# Explaining the Great Moderation Exchange Rate Volatility Puzzle

Vania Stavrakeva
London Business School

Jenny Tang
Federal Reserve Bank of Boston

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**Abstract**

In this paper we study how the volatility of both *realized* and *expected* macroeconomic variables relate to the variation in exchange rate volatility through the prism of the Great Moderation hypothesis. We find significant heterogeneity in exchange rate trend volatility across currency pairs, despite decreases in the volatility of expected future interest rate differentials and of realized yields themselves. We argue that time-variation in the relationship between macroeconomic variables and exchange rates has prevented the Great Moderation in realized yield volatility from transmitting into a decrease in exchange rate volatility. Considering a Campbell-Shiller-type decomposition of exchange rate changes into forward-looking components linked to inflation, policy rate and currency risk premia expectations, we find that the Great Moderation in volatility of expected yield differentials cannot explain the patterns in exchange rate volatility we observe. The main drivers of these patterns were trends in the volatility of the currency risk premium component and in the covariance between the components capturing the strength of the Fama puzzle and the expected responsiveness of monetary policy to inflation.

Emails: vstavrakeva@london.edu, jenny.tang@bos.frb.org. The views expressed in this paper are those of the authors and do not necessarily represent the views of the Federal Reserve Bank of Boston or the Federal Reserve System. Nikhil Rao provided invaluable research assistance on this project. We thank Pierre-Olivier Gourinchas, Hélène Rey, Kenneth Rogoff and the participants at various seminars and conferences for their useful comments.

# 1 Introduction

Exchange rate volatility is a key source of macroeconomic and financial uncertainty. It affects production and import/export decisions of firms and even long run productivity growth for countries with lower levels of financial development (see Aghion et al. (2009)). It further impacts the desire of financial firms to intermediate cross country flows given that it affects the perceived riskiness of cross-currency trades (see Kalemli-Ozcan, Papaioannou, and Peydro (2010)). The interaction between sizable foreign currency borrowing and increased exchange rate volatility often is the harbinger of financial and balance of payment crises. It comes as no surprise that given its importance for trade/external demand and financial markets' depth and stability, policy makers often directly or indirectly target exchange rate volatility.

Despite its importance, the drivers of exchange rate volatility are not well understood. Notable exceptions in the empirical literature are the papers by Rogoff (2007), Ilzetzki, Reinhart, and Rogoff (2019) and Ilzetzki, Reinhart, and Rogoff (2020) who have studied the volatility of a number of currency crosses in the context of the volatility of macroeconomic and financial variables.

We draw inspiration from these studies and in this paper, we attempt to shed further light on what could explain the time varying volatility of the 7 most liquid currency crosses against the USD (AUD, CAD, CHF, DEM/EUR, GBP, JPY, and NZD), in the context of the time trends in the volatility of *realized* and *expected* macroeconomic variables.

We have a little over five decades of data and the sample covers a number of periods of heightened macroeconomic volatility: the oil shocks in the 1980s, the global financial and European sovereign debt crises, COVID and the post-COVID high inflation period.

We first document the trends in exchange rate volatility and find significant cross currency heterogeneity. Consistent with the findings in Ilzetzki, Reinhart, and Rogoff (2020), we confirm that there is a persistent downward trend in exchange rate volatility for the CHF, DEM/EUR, and JPY against the USD, which has continued over COVID and the post COVID hugh inflation period. However, there appears to be upward trends for the commodity exporters, AUD, CAD and NZD with the trend only appearing in the most recent part of the sample for the NZD.[1]

Next, we revisit the Great Moderation hypothesis by extracting common factors from the time-varying volatility of a number of key macroeconomic variables in both country $i$ and

[1] The GBP does not fit the pattern of either one of these groups and appears to have a regime shift with a sharp drop in volatility in the early 2000s but slight upward trends in volatility both before and after this structural break.

the US for each currency pair—namely, inflation, the quarterly change in 10-year yields, the quarterly growth rate of industrial production and change of the unemployment rate. Three factors capture almost all of the variation of the time-varying volatility of these 8 series. Using a rotation of the factors that gives each one a clear interpretation results in factors that have roughly equal importance in terms of explaining the overall variation in volatility. They include a Great Moderation factor which captures declines in the volatility of mainly yields and to a lesser degree non-US inflation, a GFC factor which captures the increased volatility during the GFC primarily of US inflation, and a COVID factor which captures the increased volatility of unemployment and industrial production over the COVID period.[2]

