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In Search of Dominant Drivers of the Real Exchange Rate[*]

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Abstract

We uncover the major drivers of macro aggregates and the real exchange rate at business cycle frequencies in Group of Seven countries. The estimated main drivers of key macro variables resemble each other and account for a modest fraction of the real exchange rate variances. Dominant drivers of the real exchange rate are orthogonal to main drivers of business cycles, generate a significant deviation of the uncovered interest parity condition, and lead to small movements in net exports. We use these facts to evaluate international business cycle models accounting for the dynamics of both macro aggregates and the real exchange rate.

JEL classification: E32, F31.

Keywords: real exchange rate, international business cycles, uncovered interest parity.

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1 Introduction

Understanding the real exchange rate and its connection with the economy is foundational 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 find a seemingly low correlation, dubbed a "disconnect," between the real exchange rate and macroeconomic variables in the data. This disconnect 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 generate several properties of the real exchange rate. For example, Itskhoki and Mukhin (2021) recently argued that financial shocks in the international asset market are the main driver of the real exchange rate and 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 at business cycle frequency. Using data for each of the Group of Seven (G7) countries—Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States—vis-à-vis a composite of the rest of the world (ROW) between 1974:Q1 and 2016:Q4, 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 a cut using 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 anatomy sets to shed light on how international business cycle models could jointly explain the behaviors of the real exchange rate and macro variables.

Our empirical analysis uses the Max Share method to estimate a dominant shock to a variable, which is a structural vector autoregression 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 dynamic stochastic general equilibrium model that imposes strong cross-equation restrictions for the dynamic relationships and comovement between the real exchange rate and macroeconomic variables. Second, this approach makes it easier to analyze data from several countries and is flexible to incorporate different variables into the estimation, as opposed to the structural model estimation approach, which is much more computationally intensive. Third, this approach helps us build a rich set of business cycle properties of the real exchange rate beyond the standard unconditional moments that are informative for different theories about the types of shocks responsible for real exchange rate behavior in international business cycle models.

The empirical findings can be summarized as follows. First, dominant shocks to domestic output, consumption, hours worked, and investment relative to the ROW at business cycle frequency generate similar dynamic responses of all the variables, but each of these shocks accounts for less than 10 percent of the real exchange rate forecast variances in both the short and long run in the median country. Each of the four shocks obtained by targeting key macro quantities not only triggers similar impulse responses but also accounts for significant variations of the other quantities. This result is consistent with the view that business cycle models featuring a single, dominant shock or multiple shocks with a similar propagation mechanism can capture the movements of key real macro quantities. As such, and without loss of generality, we refer to dominant shocks to relative output as main business cycle (MBC) shocks. Our findings that MBC shocks generate limited real exchange rate movements and account for only a small percentage of the real exchange rate fluctuations in most countries could be labeled as a dynamic business cycle version of the exchange rate disconnect. Nevertheless, we also find some heterogeneity across countries in the degree of (dis)connect between the real exchange rate and business cycle shocks. For example, while dominant shocks to relative output account for only 3 percent of U.S. real exchange rate forecast error variances, these shocks explain nearly 19 percent of the forecast error variance of the Canadian real exchange rate at the five-year horizon.

Second, dominant shocks to the real exchange rate at the business cycle frequency generate small responses from macro quantities, as well as the net-exports-to-output ratio, and explain little of these macroeconomic variables' fluctuations. The responses of the relative nominal interest rate as well as the relative inflation rate are small and insignificant. In contrast, the real exchange rate response to a dominant real exchange rate shock is large and persistent, with a slightly delayed peak. Driven by the large movement of the real exchange rate relative to the interest rate and inflation differentials, 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 orthogonal to MBC shocks. Together, these two shocks explain over 90 percent of the forecast error variances of relative output and the real exchange rate and 25 to 50 percent of the forecast error variances of relative consumption, hours worked, and investment at the one-year horizon.

The empirical results have important implications for real exchange rate behavior in international business cycle models. In particular, we reject the possibility that a dominant structural shock to any key macro variable can be the major driver of the real exchange rate. While the similar transmission mechanism of dominant shocks to relative output, consumption, hours worked, and investment supports a potential dominant business cycle shock driving key macro quantities in all G7 countries, echoing the closed economy results in Angeletos, Collard, and Dellas (2020), these shocks play only a modest role in real exchange rate fluctuations. As such, it is unlikely that an open economy version of the model with a dominant propagation mechanism, i.e., a single dominant shock or multiple shocks with similar propagation patterns, can jointly explain the time series properties of both real quantities and the real exchange rate. Instead, models would need separate shocks explaining real quantities and another shock to the real exchange rate, such as the model in Itskhoki and Mukhin (2021). To verify this intuition, we examine a quantitative open economy model with TFP shocks, monetary shocks, and financial shocks to the international asset market. Simulating data from the calibrated model that match several second moments of U.S. data, 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. We also confirm that the model with a single shock, such as a TFP shock only, fails to capture the observed relationship between the real exchange rate and other macroeconomic variables.

Furthermore, we examine whether our estimated dominant shocks to the real exchange rate are consistent with drivers of the real exchange rate in leading business cycle models, such as financial shocks in Itskhoki and Mukhin (2021). In fact, our estimation approach of the dominant real exchange rate shock could be used as an empirical verification of the financial shock in international asset markets from the viewpoint of Itskhoki and Mukhin (2021). Based on this insight, we compare the impulse response functions (IRFs) for dominant shocks to the real exchange rate for empirical data with those obtained using the simulated data. The IRFs 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. Consistent with the data, financial shocks generate stronger responses by an order of magnitude to the real exchange rate relative to the responses of output differentials. However, there are two discrepancies between the responses from the simulated data and their empirical counterparts. First, financial shocks in the model with a standard autoregressive order-one process miss the delayed peak response of the real exchange rate found in the data. Second, financial shocks are strongly connected with net exports in the model, which is at odds with the empirics where dominant real exchange rate shocks lead to a small response of net exports and play a negligible role in net trade flows. Together, our analyses suggest that, while a model with financial shocks explaining the real exchange rate and MBC shocks driving real macro variables is broadly consistent with the data, the model needs to incorporate additional frictions beyond those used in Itskhoki and Mukhin (2021) to better match the time series of both the real exchange rate and net trade flows.

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

First, we contribute to the debate about the major business cycle drivers of the real exchange rate. On the one hand, 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 business cycle drivers such as monetary policy and productivity shocks. Valchev (2020) models bond convenience yields as endogenous to business cycle shocks and replicates certain movements of the exchange rate and the UIP wedge in the data. On the other hand, papers estimating structural open economy models such as Adolfson et al. (2007) and Justiniano and Preston (2010) find that conventional macro shocks are limited in accounting for the real exchange rate. Eichenbaum, Johannsen, and Rebelo (2021) estimate a three-country model for the United States, Germany, and the ROW and find that foreign demand for dollar-denominated bonds is the major driver of the real exchange rate, while Chen, Fujiwara, and Hirose (2019) estimate a general equilibrium model for the United States and find that shocks to the UIP condition play a major role in accounting for the real exchange rate. Our agnostic approach complements this literature by directly looking into the drivers of key macro and financial variables and investigating their effects on the real exchange rate without taking a stand on particular shocks through a structural model. The results suggest that the major driver of the real exchange rate may not be dominant shocks of business cycles and may be more consistent with financial shocks, as in Itskhoki and Mukhin (2021).

