object of interest, and also because the inflation target measure used in the VAR should be viewed as reflecting the variation in the (true) target itself, but potentially also other variations (due to observation, measurement or estimation errors of our target proxy). We thus set prior scales of a-coefficients highlighted in green, as well as for all cross-border relations and coefficients of the exchange rate relation, equal to 0.6, reflecting our decision to be more uninformative there. Table 2 below summarizes all prior choices on the elements of the $\boldsymbol{A}$.

Table 2. Prior Parameters of the T-Distribution on the Elements of the *A*-Matrix

Parameter	Prior Mode	Prior Scale	Truncation
Inflation Target Relation			
a_{11}	1	0.3	>0
a_{12}	0	0.6	
a_{13}	0	0.6	
a_{14}	0	0.6	
Supply Relation			
a_{21}	0	0.6	
$\{a_{22}, a_{66}\}$	1	0.3	≥0
$\{a_{23}, a_{67}\} = -\alpha^S$	–2	0.3	≤0
$\{a_{24}, a_{68}\}$	0	0.3	
Demand Relation			
a_{31}	01	0.6	
$\{a_{32}, a_{76}\}$	1	0.3	≥0
$\{a_{33}, a_{77}\} = -\beta^D$	–0.75	0.3	
$\{a_{34}, a_{78}\} = -\gamma^D$	1	0.3	≥0
Nominal Interest Rate Relation			
$a_{41} = (1 - \rho_R)\rho_\pi$	0.75	0.6	
$\{a_{42}, a_{86}\} = -(1 - \rho_R)\rho_Y$	–0.25	0.3	≤0
$\{a_{43}, a_{87}\} = -(1 - \rho_R)\rho_\pi$	–0.75	0.3	≤0
$\{a_{44}, a_{88}\}$	1	0.3	≥0
Exchange Rate Relation			
a_{54}	1	0.6	
a_{58}	–1	0.3	
$a_{55} = \rho_{ex}$	0.05	0.3	

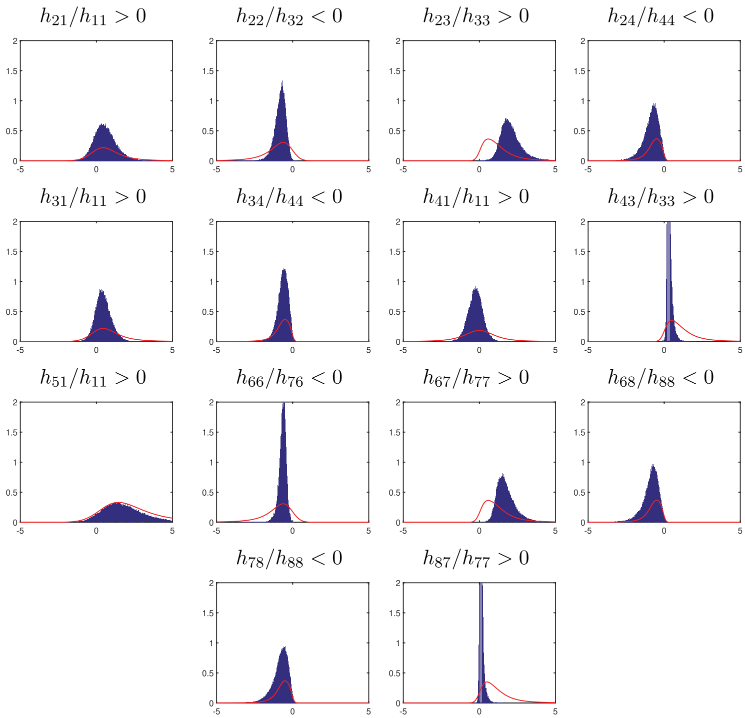
Next, let us turn to discussing additional prior information we include on the sign of impulse responses by imposing structure on the elements of the $\boldsymbol{H}$-matrix using an asymmetric t-distribution as proposed in BH2018. We center prior means of the responses of domestic (foreign) output and inflation responses such that they are negative in response to a domestic (foreign) nominal interest rate increase, i.e., $h_{24}/h_{44} < 0$, $h_{34}/h_{44} < 0$ ($h_{68}/h_{88} < 0$, $h_{78}/h_{88} < 0$). We also suggest that domestic (foreign) output growth and the nominal interest rate respond positively to a domestic (foreign) demand shock, i.e., $h_{23}/h_{33} > 0$, $h_{43}/h_{33} > 0$ ($h_{67}/h_{77} > 0$, $h_{87}/h_{77} > 0$), and that domestic (foreign) inflation responds negatively to a domestic (foreign) supply shock, i.e., $h_{22}/h_{32} < 0$ ($h_{66}/h_{76} < 0$). Additionally, we center the output growth, inflation, and nominal interest rate responses to a domestic inflation target shock around zero, but with positive skew. Similarly, we include prior information on the exchange rate, with positive prior mean (appreciation) to a domestic nominal interest rate shock and negative prior mean (depreciation) to a domestic inflation target. It is important to emphasize that the prior information on the impacts of shocks (prior information on elements of the $\boldsymbol{H}$-matrix) does not dogmatically impose a sign on the equilibrium impacts, but instead allows us to provide additional structure, which is useful in identifying the structural shocks, especially because many of the coefficients of the $\boldsymbol{A}$-matrix have not been precisely specified. That is, further information on the $\boldsymbol{H}$-matrix allows us to incorporate prior beliefs about the magnitude and signs of equilibrium impacts in a nondogmatic way. Figure 1 below summarizes the imposed prior information on the $\boldsymbol{H}$-matrix graphically.

Table 3 summarizes the prior and posterior probabilities that the response of a specified structural shock on the indicated variable is positive at horizons $h = 0$, 1, and 2. To save space, and because our focus is on the international spillovers of U.S. shocks, we do this for the domestic inflation, supply, demand, and nominal interest rate shocks only, but we look at the signs of domestic and foreign variables. Comparing prior and posterior probabilities of variables' responses being positive, we conclude that most of the implications of our choices for the impact responses, or for the $\boldsymbol{A}$-matrix, are in line with the economic intuition discussed above.