We then ask to what extent these same macroeconomic variables can explain the time-varying exchange rate volatility. We do so by first estimating time-varying relationships between exchange rate changes and these macroeconomic variables. We find that the average over time adjusted $R^2$ across currency pairs from these regressions ranges from 23 to 37 percent and regularly exceeds 50 percent. We then construct the fitted values based on these time varying relationships which capture both the time variation in the estimated coefficients and the time variation in the macroeconomic series themselves. We show that the volatility of these fitted values indeed co-moves closely with the exchange rate volatility, explaining a large fraction of the overall exchange rate volatility and the volatility trends. To isolate the impact of the volatility of the macroeconomic variables alone on exchange rate volatility, we construct a second fitted value measure that fixes the estimated coefficients at their average over time and construct its volatility. Interestingly enough, the volatility of this measure is decreasing over time and closely tracks the Great Moderation volatility factor, albeit explaining a very small fraction of overall exchange rate volatility. This result suggest that the time-varying relationship between exchange rates and macroeconomic variables and how it interacts with the level of the macroeconomic variables is key to how macroeconomic volatility propagates to exchange rate volatility.

After exploring the link between the volatility of *realized* macroeconomic variables and exchange rate volatility, we turn to the link between volatility of *expected* macroeconomic variables and exchange rates. Exchange rates like any other asset price are a forward looking

[2]The Great Moderation literature has presented a number of explanations regarding the potential drivers of lower real growth or real rate volatility ranging from better policies and better inventory management to "good luck" (See Benati and Surico (2009), Summers (2005) and Morley and Singh (2016) for a more recent review of the Great Moderation literature). Notice that these papers were focusing on a period prior to the GFC. As we document in this paper, the volatility patterns have changed since the GFC and the most robust result is around a Great Moderation of realized yield volatility. Our paper is also related to the literature studying the Mussa puzzle, which argues that exchange rate volatility is disconnected from macroeconomic volatility in the post Bretton Woods period (for a recent paper on the topic see Itskhoki and Mukhin (2022)).

variable and, as such, are a function of revisions in expectations over macroeconomic variables and risk premia. The dynamics of the volatility of expected macroeconomic variables can potentially differ from those of realized macroeconomic variables and can shed further light on the link between exchange rate and macroeconomic volatility.

We decompose the volatility of exchange rates using a novel econometric procedure to estimate a well-known exchange rate change decomposition. Using a simple accounting identity as a starting point, we provide a breakdown of nominal exchange rate changes into a lagged interest rate differential, a lagged currency expected excess return, and changes in expectations over the paths of relative short-term nominal interest rates, relative inflation rates and excess returns.[3] To estimate the exchange rate change components, we estimate a VAR, augmented with additional constraints that ensure that the VAR-based expectations match consensus forecasts from surveys of professional forecasters well.[4,5]

Calculating the various exchange rate components by generating expectations that closely match the expectations of professional forecasts is an improvement over the existing unconstrained VAR approach for two reasons. First, it helps alleviate a well-known downward-bias problem when estimating autoregressive VAR coefficients due to small samples, which leads to unrealistically flat medium- and long-run forecasts—a major issue when computing exchange rate components that are *undiscounted* sums of revisions in expectations over future outcomes at all horizons. Second, there is recent literature that argues that professional forecasters' or investors' expectations, as revealed in surveys, correlate strongly with investors' positions in a manner consistent with theory, thus, implying that these survey forecast data are a good proxy for the beliefs of the marginal trader.[6]

Once we calculate the various exchange rate change components, we first perform a variance covariance decomposition of the exchange rate change at a quarterly frequency. We

[3]Throughout the paper, we use "expected excess returns" and "currency risk premia" interchangeably though we never make any assumptions that would limit the interpretation of expected excess returns to being purely risk premia. Unless otherwise specified, the short-term nominal interest rates in our analysis will be rates on 3-month government debt, which we will often refer to as policy rates.