Second, we contribute to the empirical literature on the determinants of the real exchange rate. Several papers—such as Enders, Muller, and Scholl (2011), Juvenal (2011), Nam and Wang (2015), Schmitt-Grohe and Uribe (2022), 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. By using the Max Share method, our paper instead looks at several cuts of the data to document the properties of dominant shocks driving the real exchange rate and the business cycle to distinguish the sources of real exchange rate fluctuations.

Third, our paper fits in and contributes to the exchange rate disconnect literature. 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 macro-finance data using measures of the goodness of fit such as 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. (2022) document the link between the nominal exchange rate and financial variables in recent periods. Koijen and Yogo (2020) find that macro and policy variables explain a large fraction of nominal exchange rate variations. Stavrakeva and Tang (2020) argue that macroeconomic news can account for 70 percent of the quarterly variation in the nominal 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 on the real exchange rate for several countries. 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 finding varies across countries. For example, while output shocks in Canada can explain up to 30 percent of the real exchange rate forecast error variances at the five-year horizon, dominant shocks to net exports are more important than output shocks for the real exchange rate in Japan, and dominant shocks to global factors are more important for the United Kingdom. Our results suggest that fundamental shocks can play a nontrivial, albeit nondominant, role in driving the real exchange rate in business cycles.

Fourth, our paper also relates to the literature on the shocks driving business cycle fluctuations. We extend the analysis 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 dynamic effects on other macro variables that are similar to major shocks to consumption, hours worked, and investment at the business cycle frequency. Furthermore, these dominant business cycle shocks generate small changes in the inflation rate. Another contribution of this paper is to document the effects of these MBC shocks on the real exchange rate and their explanatory power for the fluctuations of the real exchange rate.

The rest of the paper proceeds as follows. In Section 2, we describe the empirical methods and the data series and construction for the empirical analysis. Estimated MBC shocks and their relationship with the real exchange rate are presented in Section 3. Section 4 presents the empirical findings about the dominant driver of the real exchange rate. Section 5 discusses the model implications of our empirical findings. Section 6 concludes.

2 Empirical Methods and Data

This section describes the empirical methodology implemented in the paper and 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 variable at the business cycle frequency and examine their relationship with the real exchange rate. The empirical method builds on Uhlig (2003) and, more recently, Angeletos, Collard, and Dellas (2020), who identify a dominant shock for each variable as particular linear combinations of the vector autoregression (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:

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

where X_t is an $N \times 1$ vector, containing the macroeconomic variables and the real exchange rate, $A(L) = \sum_{\tau=0}^{p} A_\tau L^\tau$ is the matrix polynomials in the lag operator L with $A(0) = A_0 = I$, where I is the identity matrix and p is the number of lags included in the VAR; and u_t is a vector of VAR residuals with $E\left(u_t u_t'\right) = \Sigma$. The baseline VAR includes two lags. Because the VAR includes a large number of variables—up to nine in some specifications—we opt to use Bayesian methods to estimate the VAR with Minnesota priors. The posterior distributions are obtained from 1,000 draws after discarding 100 initial draws.[1]

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

$$u_t = S\varepsilon_t,$$

[1]We obtain similar results when imposing Normal-Wishart priors or using more draws.

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 columns of Q to recover a subset of shocks, $\varepsilon_t = Q^{'}S_{chol}^{-1}u_t$.

The identification strategy to specify the first column of Q, denoted by 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 the business cycle frequency between 6 and 32 quarters. We can write down the spectral density of variable X at frequency w as follows:

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

where $C(L) = A^{-1}(L)S_{chol}$. We can compute the volatility of variable X over a particular 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 by taking the integral of this spectral density function over that frequency band. 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-à-vis the ROW in our data set. The baseline VAR has eight variables:

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

i.e., the output, consumption, hours worked, and investment in country s relative to, in each case, the corresponding value in the ROW, all in logs; the net-exports-to-output ratio; the logarithm of the real exchange rate; the relative nominal interest rate; and the relative inflation rate. We choose to specify the variables relative to the ROW instead of country-specific level variables.[2] We avoid repeating the word "relative" when it is obvious.

2.2 Data

We use quarterly international data from several sources. The national accounts and consumer price index data are taken from the Organisation for Economic Co-operation and Development (OECD) and national statistical agencies. The dat on hours worked are taken from Ohanian and Raffo (2012). The nominal interest rate is the end-of-period three-month government bond yield, taken from the Global Financial Database. The nominal exchange rate is the end-of-period market rate taken from the Bank for International Settlements. Our data set also includes financial variables such as the corporate bond spread, which we construct following Krishnamurthy and Muir (2017); stock prices and realized stock return volatilities; and the global risk factor data from Miranda-Agrippino and Rey (2020).[3]

We construct the ROW composite for each G7 country in the data set based on a total of 13 OECD countries—six other G7 countries (G6) and seven other OECD countries (Australia, Austria, Finland, Ireland, Korea, Norway, and Sweden)—when data are available for each variable. The data for each country in the ROW are weighted by the country's nominal GDP share calculated at the annual purchasing power parity values.

[2]As our focus is on the real exchange rate which is a relative variable, our baseline VAR uses relative variables. For other purposes and robustness, we also run our VAR with level variables in Section 3.2 and the Online Appendix.

[3]We examine the relationship between dominant shocks to these financial variables and the real exchange rate in the Online Appendix.

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

3 MBC Shocks and the Real Exchange Rate

This section presents the estimation result from the VAR. We focus on the IRF and the forecast error variance decomposition of dominant shocks associated with relative output and other variables in the business cycle frequency. We document two main findings. First, dominant shocks explaining output at the business cycle frequency, or MBC shocks, have dynamics similar to those of dominant shocks explaining consumption, hours worked, and investment but are disconnected from the inflation rate and the nominal interest rate in a median country. Second, MBC shocks are generally weakly connected to the real exchange rate, as they generate small movements of the real exchange rate and explain a modest fraction of real exchange rate fluctuations in a median country. As an aside, we also show that MBC shocks estimated from level VARs are highly correlated across countries, suggesting a potential cross-country spillover channel of MBC shocks.

