In Search of Dominant Drivers of the Real Exchange Rate*

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Abstract

Using quarterly macroeconomic variables and the real exchange rate data in seven developed economies, we uncover the major drivers of each variable in the business cycle frequency based on a VAR framework and analyze their implications on international business-cycle models. We document two new facts. First, there exists main business cycle drivers that explain a large chunk of key macro variables in each of the G7 countries, but these shocks account for less than 10 percent of the real exchange rate variances in a median country. Second, a dominant shock to the real exchange rate over the business cycle is orthogonal to the main business cycle driver, and makes up only a modest fraction of the total variation in macro variables. Furthermore, this shock generates persistent and delayed dynamics of the real exchange rate, and a significant deviation of the uncovered interest parity condition. Our findings support international business-cycle models that include separate shocks to jointly explain macro variables and the real exchange rate. In particular, a model with financial shocks such as Itskhoki and Mukhin (2021) is promising.

JEL classification: E32, F31.

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1 Introduction

Understanding the real exchange rate and its connection with the economy is core to the study of business cycle transmission across countries. The literature has two different views on the relationship between the real exchange rate and economic fundamentals. On the one hand, several papers argue that the seemingly low correlation, dubbed "disconnect" between the real exchange rate and macroeconomic variables in the data, suggests that dominant drivers of the real exchange rate may not be standard macro shocks, and that real exchange rate-specific shocks in international business cycle models can match several moments of the real exchange rate. For example, Itskhoki and Mukhin (2021) recently argue that financial shocks in the international asset market are the main driver of the real exchange rate, as it can resolve the major puzzles in the international macroeconomic literature. On the other hand, other papers attempt to match the real exchange rate properties with standard business cycle shocks, suggesting that the disconnect observed in the data masks an intricate transmission mechanism yet to be discovered. For instance, Steinsson (2008), Rabanal, Rubio-Ramirez, and Tuesta (2011), and Gornemann, Guerron-Quintana, and Saffie (2020) find that macroeconomic drivers such as total factor productivity (TFP) or shocks to the New Keynesian Phillips Curve can account for several properties of the real exchange rate.

Given these contrasting views in the literature, this paper asks whether international business cycle models need separate shocks to explain both real macro variables and the real exchange rate. In particular, we employ the "anatomy" approach in Angeletos, Collard, and Dellas (2020) and take different cuts of both key macroeconomic variables and the real exchange rate to examine the dynamic relationship between these variables in business cycle frequency. Using data for seven developed economies (G7)—the United States, the United Kingdom, Canada, Japan, Germany, France, and Italy—between 1974Q1 and 2016Q4, we first characterize the major drivers of key macro variables in the business cycle frequency (between 6 and 32 quarters) including their effects on the real exchange rate dynamics and their importance in driving the real exchange rate. Then, we take the real exchange rate data and document the properties of dominant shocks to the real exchange rate in the business cycle frequency. Finally, we use these sets of anatomy to shed light on how international business cycle models could jointly explain the behaviors of the real exchange rate and macro variables.

The empirical analysis utilizes the "max-share" approach to estimate a dominant shock to a variable, which is a structural vector autoregression (SVAR) shock that accounts for the maximal volatility of a variable over a particular frequency band. This approach, built on the work of Uhlig (2003) and more recently, Angeletos, Collard, and Dellas (2020), has several benefits for our study. First, we do not rely on a specific structural model which imposes strong cross-equation restrictions for the dynamic relationships and comovement between the real exchange rate and macroeconomic variables. Second, this approach makes it feasible to analyze data from several countries. Third, this approach helps us build a rich set of properties of several real macro variables and the real exchange rate, which can inform different theories about the types of shocks responsible for the real exchange rate behavior in international business cycle models.

The empirical findings can be summarized as follows. First, dominant shocks to domestic output, consumption, investment and hours worked relative to the rest of the world in the business cycle frequency generate similar dynamic responses of all the variables, but each of these shocks accounts for less than 10% of the real exchange rate forecast variances both in the short and long run, in the median country. Each of the four shocks obtained by targeting the key macro quantities not only triggers the same impulse responses, but also accounts for up to half of the business-cycle variations of the other quantities. This is consistent with the view that business cycle models featuring a single, dominant shock, or multiple shocks with similar propagation mechanism can capture the movements of key real macro quantities. However, these shocks generate small real exchange rate movements and account for only 5% of the real exchange rate fluctuations in most countries. This result is a dynamic business-cycle version of the exchange rate disconnect: dominant shocks at business cycle frequency are weakly connected with the real exchange rate. Nevertheless, we also find a substantial heterogeneity across countries in the degree of (dis)connect between the real exchange rate and business cycle shocks. For example, while dominant shocks to output account for only 3% of US real exchange rate forecast error variances, these shocks explain nearly 19% of the forecast error variance of the Canadian real exchange rate in the five-year horizon.

Second, dominant business-cycle shocks to the real exchange rate generate small responses from macro quantities, as well as the net export to output ratio, and explain little of these macroeconomic variables' fluctuations. In contrast, the real exchange rate response to a dominant real exchange rate shock is large and persistent with a slight delayed peak response in the G7 countries. The responses of the nominal interest rate and the inflation rate are small and insignificant. Driven by the large movement of the real exchange rate relative to the interest rate and inflation, the implied uncovered interest parity (UIP) wedge response is also economically and statistically significant and similar across all G7 countries. Furthermore, dominant shocks to the real exchange rate turn out to be almost orthogonal to dominant shocks to output in the business cycle frequency. Together, these two shocks explain over 90% of the forecast error variances of output and the real exchange rate, and 30–40% of the forecast error variances of consumption, investment and hours worked in the one-year horizon.

The empirical results have important implications on international business cycle models about their real exchange rate behavior. In particular, we reject the possibility that the dominant shock, or multiple shocks with the same propagation mechanism for key macro variables can be the major driver of the real exchange rate. While the similar transmission mechanism of dominant shocks to relative output, consumption, investment and hours worked support a potential main business cycle shock driving key macro quantities in all G7 countries, echoing the results in Angeletos, Collard, and Dellas (2020), these main business cycle shocks only have a modest role for the real exchange rate fluctuations. In other words, it is unlikely that an open economy version of the model with a dominant propagation can jointly explain the time series properties of both real quantities and the real exchange rate. Instead, models would need separating shocks explaining real quantities and another shock to the real exchange rate, such as Itskhoki and Mukhin (2021). To verify this intuition, we examine a quantitative open economy model in the same spirit as Itskhoki and Mukhin (2021) with TFP shocks and financial shocks to the international asset market. Simulating data from the model, we apply the same max-share method to find the dominant shock to the real exchange rate. The forecast error variances obtained from this exercise are consistent with our empirical results in that the real exchange rate and real quantities are weakly connected.

Furthermore, the set of anatomy from the real exchange rate helps us go further to examine whether financial shocks modeled in Itskhoki and Mukhin (2021) are consistent with our empirical dominant shocks to the real exchange rate. In fact, the impulse response functions for dominant shocks to the real exchange rate obtained from the simulated data resemble those from the financial shock in the model, including results on the UIP wedge. This suggests that from the viewpoint of Itskhoki and Mukhin (2021), our estimation approach of the dominant real exchange rate shock could be used as an empirical verification of the model's financial shocks. Based on this insight, we compare the empirical impulse response functions to dominant shocks to the real exchange rate with those obtained using the simulated data. We find that in addition to being weakly connected with macro quantities, financial shocks generate an order of magnitude stronger responses to the real exchange rate relative to interest rate differentials, consistent with the data. In other words, financial shocks can be broadly consistent with our set of anatomy for dominant shocks to the real exchange rate. However, there are two discrepancies between the responses from the simulated data and the empirical counterparts. First, financial shocks in the model miss the delayed peak response of the real exchange rate found in the data. In particular, while dominant shocks to the real exchange rate in the simulated data generate an immediate peak response of the real exchange rate, the empirical counterpart has a peak response one quarter after the shock. Consequently, the implied UIP wedge responses using the simulated data in the first few periods are different from those in the data. Second, financial shocks are strongly connected with net exports in the model which is at odds with the empirics. Together, our analyses suggest that while a model with financial shocks explaining the real exchange rate and main business cycle shocks driving real macro variables can be broadly consistent with the data, the model needs to incorporate additional frictions compared to Itskhoki and Mukhin (2021) in order to better match the time series of both the real exchange rate and real variables.

We perform several robustness checks with respect to the empirical specification and the data sample period. For example, we extend our baseline to study the relationship between the real exchange rate and expectations proxied by the consumer confidence and quarterly output forecast. None of our conclusion changes. In a median country, it is unlikely that dominant shocks for output and other variables are major drivers of the real exchange rate. Furthermore, to address the possibility that dominant shocks have confounding effects of supply and demand shocks, we identify dominant shocks of output in the business cycle frequency that are orthogonal to supply shocks in the form of news and unanticipated TFP shocks using US data. This "purified" dominant shock has a modest explanatory power on the real exchange rate. Together with our main empirical findings, this result suggests that financial shocks are likely a major source of real exchange rate, leading to the weak dynamic connect between the real exchange rate and key macro variables. We note that while dominant shocks to output and other variables may not be a main source of real exchange rate fluctuations, some dominant shocks explain a non-trivial fraction of the real exchange rate forecast variances in some country such as the United States and Canada, suggesting that shocks other than financial shocks can contribute to the variations for the real exchange rate to some extent, consistent with Chen, Fujiwara, and Hirose (2019).

Related Literature This paper fits in the international economics literature seeking to understand the determinants of the real exchange rate. We make three contributions.

First, we contribute to the literature on the determinants of the real exchange rate by documenting the properties of dominant real exchange rate drivers, which is helpful to distinguish the sources of the real exchange rate fluctuations. In the empirical literature, several papers such as Enders, Muller, and Scholl (2011), Juvenal (2011), Nam and Wang (2015), Schmitt-Grohe and Uribe (2019), Levchenko and Pandalai-Nayar (2020), and Chahrour et al. (2021) document the effects of unanticipated TFP, news, noise, fiscal and monetary shocks on the real exchange rate. Ayres, Hevia, and Nicolini (2020) find a relationship between the real exchange rate in some countries and primary commodity prices, and hypothesize that shocks to the commodity sector can be important for the real exchange rate. Our paper does not identify specific structural shocks, but looks at several cuts of the data to document the properties of dominant shocks driving the real exchange rate and the business cycle.

In the theoretical side, there is no consensus on what shocks are major drivers of the real exchange rate. Many papers match the real exchange rate properties with a set of conventional shocks. For example, Steinsson (2008), Chari, Kehoe, and McGrattan (2002), Rabanal, Rubio-Ramirez, and Tuesta (2011), and Martinez-Garcia and Sondergaard (2013) account for the persistence and the volatility of the real exchange rate in the context of a general equilibrium model with standard macro shocks such as monetary policy and productivity shocks. Valchev (2020) models the convenience yields as an endogenous response to productivity and monetary policy shocks that can replicate the movements of the uncovered interest parity in the data. At the same time, other papers estimating large scale models such as Adolfson et al. (2007) find that conventional macro shocks do not explain the real exchange rate. Recent papers by Itskhoki (2021) and Itskhoki and Mukhin (2021) argue that financial shocks in the international asset market in a general equilibrium model can help rationalize the exchange rate puzzles in the literature. Without taking a stand on a particular shock, we complement this literature by directly looking into the drivers of key macro and financial variables in several countries and investigating their effects on the real exchange rate. Our results suggest that the major driver of the real exchange rate may not be dominant shocks of the business cycles, and may be more consistent with a shock like Itskhoki and Mukhin (2021). In this regard, our paper compliments Eichenbaum, Johannsen, and Rebelo (2021), who estimate a three-country model for the United States, Germany and the rest of the world and find that foreign demand for the dollar-denominated bonds is the major driver of the real exchange rate, as well as Chen, Fujiwara, and Hirose (2019), who estimate a dynamic general equilibrium model for the United States and suggest that shocks to the uncovered interest parity plays a major role in explaining US real exchange rate. Their finding echoes Justiniano and Preston (2010) estimating a small open economy model using US-Canada data. Our empirical study does not rely on a specific structural model, but uses an agnostic approach to document how real exchange rates may be related to fundamentals. Our work suggests that not only do international business cycle models need several types of shocks in order to explain jointly the behaviors of the real exchange rate and key macro variables, these models also need other frictions so that the major shocks to the real exchange rate generate a persistent and hump-shaped response of the real exchange rate observed in the data.

Second, our paper fits in and contributes to the exchange rate disconnect literature. We focus on the dynamic relationships between the real exchange rate and other macroeconomic variables, and find that some fundamental shocks can explain a sizable fraction of the real exchange rate in the short and long horizons. Starting with the influential papers of Meese and Rogoff (1983) and Engel and West (2005), many focus on the contemporaneous disconnect between the *nominal* exchange rate and macroeconomic variables using measures of goodness of fit such as the R-squared and out-of-sample forecast errors. Recent studies are more positive about the connectedness between the nominal exchange rate and economic fundamentals. For example, Engel and Wu (2019), and Lilley et al. (2020) document the link between the nominal exchange rate and financial variables in recent periods. Koijen and Yogo (2020) find that macroeconomic and policy variables explain a large fraction of the nominal exchange rate variations. Stavrakeva and Tang (2020) argue that macroeconomic news can account for 70% of the quarterly variation in the nominal exchange rate. Using a structural model, Chen, Fujiwara, and Hirose (2019) estimate that conventional productivity, monetary policy and the uncertainty shocks can explain up to 40% of US real exchange rate. Unlike these papers, we take multiple cuts of the data and document the dynamic effects of major shocks driving key macro and financial variables to the real exchange rate for several countries, helping to distinguish models that can account for the movements of both key macro variables and the real exchange rate. Our extensive examination of the data finds that some types of dominant shocks can have a nontrivial effect on the real exchange rate, but this varies across countries: For example, while output shocks in Canada can explain up to 30% of the real exchange rate forecast error variances in the five-year horizon, dominant shocks to net exports are more important than output shocks for the real exchange rate in Japan, and dominant financial shocks are for the United Kingdom. Our results suggest that fundamental shocks can play a nontrivial role, but not dominant, in driving the real exchange rate in business cycles.

Third, our paper also relates to the literature on the shocks driving business cycle fluctuations.

We extend the analyses in Angeletos, Collard, and Dellas (2020) to an open economy setting. Our results are consistent with their paper, as we find that the major shocks explaining output in the G7 countries have similar dynamic effects on other macro variables as major shocks to consumption, investment and hours worked in the business cycle frequency. Furthermore, these dominant business cycle shocks also generate small changes in the inflation rate. Another contribution is to document the effects of this main business cycle shock on the real exchange rate, and its explanatory power for the fluctuations of the real exchange rate.

The paper proceeds as follows. In Section 2, we describe the empirical methods and the data series and construction for the empirical analyses. The relationship between real exchange rates and main business cycle shocks are presented in Section 3. Section 4 presents the empirical findings about the dominant shock that accounts for the real exchange rate. We discuss the model implications of our empirical findings in Section 5. Sections 6 and 7 discuss various extensions and robustness considering the relationship between the real exchange rate and dominant shocks of macro and financial variables. Section 8 concludes.

2 Empirical Methods and Data

This section describes the empirical methodology implemented in the paper, then discusses the data coverage and sources.

2.1 Empirical Methods

To find the dynamic relationship between the real exchange rate and other macro variables, we use the "max-share" approach to identify shocks that are important to each macro variables at business cycle frequency and examine its relationship with the real exchange rate. This empirical method builds on Uhlig (2003) and more recently, Angeletos, Collard, and Dellas (2020), which identifies a dominant shock for each variable as particular linear combinations of the VAR residuals by maximizing its contribution to the volatility of a macro variable at a particular frequency.

More specifically, we assume the following reduced form VAR:

$$A\left(L\right)X_t = u_t,$$

where X_t is an $N \times 1$ vector, containing the macroeconomic variables and the real exchange rate defined below, $A(L) = \sum_{\tau=0}^{p} A_\tau L^\tau$ is the matrix polynomials in the lag operator L with $A\left(0\right) =$

$A_0 = I$, and p is the number of lags included in the VAR, and u_t is a vector of VAR residuals with $E\left(u_t u_t^{'}\right) = \Sigma$. As the VAR includes a large number of variables—up to nine in some specifications—we opt to use Bayesian methods to estimate the VAR using Minnesota priors.[1] The posterior distributions are obtained from 10,000 draws after discarding initial draws.