[4]The estimation technique that we use has been previously applied to decompose government bond yields but to our knowledge we are the first to use it to decompose exchange rates (see Kim and Wright (2005), Wright (2011), Kim and Orphanides (2012), Piazzesi, Salomao, and Schneider (2015), and Crump, Eusepi, and Moench (2018)).

[5]This paper is closely related to studies that decompose the exchange rate using a similar accounting identity (see Froot and Ramadorai (2005), Engel and West (2005; 2006), Engel, Mark, and West (2008), Engel and West (2010), Evans (2012), and Engel (2014; 2016)). Some of these papers also perform a variance covariance decomposition but differ in other respects. Namely, they usually focus on decomposing the real exchange rate level, do not decompose *trends* in exchange rate volatility over time and, most importantly, do not use survey data in the estimation of the forward looking components.

[6]See Stavrakeva and Tang (2022) for exchange rate expectations, De Marco, Macchiavelli, and Valchev (2022) for interest rate expectations, Aguiar, Gopinath, and Kalemli-Ozcan (2021) for investment growth expectations and Greenwood and Shleifer (2014) and Giglio et al. (2020) for equity returns expectations.

find that the interest rate and inflation components are approximately .27 and .17 times as volatile as the nominal exchange rate change itself. The *subjective* currency risk premium component explains the majority of exchange rate volatility.

Last but not least, we also find that two of the covariance terms are very important drivers of the overall exchange rate volatility. We find that over the whole sample (1990-2023), higher expected future interest rates in country $i$ relative to the US are associated with higher expected future excess returns from being long the 3-month government bond of country $i$ and short the US 3-month government bond. This covariance term has contributed to lower exchange rate volatility and echoes the well-known Fama puzzle (see Fama (1984)); namely that a higher realized excess return from being long currency $i$ and short USD is associated with a higher interest rate differential in country $i$ relative to the US. Another way to interpret this result is that agents expect to make positive profits from the carry trade strategy. The stronger the Fama puzzle is, the lower the exchange rate volatility, where the sample average contribution to the exchange rate variance of this component was -24 percent.[7]

A second covariance term that has, on average, contributed to lower exchange rate change volatility implies that higher expected future interest rates in country $i$ relative to the US are associated with higher expected future inflation in country $i$ than in the US, which is consistent with short-term rates being predominantly driven by monetary policy that raises rates when inflation is high. The average contribution of this covariance term to exchange rate volatility was -18 percent.

Next we turn to the trend volatility results of the sub-components, which sum up to the trend volatility of realized exchange rate changes. We see that the Great Moderation decrease in the volatility of realized yields does not translate into lower volatility of the revisions in expectations over the policy rate path for five out of the eight countries. This could be due to either the role of forward guidance or increased sensitive of market expectations to news. Having said that, the volatility of the revisions on expectations over the *relative* policy rates has decreased for five of the seven currency crosses due to the higher covariance over time between the expected policy rate paths in country $i$ and the US. In other, words it appears global monetary policy has become more correlated with US monetary policy and market expectations reflect that. We further find that the volatility of the component which captures revisions in expectations over the *relative* inflation paths actually increased for all

[7]Notice that in contrast to the Fama puzzle and carry trade literature, our results are based on assuming subjective expectations which allow for deviation from FIRE and we consider expectations of the entire future path of subjective currency risk premia and interest rates. For a recent paper that studies the drivers of subjective currency risk premia see Kalemli-Ozcan and Varela (2022).

currency crosses but one.

What emerges as the Great Moderation exchange rate volatility puzzle is that the forward-looking inflation and policy rate components from the exchange rate change decomposition do not directly contribute to the decrease in exchange rate volatility of CHF, DEM/EUR, and JPY as they have jointly pushed towards higher exchange rate trend volatility. The opposite is true for the commodity producing currencies AUD, CAD, and NZD where the inflation and policy rate components are contributing towards lower exchange rate volatility trend while the overall exchange rate volatility for these countries actually increased over the sample.