3.1 MBC Shocks in the G7

Figure 1a plots the IRFs of five real macro variables to each dominant shock to output, consumption, hours worked, and investment in the business cycle frequency in the United States at the posterior median. In the same figure, we also plot the IRF of the G6 median, which is computed as the median of the IRFs for the other six countries taken at the posterior median. In the United States, the propagation of dominant shocks to output is similar to that of dominant shocks to consumption, hours worked, and investment. A dominant output shock that increases domestic output relative to the ROW is associated with a significant increase in consumption, hours worked, and investment and a decline in the net-exports-to-output ratio. The responses of output, consumption, hours worked, and investment are significant and larger than the response of the net-exports-to-output ratio. The IRF resemblance between all the four dominant shocks also emerges in the G6 median. In each of the G6 countries, the IRFs of the real macro variables to dominant shocks to output, consumption, hours worked, and investment resemble each other, although some of the IRFs in Canada or Germany are not as tightly synchronized as those in the United States.[4] These results for the IRFs suggest that in each G7 country, dominant shocks driving the fluctuations of relative output, consumption, hours worked, and investment are closely related.

Furthermore, each of the dominant shocks to output, consumption, hours worked, and investment plays an important role in explaining the variations of these key macro variables, especially at the shorter horizons. Table 1 summarizes the fractions of the forecast error variances attributable to dominant output shocks over the one- and five-year horizons. Dominant output shocks explain substantial fractions of the forecast error variances for consumption and investment—42.2 percent and 48.1 percent of the respective forecast error variances at the one-year horizon in a median country. The contribution of dominant output shocks to these key macro variables tends to be larger at the one-year horizon than at the five-year horizon, consistent with the short-lived impulse responses. The importance of dominant output shocks in driving these variables differs somewhat across countries. In the United States, dominant output shocks, which contribute to 95.1 percent and 68.6 percent of the output forecast error variations over the one- and five-year horizons, re-

[4]The IRFs as well as forecast error variances of dominant shocks to output, consumption, hours worked, and investment for each country are plotted in the Online Appendix.

spectively, are responsible for 42.2 percent of relative consumption volatilities and 25.5 percent of the variations in relative hours worked over the one-year horizon. In the United Kingdom and Canada, the role of dominant output shocks is somewhat smaller for consumption, investment, and hours worked.

The tight relationship between dominant shocks to relative output, consumption, hours worked, and investment are present not only in the IRFs and forecast error variance decomposition, but also in the time series of these shocks produced in the VAR. Table 2 reports the contemporaneous correlations of these dominant shocks recovered from the VAR taken as a median of G7 countries. The correlations of dominant shocks to relative output, consumption, hours worked, and investment at business cycle frequencies are highly correlated, between 0.5 and 0.72.[5] This result suggests that there is a large common component in the recovered shocks for these variables in each country.

What is the relationship between these dominant shocks and prices? It turns out that dominant output shocks in the business cycle frequency have little effect on the inflation rate. As plotted in Figure 1b, a shock that increases relative output in the United States by about 0.6 percent on impact is associated with, at most, a meager 0.05 percent increase in the relative inflation rate, and this result is similar for the G7 median. Consistent with the IRF results, dominant output shocks explain a small fraction of the inflation rate forecast error variances—3.2 percent in the G7 median at the one-year horizon—and the correlation of recovered dominant shocks to output and of those to inflation is small.

Taken together, our results about dominant shocks driving key relative macro quantities in the G7 countries support the existence of an MBC shock driving the fluctuations of real macroeco-

[5]The correlations of recovered shocks for each country's output, consumption, hours worked, and investment in the level specification, as in Section 3.2, are higher than the documented correlations here using relative variables, suggesting a possible interchangeability of dominant shocks to the main macro aggregates in each country, similar to the results in Angeletos, Collard, and Dellas (2020).

nomic variables and having a negligible effect on the inflation rate in both the United States and other 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, the unemployment rate, hours worked, and investment in the United States.

3.2 Cross-Country Relationship of MBC Shocks

We next document the relationship between MBC shocks across countries. To that end, we re-estimate the MBC shocks for each country using domestic and ROW variables separately, as earlier results based on relative variables in the baseline are not suited to studying the transmission of MBC shocks across countries. Specifically, the following variables are included in our VAR:

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

We find that domestic MBC shocks are highly correlated across G7 countries. At median, the correlation of domestic MBC shocks in the United States with the rest of the G7 countries is 0.44. The correlations of domestic MBC shocks in other countries with the rest of the G7 countries are also substantial, ranging from 0.29 to 0.38. This result is sensible given that business cycles in the G7 countries are highly synchronized. Further details on the cross-country correlations and spillovers of domestic MBC shocks are in the Online Appendix.

3.3 MBC Shocks and the Real Exchange Rate

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

First, MBC shocks tend to make the real exchange rate in the G7 countries appreciate, but the responses are small. As plotted in Figure 1b, an increase in relative output due to 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 the G6 median, the real exchange rate appreciates persistently in response to the MBC shock, although the credible bounds are rather large for some countries, such as the United Kingdom and Germany, as plotted in the Online Appendix. These results, combined with the fact that dominant output shocks also lead to an increase in relative consumption and a significant decline in the net-exports-to-output ratio in these countries, are consistent with the non-inflationary demand shock view of MBC shocks in Angeletos, Collard, and Dellas (2020) extended to the open economy. That is, in an open economy, a positive noninflationary demand shock in the domestic economy associated with an increase in relative consumption would also lead to a decline in net exports, because the aggregate demand for imported goods dominates the expenditure-switching channel when relative price movements are limited. At the same time, our finding that relative consumption increases, but the real exchange rate does not depreciate, after an MBC shock could be labeled as the conditional Backus-Smith puzzle. The international risk-sharing condition in a standard international business cycle model with complete financial markets and a separable utility function suggests that an increase in relative consumption should be associated with a depreciation of the real exchange rate.

Second, to see whether major drivers of the business cycle generate substantial deviations from the UIP condition, we compute the UIP wedge conditional on MBC shocks for each country s based on the IRFs of the nominal interest rate, the inflation rate, and the growth rate of the real exchange rate as follows:

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

The last column in Figure 1b plots the UIP wedge responses for the United States and the G6 median. The UIP wedge movements are mostly driven by the real exchange rate responses, so the impulse responses of the UIP wedge to MBC shocks are small. The peak response of the UIP wedge happens one to two quarters after the shock and is about half of the peak response of relative output. However, the responses of the UIP wedge to MBC shocks are insignificant, as shown for the United States. When we examine each country's results, reported in the Online Appendix, the UIP wedge responses are significant only in Canada and Japan, where the real exchange rates persistently appreciate.

Third, the results of the forecast error variance decomposition are consistent with the impulse responses. MBC shocks are only mildly connected with the real exchange rate in all countries, especially in the short run. As reported in Table 1, MBC shocks explain 1.2 percent of the forecast error variance of the real exchange rate at the one-year horizon in a median country. The contribution of MBC shocks to the forecast error variance of the real exchange rate is larger at the five-year horizon in all countries but remains small: only 4.2 percent of the fluctuations in the real exchange rate in the median country are attributable to MBC shocks. The country where MBC shocks explain the most variation in the real exchange rate is Canada. At the five-year horizon, up to 18.7 percent of the fluctuations in the Canadian real exchange rate are driven by MBC shocks.