We assume a structural shock ε_t has the following relationship with the VAR residuals:

$$u_t = S\varepsilon_t,$$

where S is an invertible $N \times N$ matrix, and ε_t is i.i.d. over time, $E(\varepsilon_t \varepsilon_t^{'}) = I$. We can write S as $S = S_{chol}Q$, where Q is an orthonormal matrix, i.e. $Q^{-1} = Q^{'}$ and hence $QQ^{'} = I$, and S_{chol} is the unique Cholesky decomposition of Σ. Thus, $SS^{'} = S_{chol}Q(S_{chol}Q)^{'} = \Sigma$. We need to specify Q to recover $\varepsilon_t = Q^{'}S^{-1}u_t$.

The identification strategy to specify Q is to find a shock that has the largest contribution to the volatility of a particular variable in a particular frequency. For example, we can find Q to have a shock that is the dominant shock for output at business cycle frequency between 6 and 32 quarters. We can write down the spectral density of variable X between the $[-w, w]$ frequencies as follows:

$$\Omega_X(w) = \frac{1}{2\pi} C(e^{-iw})QQ^{'}C(e^{iw})^{'},$$

where $C(L) = A^{-1}(L)\, S_{chol}$. This spectral density captures the volatility of variable X over the frequency band, such as $\left[\frac{2\pi}{32}, \frac{2\pi}{6}\right]$ for the business cycle frequencies, in terms of the contributions of all the Cholesky-transformed residuals. Then, we can find q, the column vector of Q corresponding to the shock, as an eigenvector associated with the largest eigenvalue.

We estimate this VAR for each of the seven countries vis-a-vis ROW in our data set. The baseline VAR has eight variables:

$$X_{s,t} = \left[\ln\left(\frac{Y_{s,t}}{Y_{ROW,t}}\right), \ln\left(\frac{C_{s,t}}{C_{ROW,t}}\right), \ln\left(\frac{I_{s,t}}{I_{ROW,t}}\right), \ln\left(\frac{h_{s,t}}{h_{ROW,t}}\right),\right.$$
$$\left.\frac{NX_{s,t}}{Y_{s,t}}, \ln RER_{s,t}, i_{s,t} - i_{ROW,t}, \pi_{s,t} - \pi_{ROW,t}\right],$$

i.e. the relative output, relative consumption, relative investment, and relative hours worked in country s to ROW, all in logs, the net-export-to-output ratio, the log of the real exchange rate, the relative nominal interest rate, and the relative inflation rate. We choose to specify the variables

[1] We obtain similar results when imposing Normal-Wishart priors.

in relative, instead of country-specific level variables.[2] We examine whether using country-specific level variables changes the results in one of our robustness checks.

2.2 Data

We use quarterly data for the G7 countries: the United States, the United Kingdom, Canada, Japan, Germany, France, and Italy. The data come from several sources. The national accounts data are taken from the Organization for Economic Co-operation and Development (OECD) and national statistical agencies. Hours worked are taken from Ohanian and Raffo (2012). The inflation rate is calculated based on the quarter-average consumer price index (CPI). The nominal interest rate are the end-of-period short-term treasury yields, taken from the Global Financial Database.

We construct the rest of the world (ROW) composite for each country in the data set based on a total of 13 OECD countries: six other G7 countries and seven other OECD countries—Australia, Austria, Finland, Ireland, Korea, Norway, and Sweden when data are available for each variable. Each country in the ROW is weighted by their nominal GDP shares calculated at the annual Purchasing Power Parity (PPP) values. The real exchange rate for each country is computed as the ratio of its CPI relative to the aggregate CPI of 13 OECD countries in current US dollars. To be consistent with the ROW aggregate for other variables, the CPI in current US dollars in each country is weighted with GDP shares at annual PPP values. We use the end-of-period nominal exchange rate from the Bank of International Settlement (BIS). Our data set also includes financial variables such as the short-term nominal interest rate, the corporate bond spread, which we construct following Krishnamurthy and Muir (2017), the realized return volatilities of each country's stock market, and the global risk factor data from Miranda-Agrippino and Rey (2020).

The resulting data set includes seven countries vis-a-vis ROW, with the longest coverage between 1974Q1 and 2016Q4. More details on the data for each country are in Appendix A.

3 Main Business Cycle Shocks and the Real Exchange Rate

This section presents the estimation result from the VAR. We focus on the impulse response functions (IRF) and the forecast error variance decomposition of main business cycle shocks associated with output and other variables. We document two main findings: First, the dominant shocks

[2] Intuitively, the real exchange rate is a relative variable, so using relative variables in the VAR captures the shocks that are important to the real exchange rate. We also check that intuition using simulated data from a standard international business cycle model.

explaining output in the business cycle frequency have the similar dynamics as dominant shocks explaining consumption, hours, net exports, but are disconnected from the inflation rate, the nominal interest rate in a median country. Second, dominant business cycle shocks are generally weakly connected from the real exchange rate, as it generates small movements of the real exchange rate and explains a modest fraction of real exchange rate fluctuations in a median country.

3.1 Main Business Cycle Shocks in Open Economies

Figure 1 plots the IRFs of relative output, consumption, investment, hours worked, and net exports-to-output ratio to the dominant shocks for relative output, consumption, hours worked and investment in the business cycle frequency in the United States and at median of the other G7 countries (median G6). The propagation mechanism of dominant shocks to output is similar to that of consumption, investment and hours worked in all countries. In the United States, a dominant output shock that increases domestic output relative to the rest of the world is associated with a significant increase in relative consumption, investment and hours worked, and a decline in the net exports-to-output ratio. The responses of output, consumption and hours are significant, and larger than the response of net exports-to-output ratio. Similar pictures emerge in the median G6 countries: the impulse responses of all five variables are similar across the dominant shocks to output, consumption, investment and hours worked, and the responses of net exports are relatively small compared to other variables. We note that while there are some heterogeneity across countries in terms of the significance of the responses, these results suggest that dominant shocks driving the fluctuations of relative output, consumption, hours worked, and investment in the G7 countries are closely related.

Furthermore, each of the dominant shocks to output, consumption, investment and hours worked plays an important role explaining the variations of these key macro variables, especially in the shorter horizons. Table 1 summarizes the fractions of the forecast error variances for output, consumption, hours worked and net exports attributable to dominant output shocks in the one-year and five-year horizons. Dominant output shocks explain substantial fractions of consumption and hours forecast error variances, up to 54% of the forecast error variances of consumption and 33.5% of the forecast error variances of hours worked in the one-year horizon in a median country. The contribution of dominant output shocks to key quantities variables tends to be larger in the one-year horizon than in the five-year horizon, consistent with the short-lived impulse responses. The importance of dominant output shocks in driving other variables varies across countries. In the United States, dominant output shocks, which contribute to 90.4% and 55.3% of the output forecast error variations in the one- and five-year horizons, respectively, are responsible for 53.6% and 23.5% of relative consumption volatilities in the one- and five-year horizons, and about 30% of the relative hours worked variations. In the United Kingdom and Canada, the role of dominant output shocks is slightly smaller for consumption.

What is the relationship of dominant shocks driving quantity variables and prices? It turns out that dominant shocks to output in the business cycle frequencies have little impact on the inflation rate and interest rate. As plotted in Figure 2, a shock that increase relative output in the United States by 0.6% is associated with a decline in the relative inflation rate of 0.03% and a rise in the relative nominal interest rate of 0.06% on impact. The magnitudes of the relative inflation rate and nominal interest rate responses are also small in the other countries. Consistent with the IRF results, dominant shocks to output explain a small fraction of the inflation rate forecast error variances (2.7% in the United States in the one-year horizon), but slightly larger for the nominal interest rate. On the flip side, the effects of a dominant shock to the nominal interest rate on key quantity variables are small and heterogeneous across countries. The dominant shocks to the short-term nominal interest rate and the inflation rate also explain small fractions of the forecast error variances of output, consumption and hours worked. For example, dominant nominal interest rate shocks in the business cycle frequencies explain only 5% of output forecast error variance in a median country in both one- and five-year horizons. Similarly, dominant shocks to inflation rate play a modest role in output fluctuations, explaining about 12% of output forecast error variance in a median country in the five-year horizon.[3] These findings suggest that dominant shocks explaining output, consumption, and hours worked in the business cycle frequency are weakly connected with the inflation rate.

Taken together, our results about dominant shocks driving key relative macro quantities in the G7 countries support the existence of a dominant shock or shocks with similar propagation mechanisms driving the fluctuations of real macroeconomic variables and having a negligible impact on the inflation rate in both the United States and other open developed economies. This result is in line with the closed-economy counterpart in Angeletos, Collard, and Dellas (2020), who find that dominant output shocks appear to have the same propagation mechanism on domestic variables as dominant shocks to consumption, investment, unemployment rate and hours worked in the United States. From now, we refer to dominant shocks to relative output between 6 and 32 quarters as a

[3]For detailed results, we plot in Appendix Figure C.5 the impulse responses of output to dominant nominal interest rate shocks and dominant inflation rate shocks. Appendix Table **??** reports the forecast error variance decomposition for all the variables attributed to interest rate MBC shocks and inflation rate MBC shocks.

main business cycle shock.

3.2 Main Business Cycle Shocks and the Real Exchange Rate

We next discuss the open economy aspect of output MBC shocks, focusing on its relationship with the real exchange rate.

First, MBC shocks tend to appreciate the real exchange rate in the G7 countries but the responses are small. As plotted in Figure 2, an increase in relative output due to output MBC shocks is associated with a near zero response of the real exchange rate in the United States, and a small rise in the relative inflation rate and interest rate. For a median G6 country, the real exchange rate appreciates persistently for 20 quarters in response to the output MBC shock, and the magnitude of the real exchange rate responses is about the same as that of relative output responses. The credible bounds for the estimate effects of output MBC shocks on the real exchange rate can be large, and the 16-84% credible bounds for the United Kingdom and Germany include zero, suggesting that the effects are small, and not precisely estimated. We note that as plotted in Figure 1, dominant output shocks also lead to an increase in consumption in all countries and a significant decline in net exports-to-output ratio in all countries except Germany and Canada. This result together with the real exchange rate, the relative inflation and interest rate responses are consistent with a non-inflationary demand shock view of MBC shocks: In an open economy model, a demand shock in the domestic economy associated with an increase in relative output leads to an increase in relative consumption, so net exports fall as country imports more than exports, and consequently the real exchange rate appreciates. We note that our findings that consumption increases and the real exchange appreciate after an output MBC shock is the conditional Backus-Smith puzzle.

Second, to see whether major drivers of the business cycle generate substantial deviations from the uncovered interest parity (UIP) condition, we compute the UIP wedge conditional on dominant output shocks for each country s using the IRFs of the real exchange rate, the nominal interest rate and the inflation rate as follows:

$$\text{UIP wedge}_t = \text{IRF}_{i_{s,t}-i_{ROW,t}} - \text{IRF}_{\pi_{s,t+1}-\pi_{ROW,t+1}} + IRF_{RER_t} - IRF_{RER_{t+1}}.$$

The last column of Figure 2 plots the UIP wedge for the United States and median G6 conditional on output MBC shocks. In all seven countries, there is some movement in UIP wedge in response to output MBC shocks. The peak response of the UIP wedge happens within one to two quarters after the shock, and is about half of the peak response of relative output. The responses of the UIP wedge in response to output MBC shocks, however, are imprecisely estimated: In the United States, Germany, France and Italy, the credible bounds include zero at all horizons, and in Canada, Japan and the United Kingdom, the UIP wedge responses are significantly different from zero for only a few quarters. This result suggests that main business cycle shocks generate small deviations from the UIP condition.

Third, the variance decomposition results are consistent with the impulse responses: the real exchange rate and MBC shocks have a modest connection in all countries, especially in the short run. Table 1 reports the fractions of the forecast error variances of the variables in the VAR explained by relative output MBC shocks at one- and five-year horizons for each country at the posterior median. In a median country, output MBC shocks explain only 2% of the real exchange rate forecast error variance in the one-year horizon. The contribution of dominant output shocks to the real exchange rate forecast error variance is larger in the five-year horizon in all countries, but remains small: only 5% of the fluctuations in the real exchange rate in the median country is attributable to output MBC shocks. The country where output MBC shocks explain the most of the real exchange rate variation is Canada. In the five-year horizon, up to 18.7% of the fluctuations in the Canadian real exchange rate is driven by dominant output shocks. This result is consistent with the conventional view that underlying shocks like oil shocks may be an important driver for both output and the real exchange rate in Canada. We obtain similar results if we focus on the contribution of relative consumption, hours worked and investment dominant shocks on the fluctuations of the real exchange rate: in a median country, these dominant shocks explain between 2 and 5% of the forecast error variances of the real exchange rate, and the largest connection is in Canada. The overall small contribution of MBC shocks to the real exchange rate in G7 countries highlights a conditional exchange rate disconnect: while real macro aggregates are driven by a main business cycle shock or shocks that have similar propagation mechanism, these shocks do not explain a large fraction of the real exchange rate variations especially in the short run.

Overall, the empirical results in this section suggest that while there are dominant shocks or shocks with common propagation mechanisms driving output, consumption, investment and hours worked in the business cycle frequency in the open economy setting, main business cycle shocks are not a major driver of the real exchange rate in the G7 countries.

4 Dominant Real Exchange Rate Shocks

The previous section unravels that main business cycle shocks account for only a small fraction of the real exchange rate variation in the business cycle frequency. In this section, we apply the estimation approach to document the properties of a shock that explains the largest business cycle variation of the real exchange rate. We find that a dominant business cycle shock to the real exchange rate generates a persistent movement of the real exchange rate, a conditional Backus-Smith puzzle, and a significant response of the UIP wedge. Furthermore, this dominant shock barely accounts for the forecast error variances of main real macro aggregates although with some variation across countries, and turns out to be orthogonal to main business cycle shocks. We elaborate on each of these six properties below.

First, dominant shocks to the real exchange rate have a large and persistent effect on the real exchange rate in all G7 countries. As shown in Figure 3, in response to a real appreciation shock, the real exchange rate remains appreciated for at least 12 quarters after the shock in the United States and the median G6 country.[4] The response of the real exchange rate is slightly hump-shaped, with the largest response of the real exchange rate likely occurring a quarter after the shock.

Second, dominant shocks to the real exchange rate generate small movements in key macro variables. Looking into the impulse responses of other variables in Figure 3, relative output and consumption increase in response to a real appreciation caused by the dominant real exchange rate shock, but their magnitudes are relatively small compared to those of the real exchange rate. In the United States, the largest response of relative output is only 0.2%, compared to the 4% initial responses of the real exchange rate. The rise in relative consumption is more apparent, suggesting that the major driver of the real exchange rate generates a conditional Backus-Smith puzzle, as the international risk sharing condition in standard business cycle models predict a decline in relative consumption in relation to a real appreciation. Similar to the responses of quantity variables, the responses of the relative inflation and interest rates are small for most countries, with limited variations of around 0.1 percentage point. Of note, the relative nominal interest rate response of the median G6 is muted relative to that of the United States, and this is mostly driven by the low variation of the relative nominal interest rate in the euro area countries (Germany, France, and Italy) as seen in the individual country plots in the Appendix.

Third, dominant shocks to the real exchange rate generate a meaningful deviation from the UIP

[4] Appendix Figure C.4 plots individual country responses with credible regions.

condition. As above, we use the impulse responses of the real exchange rate, the relative inflation and interest rates to compute the response of the UIP wedge to the dominant real exchange rate shock. The UIP wedge initially increases, reverses to negative then goes back to zero over the longer horizons. As the responses of the inflation and interest rates are small, the UIP wedge responses mostly reflect the expected growth rate of the real exchange rate in response to dominant shocks, and the reversal of the UIP wedge reflect the delayed peak response of the real exchange rate. This result resonates with the recent work by Kalemli-Ozcan and Varela (2021), who document that the comovement of the UIP premium and the global risk perception is explained by expected changes in exchange rates in advanced countries.