4. Results: Baseline Model

This section presents results of our baseline empirical model, described in the previous section, by comparing impulse responses to the two types of monetary shocks. Throughout this section, we report mean impulse responses and 68 percent confidence bands for

Figure 1. Distribution of the Coefficients of the $\boldsymbol{H}$-matrix



Note: Asymmetric t-distributions representing priors for the coefficients of impact response. Red line: prior distribution, blue histogram: posterior distribution.

the foreign economy (black solid and black dashed lines) alongside U.S. responses (blue lines and blue shaded areas). In our baseline model we use data from 1974:Q1 to 2019:Q1.

4.1 International Effects of a Shock to the U.S. Nominal Interest Rate

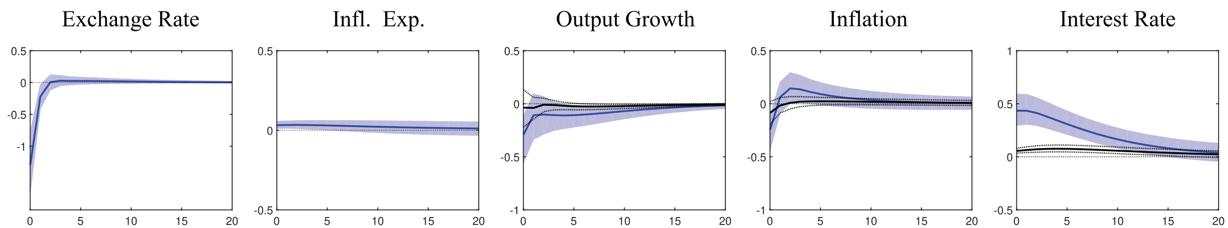
We start with the standard nominal interest rate shock, as its effects are well-documented in the literature (see Section 2). Figure 2 displays aggregate impulse responses to a nominal interest rate shock of one standard deviation in the U.S. Domestically, the effects are standard: a contractionary nominal interest rate shock translates into a

Table 3. Probabilities of Impulse Response Being Positive

	U.S Inflation Target Shock		U.S. Supply Shock		U.S. Demand Shock		U.S. Nominal Rate Shock	
Variable	**Prior**	**Posterior**	**Prior**	**Posterior**	**Prior**	**Posterior**	**Prior**	**Posterior**
				$h = 0$				
π_t^*	0.99	1.00	0.51	0.10	0.66	0.95	0.29	0.95
Δy	0.77	0.76	0.71	1.00	0.98	1.00	0.02	0.01
π	0.78	0.80	0.02	0	0.99	1.00	0.05	0.01
i	0.22	0.28	0.14	0.22	0.93	1.00	0.99	1.00
Δex_t	0.87	0.94	0.58	0.69	0.59	0.61	0.04	0.01
Δy^*	0.49	0.60	0.52	0.71	0.52	0.81	0.46	0.42
π^*	0.52	0.63	0.53	0.03	0.51	0.91	0.37	0.21
i^*	0.54	0.56	0.52	0.01	0.50	1.00	0.44	1.00
				$h = 1$				
π_t^*	0.56	1.00	0.50	0.02	0.51	0.98	0.48	0.95
Δy	0.52	0.52	0.53	1.00	0.59	0.97	0.42	0.30
π	0.52	0.85	0.40	0	0.58	1.00	0.46	0.67
i	0.48	0.62	0.43	0.47	0.56	1.00	0.60	1.00
Δex_t	0.52	0.62	0.51	0.83	0.51	0.50	0.43	0.12
Δy^*	0.50	0.73	0.51	0.88	0.50	0.87	0.49	0.34
π^*	0.50	0.76	0.51	0.00	0.50	0.85	0.48	0.41
i^*	0.50	0.64	0.50	0.04	0.50	1.00	0.51	1.00
				$h = 2$				
π_t^*	0.82	1.00	0.50	0.01	0.60	0.97	0.35	0.93
Δy	0.61	0.74	0.51	1.00	0.61	0.76	0.41	0.27
π	0.60	0.89	0.35	0	0.71	0.97	0.43	0.85
i	0.39	0.74	0.37	0.46	0.56	1.00	0.67	1.00
Δex_t	0.67	0.43	0.53	0.58	0.56	0.53	0.31	0.52
Δy^*	0.49	0.82	0.50	0.93	0.50	0.76	0.49	0.44
π^*	0.52	0.89	0.51	0.00	0.50	0.80	0.45	0.56
i^*	0.53	0.75	0.51	0.10	0.50	1.00	0.47	1.00

Note: Prior and posterior probabilities that the response of a specified structural shock on the indicated variable is positive at horizons $h = 0, 1$, and 2.

Figure 2. Impulse Responses to a Nominal Interest Rate Shock: Baseline Model



Note: Impulse responses to a U.S. nominal interest rate shock. Displayed are mean responses and 68 percent confidence intervals. Blue solid lines and blue shaded areas show U.S. responses, black solid and dashed lines show responses of foreign variables. Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (see Brayton, Laubach, and Reifschneider 2014). Sample: 1974:Q1 to 2019:Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

corresponding increase in the real rate, which leads to a decline in output growth and a drop in inflation. Internationally, the U.S. positive nominal interest rate shock leads to no significant change in foreign output growth, a mild decrease in foreign inflation, and an increase in the foreign nominal interest rate, together with a dollar appreciation.

Several aspects of these results deserve further mentioning. One, our results suggest that in response to the shock foreign variables tend to move in the same direction as U.S. variables. This is consistent with much of the literature, which finds that foreign variables react to U.S. monetary policy shocks with the same sign as U.S. variables.