This result is consistent with the conventional narrative that underlying shocks like oil shocks may be an important driver for both output and the real exchange rate in Canada. Again, we obtain similar results if we instead focus on dominant shocks to the relative consumption, relative hours worked, and relative investment. Table 3 shows that in a median country, these dominant shocks explain between 2 and 5 percent of the forecast error variances of the real exchange rate, and the largest connection is in Canada. It follows that the MBC shocks' implied contribution to the UIP wedge is small. In fact, as shown in the table, MBC shocks explain only 7.3 percent and 7.9 percent of the forecast error variances of the UIP wedge at one- and five-year horizons, respectively, in a median country.[6]

Finally, not only do dominant shocks to output, consumption, and investment explain a small fraction of the forecast error variances of the real exchange rate, but dominant shocks to other key macro variables at business cycle frequencies also contribute little to the real exchange rate variation. As shown in Table 3, dominant shocks to the net-exports-to-output ratio turn out to explain only 3.4 percent and 6.7 percent of the real exchange rate variations at the one- and five-year horizons, respectively, in a median country, suggesting a larger but still modest connection between the real exchange rate and net exports. Dominant shocks to the relative nominal interest rate at business cycle frequencies explain up to 10 percent of the forecast error variances of the real exchange rate in a median country. We find that these results are robust to several specifications and data periods, and dominant shocks to financial variables and trade variables at business cycle frequencies contribute to a small fraction of the real exchange rate variations. Details for these

[6]While the disconnect between MBC shocks and the real exchange rate is most apparent when we focus on the business cycle frequency, dominant output shocks at lower frequency bands still explain only modest fractions of the real exchange rate. For example, dominant output shocks in the 60- to 80-quarter frequency account for about 12 percent of the real exchange rate variation at the five-year horizon in the median country, as shown in the Online Appendix.

robustness checks and extensions are presented in the Online Appendix.

4 Dominant Real Exchange Rate Shocks

The previous section unravels that MBC shocks account for only a small fraction of the real exchange rate variation in the business cycle frequency. In this section, we apply the Max Share 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 and a significant response of the UIP wedge. At the same time, the responses of output, consumption, hours worked, and net exports to the dominant real exchange rate shock are muted. Furthermore, this dominant shock appears to be orthogonal to MBC shocks. We elaborate on each of these properties in the next two subsections.

4.1 Real Exchange Rate and Key Macro Variables

First, dominant shocks to the real exchange rate have a large and persistent effect on the real exchange rate in all G7 countries. As plotted in Figure 2, in response to a real appreciation shock, the real exchange rate remains appreciated for at least 12 quarters in the United States and median G6 countries. 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. As plotted in Figure 2, the impulse responses of relative output and consumption increase in response to a real appreciation caused by the dominant real exchange rate shock, but their magnitudes are small compared with those of the real exchange rate. In the United States, the largest response of relative output is only 0.2 percent, compared with the 4 percent initial response of the real exchange rate. The rise in relative consumption despite real appreciation suggests that the major driver of the real exchange rate also generates a conditional Backus-Smith puzzle, as was the case for MBC shocks. Relative hours worked barely reacts to the shock.

In addition, the responses of the net-exports-to-output ratio are also muted. More specifically, the net-exports-to-output ratio declines, but the magnitude is small and gradual in response to the real appreciation shock. This result suggests that dominant shocks to the real exchange rate are also disconnected to net trade flows. One might ask whether the result is due to a slow pass-through of the dominant real exchange rate shock to terms of trade, as terms of trade might be more relevant for net trade flows. In the Online Appendix, we add terms of trade into the VAR estimation and show that this is not the case: the responses of the net-exports-to-output ratio are also muted in countries where terms of trade appreciate significantly in response to the shock.

Similar to output, consumption, and net exports, the responses of relative inflation and relative interest rates are small for most countries, with limited variations of around 0.1 percentage point or less. Note that the relative interest rate is negative during the periods when the real exchange rate slowly depreciates from its peak appreciation. The G6 median nominal interest rate response is muted, which is driven by the low variation of the relative nominal interest rate in the euro-area countries, shown in the individual country plots in the Online Appendix.

Third, dominant shocks to the real exchange rate generate a meaningful deviation from the UIP condition. As before, we compute the responses of the UIP wedge to the dominant real exchange rate shocks from the impulse responses of the relative inflation rate, the relative interest rate, and the real exchange rate. The UIP wedge initially increases, reverses to negative, and 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 reflects the delayed peak response of the real exchange rate. This finding is related to the previous literature such as Bacchetta and van Wincoop (2010), Engel (2016), and Valchev (2020), which document the reversal of the UIP deviations using different statistical methods. The decomposition in Valchev (2020) suggests that the reversal in the UIP deviation is mostly driven by the nonmonotonicity of the exchange rate dynamics. In our case, the reversal in the UIP deviation is conditional on the main driver of the real exchange rate. In this sense, our finding complements the previous literature. Moreover, the result that the UIP wedge response mostly reflects the expected growth rate of the real exchange rate resonates with the recent work by Kalemli-Ozcan and Varela (2021), who document that in advanced countries, the comovement of the UIP premium and the global risk perception is explained by expected changes in exchange rates.

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 at the one- and five-year horizons attributable to dominant real exchange rate shocks. In the G7 median, the dominant real exchange rate shock accounts for 95 percent and 70.3 percent of the real exchange rate forecast error variance at the one- and five-year horizons, respectively. However, dominant shocks to the real exchange rate are limited in driving the fluctuations of aggregate variables. The shock accounts for only 1.6 percent and 6.3 percent of the forecast error variances of relative output at the one- and five-year horizons, respectively. Similarly, less than 11 percent of the one-year forecast error variances of any macro variables in the VAR are attributable to dominant real exchange rate shocks. These results are consistent with the negligible correlations between recovered dominant real exchange rate shocks and recovered dominant shocks of other variables, documented in the Online Appendix. The connection is stronger at the longer horizons for all variables, and the strongest connection is with the net-exports-to-output ratio. In a median G7 country, for example, dominant shocks to the real exchange rate are responsible for 10.9 percent of the forecast error variances of the net-exports-to-output ratio at the five-year horizon, compared with 1.7 percent at the one-year horizon. These dominant shocks contribute to nearly 8 percent of the five-year forecast error variances of the relative nominal interest rate and the relative inflation rate in a median country, substantially larger than that at the one-year horizon. Finally, dominant real exchange rate shocks explain 41 percent of the UIP wedge in the United States, and 35.4 percent of the UIP wedge at median across G7 countries at a five-year horizon. These results suggest a tight link between the real exchange rate shock and the UIP wedge.

Finally, while the overall pattern that emerges in the median country is the disconnect between the real exchange rate dominant shock and key macro and trade variables, the degree to which dominant shocks to the real exchange rate are connected with macro variables has some variation across the G7 countries. For example, 31.4 percent of the U.S. and 25.3 percent of German relative consumption variations at the five-year horizon are attributed to dominant real exchange rate shocks, a much larger fraction 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 variances of U.K. relative hours worked at the five-year horizon are driven by dominant shocks to the real exchange rate. Even so, the overall picture that emerges 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.