Fourth, dominant shocks to the real exchange rate are limited in driving the fluctuations of aggregate variables. The last panel of Table 1 reports the fractions of the forecast error variances of the macro variables in the one- and five-year horizons attributable to this shock. In a median G7 country, the dominant real exchange rate shock accounts for 95% and 70.3% of the real exchange rate forecast error variance in the one- and five-year horizons, respectively. However, the shock accounts for less than 7% of the forecast error variances of relative output in the one- and five-year horizons. Similarly, less than 11% of the one-year forecast error variances of any macro variables in the VAR are attributable to dominant real exchange rate shocks. The connection is stronger in the longer horizons for all variables, and the strongest connection is with net exports-to-output ratio. For example, dominant shocks to the real exchange rate are responsible for 10.9% of the forecast error variances of net exports-to-output ratio the five-year horizon, compared to 1.7% in the one-year horizon in a median country. Dominant shocks to the real exchange rate contribute to nearly 8% of the five-year forecast error variances of relative nominal interest rate and inflation rate in a median country, substantially larger than that in the one-year horizon.

Fifth, there is nevertheless some variation across countries and variables in the degree to which dominant shocks to the real exchange rate are connected with macro variables. For example, 31.4% of the US and 25.3% of German relative consumption variations in the five-year horizon are attributed to dominant real exchange rate shocks, much larger than in other countries. While the connection between hours worked and dominant shocks to the real exchange rate is small for most countries, almost one-third of the UK relative hours worked variances in the five-year horizon are driven by dominant shocks to the real exchange rate. Even so, the overall picture emerged from the variance decomposition exercise is a modest connection between dominant real exchange rate shocks and both real and nominal variables, especially in the short run.

Finally, dominant shocks to the real exchange rate are orthogonal to main business cycle shocks. Since our approach uncovers dominant shocks to each variable by targeting one variable in the VAR at a time separately, it is possible that dominant shocks are correlated with each other. To examine whether dominant real exchange rate shocks may be correlated with main business cycle shocks, we identify an "orthogonal" dominant real exchange rate shock that are constrained to be orthogonal to dominant output shocks. As plotted in Figure 4, the orthogonalized dominant real exchange rate shocks and the unconstrained dominant real exchange rate shocks have almost identical effects on other variables. In other words, dominant shocks to the real exchange rate in each country is clearly not correlated to dominant shocks to output. We get similar results if we identify dominant shocks to the real exchange rate orthogonal to consumption or investment in the business cycle frequency. This result suggests that we may need at least two factors in order to explain both main real aggregate variables and the real exchange rate.

5 Implications for International Business Cycle Models

With the multiple cuts of the data, we now draw lessons for international business cycle models that aim to account for the behaviors of the real exchange rate and key macroeconomic variables. To demonstrate the intuition, we study a two-country New Keynesian model in the spirit of Itskhoki and Mukhin (2021) which fits the data for the real exchange rate and resolves several puzzles in the international macro literature.

Itskhoki and Mukhin (2021) introduce a financial sector with noisy traders and risk-averse intermediaries to an otherwise standard international business cycle model that encompasses Chari, Kehoe, and McGrattan (2002) and Steinsson (2008). An exogenous shock to the international currency position of noisy traders, referred to as the *financial shock*, results in an equilibrium UIP deviation due to the intermediaries' demand for risk premium on their carry trade activity in a segmented market. The financial shock, combined with conventional ingredients that mute the pass-through of exchange rate movements into macro variables, generate several desirable unconditional business-cycle moments related to the real exchange rate, such as the excess volatility of the real exchange rate relative to macro aggregates. Nevertheless, the authors also note that the model generates a counterfactual strong correlation between the real exchange rate and net exports.

Following Itskhoki and Mukhin (2021), we introduce a financial shock as well as a standard portfolio adjustment cost to our model which give rise to deviations in the UIP condition. Consumption, investment and intermediate goods are composites of home and foreign goods, with a home biased preference. We assume that labor is not mobile across countries. In each country, monopolistically competitive firms combine labor, capital, and intermediate inputs to produce output and are subject to country-common TFP shocks. Firms are able to price to market, and there is incomplete pass-through. Firms in each country face staggered price and wage settings, *à la* Calvo (1983). The model includes monetary policy shocks as exogenous deviations from the Taylor rule. We calibrate the model to match the following moments from our US data: the relative standard deviations of the growth rate of investment and output to calibrate the capital adjustment cost; the trade-to-GDP ratio to calibrate the imports-to-expenditure ratio; and the relative standard deviations of the growth rate of the real exchange rate and output to calibrate the sizes of the shocks. Details of the model and its calibration are in Appendix B.

5.1 Model with One Dominant Factor

We first show that the model with one dominant driving force is not consistent with our empirical regularities. To that end, we generate simulated data with measurement errors from the model with only the TFP shock as the driving force and apply our estimation methods. The blue dashed line in Figure 5 plots the forecast error variance decomposition for relative output, consumption, hours worked, investment, net exports-to-output ratio, the inflation rate, the nominal interest rate and the real exchange rate attributable to dominant shocks to relative output in the simulated data generated with only TFP shocks. The estimation of the simulated data precisely captures the dominant driver in the model, which accounts for most of the fluctuations in output, consumption, hours worked, investment, net exports-to-output ratio and the real exchange rate.[5] Note that this result is at odds with our empirical main business cycle shock which accounts for less than 5% of the real exchange rate variation (Table 1).

More generally, our analyses suggest that models with multiple shocks with a similar propagation mechanism are not able to generate the observed disconnect between the real exchange rate and real quantities. For example, our approach may identify dominant shocks to relative output or consumption as a combination of structural shocks in the model. However, if these shocks in the model generate similar dynamics of the real exchange rate, the identified dominant output or consumption shocks would also drive all the fluctuations of the real exchange rate, inconsistent

[5] In the estimation of simulated data, neither the source of the single shock in the model nor the target max-share variable in the estimation matters for the result that the dominant shock accounts for most of the variation in all variables.

with the variance decomposition in our empirics. We also note that in the model, both TFP shocks and monetary policy shocks generate negligible deviations from the UIP condition, so the model with these shocks cannot be consistent with the documented effects of dominant shocks to the real exchange rate. Therefore, the model needs separate shocks that explain real macro variables and the real exchange rate.

5.2 Model with Separate Factors Explaining Business Cycles and the Real Exchange Rate

In the previous sections, we constructed several new business-cycle moments conditional on the estimated dominant driver of output and of the real exchange rate. To examine whether a leading quantitative international business cycle model is consistent with our empirical findings, this section analyzes our full model with all three shocks (TFP, monetary, and financial).

We simulate the full model with measurement errors several times and apply our approach to find the dominant driver of the relative output and of the real exchange rate. The black solid line in Figure 5 plots the forecast error variance decomposition for the eight variables attributable to the dominant driver of relative output using simulated data generated with all three shocks. The pattern emerging from this graph is broadly consistent with the result that main business cycle shocks account for little of the real exchange rate fluctuations.[6]

Figure 6 plots the forecast error variance decomposition for eight variables in our VAR attributable to the dominant driver of the real exchange rate using simulated data. Three observations arise from this exercise. First, the forecast error variance explained by dominant real exchange rate shocks using simulated data is similar to that explained by financial shocks in the model. This suggests that our empirical approach could identify the "structural" dominant driver of the real exchange rate in a class of models. Second, the dominant driver of the real exchange rate in the model generates low explanatory power on the dynamics of relative output, consumption, hours worked and investment, consistent with our empirical dominant real exchange rate shock. Third, the main discrepancy between the dominant real exchange rate shock in the model and our empirical counterpart is that the model shock accounts for *most* of the variations in net exports-to-output ratio, whereas the empirical driver accounts for only 17% of the forecast error variances of net

[6] We note that we do not take a stand on what constitutes main business cycle shocks. While our finding for the US and Angeletos, Collard, and Dellas (2020) both find low connections between dominant TFP shocks and output, our use of TFP shocks in the model is to demonstrate that models with separating shocks explaining real macro variables and the real exchange rate can be broadly consistent with the observed low connection between main business cycle shocks and the real exchange rate.

exports-to-output ratio in the United States (and 11% in the median country) at the five-year horizon. This result is driven by the fact that in Itskhoki and Mukhin (2021), financial shocks, which play a major role in driving the real exchange rate, account for most of the net export variations, as plotted by the blue dashed line in Figure 6. Overall, the comparison of forecast error variances attributable to dominant real exchange rate shocks indicates that a model with a financial shock explaining the real exchange rate and other shocks explaining the other variables resembles the data. Nevertheless, as the financial shock disproportionately affects the real exchange rate through changes in the domestic holdings of foreign bonds, and since the model exhibits a tight link between net foreign asset positions and net exports, the shock also plays a decisive role in the dynamics of net exports. This result is at odds with our empirics.

We further examine whether the model is consistent with the observed effects of the dominant shock to the real exchange rate. Figure 7 plots the impulse responses of dominant real exchange rate shocks using simulated data. For ease of comparison, we also plot the median of the impulse responses estimated from the G7 data. We document two findings that support our estimation and modeling approaches. First, the dominant real exchange rate shock in the simulated data generates similar impulse responses to the financial shock in the model, providing some support to our "structural" estimation of the model's financial shock. Second, the dominant real exchange rate shock in the simulated data generates broadly similar impulse responses to the dominant real exchange rate shock in the actual data, providing support to the model channels. In particular, both shocks give rise to a large and persistent real appreciation, a small decrease in the inflation and interest rates, and a worsening pattern of net exports.

However, there are two main differences between the dynamics of the dominant real exchange rate shock in the model and in our empirics. First, while dominant real exchange rate shocks generate a one-quarter delayed peak in the real exchange rate in the G7 countries, the model's peak response occurs on impact. The reason is that in the model, the real exchange rate dynamics is driven by financial shocks, which has a first-order autoregressive process. As the shock is persistent with the quarterly autoregressive parameter of 0.97, the real exchange rate response is persistent, but does not generate a delayed response as in the data. As a result, the implied UIP wedge, which is mostly driven by expected growth rate of the real exchange rate, conditional on dominant real exchange rate shocks exhibits different dynamics in the simulated data from that in the empirical counterparts. While the UIP wedge conditional on dominant real exchange rate shocks is positive on impact, then reverses in the G7 countries, the UIP wedge from simulated data is persistently negative. Second, the response of net exports is much more pronounced in the model than in the median G7 data, as net exports in the model are tightly linked to the net foreign asset position which the financial shock directly affects.

In sum, we find that the quantitative model in Itskhoki and Mukhin (2021) with a dominant driver of the real exchange rate separate from drivers of other standard business cycle variables is consistent with several cuts of the data through our empirical approach. These analyses suggest that the dominant driver to the real exchange rate resembles a financial shock in the international bond market in the model. At the same time, we uncover that the model lacks a mechanism that generates the delayed peak response of the real exchange rate and generates a spurious tight link between the dominant real exchange rate shock and net exports. The model's monotone peak response of the real exchange rate in response to the dominant real exchange rate shock suggests the need of an adjustment cost feature such as the imperfect information model of Candian (2019). Moreover, our finding of a tight link between the dominant real exchange rate shock and net exports in the simulated data suggests an angle of improvement of the model beyond what is discussed in Itskhoki and Mukhin (2021). Itskhoki and Mukhin (2021) document the counterfactual strong unconditional correlation between the real exchange rate and net exports in their model. However, the unconditional correlation in the data does not tell us which of the three shock propagation mechanisms is problematic. Our finding implies that an important extension should be to mute the net exports response *conditional* on a financial shock. This might be even more challenging than fixing the propagation of other shocks as the financial shock mainly works through shifting the net foreign asset position, which directly affects net exports in equilibrium. A model that breaks the tight link between the net foreign asset position and net exports, such as a model where the change in net foreign assets is also significantly driven by valuation effects due to movements in exchange rates or asset returns, might be necessary.

6 Other Shocks and The Real Exchange Rate

While we find that main business cycle shocks which are important for real variables in the G7 countries are not major shocks of the real exchange rate, our estimation above is far from exhaustive in our search for dominant drivers of the real exchange rate. With insights taken from the model as well as from the existing literature, we shift our interest back to the empirics to examine further the relationship between the real exchange rate and dominant shocks of several other variables. We explore the drivers of trade, interest rates, consumer expectations, and several financial variables that might be connected to the real exchange rate. We also study how dominant shocks to TFP are related to the real exchange rate in the business cycle frequency in the United States where data for TFP is available.

Trade Variables: Net exports-to-output ratio, Real Exports and Real Imports Dominant shocks to trade variables such as the net exports-to-output ratio, real exports and real imports, play a modest role in explaining the real exchange rate volatility at both short and long horizons. The forecast error variance decomposition of the real exchange rate attributable to dominant net exports-to-output ratio (NXY), real exports, and real imports shocks is summarized in Table 2. In a median country, dominant shocks to net exports account for only 3.4% and 6.7% of the real exchange rate forecast variances in the one- and five-year horizons, respectively.[7] Similarly, less than 4% of the real exchange rate forecast error variances are attributed to dominant shocks to real exports and real imports. The business cycle disconnect between the drivers of trade variables and the real exchange rate complements the earlier results where the dominant driver of the real exchange rate shows limited influence on net exports dynamics.

Relative Inflation Rate Dominant shocks to the relative inflation rate generate small movements in the real exchange rate. The direction of the real exchange rate movement is heterogeneous across G7 countries. Consistent with this result, we find that only small fractions of the real exchange rate forecast error variances in both short and long horizons are driven by dominant shocks to the relative inflation rate in the business cycle frequency. For example, only 5.5% and 5% of the US real exchange rate forecast error variances in the one-year and five-year horizons, respectively, are explained by dominant shocks to the inflation rate. The results for other countries are similar to the United States, suggesting a negligible role of the inflation rate in driving the real exchange rate.

Short-term Nominal Interest Rate Dominant shocks to the relative short-term nominal interest rate, which increase home interest rate relative to the rest of the world, are associated with an appreciation of the real exchange rate and an increase in the inflation rate.[8] These impulse

[7]Still the connection between dominant net exports shocks and the real exchange rate is more substantial in Germany and Japan in the longer horizon.

[8]See Figure C.5 in the Appendix for plots of the IRFs of relative output, the real exchange rate, the relative interest rate and the relative inflation rate to an increase in interest rate shock (upper panel), and an increase in relative inflation shock (lower panel) in the G7 countries.

responses are consistent with a standard mechanism in which an increase in the nominal interest rate relative to the rest of the world appreciates the nominal exchange rate. As the relative inflation rate changes are small, the real exchange rate also appreciates.

Nevertheless, dominant shocks to the nominal interest rate are not major shocks driving the real exchange rate. In particular, this shock explains a large fraction of the real exchange rate variations in both the short and the long runs. As detailed in Table 2, the forecast error variances of the real exchange rate attributed to dominant short-term nominal interest rate shocks is less than 6% in all countries in the one-year horizon. The contribution of dominant short-term nominal interest rate shocks is larger in the five-year horizon: 10% in the median country, and up to 16.4% of the United Kingdom real exchange rate forecast error variances. While the role of dominant shocks to the short-term interest rate in driving the real exchange rate is larger than real variables in the VAR, this shock is unlikely major shocks for the real exchange rate in the business cycle frequency.

Other Financial Variables: Corporate Bond Spread, Global Risk Factor, Stock Market Volatility We consider other financial variables that may play an important role explaining the real exchange rate. Our motivation comes from recent work such as Lilley et al. (2020) and Engel and Wu (2019), who suggest that financial variables have some contemporaneous explanatory power to the nominal exchange rate. As such, we add financial variables to our VAR specification and apply our approach to find dominant shocks driving each of the financial variables in the business cycle frequency. We consider three financial variables: the relative corporate bond spread, the global risk factor, and realized stock market volatility (VIX). The relative corporate bond spread for country S is computed as the difference between the corporate bond spread in country S and that in the ROW, which is a sum of other countries' corporate bond spreads weighted by each country's share of GDP in PPP. The global risk factor, taken from Miranda-Agrippino and Rey (2020), is constructed as the common world factor in international risky asset prices to summarize the fluctuations in global financial market conditions.