Two, we find that the spillover effects of nominal interest rate shocks in Figure 2 tend to be somewhat smaller in magnitude compared to some earlier studies, even though a direct comparison is difficult, as the size of the international spillover of nominal interest rate shocks may be affected by our time samples and precise model specification.[11] Table A.1 in Appendix A provides a more detailed discussion of results on international spillovers from the literature and the various modeling frameworks used. Our sample period of 1974–2019 differs substantially from the existing literature's earlier starting and ending dates, before the crisis. Moreover, our model specification is often different from the existing studies, in that we include foreign macroeconomic variables explicitly in our model—as, on the one hand, our interest is in the size of international macroeconomic spillovers and not exchange rate behavior only and, on the other hand, in understanding the international transmission channel of U.S. inflation target shocks and inflation spillovers. Finally, our identification strategy is different, as we aim to account for the effects of both temporary and persistent U.S. monetary shocks, which can

[11]Studies using sign restrictions to identify the nominal interest rate shock, for example Scholl and Uhlig (2008), report insignificant international spillovers (see the working paper version). Kim, Moon, and Velasco (2017) point to a structural break in international spillovers after the Volcker era: the exchange rate reaction is smaller and has no delayed overshooting behavior. In a global VAR model, Georgiadis (2016) reports a maximum response of real GDP of –0.15bp after a 100bp contractionary monetary policy shock. As Georgiadis (2016) uses sign restrictions to identify the shock, the trough response should lie on the border of the confidence interval, making the finding consistent with this paper.

change the results of the nominal interest rate shock as compared to the specification with the temporary monetary shocks only.

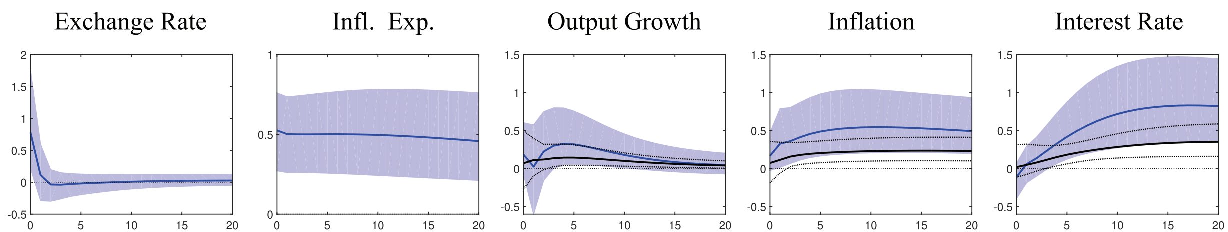
Three, in response to the contractionary U.S. nominal interest rate shock, the nominal exchange rate tends to appreciate on impact. The peak response appears to be on impact of the shock, i.e., the data do not support the overshooting result. This finding is consistent with Inoue and Rossi (2019). Our measure of the inflation target is unaffected by the nominal interest rate shock. Given the estimation sample, during which central banks in advanced countries implemented consistent policies toward inflation anchoring, we do not expect the long-run inflation expectations to react to short-lived monetary policy shocks, like a shock to the nominal interest rate.

4.2 International Effects of the U.S. Inflation Target Shock

Now we move on to the persistent monetary policy shock. To give some intuition, this shock can be thought of as a shock to the perceived inflation target that increases the inflation goal of the Federal Reserve in the medium to long run. It propagates into the economy by moving long-run inflation expectations in the U.S. upward. This, in turn, pushes the real rate down, stimulating aggregate demand, creating upward pressure on prices, and thus driving up actual inflation. The central bank responds in a Taylor rule logic by increasing the policy rate to cool down prices and demand. Figure 3 displays impulse responses to this shock in the baseline model. At home (responses in blue on Figure 3), the inflation target shock leads to persistent positive effects on long-run inflation expectations. In response, domestic demand increases and we observe increases in output growth and actual inflation.[12] The Fed gradually increases the policy rate to prevent the economy from overheating and to

[12]The response of U.S. output growth on impact of a positive inflation target shock is insignificant and it turns significantly positive several periods after the shock. This is in line with the empirical evidence on the effects of inflation target shocks in a closed-economy VAR setup estimated on U.S. data in Lukmanova and Rabitsch (2023). The authors show that the delay in output effects is due to the fact that economic agents need time to adjust their expectations and, as a result, their economic behavior to increase consumption demand. Gradually, this leads to higher economic growth.

Figure 3. Impulse Response to an Inflation Target Shock: Baseline Model



Note: Impulse response to an inflation target shock. Displayed are mean responses and 68 percent confidence intervals. Blue solid lines and blue shaded areas show U.S. responses, black solid and dashed lines show responses of foreign variables. Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (see Brayton, Laubach, and Reifschneider 2014). Sample: 1974:Q1 to 2019:Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

control inflation. Overall, the shock leads to expansionary effects in the U.S., which is consistent with the closed-economy literature on the effects of U.S. inflation target shocks (DeMichelis and Iacoviello 2016; Mumtaz and Theodoridis 2018; Uribe 2022; Lukmanova and Rabitsch 2023).

Internationally, we find that the shock spills over abroad. On average, foreign countries experience an increase in inflation and nominal rates, following a similar pattern to U.S. variables. In the aftermath of the inflation target shock in the U.S., foreign countries are confronted with permanently higher inflation from abroad (U.S.), thus facing a threat of importing this higher inflation. However, on impact of the shock, foreign central banks do not raise interest rates to counteract U.S. inflation (black line on the last subfigure of Figure 3 is insignificant from zero). In other words, even when U.S. inflation is already significantly above zero, foreign central banks do not increase policy rates in time to prevent importing higher inflation from the U.S. This leads to an increase in inflation expectations outside the U.S. and, due to an insufficient monetary policy response abroad, foreign real rates drop. This, in turn, leads to expansion-like effects abroad: foreign inflation goes up, as does foreign output growth (although, just as in the case of the U.S. economy, we do not observe the output increase on impact of the shock, but rather with some delay).

An additional amplification channel comes via exchange rates. We observe a strong dollar depreciation resulting from a shift away from domestic assets as the uncovered interest rate differential, $i_t - i_t^* - E_t\left(ex_{t+1} - ex_t\right)$, declines.[13] Note that the variable included in the VAR is the change in the nominal exchange rate, so that even though the change quickly converges back, the nominal exchange rate depreciates to a higher level. The initial depreciation can be understood as the result of stronger inflation reactions in the U.S. compared to abroad, and a negative on-impact response of the nominal rate, in contrast to the near zero-impact response of the foreign nominal rate. A few periods after the shock, it appears that the downward pressure caused by the higher inflation rate in the U.S. compared to other countries is more or less balanced by the upward

[13] Schmitt-Grohé and Uribe (2022) report a similar exchange rate response to their permanent nominal interest rate shock.

pressure from the higher interest rates in the U.S. as opposed to those abroad.