4.2 Dominant Shocks to Real Exchange Rate and MBC Shocks

Since our approach uncovers dominant shocks to each variable by separately targeting one variable in the VAR at a time, it is possible that dominant shocks are correlated with each other. To examine whether dominant real exchange rate shocks may be correlated with MBC shocks, we identify a dominant real exchange rate shock that is constrained to be orthogonal to MBC shocks using the identification scheme in Cascaldi-Garcia and Galvao (2021). As plotted in Figure 3, the orthogonalized dominant real exchange rate shocks and the unconstrained dominant real exchange rate shocks have almost identical effects on other variables in the United States. This result also holds in the other six countries. In other words, dominant shocks to the real exchange rate in each country are orthogonal to MBC shocks. We further check that dominant shocks to the real exchange rate are almost identical to dominant shocks to the real exchange rate constrained to be orthogonal to dominant shocks 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 documented earlier, 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), that fits the data for the real exchange rate and resolves several puzzles in the international macro literature. We first present the overview of the model. We then simulate data from calibrated versions of the model, estimate both MBC and dominant real exchange rate shocks using the same method as in the previous sections, and compare them with our empirical facts.

5.1 Model Overview

We incorporate key ingredients in Itskhoki and Mukhin (2021) into our two-country model with incomplete financial markets, where only foreign-currency-denominated non-contingent bonds are traded in the international financial market. In our model, we introduce a shock to the UIP condition, called *financial shocks*, as well as a standard portfolio adjustment cost to our model, which give rise to deviations in the UIP condition. While the financial shock in our model is simply an exogenous wedge on the UIP condition, Itskhoki and Mukhin (2021) provide a micro-foundation for such a shock—using 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 a risk premium on their carry trade activity in a segmented market. The financial shock, combined with conventional ingredients in the model—home bias in consumption, pricing to markets, and weak substitutability between home and foreign goods that mutes the pass-through of exchange rate movements into macro variables—generates several desirable unconditional business cycle moments related to the real exchange rate, such as excess volatility of the real exchange rate relative to macro aggregates and the Backus-Smith puzzle.

The rest of the model is standard. 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 subject to aggregate TFP shocks combine labor, capital, and intermediate inputs to produce output. Firms are able to price to market, and there is incomplete pass-through. Firms in each country face staggered prices, and households face staggered 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 the U.S. data: (1) the relative standard deviations of the growth rate of investment and output to calibrate the investment adjustment cost and (2) the trade-to-GDP ratio to calibrate the imports-to-expenditure ratio. The sizes of the three shocks are set as follows. We target the relative standard deviations of the growth rate of the real exchange rate and output to calibrate the size of financial shocks. The sizes of TFP and monetary shocks are set such that both explain the same fraction of the standard deviation of output. The correlations of TFP and monetary shocks between countries are set by targeting the correlation of output between the United States and the ROW. Note that we compute the correlations of TFP and monetary shocks across countries in the full model based on the model with a single shock.[7] The calibrated model matches the unconditional second moments of U.S. data reasonably well, similar to the performance of Itskhoki and Mukhin (2021). In the calibrated model with three shocks, TFP, monetary and financial shocks account for 49 percent, 49.7 percent, and 1.3 percent of the (unconditional) variance of the output growth rate, respectively. The variance contributions to the growth rate of the real exchange rate are 1.3 percent for TFP shocks, 5.1 percent for monetary shocks, and 93.6 percent for financial shocks. In the Online Appendix, we present details of the model ingredients as well as the calibrated parameters.

[7]This computation implies that our model with all three shocks may underpredict the correlations of output across countries because of financial shocks. In our model with three shocks, the model-implied cross-country output correlation is slightly lower than in the data.

5.2 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 TFP shocks as the driving force and apply our estimation methods.[8] 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, the net-exports-to-output ratio, and the real exchange rate. This result is at odds with our documented MBC shocks which account for less than 5 percent of the real exchange rate variation.

More generally, our analysis suggests 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 in relation to relative output and other quantity variables, the identified dominant output or consumption shocks would also drive all the fluctuations of the real exchange rate, inconsistent with the variance decomposition in our empirics. Additionally, in this model, both TFP shocks and monetary policy shocks generate negligible deviations from the UIP condition, so this model with these shocks cannot be consistent with the documented effects of dominant shocks to the real exchange rate. Overall, the model with monetary shocks or TFP shocks only—or with both TFP and monetary shocks—does not work. Therefore, the model needs separate shocks to explain real macro variables and the real exchange

[8] The size of the measurement errors is 1 percent of the standard deviation of each variable. We do 1,000 simulations with 100 burn-ins. The data length is 172, which is the same as that of our actual data. Also, in the estimation of simulated data, neither the source of the single shock (TFP, monetary, or financial shocks) 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.

rate.

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

We now examine whether a leading quantitative international business cycle model can be consistent with our empirical results. To that end, we consider the model with all three shocks: TFP, monetary, and financial shocks. Our analysis suggests that this model has the potential to generate the empirical patterns observed for both MBC shocks and dominant real exchange rate shocks. However, the model misses the initial movements of the UIP wedge, as well as the muted response of net exports to dominant real exchange rate shocks.

We first simulate the full model with measurement errors and apply our approach to find the dominant drivers of relative output and of the real exchange rate. As shown in the first panel of Table 4, the model's MBC shock accounts for just about 20 percent of the total variance of the real exchange rate at all horizons. The pattern that emerges from this figure is broadly consistent with the result that MBC shocks account for little of the fluctuations in the real exchange rate.[9]

We next compare the model's predictions about dominant drivers of the real exchange rate with the empirical counterparts. The second panel of Table 4, labeled "Dominant Real Exchange Rate Shock," displays the forecast error variance decomposition for the 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

[9]We do not take a stand on what constitute MBC shocks. While Angeletos, Collard, and Dellas (2020) 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 MBC shocks and the real exchange rate.

shocks using simulated data is similar to that explained by financial shocks in the model, as shown in the third panel of the table. This outcome suggests that our empirical approach could be used to 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 the net-exports-to-output ratio, whereas the empirical driver accounts for only 17 percent of the forecast error variances of the net-exports-to-output ratio in the United States and 11 percent in the median country at the five-year horizon. This result is driven by the fact that, just as in Itskhoki and Mukhin (2021), financial shocks in our model, which play a major role in driving the real exchange rate, account for most of the net export variations, as displayed in the second and third panels of Table 4. 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 4 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 impulse responses similar 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.

There are two main differences, however, between the dynamics of the dominant real exchange rate shock in the model and the dynamics of that 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 are governed by financial shocks, which have a first-order autoregressive process. As the shock is persistent, with a 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 the expected growth rate of the real exchange rate conditional on dominant real exchange rate shocks, exhibits different dynamics in the simulated data from those in the empirical counterparts. While the UIP wedge conditional on dominant real exchange rate shocks is positive on impact and 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.