Compared to the importance of output shocks, dominant shocks to financial variables tend to explain more of the real exchange rate fluctuations. At the same time, these shocks are still not dominant driver of the real exchange rate in both the short and long horizons. In particular, as displayed in Table 2, dominant relative corporate bond spread shocks contribute to only 2% and 6.3% of the real exchange rate fluctuations in the one- and five-year horizons, respectively, in a median country. Dominant global risk factor shocks account for about 9% of the real exchange rate forecast error variations in both horizons in a median country, and up to 25% in the United Kingdom. Dominant VIX shocks are less important than dominant global risk factor shocks: about 5% of the real exchange rate forecast error variances is attributable to this shock. These results suggest that financial shocks are more connected with the real exchange rate than dominant business cycle shocks. At the same time, dominant shocks to these financial variables are unlikely to be major real exchange rate shocks.

Expectations Since shocks to consumer sentiments or expectations transmitted across countries can drive the real exchange rate, as in Levchenko and Pandalai-Nayar (2020), we extend our analysis to examine whether dominant shocks to expectations in the business cycle frequency are also dominant drivers of the real exchange rate. Expectations are proxied by consumer confidence, obtained from the OECD, and four-quarter ahead forecast of output growth rates in each country, from the Consensus Forecast.[9] Similar to the financial variable above, we add to the baseline VAR specification one expectation variables at a time for each country, and find dominant shocks to the expectations variable by maximizing its contribution to the variances of the expectation variables in business cycle frequencies.

Columns (11) and (12) of Table 2 summarize the contribution of dominant consumer confidence shocks and forecast shocks to the real exchange rate in the one- and five-year horizons. Dominant shocks to consumer confidence in the business cycle frequency contributes to at most 15% of the forecast error variance of the real exchange rate, with a median of 6% and 7.25% in the one- and five-year horizons. Dominant shocks to the four-quarter ahead output forecast in each country are more important: they account for 9.3% and 17.3% of the real exchange rate variations in the one- and five-year horizons in a median country. Notably dominant shocks to output forecast explains nearly 20% of Japanese real exchange rate variations and 27% of the UK real exchange rate forecast error variances in the five-year horizon. At the same time, we note that these expectational shocks explain up to 10-20% of the forecast error variances of real variables such as relative output, consumption. hours and investment. This result suggests that shocks to expectations can be a non-negligible source of fluctuations for both real variables and the real exchange rate in the longer horizons.

[9] We do not include Canada in this exercise as it has no consumer confidence before 2002.

TFP We next consider TFP shocks as the major shock driving the real exchange rate. Since quarterly utilization-adjusted TFP data is only available for the United States, we only analyze the US case. First, we identify dominant shocks to TFP, which contribute the most to the fluctuations of TFP in the business cycle frequency. Similar to Angeletos, Collard, and Dellas (2020), dominant TFP shocks do not have similar effects on the economy as main business cycle shocks. Furthermore, dominant TFP shocks also have a negligible connection with the real exchange rate.

Overall, we summarize our empirical findings as follows:

- Main business cycle shocks, which explain a large fraction of output, consumption and hours variations, account for a small fraction of the real exchange rate volatility. Dominant shocks to the real exchange rate orthogonal to main business cycle shocks. In other words, main business cycle shocks are disconnected from the real exchange rate.

- Dominant real exchange rate shocks in the business cycle frequency generate large and persistent real exchange rate movements with a short peak delay, and a meaningful deviation from the uncovered interest parity, while the movements of real variables and net exports are small.

- Dominant shocks in the business cycle frequency to the inflation rate, trade variables and several financial variables account for a modest fraction of the real exchange rate volatility. The shock that accounts for the largest fraction of the real exchange rate fluctuations is dominant shocks to four-quarter ahead output forecast, explaining up to 18% of the real exchange rate forecast errors in the five-year horizon in a median country.

7 Robustness Checks

This section examines the sensitivity of the results to data features and specifications. For example, we include four lags in the VAR specification and use the data prior to the 2008-2009 Global Financial Crisis. We also specify the VAR to include country-specific (level) variables to study whether the real exchange rate is related to the shocks important to country-specific real variables. Finally, we examine the relationship between dominant shocks of real variables in low and high frequencies with the real exchange rate.

7.1 Lags and Data Period

We first include four lags into the VAR specification. The first two columns of Table 3 show the fractions of the real exchange rate forecast error variances explained by the output MBC shocks and the output forecast error variances explained by dominant real exchange rate shocks. Similar to the baseline results, main business cycle shocks explain less than 10% of the forecast error variances of the real exchange rate in both the one- and five-year horizons in a median country, and main business cycle shocks are more important in the long horizons than in the short horizons. On the flip side, dominant real exchange rate shocks do not explain much of the output variations, either, consistent with our baseline results.

Second, since the 2008-2009 Global Financial Crisis and its aftermath can affect business cycles in a non-trivial way, as highlighted in Lilley et al. (2020), we restrict our sample to the 1974Q1–2006Q4 period. As summarized in Columns (3) and (4) of Table 3, the forecast error variance decomposition results for the restricted sample are similar to the results for the whole sample: output MBC shocks and the real exchange rate have a weak relationship both in the short run and in the long run.

7.2 Country-Specific Level Variables

Since the variables in the baseline VAR are all specified as relative to the ROW, our main business cycle shocks capture the shocks most important in explaining a country's output relative to the ROW. However, it is possible that shocks important to country-specific output may play a more important role in driving the real exchange rate fluctuations. To examine this possibility, we apply our econometric approach to a VAR with the following ten variables:

$$X_{s,t} = \left[\ln Y_{s,t}, \ln C_{s,t}, \ln I_{s,t}, \ln h_{s,t}, \frac{NX_{s,t}}{Y_{s,t}}, \ln REER_{s,t}, \ln Y_{ROW,t} \ln C_{ROW,t}, \ln I_{ROW,t}, \ln h_{ROW,t}\right].$$

Columns (5) and (6) of Table 3 report the forecast error variances of the real exchange rate attributed to country-specific output MBC shocks. Output shocks explain 1.1% and 4.2% of the real exchange rate forecast error variances in the one- and five-year horizons in a median country. Among the G7 countries, dominant output shocks for the United Kingdom have the largest explanatory power for its real exchange rate: 11% of the real exchange rate fluctuations in the five-year horizon is attributable to main business cycle shocks. Similar to the baseline results with relative variables, dominant shocks to the real exchange rate also have small effects on output and other variables in all G7 countries. In a median country, real exchange rate shocks account for just 1.1% and 4.1% of output fluctuations in the one- and five-year horizons, respectively.

We note that consistent with the variance decomposition results, main business cycle shocks have small and insignificant impact on the real exchange rate in most countries, and the responses of the real exchange rate are heterogeneous across countries. Furthermore, shocks important for country-specific consumption, hours worked or the rest-of-the-world variables also contribute to less than 10% of the real exchange rate forecast error variances at both one- and five-year horizons in a median country. These results suggest that shocks that are important for domestic output may not be an important driver of the real exchange rate fluctuations.

7.3 "Purified" Main Business Cycle Shocks

One concern for the main business cycle shocks is that it may be a mixture of several shocks that have offsetting effects on the real exchange rate, which lead to the observed small explanatory power of main business cycle shocks on the real exchange rate. For example, a positive TFP shock can lead to an increase in relative output and a real depreciation of the exchange rate, while a demand shock can also raise relative output and appreciate the real exchange rate at the same time. In this case, an identified shock that explains the most output variation can be a combination of TFP and demand shocks, which explain a small fraction of the real exchange rate fluctuations. To address this potential problem, this section focuses on "purifying" dominant output shocks of supply shocks, which we consider TFP news and unanticipated TFP shocks. Since we only have reliable utilization-adjusted TFP data for the United States, this section focuses on the results of the United States only. We find that this purified shock still explains a substantial fraction of output variations and is disconnected from the real exchange rate.

Our empirical approach is modified as follows. First, we identify TFP news and unanticipated TFP shocks, using the Barsky and Sims (2011) identification with the method proposed in Kurmann and Sims (2019). In particular, TFP news shocks are shocks that account for the largest forecast error variances of TFP at $H = 40$ quarters, as targeting longer horizons does not alter the results. The shock that increases TFP on impact is unanticipated. Second, we recover the purified dominant output shocks by restricting that the shocks that explain the most of the relative output variations in the business cycle frequency must be orthogonal to identified TFP news and unanticipated TFP shocks.[10]

[10] Cascaldi-Garcia and Galvao (2021) use the same identification scheme to orthogonalize news and uncertainty

We find that the effects of the purified dominant output shocks on the macro variables are similar to the baseline output shocks in the United States. The purified dominant shocks to the relative output still play an important role explaining the forecast error variances of hours worked and consumption, but contribute to less than 7% of the real exchange rate forecast error variances in both one- and five-year horizons. This modest contribution of the purified main business cycle shocks to the real exchange rate volatility further supports that the dominant shocks driving real macro variables are not the dominant source of uncertainty driving the real exchange rate.

The byproduct of this exercise is that we can examine whether TFP news shocks and unanticipated TFP shocks are major drivers of US real exchange rate. While unanticipated TFP shocks explain up to 90% of the variations in TFP in a one-year horizon, its explanatory power for other variables including output, hours worked and the real exchange rate is small. TFP news shocks are much more sizable. Consistent with Nam and Wang (2015), we find that TFP news shocks can account for nearly 20% of the US real exchange rate volatility in the one- and five-year horizons, and about the same for US output relative to the ROW forecast error variances. Together with the results with forecast data above, these results suggest that while dominant business cycle shocks account for a modest fraction of the real exchange rate volatility, expectational shocks such as TFP news can play a non-trivial role in explaining the real exchange rate behaviors. In that sense, the real exchange rate is not completely disconnected from macro fundamentals. Nevertheless, these expectational shocks do not explain more than 50% of real exchange rate fluctuations, so they are unlikely to be dominant real exchange rate shocks.

7.4 Different Frequencies

Our baseline results focus on the shocks important to relative output and the real exchange rate in business cycle frequencies, but the econometric approach also allows us to identify low and high frequency shocks. In this extension, we recover dominant output shocks and dominant real exchange rate shocks by targeting over $\left[\frac{2\pi}{2}, \frac{2\pi}{6}\right]$, which corresponds to the high frequencies between 2 and 6 quarters, and over $\left[\frac{2\pi}{80}, \frac{2\pi}{100}\right]$, which corresponds to the low frequencies between 80 and 100 quarters.

Columns (7) to (10) of Table 3 display the forecast error variance decompositions for the output and real exchange rate shocks in the low and high frequencies. Dominant shocks to output at the low frequency explain 7.8% and 12.7% of the real exchange rate variations in the one- and five-year

shocks.

horizons, in a median country, which is much higher than that in the business cycle frequency and high frequency. In fact, dominant output shocks in the low frequency can account for 26-33% of Italy, UK and German real exchange rate volatilities in the five-year horizon, which are substantially larger than in the business cycle frequency. Dominant shocks of the real exchange rate in low frequency contribute to output fluctuations more than in the business cycle frequency in several countries: dominant real exchange rate shocks account for 15% of the output forecast error variances in the five-year horizon in a median country. Notably, between 24% and 42% of the output forecast error variances in France and Japan are attributed to dominant real exchange rate shocks in the five-year horizon. These results support a much more substantial connection between the relative output growth rate and the real exchange rate in the low frequency than in the business cycle frequency.

Dominant shocks to output in the higher frequency are not important for the real exchange rate in any countries in the one-year horizon, explaining less than 5% of the forecast error variances. In the five-year horizon, the connection is slightly stronger, but output shocks still explain just 7.4% of the real exchange rate fluctuations in a median country. On the flip side, dominant real exchange rate shocks in the high frequency contribute to less than 5% of output forecast error variances in all countries at all horizons.

To summarize, output and the real exchange rate are more connected in the low frequency than in business cycle frequency in the G7 countries.

8 Conclusion

We document the relationship between the real exchange rate and several macroeconomic variables in G7 advanced countries between 1974 and 2016. We find an existence of main business cycle shocks, which generate similar effects to the macro variables in the business cycle. However, this shock contributes little to the fluctuations of the real exchange rate. Furthermore, we document several facts of dominant shocks to the real exchange rate: it is orthogonal to main business cycle shocks, but generates large, persistent and delayed responses of the real exchange rate, a small response of the net exports-to-output ratio and a meaningful deviation from the UIP condition.

Our findings have a strong implication about international macro models. In particular, it rejects the possibility that shocks with similar propagation mechanism can explain both real, nominal and financial variables and the real exchange rate behaviors. It is more likely that model needs separating shocks driving business cycles and the real exchange rate. These shocks working in different ways make the overall dynamic correlations weak, and possibly creating cross country differences depending on the importance of different shocks. Furthermore, our analyses suggest that financial shocks as in Itskhoki and Mukhin (2021) can be broadly consistent with our empirical regularities, but the model itself still falls short at generating the delayed response of the real exchange rate and the muted net exports-to-output ratio. While a delayed response of the real exchange rate may be generated by some frictions in the model such as information frictions, future work can further examine the relationship between the real exchange rate and net exports in the model to resolve this inconsistency.

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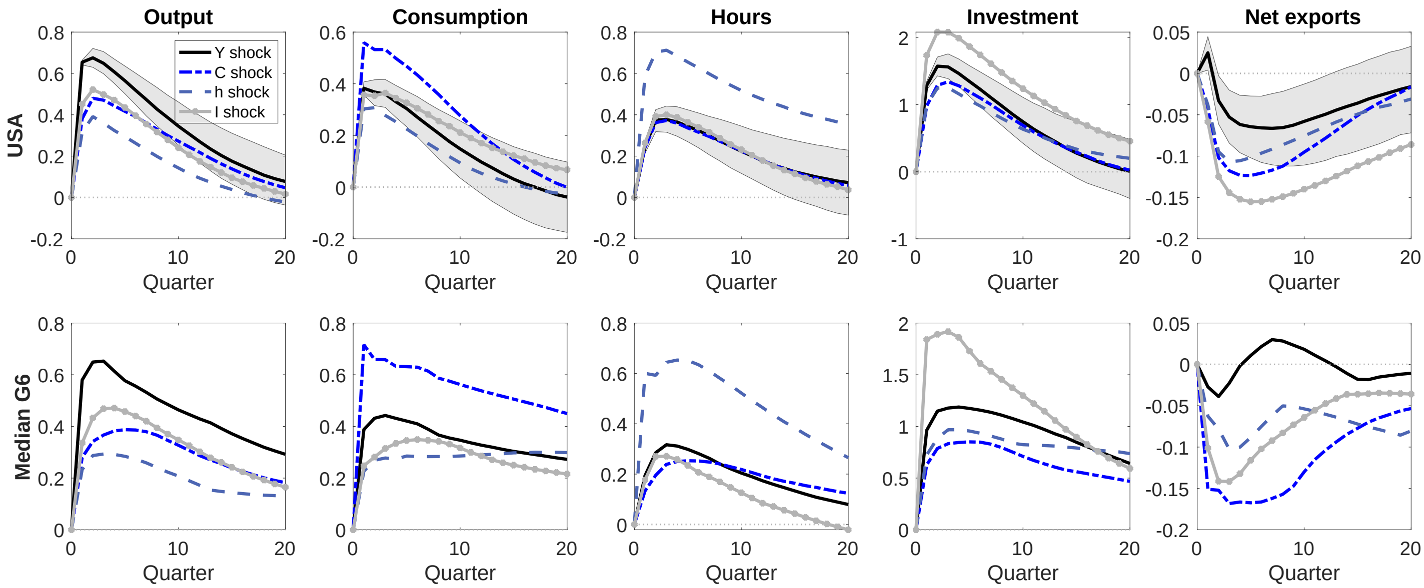
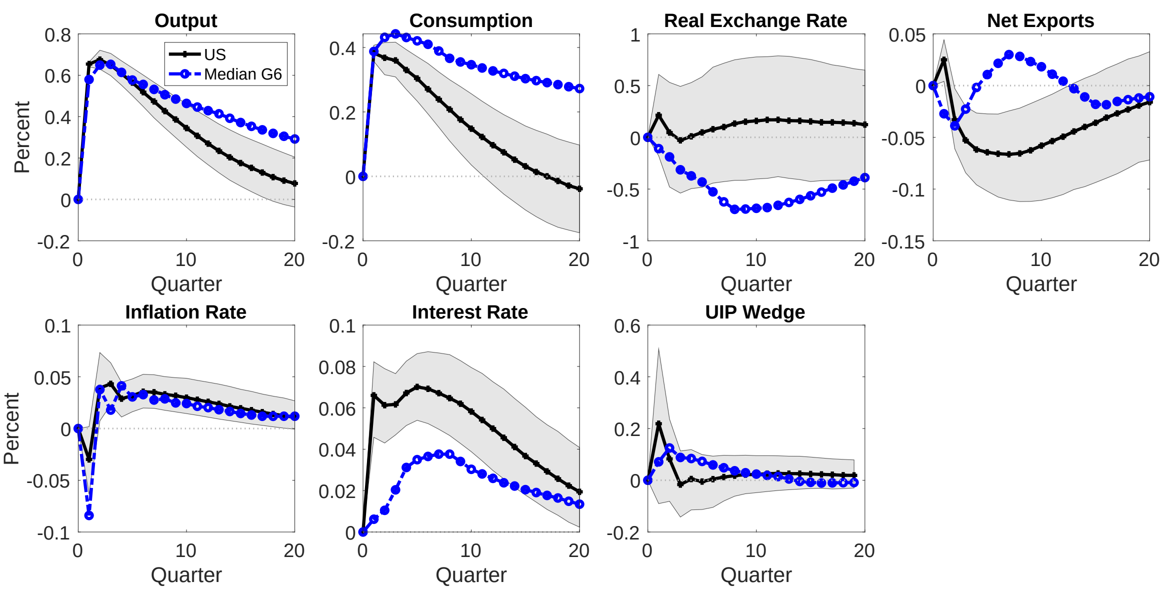
Figures and Tables

Figure 1: Impulse responses to relative output, consumption, and hours worked dominant shocks in business cycle frequency.