Our findings are consistent with the related literature. Using a structural open-economy DSGE model, Chin et al. (2018) also show that an inflation target shock originating in the U.S. leads to expansionary effects domestically as well as abroad. They show that an important element is an insufficient reaction of the foreign central bank to permanently higher inflation in the U.S. We confirm this using a purely empirical setup using data for the U.S. and other advanced economies (in contrast, Chin et al (2018) focus on U.S.–U.K. transmission only). Inoue and Rossi (2019) also emphasize a real rate and an inflation expectations channel as important for the international transmission of monetary policy shocks. Our results emphasize that inflation expectations abroad go up due to a weak response of the policy rate. This, using the logic of the Fisher equation, leads to a decline in the real rate abroad, triggering further real and nominal effects in foreign economies.

Trend inflation and interest rates (long- and short-term) have gone down more or less at the same time in advanced economies since the mid-1980s, as central banks switched toward (implicit or explicit) inflation targeting regimes. One interpretation could be that the global reorientation of monetary policy was a reaction to the Federal Reserve leading the way. At the same time, there are global common trends in low-frequency inflation dynamics, and it is possible to speculate about the degree to which these are the result of this global reorientation toward inflation targeting regimes or a reaction to the Fed leading the way. Our structural inflation target shock can be interpreted as a shock to global long-run inflation, proxied by the U.S. (leading the way), providing more structural and theory-based evidence behind the comovement in interest rates as we attempt to rationalize the common trends in inflation. With this, we do not exclude the possibility that there are other factors driving the inflation comovement across countries. However, we show that U.S. inflation target shocks are one of the reasons behind it.

Finally, compared to the effects of the U.S. nominal interest rate shock, international spillovers stemming from the inflation target shock are more persistent: inflation expectations, inflation, and nominal rates are away from the steady state even 20 quarters after the inflation target shock. The nature of the two shocks is different too:

while both types of shocks lead to an increase in U.S. interest rates, only the inflation target shock leads to an expansion in the U.S. These differences are the result of the relative movements in inflation expectations and real rates: while the inflation target shock increases inflation expectations, leading to a decrease in the real rate, given an insufficient reaction from the central bank, the nominal interest rate shock increases the real rate due to nominal rigidities pushing inflation expectations down. Internationally, these dynamics are largely mirrored as foreign economies tend to move in tandem with the U.S. Thus, our results suggest that U.S. inflation target shocks are important for understanding dynamics of economic variables not only in the U.S., but also abroad.

4.3 Robustness

We provide impulse responses to U.S. monetary policy shocks generated from two variations of our estimated model as robustness exercises. In the first variation, we evaluate the effect of a change in the time sample used. The choice of sample period might be particularly relevant for the size of international spillovers, as many of the earlier studies employ data that end before the Global Financial Crisis (GFC) of 2007–08. Until after the GFC, the time series of inflation or nominal interest rates are not subject to a lot of fluctuations. On the one hand, central banks were focused on stabilizing and anchoring inflation. On the other hand, the aftermath of the GFC was associated with the period of a binding zero lower bound on the nominal interest rate. In particular, the federal funds rate was pushed to nearly zero for about eight years, a substantial fraction of our sample, during which the Federal Reserve was conducting unconventional monetary policies, mainly aiming at decreasing interest rates at longer maturities, targeting term spreads. The specification of our baseline model does not provide a channel to account for the effects of unconventional monetary policy, again leading to a potential downplaying of the size of international spillovers in our sample. As a consequence, we report impulse responses from a model estimated over the time sample 1974:Q1–2008:Q2, summarized by Figures B.1 and B.2 in Appendix B.1. The results are robust to the estimation sample: excluding data after the GFC still leads to similar effects of the U.S. nominal interest rate shock (Figure B.1) and inflation target shock (Figure B.2). We interpret this as having enough information in the precrisis sample to inform our model on the effects of U.S. monetary policy shocks and their international transmission. In the next section, we extend the model to include long-term rates to bring in additional information on financial markets.

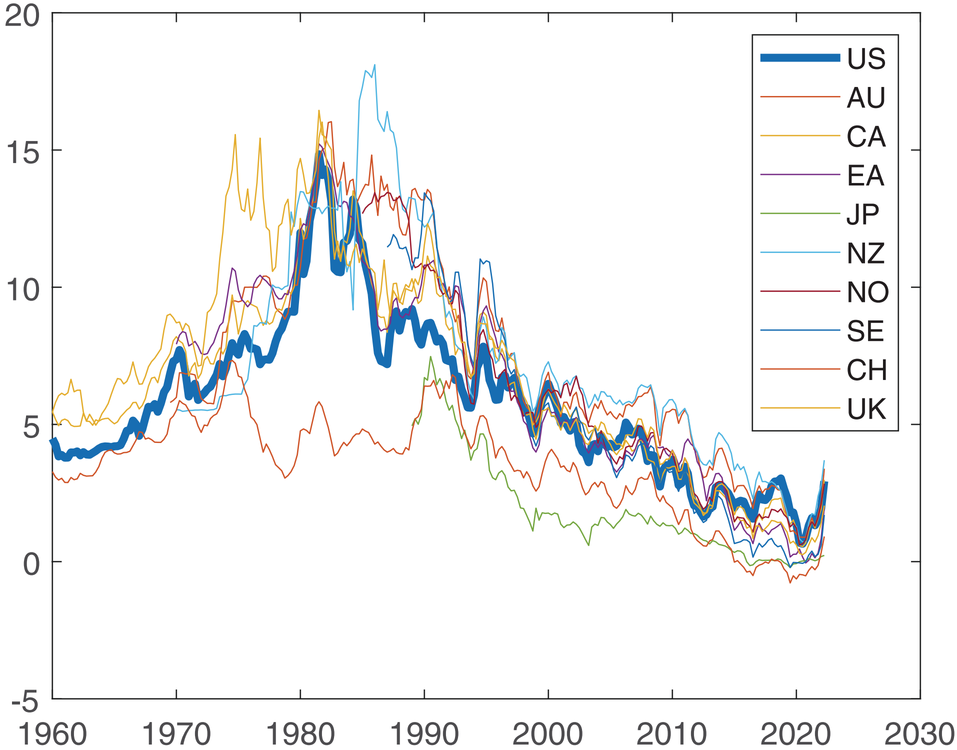
In the second variation, we present impulse responses to a U.S. nominal interest rate shock when the variable capturing the U.S. inflation target is dropped, and only the other seven macro time series are used, reported in Figure B.3 in Appendix B.2. The impulse responses to the nominal interest rate shock are similar to the baseline model, yet the foreign output growth response is positive, while the foreign inflation response is insignificant. We read this as evidence that (i) long-run inflation expectations bring important additional information into the system, and (ii) separating the effects of temporary and persistent monetary policy shocks helps to identify the effects of the former.