5.4 Discussion

We find that quantitative models such as Itskhoki and Mukhin (2021), in which a dominant driver of the real exchange rate is separated from drivers of other standard business cycle variables, are consistent with several cuts of the data through our empirical approach. These analyses suggest that the dominant driver of the real exchange rate resembles a financial shock in the international bond market in the model. At the same time, the model lacks a mechanism that generates the delayed peak response of the real exchange rate and implies a tight link between the dominant real exchange rate shock and net exports that is inconsistent with the empirical counterpart. The model's monotonic 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, the spurious 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), who document the counterfactually strong unconditional correlation between the real exchange rate and net exports in their model. While unconditional correlation in the data does not tell us which of the three shock propagation mechanisms is problematic, our finding implies that the model needs features that mute the net exports response *conditional* on a financial shock. This finding 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 might be necessary, such as a model in which the change in net foreign assets is also significantly driven by valuation effects due to movements in exchange rates or asset returns.

Finally, we note that financial shocks in our model are well micro founded in recent literature. The financial shock modeled as a wedge to the UIP condition is consistent with the UIP deviations derived by the risk aversion of financial intermediaries, as in Gabaix and Maggiori (2015), Fang and Liu (2021), and Itskhoki and Mukhin (2021).

6 Conclusion

We document the relationship between the real exchange rate and several macroeconomic variables in G7 advanced countries between 1974 and 2016. We find that MBC shocks 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 the dominant driver of the real exchange rate: (i) it is orthogonal to MBC shocks; (ii) it generates large, persistent, and delayed responses of the real exchange rate; (iii) it generates a meaningful deviation from the UIP condition; and (iv) it generates a small response of the net-exports-to-output ratio. Our paper also documents the weak relationships between the real exchange rate and dominant shocks to several other variables, such as real exports and imports, the relative corporate bond spread, and confidence-related variables.

Our findings have strong implications for open economy macro models. In particular, they reject the possibility that shocks with similar propagation mechanisms can explain both key macro variables and real exchange rate behaviors. It is more likely that models need separate shocks driving business cycles and the real exchange rate. These shocks work in different ways to make the overall dynamic correlations weak, and they possibly create cross-country differences depending on the importance of different shocks. Furthermore, our analysis suggests that financial shocks as in Itskhoki and Mukhin (2021) can be broadly consistent with our empirical regularities, but the model itself still falls short in 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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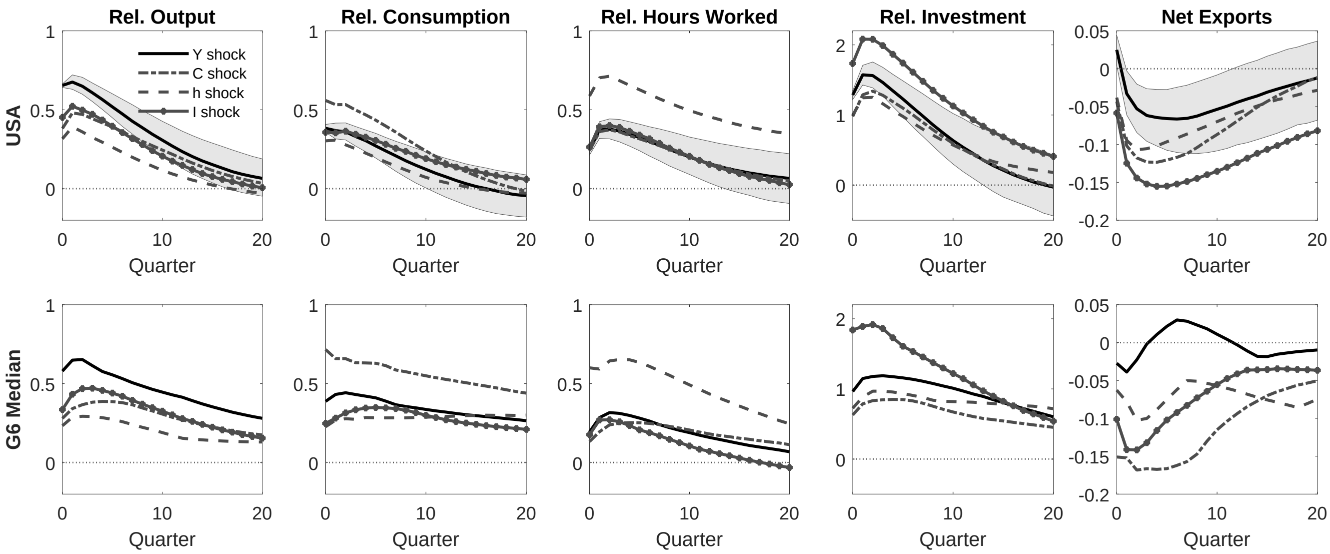
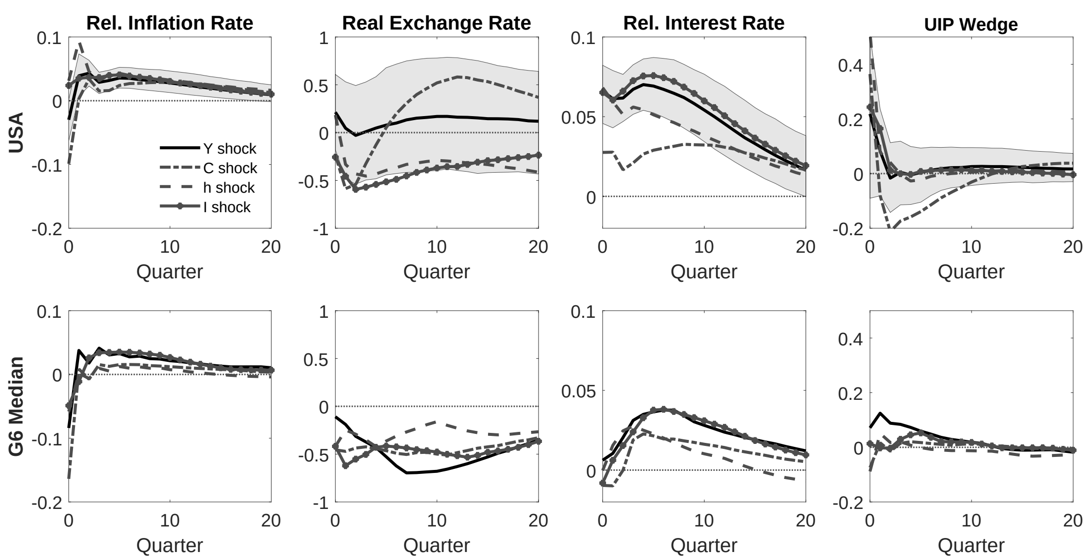
Figures and Tables