Starting with the three crosses where we see a significant decrease in trend volatility (CHF, DEM/EUR, and JPY), we find that the main source of the decrease in this volatility is the declining variance of the currency risk premium term.[8] Regarding the commodity producers. the main source of higher exchange rate trend volatility is the weakening of the Fama puzzle and of the relationship between expected relative inflation and policy rate paths.[9] The latter implies that monetary policy is expected to respond less to inflation movements over time.

The paper proceeds as follows. Section 2 presents the facts around exchange rate and *realized* macroeconomic volatility. Section 3 outlines a decomposition of exchange rate changes that linked exchange rate volatility to *expected* macroeconomic volatility and relies only on a definition of the expected excess one-period currency return. Section 3.1 describes our survey-augmented VAR methodology, which is used to construct the components of the decomposition outlined in the previous section, and discusses the survey data that we use. Section 4 presents broad overview of the results from our decomposition and the baseline variance-covariance decomposition of the volatility of exchange rate changes. Section 5 discussed the drivers of trends in realized time varying exchange rate change volatility through the prism of the decomposition components. Section 6 concludes.

# 2 Exchange Rate and Macroeconomic Volatility

In this section we construct time-varying exchange rate and macroeconomic volatility measures and document the patterns over the past five decades. Moreover, we attempt to understand the extent to which changes in the volatility of *realized* macroeconomic variables

[8]Additionally, for the CHF and DEM/EUR, the strengthening of the Fama puzzle also contributed towards lower volatility and so did the forward-looking relative yield component for CHF, but this last effect was minor.

[9]Regarding the Fama puzzle result, Baillie and Bollerslev (2000), Burnside (2019), Engel et al. (2022) find similar results using realized exchange rate changes and interest rate differential which is more in line with the original puzzle.

transmits to exchange rate volatility and the key channels involved in this relationship.

First, we present plots of the quarterly exchange rate change volatility. We use monthly data from Jan 1973 through July 2023, a little over five decades of data. $s_t$ is the log of the nominal exchange rate defined as units of currency $i$ per USD and the one-quarter exchange rate change is constructed as $s_t - s_{t-3}$. The currencies we study are CHF, JPY, GBP, DEM/EUR, AUD, CAD and NZD against the USD. Figure 1 presents rolling variances of these changes using a 60-month rolling window along with time trends starting in 1973 and 1998 (over the last 50 and 25 years, respectively).

If one considers the whole sample, there is a large degree of heterogeneity across currency pairs. Exchange rate volatility has been trending downward for the large financial centers: DEM/EUR, CHF and JPY. For the GBP, there appears to be a regime shift where exchange rate volatility fell abruptly in the mid- to late-1990s followed by a slight upward trend since then. The opposite appears to be true for the largest commodity producers. Volatility of the AUD and CAD against the USD appear to have increased over time while there is not much of a trend in the volatility of NZD.

The lack of consistent patterns in exchange rate volatility across currencies might appear puzzling, granted that it has been hypothesized that macroeconomic volatility has decreased over time, a fact that we refer to as the Great Moderation puzzle. Recent sizable macroeconomic shocks due to the GFC and COVID have cast doubt on whether the Great Moderation period has come to an end. This could potentially explain the heterogeneous trends we observe in exchange rate volatility.

To address this hypothesis, we re-examine whether we indeed see a Great Moderation of macroeconomic volatility in the country pairs that we consider. For each country pair, we perform a principal component analysis of the 60-month rolling variances of key macroeconomic variables in each country and extract the three most important components. The set of variables we consider are included in the matrix

$$\mathbf{X}_t = [\pi^i_{t,t-3}, \pi^{us}_{t,t-3}, \Delta ur^i_{t,t-3}, \Delta ur^{us}_{t,t-3}, \Delta y^{10y,i}_{t,t-3}, \Delta y^{10y,us}_{t,t-3}, \Delta ip^i_{t,t-3}, \Delta ip^{us}_{t,t-3}],$$

where $\pi_{t,t-3}$ is the one-quarter inflation rate, $\Delta ur_{t,t-3}$ is the quarterly change in the unemployment rate, $\Delta y^{10y}_{t,t-3}$ is the quarterly change of the 10-year government debt yield and $\Delta ip_{t,t-3}$ is the quarterly change of the log industrial production index.