5. Results: Extended Model with Long-Term Rates

In this section we extend our model to include long-term interest rates. As is evident from Figure 4, and as discussed in the literature (e.g., Wright 2011), long-term interest rates strongly comove across advanced countries. Our baseline model results indicate that U.S. inflation target shocks lead to comovement in short-term rates. Here, we investigate if U.S. inflation target shocks also lead to comovement in long-term rates. Using an open-economy DSGE model, Chin et al. (2018) show that inflation target shocks originated in the U.S. can cause U.S.–U.K. long-term rates to comove. We tackle this question using an empirical VAR model including not only U.S.–U.K. but other advanced countries as well. With our identification strategy, which takes into account uncertainty about the effects of the inflation target shock at home and abroad, we do not need to impose a structure on the effects of the inflation target shock. Rather, we let the data speak. To do so, we extend the vector of observed data to include the long-term rates such that:

$$\boldsymbol{x}_t = [\widehat{\pi}_t, \Delta y_t, \pi_t, i_t, i_t^L, \Delta ex_t, \Delta y_t^*, \pi_t^*, i_t^*, i_t^{L,*}],$$

Figure 4. Long-Term Rates in Advanced Countries



Note: This figure plots 10-year government bond yields across advanced countries. The data start in 1960:Q1 (subject to availability for a particular country) and continue until 2022:Q2.

where i_t^L is the long-term rate that we measure as the return on 10-year government bonds. We use the same set of identifying restrictions (no additional restrictions are placed on long-term rates, as we are interested in their responses). In particular, we impose uninformative t-distributed priors with zero mean on the coefficients of the $\boldsymbol{A}$-matrix governing responses of long-term rates. We do not impose any additional restrictions on the $\boldsymbol{H}$-matrix that would guide the responses of long-term rates. At the same time, all previous prior restrictions remain. That is, with respect to the inflation target shock we expect that it causes an increase in our measure of long-term inflation expectations and we let the data determine corresponding effects on other variables in the model, both domestically and abroad.

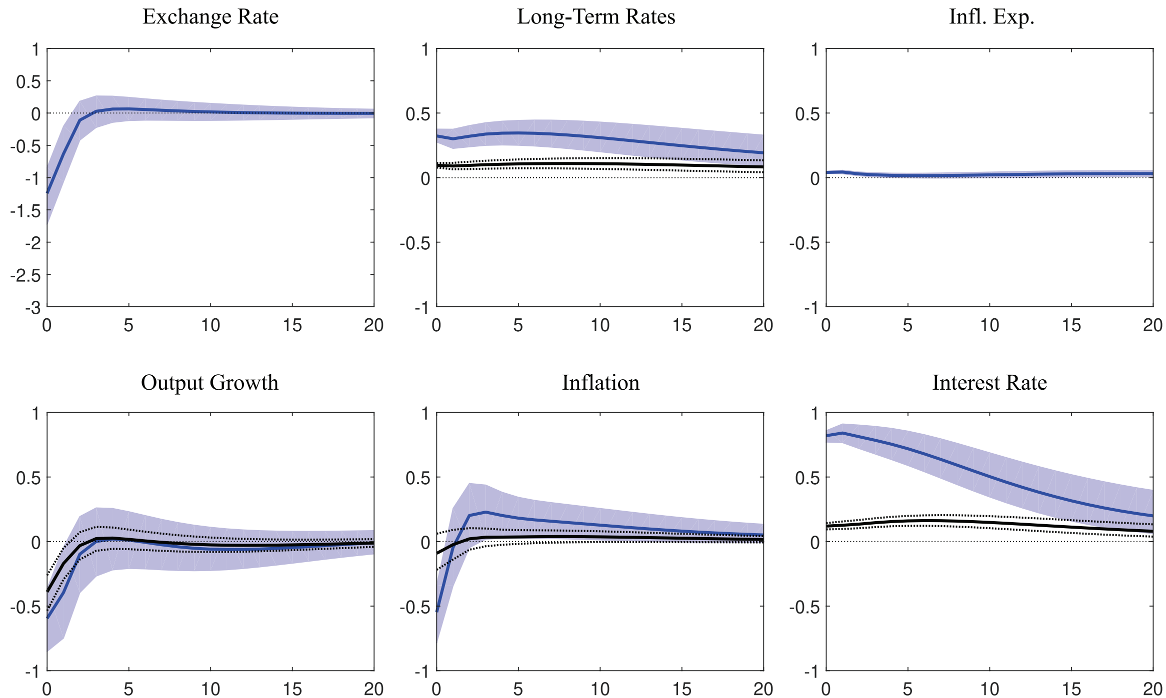
Results of the estimation of the extended model are reported in Figures 5 and 6. The inclusion of long-term rates helps to identify the effects of both temporary and persistent monetary shocks: the estimated impulse responses from the extended model have narrower confidence bands. A number of studies (Krishnamurthy and Vissing-Jorgensen 2012; Passari and Rey 2015; Rey 2016; Chin et al. 2018) point to an important role of adjustments in the term premium in determining the international transmission of monetary policy. The term premium is the difference in returns between the long-term bonds and average short-term bonds across the maturity of the long-term bond. Information from long-term rates gives us exactly this: it allows us to take into account the relative dynamics of short-term and long-term interest rates determined in financial markets. This is especially important with respect to the past decade, when short-term rates were bound at zero.[14] The unconventional monetary policies, such as quantitative easing, employed by major central banks during this period targeted the spread between short- and long-term rates. Including long-term rates helps us to account for this information.

For the nominal interest rate shock (Figure 5), information from long-term rates helps to pin down the response of foreign output, making it significantly negative, all else equal. While both domestic and foreign long-term rates increase in response to the shock, quantitatively the response of foreign long-term rates is very small.