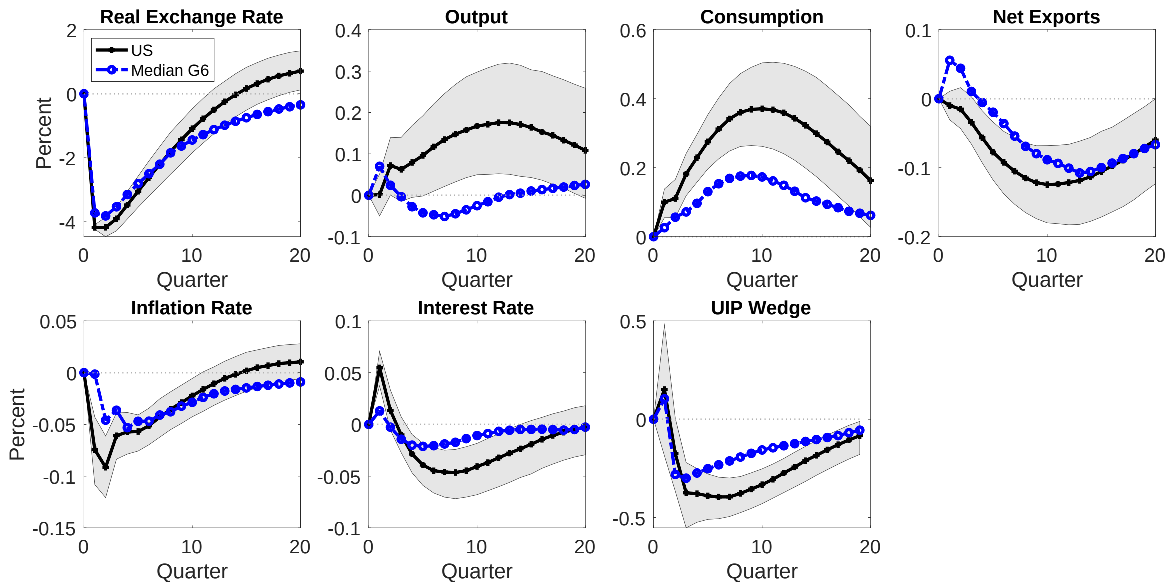
Note: A decrease in the real exchange rate is an appreciation. The gray area in each plot indicates the 16-84 percent credible bound of the variable response to a relative output dominant shock.

Figure 2: Impulse responses to relative output dominant shocks in business cycle frequency.



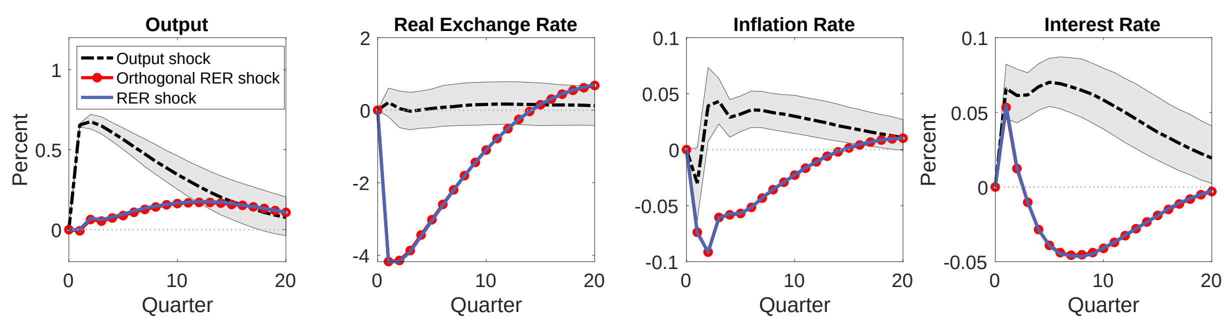
Note: A decrease in the real exchange rate is an appreciation. The gray area in each plot indicates the 16-84 percent credible bound of the variable response to a relative output dominant shock.

Figure 3: Impulse responses to real exchange rate dominant shocks in business cycle frequency.



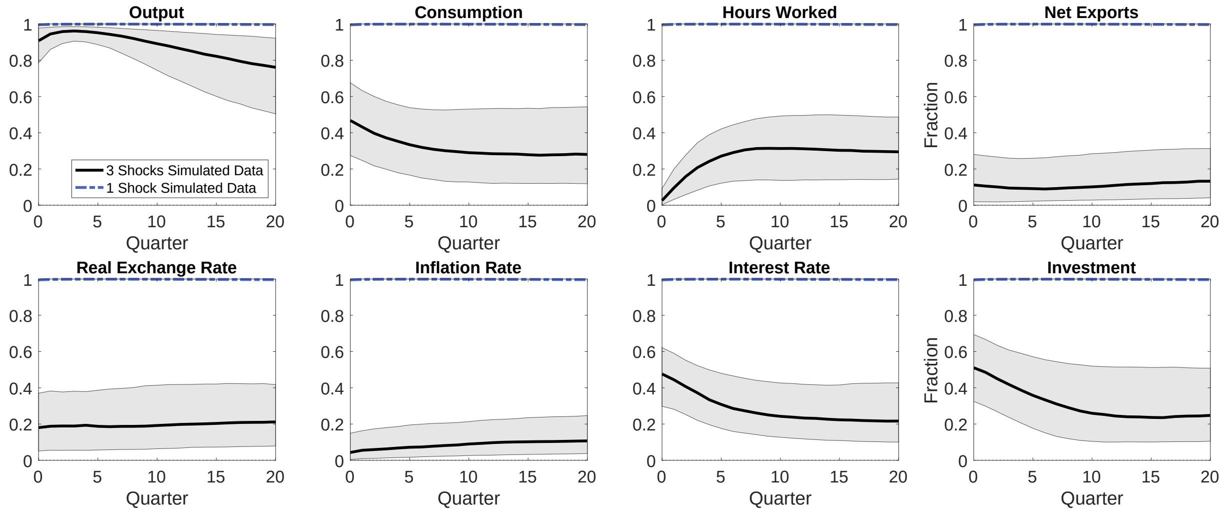
Note: A decrease in the real exchange rate is an appreciation. The gray area in each plot indicates the 16-84 percent credible bound of the variable response to a real exchange rate dominant shock.

Figure 4: Real exchange rate and Output dominant shocks in business cycle frequency: Impulse responses using US data.



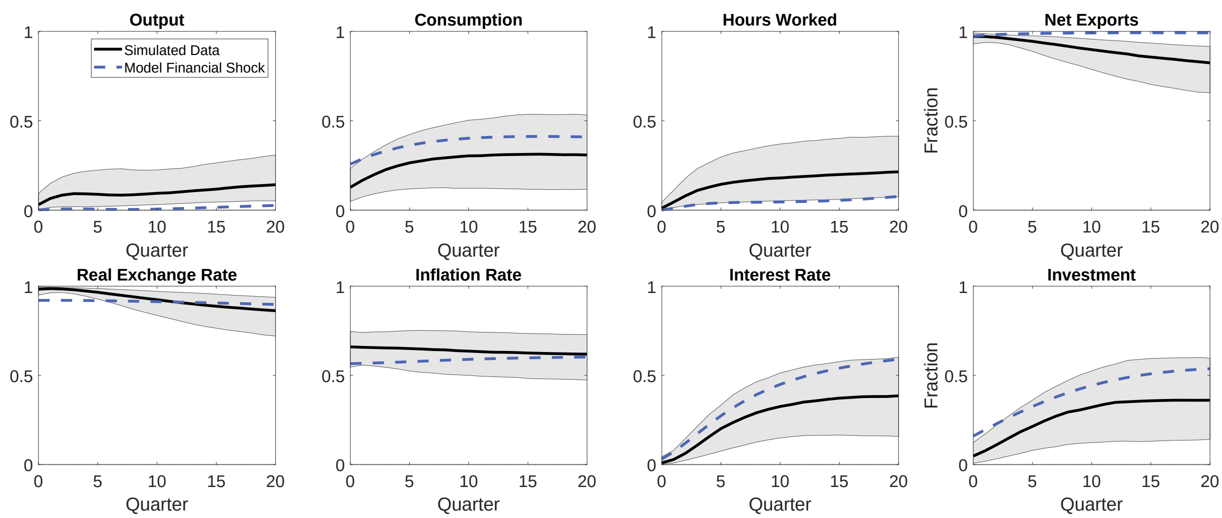
Note: A decrease in the real exchange rate is an appreciation. The gray area in each plot indicates the 16-84 percent credible bound of the variable response to a real exchange rate dominant shock.

Figure 5: Forecast error variance contribution of estimated dominant shocks to relative output with simulated data in two versions.



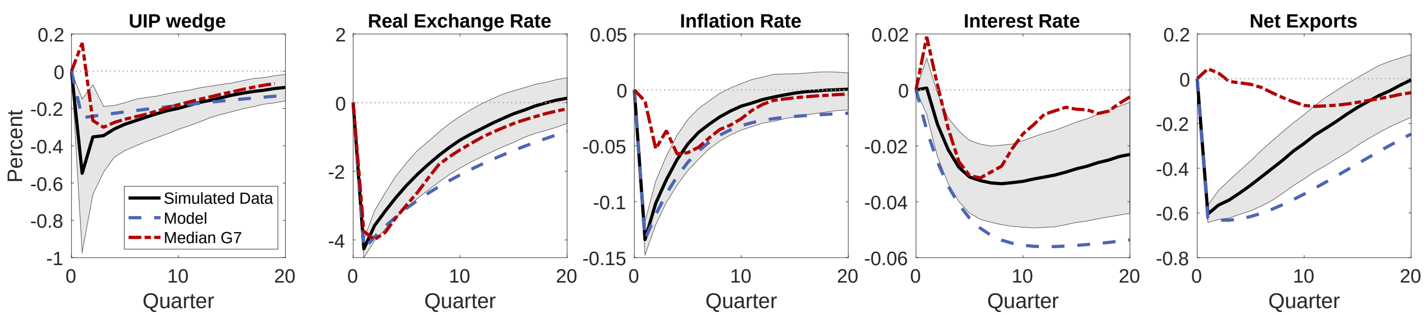
Note: The black solid lines show the median fraction of the forecast error variances of different variables explained by dominant relative output shocks using simulated data from the model with TFP, monetary, and financial shocks. The shaded areas indicate the 16-84 percent credible bound of the forecast error variance decomposition. The blue dashed lines show the median fraction of the forecast error variances explained by dominant relative output shocks using simulated data from the model with only a TFP shock.

Figure 6: Forecast error variance contribution of estimated dominant real exchange rate shocks with simulated data and of financial shocks in the model.



Note: The black solid lines show the median fraction of the forecast error variances of different variables explained by dominant real exchange rate shocks using simulated data from the model with TFP, monetary, and financial shocks. The shaded areas indicate the 16-84 percent credible bound of the forecast error variance decomposition using simulated data. The blue dashed lines show the fraction of the forecast error variances explained by financial shocks in the model.

Figure 7: Impulse Response Functions to Dominant Real Exchange Rate Shocks in Model and Empirics



Note: Theoretical impulse responses to financial shocks (blue dashed lines) and impulse responses to dominant real exchange rate shocks in simulated data (black solid lines) from the model with TFP, monetary and financial shocks along with the 16-84% credible bounds. The red dash-dotted lines plot the median G7 empirical impulse responses to dominant real exchange rate shocks.

Table 1: Forecast Error Variance Decomposition of Variables due to each shock targeted to a variable at the business cycle frequency for all countries.

Shocks	Country	Output	Consumption	Investment	Hours	NXY	RER	Inflation Rate	Interest Rate
Dominant Relative Output Shocks									
h=4	**G7 Median**	**94.9**	**42.2**	**48.1**	**22.1**	**2.1**	**1.2**	**3.2**	**6.1**
	USA	95.1	42.2	53.4	25.5	2.4	0.9	2.7	16.7
	CAN	92.9	24.7	27.1	19.3	1.9	1	6	6.1
	JPN	96.2	54	36.8	15.6	0.5	0.9	8	1.4
	GBR	90.9	22	15.5	15.8	24.2	1.2	11	9
	DEU	94.9	13.5	53.7	25.8	1.2	1.8	2.9	8.4
	FRA	96.6	51.8	55.4	26.5	2.1	1.5	2.2	1.9
	ITA	91.8	54.4	48.1	22.1	15.9	1.8	3.2	2.3
h=20	**G7 Median**	**68.6**	**18.4**	**28.9**	**13.5**	**5.5**	**4.2**	**6.3**	**14.8**
	USA	68.6	18.4	28.3	15.6	5.5	2.8	6.3	27.3
	CAN	56.6	17.6	26.1	13.5	3.9	18.7	7.7	17.2
	JPN	73.8	44	28.9	9.9	5.2	12.2	8.7	4
	GBR	68.7	10.8	20.2	12.8	29.5	4	11.6	16.6
	DEU	63	6.3	38.4	11.4	2.2	3.7	5.5	14.8
	FRA	77.6	59.8	44.5	40.1	5.9	7.3	3.4	11.8
	ITA	58.3	53.3	48.9	26.5	20.7	4.2	4.1	8.5
Dominant RER Shocks									
h=4	**G7 Median**	**1.6**	**1.4**	**1.4**	**4.1**	**1.7**	**95**	**4.6**	**2.9**
	USA	1.3	9	2.1	1	1.6	95.3	8.8	4.9
	CAN	1.6	0.7	4.2	2.7	3.3	93.3	9.1	3
	JPN	0.9	1.1	0.8	5	1.7	93.2	3.6	2.9
	GBR	1.7	4.4	0.7	4.3	7.8	95	1.7	7.1
	DEU	3.4	8.7	5.2	4.1	3.1	94.8	2.1	0.8
	FRA	0.7	1.4	1.4	2.4	0.6	96.3	4.6	1.5
	ITA	1.9	1	1.4	4.7	1.5	97.3	10	2.3
h=20	**G7 Median**	**6.3**	**5.1**	**5.6**	**4.3**	**10.9**	**70.3**	**7.9**	**7.6**
	USA	9	31.4	6.1	3.1	16.6	66.3	11.8	11.4
	CAN	6.3	2.5	5.7	12.7	17.7	56.4	14.1	10.6
	JPN	2.7	5.1	2.5	7.7	20.1	55.7	6.9	14.9
	GBR	4.1	15.3	3.4	32.7	10.6	79.2	7.9	7.6
	DEU	12.4	25.3	21.3	4.1	10.9	70.3	3.6	2.5
	FRA	2.3	3.1	2.8	3.9	3.9	71.2	5.6	3
	ITA	6.4	4.6	5.6	4.3	4.1	84.9	20.5	5.1

Note: We report the median from 1000 draws for each country after burn-in.