Figure 2 plots the rotated factors where we use a varimax rotation that produces factors such that each variable primarily loads on a single factor—a method that produces more easily interpretable factors. They jointly explain the vast majority of the variation of the macroeconomic series: between 79 and 95 percent of the overall variation of the rolling volatilities of these macroeconomic variables, where the three factors are about equally important in terms of explanatory power. One of the three factors is always downward trending, so we label it as the Great Moderation factor. It explains between 22 and 38 percent of the overall variation. The variables that load the most on this factor are the quarterly changes in long-term yields for both country $i$ and the US and, to a lesser degree, inflation in country $i$. The second factor captures the heightened volatility of macroeconomic variables during the GFC, which is why we label it the GFC factor. It explains between 15 and 33 percent of the overall variation. The variable that loads the most on this factor is US inflation. Finally, the last macroeconomic variance factor is elevated only during COVID and we label this factor the COVID factor. It explains between 25 and 47 percent of the overall variation. The variables that load the most on this factor are the unemployment rate and industrial production of the US and for most countries, also the same variables for country $i$.

Next we examine which one of these macroeconomic volatility factors can explain the link between macroeconomic volatility and exchange rate volatility, if any. We do so by performing a two-stage exchange rate change volatility decomposition, as a function of the volatility of realized macroeconomic variables accounting for a time-varying relationship between macroeconomic variables and exchange rates.

We take seriously the fact that over 50 years, it is inevitable that the relationship between exchange rates and macroeconomic variables has changed over time. In light of this fact, we first estimate a time-varying relationship between the quarterly log exchange rate change and the macroeconomic variables in $\mathbf{X}_t$ using rolling regressions with a window of 60 months. Then, we can express the exchange rate change as follows:

$$\Delta s_{t,t-3} = \beta_t \mathbf{X}_t + \varepsilon_t, \tag{1}$$

where $\beta_t$ is a row vector estimated by regressing $y_t$ on $\mathbf{X}_t$ for $t \in [t, t-59]$. If the relationship between the macroeconomic variables and the exchange rate was stable over time, $\beta_t \mathbf{X}_t$ would remain close to $\beta_{avg} \mathbf{X}_t$, the full-sample average of $\beta_t$, and the link between exchange rate and macroeconomic volatility will be entirely captured by the volatility of the realized macroeconomic variables $\mathbf{X}_t$. Since the principal components we constructed are also a linear combination of the time-varying variance of the realized macroeconomic variable, then the variance of $\beta_t \mathbf{X}_t$ should be captured by a subset of our macroeconomic volatility factors. However, if $\beta_t$ is very volatile, then the time-varying relationship between exchange rates and macroeconomic variables can play a crucial role in explaining the overall volatility of $\beta_t \mathbf{X}_t$. As a result, even if we find that the volatility $\beta_{avg} \mathbf{X}_t$ is trending down, for example, driven by the Great Moderation macroeconomic factor, the volatility of $\beta_t \mathbf{X}_t$ can still trend upward due to time variation in the relationship between exchange rates and macro variables and how it interacts with the level of the macroeconomic variables.

We start by reporting the adjusted $R^2$s in Figure 3 from the first-stage rolling regression of exchange rate changes on the macroeconomic variables[10] One sees large variations in the explanatory power of the macroeconomic variables over time. The average adjusted $R^2$ across countries ranges from 23 to 37 percent, with the explanatory power reaching up to 50 percent. The adjusted $R^2$ is much lower (less than 10 percent) in a full-sample regression, suggesting important time-variation in the relationship between macroeconomic variables and the exchange rate change.

Based on equation (1), we can examine the importance of macroeconomic volatility as an explanatory variable of exchange rate volatility by plotting the variances of $s_{t,t-3}$ and $\beta_t \mathbf{X}_t$ in Figure 4. One can see that indeed a sizable fraction of the exchange rate volatility can be explained by macroeconomic volatility, which is expected given the high adjusted $R^2$s we observed in the rolling regressions. Moreover the trends and overall co-movement of $Var(s_{t,t-3})$ and $Var(\beta_t \mathbf{X}_t)$ are similar with the exception of GBP/USD, implying that macroeconomic volatility has contributed to the exchange rate volatility patterns that we observe.