Instead, in response to the U.S. inflation target shock, we also observe that both domestic and foreign output react positively, with responses significantly above zero. This serves as a further proof of the international transmission channel of the U.S. inflation target shock: the shock lifts up inflation expectations in the U.S., creating persistent domestic inflation. Foreign central banks do not react sufficiently to persistently higher U.S. inflation, as is evident from the response of the foreign short-term rate: it goes down on impact.

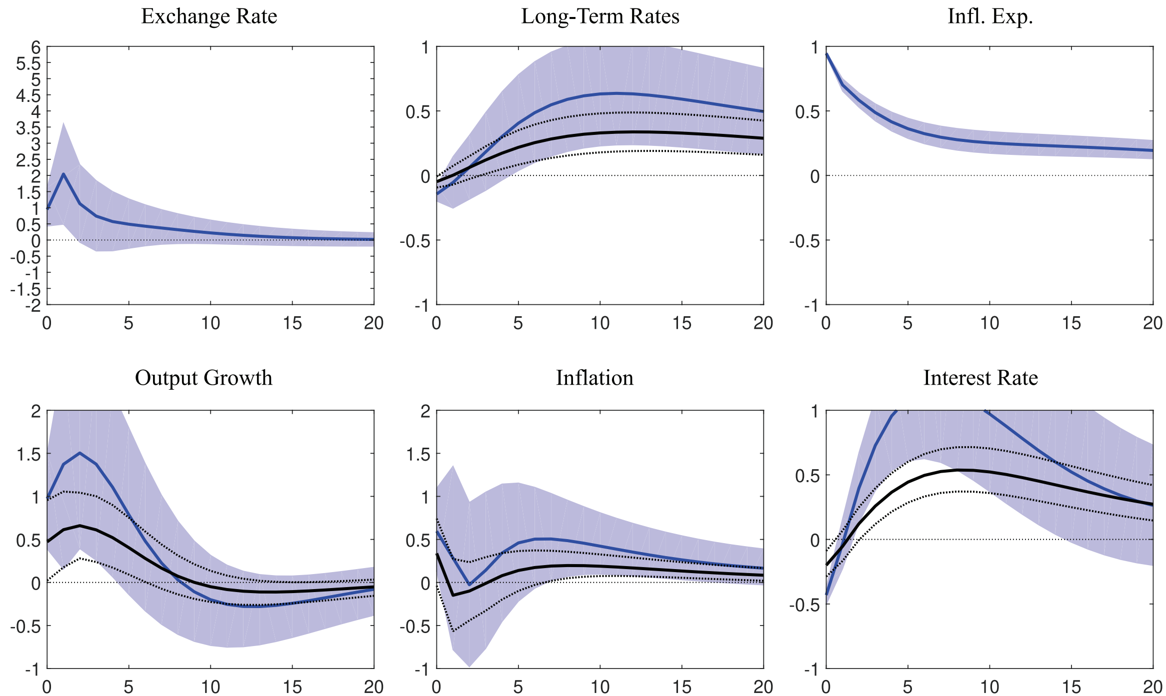
[14]For Japan, the binding zero lower bound period includes almost the whole estimation sample.

Figure 5. Impulse Response to a Nominal Interest Rate Shock: Extended Model



Note: Impulse response to a U.S. nominal interest rate shock. Displayed are mean responses and 68 percent confidence intervals. Blue solid lines and blue shaded areas show U.S. responses, black solid and dashed lines show responses of foreign variables. Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (see Brayton, Laubach, and Reifschneider 2014). Sample: 1989:Q1 to 2019:Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

Figure 6. Impulse Response to an Inflation Target Shock: Extended Model



Note: Impulse response to an inflation target shock. Displayed are mean responses and 68 percent confidence intervals. Blue solid lines and blue shaded areas show U.S. responses, black solid and dashed lines show responses of foreign variables. Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (see Brayton, Laubach, and Reifschneider 2014). Sample: 1989:Q1 to 2019:Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

This creates enough inflationary pressure from abroad to push foreign real rates down so that we observe an increase in foreign demand and foreign output going up. Eventually, foreign inflation also picks up, prompting central banks to increase short-term rates. Importantly, we observe a strong comovement in long-term rates across the U.S. and other advanced economies: they move nearly one-to-one in response to the U.S. inflation target shock. Thus, we conclude that the comovement of long-term rates across advanced economies can be explained by a rise in inflation expectations caused by a positive inflation target shock originated in the U.S.

Finally, once we include long-term rates, the response of exchange rates changes, but only in response to the inflation target shock. We still observe a dollar depreciation, but it peaks not on impact but rather one to two periods after the shock. In the extended model, domestic and foreign inflation reactions are almost the same. As time passes, U.S. inflation increases faster than foreign inflation and the Federal Reserve increases the interest rate more strongly compared to foreign central banks, all of which culminates in the peak reaction of the exchange rate about two quarters after the shock itself. Soon after, as foreign interest rates rise and U.S. inflation stabilizes persistently above foreign inflation, the change in the exchange rate goes back to the steady-state value.

6. Conclusions

This paper proposes a simple empirical model to estimate international effects of U.S. monetary policy shocks, allowing for both a nominal interest rate shock and an inflation target shock. We employ a novel identification methodology from Baumeister and Hamilton (2018) that allows us to distinguish between the two shocks. Our sample covers eight advanced economies and the U.S., with a baseline sample period of 1974:Q1 to 2019:Q1.

We find sizable international spillovers from the U.S. inflation target shock. At home the shock has persistent expansionary effects, through an increase in inflation expectations and a decrease in the real rate, followed by an increase in domestic consumption demand and inflation. Foreign countries import persistently higher inflation from the U.S. and, given an insufficient response of foreign central banks, inflation expectations abroad rise as well, also decreasing the foreign real rate. As a result, we observe expansionary effects abroad as well as at home, and a strong dollar depreciation from U.S. inflation target shocks.

We use the empirical evidence on the effects of U.S. inflation target shocks to take a step toward explaining the comovement in long-term rates across advanced countries that we observe in the data. In particular, as we separate the effects of temporary and persistent monetary policy shocks, we show that it is the persistent inflation target shock that generates long-lasting comovement in long-term rates between the U.S. and foreign countries.