Table 2: Forecast Error Variance Decomposition of the Real Exchange Rate due to dominant shocks targeted to different variables the business cycle frequency for all countries.

	Shock	Output	Consumption	Investment	Hours	NXY	Exports	Imports	Inflation Rate	Interest Rate	Spread	Global Factor	VIX	Confidence	Forecast	Commodity TOT
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
h=4	**G7 Median**	**1.2**	**2.1**	**2.2**	**3**	**3.4**	**2.6**	**1.7**	**2.7**	**2**	**2**	**9**	**4.5**	**5.3**	**9.3**	**4.8**
	USA	0.9	2.1	1.8	1.3	1.2	14.8	1.9	5.5	6.5	2	9	0.8	6.7	2.8	5.5
	CAN	1	2.9	16.7	0.9	1.2	1.4	2.6	2.8	1.3	1.3	12.7	10.2	0	12.7	7.7
	JPN	0.9	1	0.7	7.4	3.7	8.1	2.2	2.7	2.3	7.8	9.2	8	1.1	9.3	1.1
	GBR	1.2	2.2	0.8	2.2	8.8	1.5	1.7	1.7	7.5	12	22.7	9.8	3.7	18.4	4.8
	DEU	1.8	4.9	2.2	5.7	8.8	2.6	0.6	0.9	0.9	0.8	1.4	1.2	11.3	10.4	3.5
	FRA	1.5	2.1	3.5	3	0.6	2.5	1	5.1	0.9	12.1	4.9	2.2	15	2.4	12.3
	ITA	1.8	1.2	3.5	6.1	3.4	5.6	0.8	2.1	2	1.9	2.7	4.5	5.3	2.8	1.3
h=20	**G7 Median**	**4.2**	**5**	**4.7**	**4.2**	**6.7**	**3.8**	**3.2**	**4.5**	**10**	**6.3**	**8.4**	**5.8**	**6.9**	**17.3**	**11.2**
	USA	2.8	5.5	4.7	3.3	5.7	11.4	4.1	5	12.4	6.3	8.4	2.6	7.6	5.2	12.4
	CAN	18.7	8.1	36	19.3	3.1	3.8	3.2	5	4.1	3.8	9.5	5.8	0	10.3	13.4
	JPN	12.2	4	4.7	6.2	14.8	7.8	8.9	4.5	10.5	11.2	18.5	6.3	3.4	19.9	10.4
	GBR	4	5.1	2.7	3.4	7.1	1.7	1.9	2	16.4	14.1	24.4	15.1	6.9	26.6	11.2
	DEU	3.7	5	3.5	4.2	17.2	2.5	1.4	1.5	10	2.3	3.3	2	8.9	17.3	5.4
	FRA	7.3	4.8	13	3.4	2.7	3.3	2.3	6.1	2	15.4	7.5	4	15.1	5.5	10.4
	ITA	4.2	2.6	3.7	8.5	6.7	5.6	5.7	3.3	4.6	3.3	4.6	6.6	5.2	17.7	11.8

Note: Each column is the contribution to the fluctuations of the real exchange rate due to the dominant shocks at business cycle frequency of Output, Inflation Rate, Interest Rate, Credit Spread, Global Factor, country-specific realized stock volatility (VIX), Consumer Confidence and four-quarter ahead Output Forecast. We report the median from 1000 draws for each country.

Table 3: Robustness check: Forecast Error Variance Decomposition of the Real Exchange Rate and Output due to the dominant shocks of Output and RER in different specifications and data.

Horizon	Case	Four lags		1974-2006		Level variables		Low Frequency		High Frequency	
	Shock	Output	RER	Output	RER	Output	RER	Output	RER	Output	RER
	Variable	RER	Output	RER	Output	RER	Output	RER	Output	RER	Output
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
h=4	**G7 Median**	**1.4**	**2**	**1.5**	**2.6**	**1.1**	**1.1**	**7.8**	**7.9**	**1.3**	**0.4**
	USA	1.1	1.7	1.6	1.4	3.5	1	7.8	5.2	0.3	0.4
	CAN	1	2.9	1.3	2.6	1	0.9	3.5	24.9	1	0.4
	JPN	1.4	2	1.1	2.2	0.8	1.1	3	39.1	0.8	0.4
	GBR	1.5	1.8	2.2	3.8	1.6	2.7	21.7	5.1	3.9	1.5
	DEU	3.1	5.7	4.6	5.3	0.8	1.4	26.8	7.9	1.3	1.9
	FRA	1.1	1.1	0.9	1	1.1	1	4.6	17.9	2.2	0.3
	ITA	1.9	2.2	1.5	2.7	5.9	2.5	19.5	3.1	6	0.7
h=20	**G7 Median**	**5**	**4.9**	**5.9**	**9.1**	**4.2**	**4.1**	**12.7**	**14.7**	**7.4**	**3.8**
	USA	3.4	10.4	4.7	10.8	4.2	19.5	11.7	10.2	2	6.9
	CAN	21.5	4.9	18.6	9.1	3.4	4.1	9.6	18	8.6	2.4
	JPN	13.3	4	14.5	4.4	5.1	2.5	6.8	41.5	11.7	2.2
	GBR	4	4.7	5.9	10.6	11.8	13.9	31.9	7.9	7.4	3.8
	DEU	5.2	16.4	11.2	11	2.3	3.5	33	14.7	2.9	10
	FRA	5	3.2	3.6	3.6	3.4	13.2	12.7	24.2	6.5	1.7
	ITA	3.7	7.8	4.6	6.4	14.8	3.7	25.7	9.8	10.5	7.1

Note: We report the median from 1000 draws for each country.

A Data Details

Rest of the World Data Construction The rest of the world for the US is a composite of Australia, Austria, Finland, Ireland, Italy, Korea, Norway, Sweden, Canada, Japan, the UK, Germany and France. This choice was dictated by data availability for hours worked and other macro variables. The construction for the rest of the world for other countries are similar.

Individual country's variables are aggregated as follows: first, we take quarterly growth rates to remove national basis effects, then we take a weighted cross-country average growth rates, where the weights are based on each country's GDP share in the 13-country aggregate calculated at annual purchasing power parity (PPP) values. The GDP data at annual PPP value come from the OECD. We then accumulate the growth rate to obtain the level. For interest rates and spread, the rest of the world rates are simply the weighted sum of the 13-country individual rates. If the data for some countries are missing, we omit the country from the rest of the world calculation during that period.

The real exchange rate for country i is computed using the ratio of CPI in country i and the rest of the world CPI as follows:

$$\text{RER}_i = \frac{\Pi_j \left(CPI_j \times \frac{1}{\varepsilon_{j,US}} \right)^{w_j}}{CPI_i \times \frac{1}{\varepsilon_{i,US}}}$$

$$\Delta \ln Y_{ROW} = \sum_j \left(w_j \Delta \ln Y_j \right)$$

where $\varepsilon_{i,US}$ is currency i per USD. This definition is consistent with the model's definition: the real exchange rate is the price of foreign consumption basket in the domestic unit.

Spread We construct each country's spread following Krishnamurthy and Muir (2017). For the United States, the spread is the Moody's Baa-Aaa spread. For all other countries, we use data from Global Financial Data, and calculate the spread as the difference between corporate bond yield (IN-ISO, where ISO is the three letter ISO country code) and government bond yields (IG-ISO-10 and IG-ISO-5 for ten and five year government yields, respectively). Since the average maturity of the corporate bond yield index is not given, we use 10 year government yield. Note that we tried Krishnamurthy and Muir (2017) method to define $spread = yield_{corp} - (\omega \times yield_{gov,5} + (1 - \omega) \times yield_{gov,10}$, with the weight coming from the regression of corporate yield on both government yields, Nevertheless, the weight is almost always negligible for 5 year yield, and the data for 5 year yield are shorter than 10 year yield for most countries, so we opt to calculate the spread as above.

Table A.1: Data Summary

	Baseline Variables	Nominal Interest rate	Spread	Global Factor
USA	1974Q1-2016Q4	1974Q1-2016Q4	1974Q1-2016Q4	1980Q1-2016Q4
CAN	1981Q2-2016Q4	1981Q2-2016Q4	1981Q2-2006Q2	1981Q2-2016Q4
JPN	1974Q2-2016Q4	1974Q2-2016Q4	1974Q2-2016Q4	1980Q1-2016Q4
GBR	1978Q2-2016Q4	1978Q2-2016Q4	1978Q2-2016Q4	1980Q1-2016Q4
DEU	1974Q2-2016Q4	1974Q2-2016Q4	1974Q2-2016Q4	1980Q1-2016Q4
FRA	1980Q2-2016Q4	1980Q2-2016Q4	1984Q1-1998Q4	1980Q1-2016Q4
ITA	1978Q4-2016Q4	1978Q4-2016Q4	1978Q4-2016Q4	1980Q1-2016Q4

Note: Baseline variables include output, TFP, consumption, hours, net exports-to-output ratio, the real exchange rate (RER) and the inflation rate. Nominal interest rate is the three month government bond yield. The spread is the difference between corporate bond yield and government bond yield, the Global Factor is taken from Miranda-Agrippino and Rey (2020).

B Open Economy Business Cycle Model

The model is an extended version of the standard two-country New Keynesian Open Economy model as in Steinsson (2008) with an Itskhoki and Mukhin (2021) financial shock. The standard features of the model include staggered price setting, a la Calvo (1983), local currency pricing, and home biased preferences. The world includes two countries, indexed by 1 and 2, with size n_1 and n_2, respectively. Households in both countries have access to incomplete financial markets where they can trade one period non-state contingent bonds internationally. Country 1 produces good H and country 2 produces good F. Denote C_t^i final consumption for country i with the corresponding price, P_t^i.

We describe the problem of country 1.

Households Household in country i chooses consumption, C_t^1, and hours worked, h_t^1, to maximize her lifetime expected utility:

$$\max \sum_{t=0}^{\infty} \beta^t \mathbb{E}_0 U(C_t^1, h_t^1)$$

subject to a period-by-period budget constraint. The period-by-period utility function is given by:

$$U(C,H) = \frac{C^{1-\sigma}}{1-\sigma} - \phi_H \frac{H^{1+\frac{1}{v}}}{1+\frac{1}{v}}$$

For country 1, the budget constraint is given by

$$
\begin{aligned}
&P_t^1 C_t^1 + P_t^1 I_t^1 + \frac{1}{R_t^1} B_{D,t+1}^1 + \frac{1}{R_t^2 \psi_t} B_{F,t+1}^1 Q_t^D + P_t^1 \phi_B^1 \left(\frac{B_{F,t+1}^1 Q_t^D}{P_t^1} \right) \\
=&B_{D,t}^1 + B_{F,t}^1 Q_t^D + W_t^1 H_t^1 + R_t^{K1} K_t^1 + \Pi_t^1 + D_t^1
\end{aligned}
$$

where I_t^1 is investment for country 1, with the corresponding price P_{It}^1, $B_{D,t}^1$ is the one period non-state contingent bond denominated in country 1's currency, and in the next period, paid with interest rate R_t^1, W_t^1 is the nominal wage, R_t^{K1} is the rental rate of capital in country 1, $B_{F,t}^1$ is the one period non-state contingent bond denominated in country 2's currency, with an associated interest rate R_t^2, Q_t^D is the nominal exchange rate of currency 1 in terms of foreign currency, and Π_1^1 is the payment from firms' profit. We include a bond adjustment cost, as standard in this literature following Schmitt-Grohe and Uribe (2003), to induce stationarity in the model with incomplete financial markets. The functional form for this adjustment cost is given by:

$$
\phi_B^1 \left(\frac{B_{F,t+1}^1 Q_t^D}{P_t^1} \right) = \frac{\phi_B^1}{2} \left(\frac{B_{F,t+1}^1 Q_t^D}{P_t^1} - B_{Fss}^1 \right)^2,
$$

where B_{Fss}^1 is the steady-state foreign bond holding in country 1. Note that similar to Itskhoki and Mukhin (2021), there is a wedge ψ_t which is an exogenous financial shock that affects the return of holding foreign bond. Because of this financial wedge, household also receives D_t^1, given by

$$
D_t^1 = \frac{1}{R_t^2 \psi_t} B_{F,t+1}^1 Q_t^D - \frac{1}{R_t^2} B_{F,t+1}^1 Q_t^D + P_t^1 \phi_B^1 \left(\frac{B_{F,t+1}^1 Q_t^D}{P_t^1} \right).
$$

Household is assumed to own capital K_t^1, which evolves over time under the standard law of motion:

$$
K_{t+1}^1 = (1-\delta) K_t^1 + I_t^1 \Phi \left(\frac{I_t^1}{I_{t-1}^1} \right),
$$

where Φ denotes the investment adjustment cost. Then the first order conditions for households are given by

$$
\begin{aligned}
\left(C_t^1\right)^{-\sigma} &= \lambda_t^1, \\
\phi_H \left(H_t^1\right)^{\frac{1}{v}} &= \lambda_t^1 \frac{W_t^1}{P_t^1}, \\
1 &= \beta E_t R_t^1 \frac{\lambda_{t+1}^1}{\lambda_t^1} \frac{P_t^1}{P_{t+1}^1}, \\
1 + \phi_B^1 \left(\frac{B_{Ft+1}^1 Q_t^D}{P_t^1} - B_{Fss}^1 \right) R_t^2 \psi_t &= \beta E_t R_t^2 \psi_t \frac{\lambda_{t+1}^1}{\lambda_t^1} \frac{Q_{t+1}^D}{Q_t^D} \frac{P_t^1}{P_{t+1}^1}
\end{aligned}
$$

Aggregate consumption, investment, and intermediate goods are a CES composite index of H and F goods, as follows:

$$
C_t^1 + I_t^1 + M_t^1 = \left[(\omega_1)^{1/\mu} D_{Ht}^{1,\frac{\mu-1}{\mu}} + (1-\omega_1)^{1/\mu} D_{Ft}^{1,\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}},
$$

where ω_1 is the home-biased preference, μ_1 is the elasticity of substitution of home and foreign goods in country 1.

Each good is also a CES composite of goods from intermediate firms as follows:

$$
D_{Ht}^1 = \left[\int D_{Ht}^1(z)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}} \qquad \text{and} \qquad D_{Ft}^1 = \left[\int D_{Ft}^1(z)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}},
$$

where θ's are the elasticity of substitution between differentiated goods (assumed to be the same for goods produced in the same country, no pricing to market). Note that in our set up $P_t^1 = P_{It}^1$.