Figure 1: Impulse responses to dominant business cycle shocks



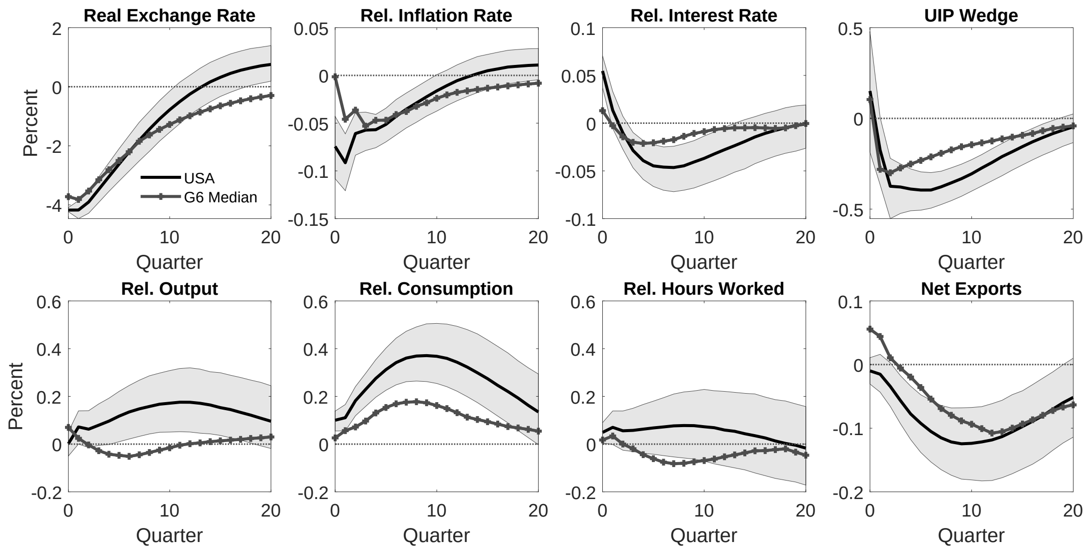
(a) Quantity variables in the United States (first row) and the median G6 countries (second row)



(b) Price variables in the United States (first row) and the median G6 countries (second row)

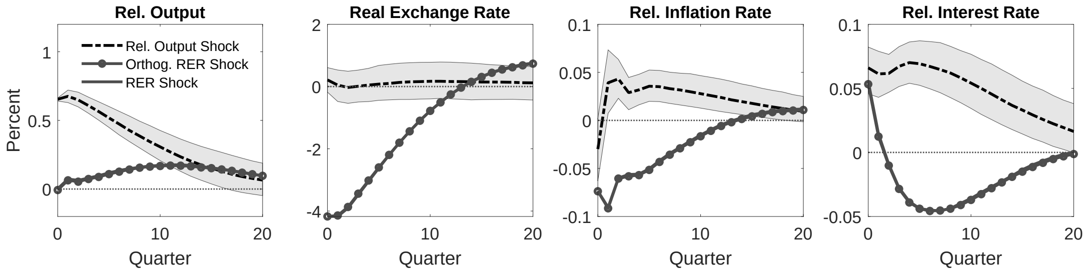
Note: A decrease in the real exchange rate is an appreciation. Posterior median impulse responses to dominant business cycle shocks of relative output (Y), relative consumption (C), relative hours worked (h), and relative investment (I) in both the United States and the median G6 countries are plotted. The shaded area in the U.S. plot indicates the 16 to 84 percent credible bound of the variable response to a dominant relative output shock.

Figure 2: Impulse responses to dominant real exchange rate shocks



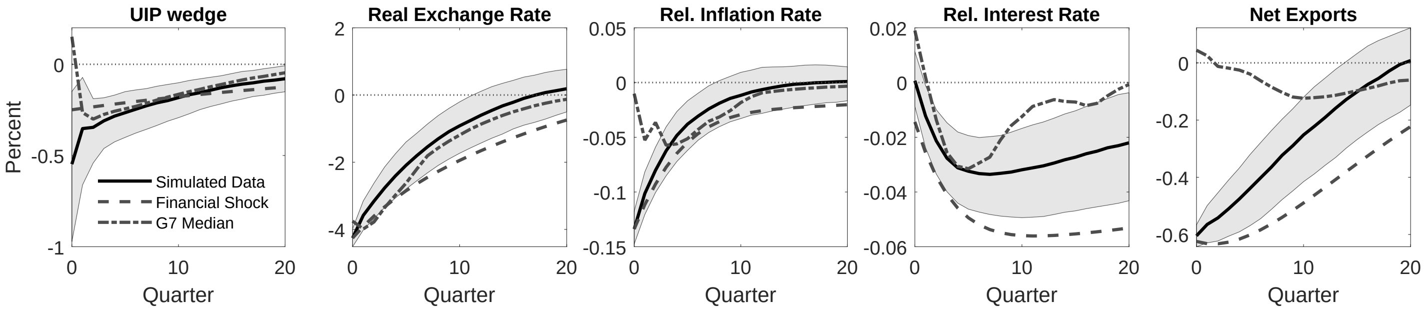
Note: A decrease in the real exchange rate is an appreciation. The shaded area indicates the 16 to 84 percent credible bound of the variable response to a dominant real exchange rate shock in the United States.

Figure 3: Impulse responses to orthogonalized dominant real exchange rate shocks using U.S. data



Note: A decrease in the real exchange rate is an appreciation. The shaded area indicates the 16 to 84 percent credible bound of the variable response to a dominant relative output shock. The orthogonalized real exchange rate shock indicates a conditional dominant real exchange rate shock that is orthogonal to the dominant relative output shock.

Figure 4: Impulse response functions to dominant real exchange rate shocks in model and empirics



Note: The label "Simulated Data" indicates the posterior median impulse response to a dominant real exchange rate shock using simulated data from the model with TFP, monetary, and financial shocks, and the shaded area shows its 16 to 84 percent credible bound. The label "Financial Shock" indicates the model's impulse response to a financial shock. The label "G7 Median" indicates the median of the posterior median empirical impulse responses to each dominant real exchange rate shock in G7 countries. Both the shock from the VAR using the simulated data and the model's financial shock are normalized to match the G7 median real exchange rate response on impact.

Table 1: Forecast error variance due to dominant output and real exchange rate shocks