Next we examine to what extent the volatility of the macroeconomic variables alone, captured by $\beta_{avg} \mathbf{X}_t$, can explain the patterns we observe or time variation in $\beta_t$ is key. Interestingly enough, when we plot $Var(\beta_{avg} \mathbf{X}_t)$ in Figure 5, we find that it is downward sloping and greatly resembles the Great Moderation Volatility factor. However, $Var(\beta_{avg} \mathbf{X}_t)$ itself can explain only a small fraction of $Var(\beta_t \mathbf{X}_t)$. These results imply that the reason why exchange rate volatility has not decreased over time is due to the changing relationship between macroeconomic variables and currencies. If the relationship had stayed stable over time, as measured by the average rolling regression coefficients, then the Great Moderation volatility factor would have been the channel through which macroeconomic volatility would have transmitted to exchange rate volatility and we would have observed a Great Moderation driven decrease in exchange rate volatility.

In this section we considered explaining exchange rate volatility with the volatility of *realized* macroeconomic variables. Exchange rates are forward looking variables and, as such, it's macroeconomic news that should be the key driver of exchange rates, which make traders revise their expectations over macroeconomic variables. The volatility of these revisions in

[10]The results are similar if we use relative macroeconomic variables, thus decreasing the number of regressors by half. However, since we would like to make our results comparable to the macroeconomic volatility factors obtained from a PCA of non-relative variables, we choose to use non-relative variables in the rolling regressions as well.

expectations over macroeconomic variables due to news might have different patterns than the volatility of realized macro variables.

## 3 Forward-Looking Exchange Rate Decomposition

In this section, we examine the connection between exchange rate volatility and the revision in expectations over the path of macroeconomic variables, by performing a well-known exchange rate decomposition in the spirit of the Campbell and Shiller (1988) decomposition. The decomposition can be derived from a definition of the expected excess return from taking a long position in a one-quarter, risk-free bond denominated in USD and a simultaneous short position in a one-quarter, risk-free bond denominated in currency $i$. We define the expected excess return from this trade as:

$$\lambda_t \equiv \check{E}_t \Delta s_{t+1} - \tilde{\imath}_t, \tag{2}$$

where $\tilde{\imath}_t$ represents the relative one-quarter interest rate differential calculated as country $i$ minus the US. We use the tilde in the same way with respect to other variables. $\check{E}_t$ is the expectations operator which can capture any type of beliefs which are consistent with the law of iterated expectations (LIE). Later on, we will discipline the beliefs with survey data on expectations from professional forecasters.

Using this definition, the actual change in the exchange rate can be written as:

$$\Delta s_t = \tilde{\imath}_{t-1} + \lambda_{t-1} + \Delta s_t - \check{E}_{t-1} \Delta s_t. \tag{3}$$

Iterating equation (3) forward, we derive the following expression for the level of the nominal exchange rate:

$$s_t = -\check{E}_t \sum_{k=0}^{\infty} \left[\tilde{\imath}_{t+k} + \lambda_{t+k}\right] + \lim_{K\to\infty} \check{E}_t s_{t+K}. \tag{4}$$

Taking the first-difference of equation (4) and combining the resulting expression with equation (3) implies that the forecast error can be expressed as:

$$\Delta s_t - \check{E}_{t-1}\Delta s_t = -\underbrace{\sum_{k=0}^{\infty} \left(\check{E}_t \tilde{\imath}_{t+k} - \check{E}_{t-1}\tilde{\imath}_{t+k}\right)}_{\varphi_t^{EH,F}} - \underbrace{\sum_{k=0}^{\infty} \left(\check{E}_t \lambda_{t+k} - \check{E}_{t-1}\lambda_{t+k}\right)}_{\varphi_t^{\lambda,F}}$$
$$+ \underbrace{\check{E}_t \lim_{K\to\infty} s_{t+K} - \check{E}_{t-1} \lim_{K\to\infty} s_{t+K}}_{\varphi_t^{LR}}. \tag{5}$$