Associated prices are as follows:

$$
\begin{aligned}
P_t^1 &= \left[\omega_1 P_{Ht}^{1,1-\mu} + (1-\omega_1) P_{Ft}^{1,1-\mu} \right]^{\frac{1}{1-\mu}}, \\
P_{Ht}^1 &= \left(\int P_{Ht}^1(z)^{1-\theta} dz \right)^{\frac{1}{1-\theta}}, \\
P_{Ft}^1 &= \left(\int P_{Ft}^1(z)^{1-\theta} dz \right)^{\frac{1}{1-\theta}}.
\end{aligned}
$$

Demand functions for country 1 are then given by:

$$D^1_{Ht} = \omega_1 \left(\frac{P^1_{Ht}}{P^1_t} \right)^{-\mu} \left(C^1_t + I^1_t M^1_t \right),$$

$$D^1_{Ft} = (1-\omega_1) \left(\frac{P^1_{Ft}}{P^1_t} \right)^{-\mu} \left(C^1_t + I^1_t + M^1_t \right),$$

$$D^1_{Ht}(z) = \left(\frac{P^1_{Ht}}{P^1_t} \right)^{-\theta} D^1_{Ht},$$

$$D^1_{Ft}(z) = \left(\frac{P^1_{Ft}}{P^1_t} \right)^{-\theta} D^1_{Ft}.$$

The problem for households in country 2 is analogous to that in country 1 with the following budget constraint:

$$P^2_t C^2_t + P^2_t I^2_t + \frac{1}{R^2_t} B^2_{F,t+1} = B^2_{F,t} + W^2_t H^2_t + R^{K2}_t K^2_t + \Pi^2_t + D^2_t,$$

and aggregate consumption, investment, and intermediate goods in country 2 are also a CES composite index of H and F goods, as follows:

$$C^2_t + I^2_t + M^2_t = \left[(\omega_2)^{1/\mu} D_{Ft}^{2,\frac{\mu-1}{\mu}} + (1-\omega_2)^{1/\mu} D_{Ht}^{2,\frac{\mu-1}{\mu}} \right]^{\frac{\mu}{\mu-1}},$$

where ω_2 is the home-biased preference, μ_2 is the elasticity of substitution of home and foreign goods in country 2. We assume that labor are not mobile across countries.

Note that the log-linearized equilibrium conditions imply the following UIP condition:

$$\hat{R}^1_t - \hat{R}^2_t - \left(E_t \hat{\pi}^1_{t+1} - E_t \hat{\pi}^2_{t+1} \right) - \left(E_t \hat{q}_{t+1} - \hat{q}_t \right) = \hat{\psi}_t - \tilde{\phi}^1_B \hat{b}^1_{F,t+1},$$

where hatted variables denote log deviations from steady states, and q_t denotes the real exchange rate.

Firms In each country, there is a continuum of firms. Country 1's firms have indexes on the interval $[0, 1]$, and country 2's firms on the interval $(1, 2]$. Firms of type z specializes in the production of differentiated goods $Y_t(z)$. The production function of firms of type z is given by

$$Y_t(z) = A^1_t F(K^1_t(z), h^1_t(z)) - FC^1_t,$$

where A_t denotes the exogenous productivity factor, and FC is the fixed cost. Firms of type z is able to change prices at time t with a probability α_1. Firms in country 1 maximize expected profit by choosing price $P_H^1(z)$ and $P_H^2(z)$ at the time they can change prices as follows:

$$E_t \sum_{s=t}^{\infty} r_{t,s}\alpha_1^{s-t}[\left(\frac{P_H^1(z)}{P_H^1}\right)^{-\theta_t}(C_{Hs}^1+I_{Hs}^1)P_H^1(z)+\left(\frac{P_H^2(z)}{P_H^2}\right)^{-\theta_t}(C_{Hs}^2+I_{Hs}^2)P_H^2(z)\varepsilon_s-W_s^1h_s^1(z)-R_s^{k1}K_s^1(z)$$
$$+\mu_s\left(A_s^1F(K_s^1(z),h_s^1(z))-FC_s^1-\left(\frac{P_H^1(z)}{P_H^1}\right)^{-\theta_t}(C_{Hs}^1+I_{Hs}^1)-\left(\frac{P_H^2(z)}{P_H^2}\right)^{-\theta_t}(C_{Hs}^2+I_{Hs}^2)\right)],$$

Note that the constraint is that the firm produces as much as it sells, and we assume that it can price to market.

Besides the price rigidities, firms also face nominal wage rigidities.

The same problem faces the firms in country 2:

$$E_t \sum_{s=t}^{\infty} r_{t,s}\alpha_2^{s-t}\varepsilon_s[\left(\frac{P_F^1(z)}{P_F^1}\right)^{-\theta_t}(C_{Fs}^1+I_{Fs}^1)P_F^1(z)\frac{1}{\varepsilon_s}+\left(\frac{P_F^2(z)}{P_F^2}\right)^{-\theta_t}(C_{Fs}^2+I_{Fs}^2)P_F^2(z)-W_s^2h_s^2(z)-R_s^{k2}K_s^2(z)$$
$$+\mu_t\left(A_t^2F(K_t^2(z),h_t^2(z))-FC_t^2-\left(\frac{P_F^1(z)}{P_F^1}\right)^{-\theta_t}(C_{Fs}^1+I_{Fs}^1)-\left(\frac{P_F^2(z)}{P_F^2}\right)^{-\theta_t}(C_{Fs}^2+I_{Fs}^2)\right)].$$

Monetary Policy The central bank in each country operates following the rule:

$$\ln R_t^1 = \rho_1 \ln R_{t-1}^1 + (1-\rho_1)(\ln R_1^{ss} + s_y^1 \ln Y_t^1 + s_\pi^1 \pi_t^1) + \ln m_t^1,$$

where Y_{ss} denotes the steady state level of output, and ϵ_t^1 is the exogenous monetary policy shock. Similarly, the monetary policy rule for country 2 is given by

$$\ln R_t^2 = \rho_2 \ln R_{t-1}^2 + (1-\rho_2)(\ln R_2^{ss} + s_y^2 \ln Y_t^2 + s_\pi^2 \pi_t^2) + \ln m_t^2.$$

Resource Constraints The resource constraints in the model are given as follows:

$$n_1 D_H^1 + n_2 D_H^2 = n_1(A^1 K_t^{1\alpha} h_t^{1,1-\alpha} - FC^1)$$
$$n_1 D_F^1 + n_2 D_F^2 = n_2(A^2 K_t^{2\alpha} h_t^{2,1-\alpha} - FC^2)$$

Shock Processes The model has exogenous productivity (TFP) shocks (A_t), financial shocks (ψ_t). These shocks follow a standard AR(1) process. Monetary policy shocks are i.i.d.

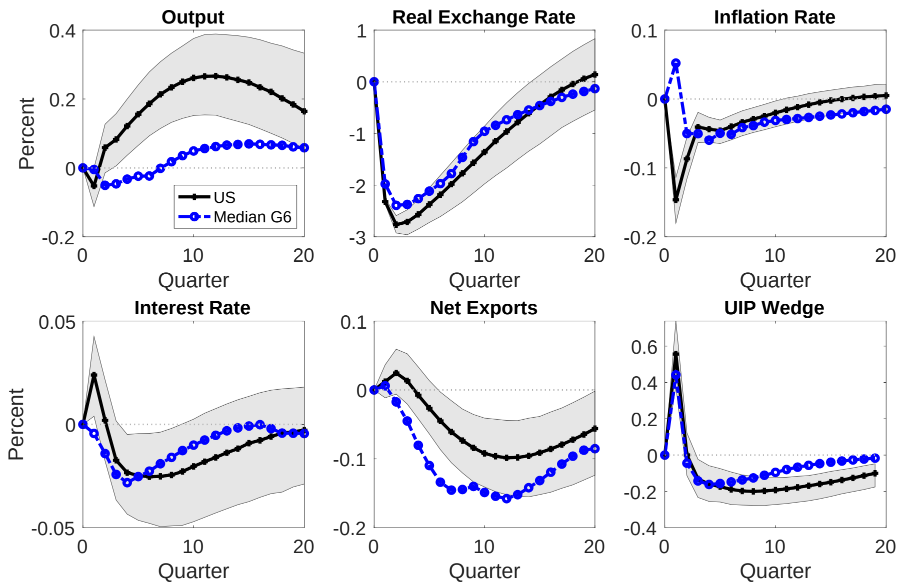
Calibration We calibrate the model using standard parameterization in the literature. Table B.1 presents the commonly calibrated parameters. For brevity, we only recorded the common parameters and country 1's parameters. Country 2's parameters are the same. We also set the steady state hours worked to be 0.3.

Table B.1: Calibrated Parameters

Parameter		Value
β	Discount rate	0.99
α_1	Calvo parameter for country 1	0.75
θ_{ss}	Steady state markup	10
ν	Labor supply elasticity parameter	1/3
s	Investment adjustment cost	1
δ	Depreciation cost	0.025
μ	Elasticity of substitution between home and foreign goods	1.5
ω	$1-\omega$ import share	0.85
α	Production function parameter	0.3
n_1	Country size	0.5
ψ_1	Bond adjustment cost	0.01
s_π	Taylor rule parameter	2
s_y	Taylor rule parameter	0.05
ρ_1	Taylor rule persistence	0.85
ρ_{a1}	Persistence of TFP shock	0.9
ρ_{v1}	Persistence of UIP shock	0.5
ρ_{mei}	Persistence of MEI shock	0.5

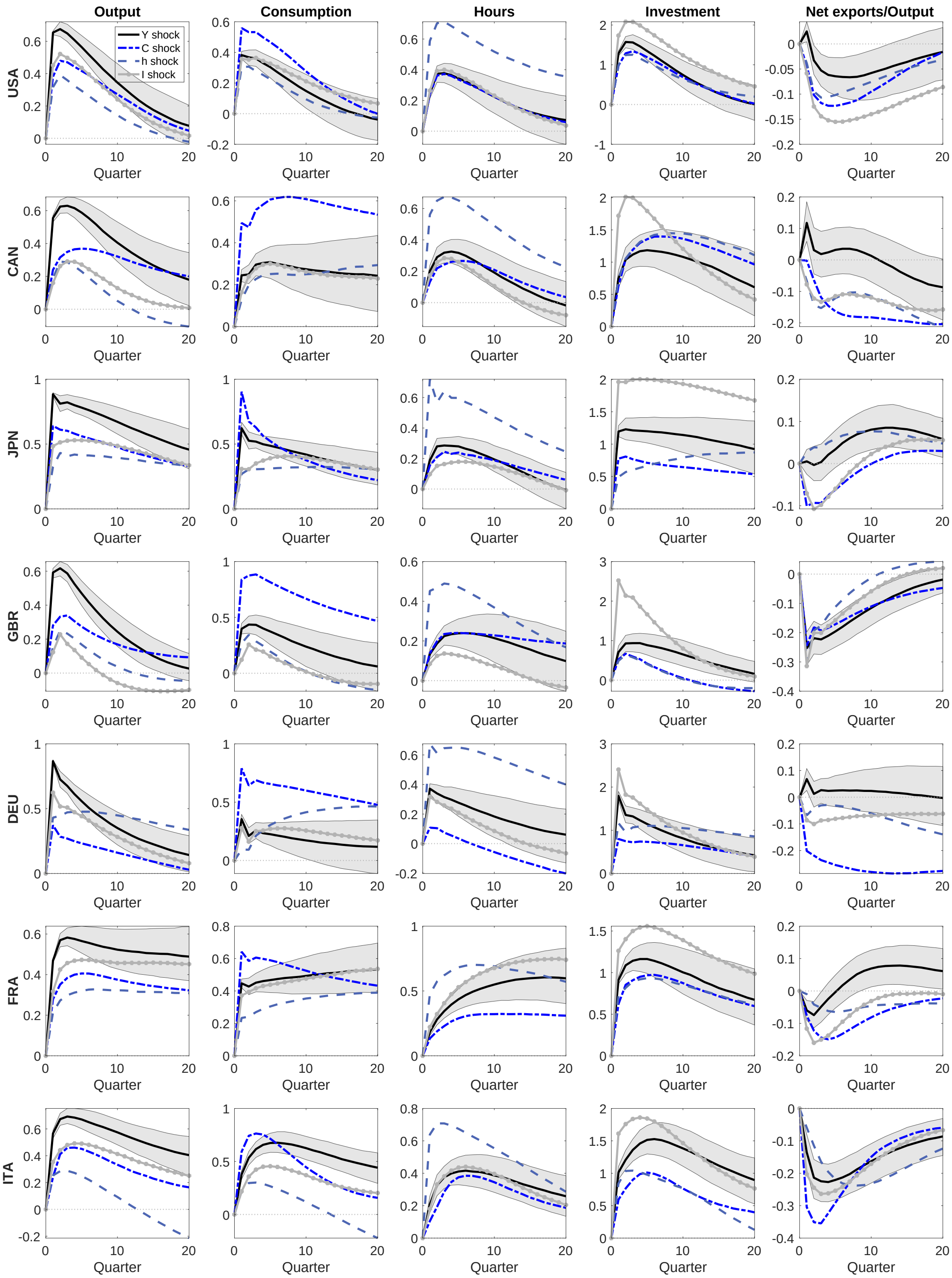
C Additional Figures and Tables

Figure C.1: Impulse responses to real exchange rate dominant shocks in business cycle frequency using BIS real effective exchange rate.



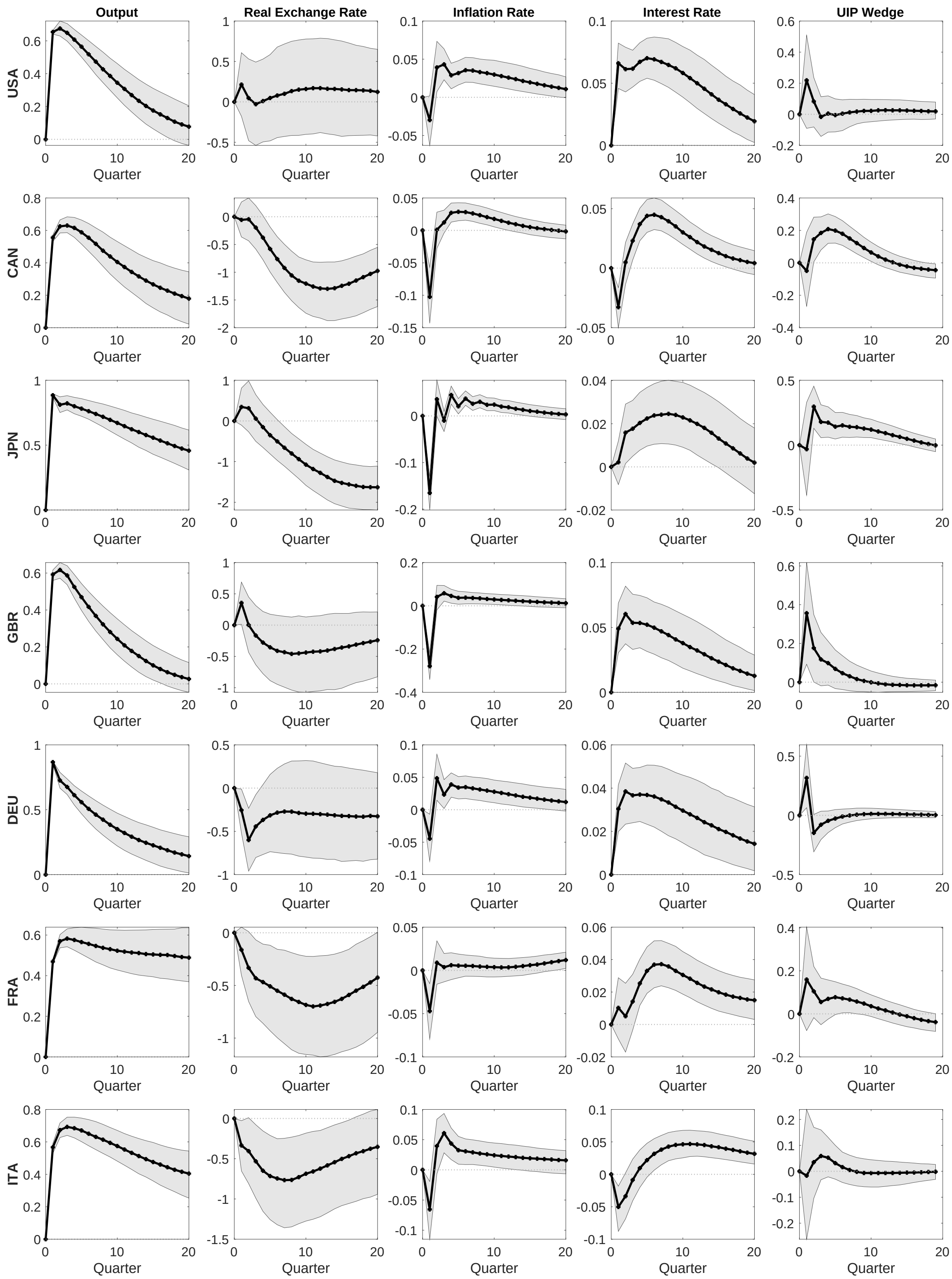
Note: A decrease in the real exchange rate is an appreciation. The gray area in each plot indicates the 16-84 percent credible bound of the variable response to a real exchange rate dominant shock.