Horizon	Country	Output	Consumption	Investment	Hours Worked	NXY	RER	Inflation Rate	Interest Rate	UIP Wedge
Dominant Relative Output Shock										
h=4	**G7 Median**	**94.9**	**42.2**	**48.1**	**22.1**	**2.1**	**1.2**	**3.2**	**6.1**	**7.3**
	USA	95.1	42.2	53.4	25.5	2.4	0.9	2.7	16.7	5.0
	CAN	92.9	24.7	27.1	19.3	1.9	1.0	6.0	6.1	10.9
	JPN	96.2	54.0	36.8	15.6	0.5	0.9	8.0	1.4	7.3
	GBR	90.9	22.0	15.5	15.8	24.2	1.2	11.0	9.0	9.1
	DEU	94.9	13.5	53.7	25.8	1.2	1.8	2.9	8.4	8.4
	FRA	96.6	51.8	55.4	26.5	2.1	1.5	2.2	1.9	7.1
	ITA	91.8	54.4	48.1	22.1	15.9	1.8	3.2	2.3	4.9
h=20	**G7 Median**	**68.6**	**18.4**	**28.9**	**13.5**	**5.5**	**4.2**	**6.3**	**14.8**	**7.9**
	USA	68.6	18.4	28.3	15.6	5.5	2.8	6.3	27.3	5.3
	CAN	56.6	17.6	26.1	13.5	3.9	18.7	7.7	17.2	12.4
	JPN	73.8	44.0	28.9	9.9	5.2	12.2	8.7	4.0	7.6
	GBR	68.7	10.8	20.2	12.8	29.5	4.0	11.6	16.6	9.4
	DEU	63.0	6.3	38.4	11.4	2.2	3.7	5.5	14.8	8.2
	FRA	77.6	59.8	44.5	40.1	5.9	7.3	3.4	11.8	7.9
	ITA	58.3	53.3	48.9	26.5	20.7	4.2	4.1	8.5	5.5
Dominant Real Exchange Rate Shock										
h=4	**G7 Median**	**1.6**	**1.4**	**1.4**	**4.1**	**1.7**	**95.0**	**4.6**	**2.9**	**20.5**
	USA	1.3	9.0	2.1	1.0	1.6	95.3	8.8	4.9	20.5
	CAN	1.6	0.7	4.2	2.7	3.3	93.3	9.1	3.0	26.5
	JPN	0.9	1.1	0.8	5.0	1.7	93.2	3.6	2.9	33.2
	GBR	1.7	4.4	0.7	4.3	7.8	95.0	1.7	7.1	20.3
	DEU	3.4	8.7	5.2	4.1	3.1	94.8	2.1	0.8	17.2
	FRA	0.7	1.4	1.4	2.4	0.6	96.3	4.6	1.5	23.5
	ITA	1.9	1.0	1.4	4.7	1.5	97.3	10.0	2.3	14.2
h=20	**G7 Median**	**6.3**	**5.1**	**5.6**	**4.3**	**10.9**	**70.3**	**7.9**	**7.6**	**35.4**
	USA	9.0	31.4	6.1	3.1	16.6	66.3	11.8	11.4	41.0
	CAN	6.3	2.5	5.7	12.7	17.7	56.4	14.1	10.6	37.8
	JPN	2.7	5.1	2.5	7.7	20.1	55.7	6.9	14.9	47.9
	GBR	4.1	15.3	3.4	32.7	10.6	79.2	7.9	7.6	23.3
	DEU	12.4	25.3	21.3	4.1	10.9	70.3	3.6	2.5	23.9
	FRA	2.3	3.1	2.8	3.9	3.9	71.2	5.6	3.0	35.4
	ITA	6.4	4.6	5.6	4.3	4.1	84.9	20.5	5.1	24.2

Note: The units are percent of the total forecast error variance of the column variable at the horizon. For each country, the median from 1,000 draws is reported.

Table 2: Correlations of different dominant shocks extracted in the baseline

MBC shock	Output	Consumption	Hours Worked	Investment
Output	1.00	-	-	-
Consumption	0.68	1.00	-	-
Hours Worked	0.51	0.40	1.00	-
Investment	0.72	0.52	0.50	1.00

Note: For each country, we compute the correlations of the median of recovered shocks from 1,000 draws in the baseline VAR specification. To get these numbers, we take the median of the correlations across G7 countries.

Table 3: The forecast error variance of the real exchange rate attributed to each dominant shock

Horizon	Country	Output Shock	Consumption Shock	Investment Shock	Hours Worked Shock	NXY Shock	Inflation Rate Shock	Interest Rate Shock
h=4	**G7 Median**	**1.2**	**2.1**	**2.2**	**3.0**	**3.4**	**2.7**	**2.0**
	USA	0.9	2.1	1.8	1.3	1.2	5.5	6.5
	CAN	1.0	2.9	16.7	0.9	1.2	2.8	1.3
	JPN	0.9	1.0	0.7	7.4	3.7	2.7	2.3
	GBR	1.2	2.2	0.8	2.2	8.8	1.7	7.5
	DEU	1.8	4.9	2.2	5.7	8.8	0.9	0.9
	FRA	1.5	2.1	3.5	3.0	0.6	5.1	0.9
	ITA	1.8	1.2	3.5	6.1	3.4	2.1	2.0
h=20	**G7 Median**	**4.2**	**5.0**	**4.7**	**4.2**	**6.7**	**4.5**	**10.0**
	USA	2.8	5.5	4.7	3.3	5.7	5.0	12.4
	CAN	18.7	8.1	36	19.3	3.1	5.0	4.1
	JPN	12.2	4.0	4.7	6.2	14.8	4.5	10.5
	GBR	4.0	5.1	2.7	3.4	7.1	2.0	16.4
	DEU	3.7	5.0	3.5	4.2	17.2	1.5	10.0
	FRA	7.3	4.8	13.0	3.4	2.7	6.1	2.0
	ITA	4.2	2.6	3.7	8.5	6.7	3.3	4.6

Note: Each column reports the contribution (in percent) of the dominant shock of the listed variable to the real exchange rate variance. For each country, the median from 1,000 draws is reported.

Table 4: Model-based forecast error variance

Horizon	Percentile	Output	Consumption	Investment	Hours Worked	NXY	RER	Inflation Rate	Interest Rate
Dominant Relative Output Shock									
h=4	**Median**	**95.8**	**35.3**	**24.2**	**38.7**	**9.3**	**19.3**	**6.8**	**33.4**
	16	90.1	17.9	10.7	20.5	2.1	5.5	1.5	19.6
	84	98.5	55.4	38.9	59.0	25.8	37.9	18.6	49.9
h=20	**Median**	**76.1**	**28.0**	**29.5**	**24.8**	**13.3**	**21.2**	**10.7**	**21.6**
	16	50.5	11.9	14.4	10.5	4.1	7.9	3.7	10.0
	84	92.2	54.3	48.7	50.8	31.3	41.7	24.7	42.7
Dominant Real Exchange Rate Shock									
h=4	**Median**	**9.1**	**24.8**	**12.9**	**18.4**	**95.2**	**97.3**	**65.3**	**15.6**
	16	1.9	11.3	3.7	6.3	90.7	94.4	53.6	5.8
	84	21.7	39.9	26.6	32.0	97.7	98.9	74.8	28.1
h=20	**Median**	**14.2**	**30.9**	**21.4**	**36.1**	**82.4**	**86.2**	**61.9**	**38.5**
	16	5.2	11.7	7.5	14.1	65.7	72.0	47.4	15.8
	84	30.8	53.3	41.4	59.6	91.5	93.7	72.9	60.2
Model Financial Shock									
h=4		0.6	34.9	3.7	29.5	98.6	91.9	57.4	22.5
h=20		2.6	41.0	7.7	53.7	99.1	89.8	60.3	59.0

Note: The table shows the median fraction (in percent) of the forecast error variance explained by dominant relative output and real exchange rate shocks using simulated data from the model with TFP, monetary, and financial shocks, along with its 16 to 84 percent credible bound. In the third panel, we report the true contribution of financial shocks to these variables in the model.