Appendix A. Selected Literature on International Effects of U.S. Nominal Interest Rate Shocks

Table A.1. Selected Literature on International Spillovers of U.S. Monetary Policy Shocks

Paper	Time and Country Sample	Identification	Model Specification	Spillover Effects
Kim (2001)	1974–96, U.S. + G6	Cholesky decomposition. Monetary policy shock – shock to federal funds rate or to ratio of nonborrowed reserves to total reserves.	U.S. model: Real GDP, inflation, commodity price (PC), federal funds rate (and ratio of nonborrowed reserves to total reserves). International variables: trade balance, exports, imports, nominal exchange rate, terms of trade, real GDP, industrial production, inflation.	Expansionary MPS: nominal exchange rate depreciates, boom in foreign economies with an increase in real GDP by 0.05–0.2 percent (compared to 0.2–0.4 percent in the U.S.) explaining about 4–4.3 percent of foreign GDP.
Scholl and Uhlig (2008)	1990–2002, U.S. + Germany, Japan, U.K., and G7 aggregate	Sign restrictions for contractionary MPS (horizon of one year): U.S. interest rates do not fall, prices and the ratio of nonborrowed to total reserves do not rise.	U.S. and foreign industrial production, U.S. and foreign three-month interest rates, the U.S. ratio of nonborrowed to total reserves, the U.S. consumer price index and the nominal exchange rate.	Contractionary MPS: WP version reports small negligible effects on foreign output, not significantly different from zero.
Dedola, Rivolta, and Stracca (2017)	1981–2013, 36 countries	Estimate shocks from large-scale Bayesian VAR with U.S. data, sign restrictions: interest rate positive, output and inflation negative.	Quarterly data: foreign real GDP, GDP deflator, unemployment rate, real house prices, real domestic credit, total portfolio, total bank inflows.	Report aggregated IRFs. Foreign inflation's reactions are of little significance.

(*continued*)

Table A.1. (Continued)

Paper	Time and Country Sample	Identification	Model Specification	Spillover Effects
Bluedorn and Bowdler (2011)	1974–2001, U.S. + G7	Identification as in Romer and Romer (2004): In the first step, determine intended changes in the U.S. target federal funds rate announced during the FOMC meetings. In the second step, these federal funds rate changes are decomposed into two components, one that can be explained by the Federal Reserve's Greenbook forecasts, and one that cannot be explained by those forecasts. The second component defines the monetary policy shock.	U.S. output, prices and bank reserves, exchange rate, foreign interest rates, and foreign output.	Contractionary MPS: Foreign output shows a mixed initial response which becomes negative after four years. The U.S. price responses show a price puzzle. The price response depends critically on the number of lags of the policy shock included in the model. As the number of policy shock lags is increased, the price puzzle disappears while preserving many of the other impulse responses.
Kim, Moon, and Velasco (2017)	1974–2006, 12 U.S. trading partners from Europe, Canada, and Japan	Sign restrictions: prices and nonborrowed reserve ratio are required not to rise and interest rates are required not to fall for one year in response to a U.S. contractionary monetary shock. They find that identification via Cholesky leads to a persistent price puzzle, which is the reason why they do not study results obtained via this identification.	U.S. and foreign industrial production, U.S. and foreign three-month interest rates, the ratio of U.S. nonborrowed to total reserves, the U.S. consumer price index, and the real exchange rate.	Delayed overshooting is a phenomenon of the 1980s. UIP fails to hold during the Volcker era and tends to hold in the other periods considered. U.S. monetary policy shocks have substantial impacts on exchange rate variations but misleadingly appear to have small impacts when monetary policy regimes are pooled.
Georgiadis (2016)	1999–2009, 61 countries	Sign restrictions: short-term interest rates rise on impact, inflation turns negative after four quarters.	GVAR model, for each economy include: output, prices, bilateral nominal exchange rates, oil prices.	Figure 2 presents maximum response of real GDP. For countries included in our paper, the maximum response reported by Georgiadis (2016) is a 0.15 bp decrease after a contractionary MPS of 100 bp.

(continued)

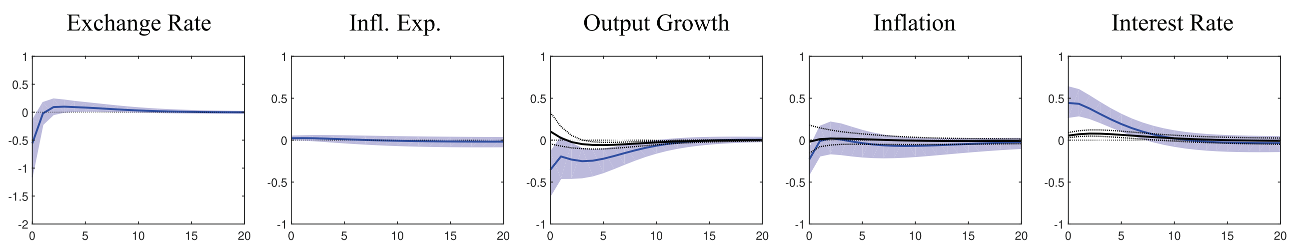
Table A.1. (Continued)

Paper	Time and Country Sample	Identification	Model Specification	Spillover Effects
Faust et al. (2003)	1974–2001, U.S.-U.K., U.S.-Germany	Identification sign restrictions from high-frequency data: a surprise loosening of monetary policy cannot lower output (foreign or domestic), prices, or NBRX contemporaneously, it cannot cause the dollar to appreciate contemporaneously and it cannot cause foreign interest rates to rise contemporaneously.	Domestic and foreign output, U.S. prices (measured as the CPI), the three-month U.S. and foreign interest rates, the ratio of nonborrowed reserves to total reserves in the U.S., and the exchange rate.	Expansionary MPS: foreign output contemporaneous reaction is weak around zero, increases and is positive 20 months after the shock, between 0.05 and 0.4 bp. Foreign nominal interest rate is between –0.2 and 0 bp on impacts, decreasing and is negative after the first year, between –0.3 and –0.1 bp.
Faust and Rogers (2003)	1974–97, U.S.-U.K., U.S.-Germany	Sign restrictions.	Standard seven-variable model (U.S. and foreign output, the U.S. consumer price index, U.S. and foreign short-term interest rates, the ratio of U.S. nonborrowed reserves to total reserves, and the exchange rate), and a new 14-variable model.	Expansionary MPS: foreign output increases by 0.2 and 0.1 bp depending on identification, foreign prices drop by 0.1 and 0 on impact, positive (about 0.1 bp) after four years.