Figure C.2: Impulse responses to relative output, consumption, and hours worked dominant shocks in business cycle frequency for each country.



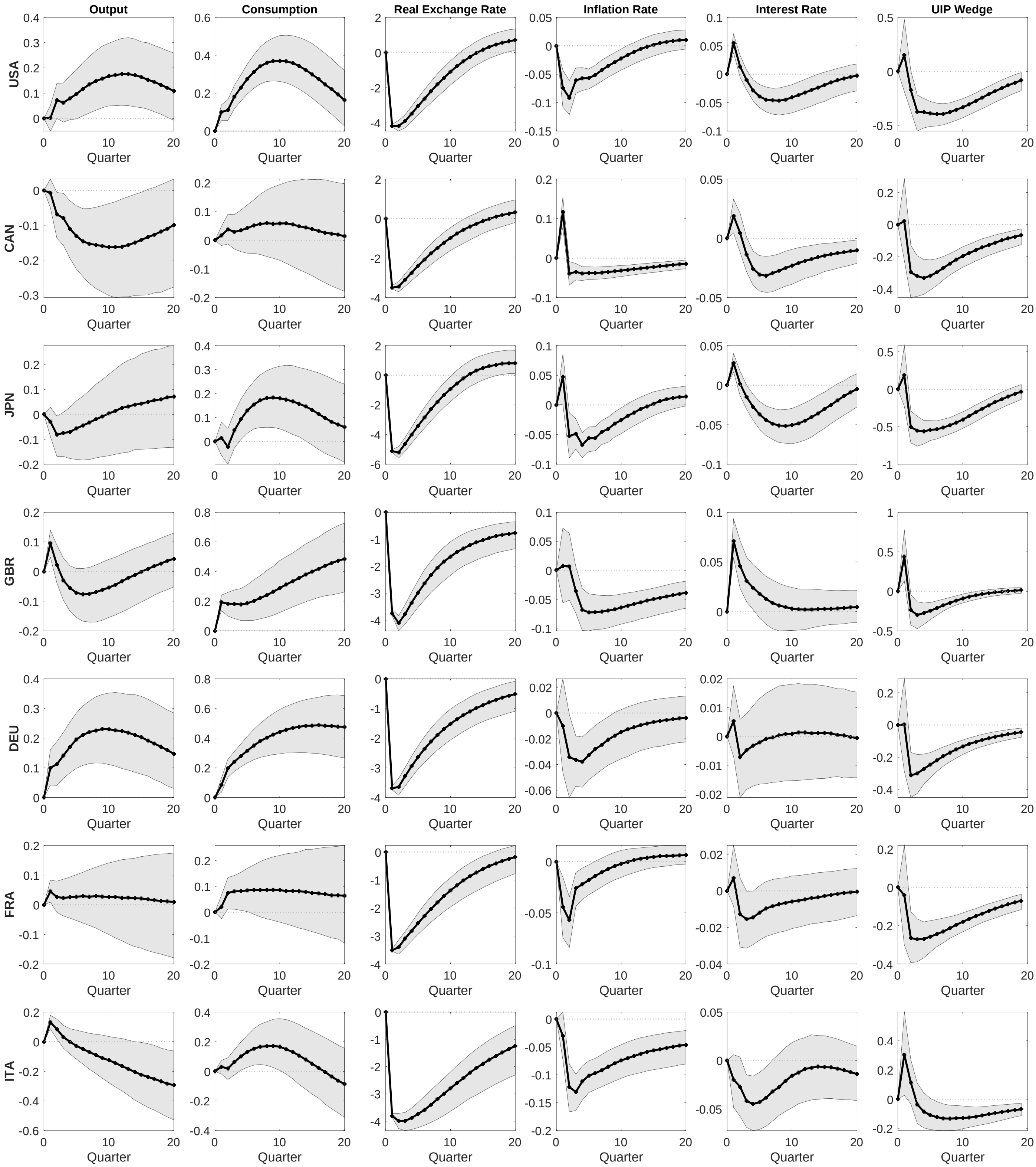
Note: A decrease in the real exchange rate is an appreciation. The gray area in each plot indicates the 16-84 percent credible bound of the variable response to a relative output dominant shock.

Figure C.3: Impulse responses to relative output dominant shocks in business cycle frequency.



Note: A decrease in the real exchange rate is an appreciation. The gray area in each plot indicates the 16-84 percent credible bound of the variable response to a relative output dominant shock.

Figure C.4: Impulse responses to real exchange rate dominant shocks in business cycle frequency.



Note: A decrease in the real exchange rate is an appreciation. The gray area in each plot indicates the 16-84 percent credible bound of the variable response to a real exchange rate dominant shock.

Figure C.5: Impulse response functions to dominant shocks in the short-term nominal interest rate and the inflation rate.

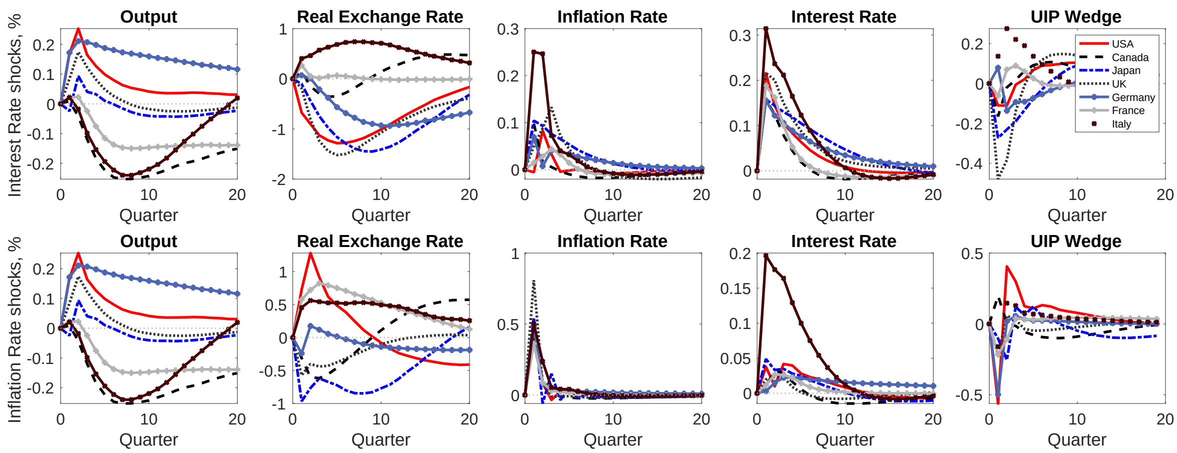


Table C.1: FEVD for all shocks in the baseline VAR

Shocks	Country	Output	Consumption	Investment	Hours	NXY	RER	Inflation Rate	Interest Rate
Relative Consumption Shocks									
h=4	**G7 Median**	**35**	**90.8**	**20.3**	**12.2**	**11.5**	**2.1**	**9.6**	**2.6**
	USA	45.3	91.1	37.3	24.3	11.5	2.1	5.2	2.6
	CAN	26.2	90.8	29.4	11.2	3.2	2.9	12.6	14.5
	JPN	51.7	90.3	15.3	10.4	4.7	1	9.6	1.6
	GBR	27	93.1	6.9	17.2	19.3	2.2	21.1	2.9
	DEU	16.1	89.8	14.7	2	23.1	4.9	10.8	1.1
	FRA	40.9	95.8	34	12.4	10.3	2.1	1	2.5
	ITA	35	90.7	20.3	12.2	42.8	1.2	5.7	7.1
h=20	**G7 Median**	**26.5**	**56.2**	**17.5**	**13**	**18**	**5**	**10**	**7.9**
	USA	36	41.4	21.5	15.2	14.3	5.5	8.1	7.9
	CAN	26.5	76.6	39.1	10.8	18	8.1	12.2	13.6
	JPN	39.7	48.7	10.9	8.6	4.4	4	10	3.1
	GBR	25.3	64.3	6.2	16	24.4	5.1	18.8	4.4
	DEU	11.1	56.2	17.5	4.2	40.2	5	10	2.5
	FRA	37.8	68.8	32.3	13	10.2	4.8	2.5	20.2
	ITA	20.3	40.6	16.5	19	31.5	2.6	6.7	11.1
Relative Hours Worked Shocks									
h=4	**G7 Median**	**22**	**14**	**29.3**	**94**	**5**	**3**	**4**	**7.5**
	USA	27.7	26.7	33.6	96.5	9.1	1.3	5.4	13.8
	CAN	17.1	13.6	30.7	95.6	5	0.9	4	4.5
	JPN	22	16.3	8.5	91.1	1.3	7.4	4.2	3.8
	GBR	12.7	10.4	6.3	89.9	21.5	2.2	4.1	8.1
	DEU	37.5	6.2	29.3	96.4	1.2	5.7	1.3	7.5
	FRA	24.4	17.7	33.6	94	1.6	3	3	7.5
	ITA	16.3	14	29.1	91.5	8	6.1	1.5	2.8
h=20	**G7 Median**	**17.1**	**15.1**	**18.7**	**64**	**9.8**	**4.2**	**5.4**	**6.5**
	USA	17.1	10.6	18.7	74.1	9.8	3.3	9.9	16.8
	CAN	9.3	15.1	45.9	73.9	13.8	19.3	5.6	11.9
	JPN	24.6	24.2	14	59.6	5.4	6.2	4.6	5
	GBR	9.8	5.3	6	47.9	17.1	3.4	6.6	9.4
	DEU	57.4	22.3	43.7	73.2	4.1	4.2	2.1	6.3
	FRA	27	29	32.7	63.4	3.1	3.4	5.4	6.5
	ITA	8.3	8.4	16.9	64	28.3	8.5	2.6	4.7
Relative Investment Shocks									
h=4	**G7 Median**	**42.6**	**20.7**	**94.3**	**17.9**	**12.8**	**2.2**	**2.4**	**4.8**
	USA	53.6	40.9	96	28.5	17.3	1.8	2.4	17.6
	CAN	16.7	20.7	92.6	15.3	4.1	16.7	3.3	5.7
	JPN	36.6	20.4	97.8	5.2	4.8	0.7	1.6	3.2
	GBR	7.9	5.2	92.8	6	25.2	0.8	2.2	4.8
	DEU	51.6	10.9	94.3	17.9	3.8	2.2	4.2	5.8
	FRA	56.8	42.5	96.5	37.2	12.8	3.5	2.4	2.5
	ITA	42.6	24.7	93	22.5	23	3.5	1.6	2.8
h=20	**G7 Median**	**35.2**	**19.3**	**62**	**10.8**	**11.6**	**4.7**	**4.1**	**13**
	USA	37.1	22	60.7	16.8	29.3	4.7	6.8	32.3
	CAN	10.2	15.4	48.1	10.8	11.6	36	4.9	9.4
	JPN	35.2	31.7	82.1	4.9	5.4	4.7	3.5	4.6
	GBR	9.1	3.9	70.6	4.3	22.6	2.7	4.1	14.9
	DEU	36.8	8.5	60	7.6	4	3.5	8.4	13
	FRA	58.4	55.5	84.3	61.1	8.7	13	3.4	14.9
	ITA	28.1	19.3	62	26.4	24.7	3.7	4	11.2
Net Exports Shocks									
h=4	**G7 Median**	**2.7**	**9.1**	**6.4**	**2**	**91.7**	**3.4**	**3.7**	**2.8**
	USA	0.7	4.2	6.4	5	94	1.2	9.3	1.1
	CAN	2.7	0.7	1.9	2	90.2	1.2	1.9	5
	JPN	1.1	7.4	8.2	1.2	95.1	3.7	3	2.8
	GBR	16.3	9.1	24.2	23	91	8.8	4.8	15.8
	DEU	0.8	13.5	3.4	0.5	93.2	8.8	3.7	1.9
	FRA	3.5	9.3	16.4	1	91.7	0.6	3.2	2.8
	ITA	4.9	21	6.2	2.3	85.1	3.4	12.8	7.9
h=20	**G7 Median**	**7.2**	**7.7**	**8.2**	**3.7**	**54.6**	**6.7**	**8.7**	**10.5**
	USA	7.8	9.8	8.2	4.4	53.6	5.7	11.8	3
	CAN	17.1	5.4	4.1	2.8	46.4	3.1	3.3	10
	JPN	7.2	13.9	12.7	18.3	63.5	14.8	8.7	10.5
	GBR	14.4	6.1	23.6	27	70.4	7.1	9.9	20.2
	DEU	1.6	14.9	3.4	1.7	54.6	17.2	4.4	5.7
	FRA	2.9	4.5	14.4	2	58.1	2.7	5.2	12
	ITA	2.8	7.7	4.5	3.7	40.9	6.7	15.3	21.3

Table C.2: FEVD for all shocks in the baseline VAR (cont'd)

Shocks	Country	Output	Consumption	Investment	Hours	NXY	RER	Inflation Rate	Interest Rate
Relative Inflation Shocks									
h=4	**G7 Median**	**1.7**	**9.1**	**1.9**	**2**	**4.2**	**2.7**	**81.7**	**4.1**
	USA	1.7	9.1	1	2.5	5.6	5.5	75.2	5.4
	CAN	8.3	12.2	6.4	5.4	1.8	2.8	88.8	4.1
	JPN	12.2	12.8	3.4	5.7	4	2.7	81	6.9
	GBR	10	17.8	2	2	6	1.7	81.7	1.6
	DEU	0.9	6.7	0.7	0.7	4.8	0.9	84.3	2.2
	FRA	1.3	0.7	1.9	1.8	1.3	5.1	85	2.8
	ITA	1.4	1.5	1.1	2	4.2	2.1	65.1	46.1
h=20	**G7 Median**	**7.4**	**12.3**	**3.3**	**8.6**	**4.7**	**4.5**	**70.2**	**5.1**
	USA	7.4	12.3	2.2	2	3.3	5	63.8	5.1
	CAN	14	18.6	17.7	9.3	3.2	5	79.7	6
	JPN	17.1	14.9	5.5	13.4	4.7	4.5	70.2	5.8
	GBR	12.9	14.4	2.6	8.6	10.9	2	70.9	2.4
	DEU	1.3	6.4	1.4	1	6.9	1.5	69.6	4.6
	FRA	3.5	2.6	3.3	5.9	1.8	6.1	75.9	2.9
	ITA	2.7	4.5	6.5	14	15.1	3.3	50.4	33.7
Relative Nominal Interest Rate Shocks									
h=4	**G7 Median**	**3.5**	**3.1**	**3.8**	**3.9**	**2**	**2**	**5**	**89.8**
	USA	8.1	2.7	8.3	8.2	1.2	6.5	4.1	85
	CAN	3.5	14.1	7.3	1.9	1.7	1.3	5.6	79.6
	JPN	0.8	1.5	3	1.6	2	2.3	8	93.9
	GBR	4.3	3.1	2.8	2.8	10.2	7.5	5	93
	DEU	7.1	0.7	4.9	7.8	1.5	0.9	3.5	94.1
	FRA	1.3	4.7	3.1	5.9	3.4	0.9	3.2	89.7
	ITA	2.1	4.6	3.8	3.9	5.3	2	27.7	89.8
h=20	**G7 Median**	**5.3**	**4.6**	**9**	**6.1**	**4.7**	**10**	**5.8**	**62.6**
	USA	5.3	4.6	6.3	4.4	4.3	12.4	4.6	46.7
	CAN	11.9	24.2	17.5	6.9	4.7	4.1	6.7	55.8
	JPN	2.1	2.4	3	2.6	4.3	10.5	9.1	64.3
	GBR	4.4	2.5	4.2	6.1	8.7	16.4	5.8	73.1
	DEU	9.1	3.1	9	5.1	3.1	10	4.5	69.7
	FRA	5.2	8.7	13.3	12.6	11	2	4.3	62.4
	ITA	5.3	9.8	16.9	28.2	30.2	4.6	22.3	62.6