Appendix B. Robustness Checks

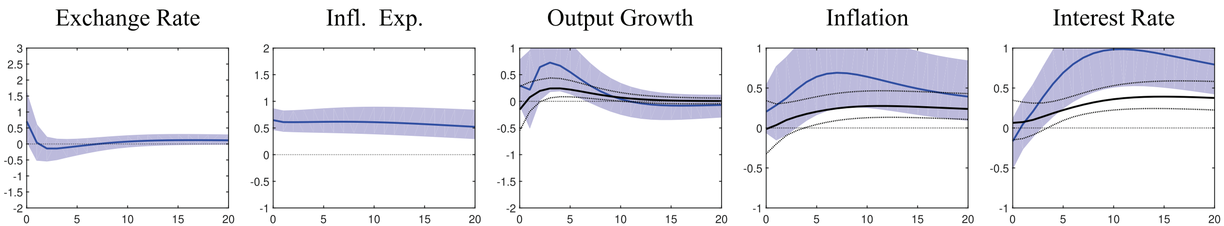
B.1 Excluding the Binding Zero Lower Bound Period

Figure B.1. Impulse Response to a Nominal Interest Rate Shock: Excluding Zero Lower Bound Period



Note: Impulse responses to a U.S.nominal interest rate shock. The blue shaded area is the U.S. response; the black line shows the response of foreign variables. Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (see Brayton, Laubach, and Reifschneider 2014) when prior mode for the ***A***-matrix is fully consistent with a four-equation DSGE model. The shaded area shows the 68 percent confidence interval and the blue dotted line the 90 percent confidence interval. Sample: 1974:Q1 to 2008:Q2. Horizontal axis: periods after the shock. Vertical axis: percentage change.

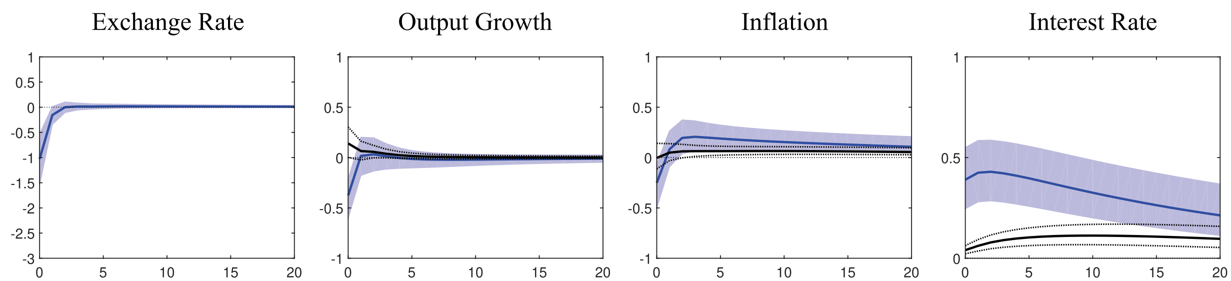
Figure B.2. Impulse Response to an Inflation Target Shock: Excluding Zero Lower Bound Period



Note: Impulse responses to a U.S. inflation target shock. The blue shaded area is the U.S. response; the black line shows the response of foreign variables. Baseline model with perceived inflation target rate (PTR) measure from the FRB/US model (see Brayton, Laubach, and Reifschneider 2014) when prior mode for the $\boldsymbol{A}$-matrix is fully consistent with a four-equation DSGE model. The shaded area shows the 68 percent confidence interval and the blue dotted line the 90 percent confidence interval. Sample: 1974:Q1 to 2008:Q2. Horizontal axis: periods after the shock. Vertical axis: percentage change.

B.2 Seven-Variable Model Without Inflation Target Variable

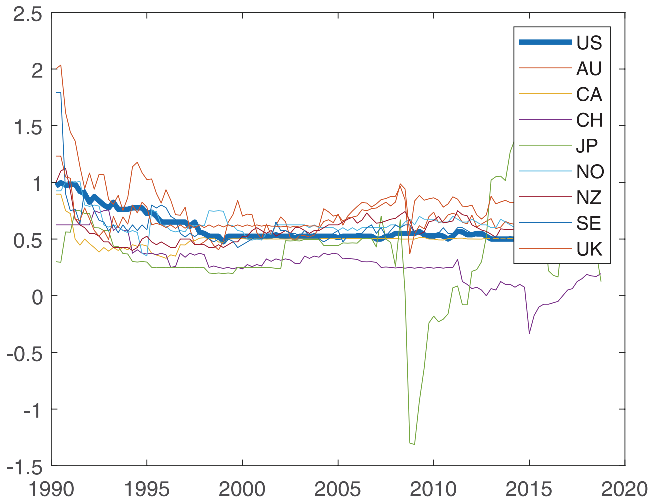
Figure B.3. Impulse Responses to a Nominal Interest Rate Shock: Seven-Variable Model without Inflation Target Variable



Note: Impulse responses to a U.S. nominal interest rate shock. Displayed are mean responses and 68 percent confidence intervals. Blue solid lines and blue shaded areas are U.S. responses; black solid and dashed lines show responses of foreign variables. Reduced model with only seven variables, without inflation target variable. Sample: 1974:Q1 to 2019:Q1. Horizontal axis: periods after the shock. Vertical axis: percentage change.

Appendix C. Inflation Expectations in Advanced Countries

Figure C.1. Inflation Expectations in Advanced Countries



Note: This figure plots inflation expectations across countries from our sample. The data start in 1990:Q2 and continue until 2018:Q4. For the U.S., we use the PTR measure of long-run inflation (see Brayton, Laubach, and Reifschneider 2014). For Australia, we use 10-year inflation expectations. For Canada, we use 6–10 year inflation expectations. For Japan, Norway, Sweden, Switzerland, and the U.K., we use five-year inflation expectations (and 10-year forecasts from 2004 onward for the U.K.). For New Zealand, we use two-year inflation expectations. All data are from national sources.

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