Equation (5) allows us to express the realized exchange rate change in terms of lagged interest rate differentials and expected excess returns in addition to changes in expectations in: (i) contemporaneous – period $t$ – and future relative short-term rates, $\varphi_t^{EH,F}$, (ii) contemporaneous and future expected excess returns, $\varphi_t^{\lambda,F}$ and (iii) long-run nominal exchange rate levels, $\varphi_t^{LR}$. If the real exchange rate, defined as $\Delta q_{t+k+1} = \Delta s_{t+k+1} - \tilde{\pi}_{t+k+1}$, is trend-stationary, the change in expectations over long-run real exchange rate levels will be zero and $\varphi_t^{LR}$ will reflect changes in expectations over long-run relative price levels or the entire future path of relative inflation starting from the contemporaneous surprise. More precisely,

$$\begin{aligned}\varphi_t^{LR} &= \lim_{K\to\infty} \check{E}_t\left(s_{t+K} - s_{t-1}\right) - \lim_{K\to\infty} \check{E}_{t-1}\left(s_{t+K} - s_{t-1}\right) \\ &= \lim_{K\to\infty} \sum_{k=0}^{K} \left(\check{E}_t\left[\Delta q_{t+k} + \tilde{\pi}_{t+k}\right] - \check{E}_{t-1}\left[\Delta q_{t+k} + \tilde{\pi}_{t+k}\right]\right) \\ &= \sum_{k=0}^{\infty} \left(\check{E}_t \tilde{\pi}_{t+k} - \check{E}_{t-1}\tilde{\pi}_{t+k}\right),\end{aligned}$$

where $\tilde{\pi}$ is the inflation rate in country $i$ minus the inflation rate in the US. Combining equations (2) and (5) implies that:

$$\Delta s_t = \underbrace{\tilde{\imath}_{t-1} - \varphi_t^{EH,F}}_{\varphi_t^{EH}} + \underbrace{\lambda_{t-1} - \varphi_t^{\lambda,F}}_{\varphi_t^{\lambda}} + \varphi_t^{LR}. \tag{6}$$

## 3.1 Estimating the Components

To compute the terms in our decomposition, we need expectations of interest rates, inflation, and exchange rates in all future dates starting in period $t$. To obtain estimates of these expectations, we would ideally like to have a proxy of the beliefs of the marginal trader.

We choose to proxy these beliefs using data on consensus (i.e., average) professional forecasts for exchange rates, 3-month interest rates, and inflation at various horizons obtained from *Blue Chip* and *Consensus Economics*.

There are a number of reasons why using survey data on expectations is desirable.

First, it can alleviate a well known empirical bias; namely, that the estimated autoregressive VAR coefficients tend to be biased downwards due to the use of small samples. This bias leads to flat medium- to long- run forecasts (see Jarocinski and Marcet (2011) and the references within the paper). The bias is particularly problematic when using the VAR-based expectations to calculate the components of the exchange rate change decomposition as they are functions of *undiscounted* infinite sums of expectations. More recent alternative ways used in the literature to alleviate this bias include long run priors (see Giannone, Lenza, and Primiceri (2019)) and informative priors on the observables (see Jarocinski and Marcet (2011)), among others.

Second, survey data on professional forecasts has been shown to correlate with investors' positions in a theory-consistent way. Stavrakeva and Tang (2022) show that *Consensus Economics* exchange rate forecasts are consistent with the positions and, hence, beliefs of the average trader in the over-the-counter (OTC) market, which is the largest foreign exchange rate market. De Marco, Macchiavelli, and Valchev (2022) show that during the European sovereign debt crisis, European banks' sovereign debt positions are higher when the bank expects the sovereign bond to have lower yields (higher prices) in the future, where they proxy banker's beliefs also using *Consensus Economics* survey data. Using EPFR positions data, Aguiar, Gopinath, and Kalemli-Ozcan (2021) show that *Consensus Economics* expectations about future investment growth in a given country correlate positively and significantly with portfolio managers' investment in that country. These papers argue that the *Consensus Economics* survey data is consistent with market participants' positions and, hence, provide support as to why it can be used as a proxy for the marginal trader's beliefs, whose expectations are represented in the exchange rate decomposition in equation (6).

Ideally, we would like to have the survey-based forecasts at every horizon in the future. However, survey data on expectations are not available at every horizon. To overcome this obstacle we use an approach first developed in the term structure literature which decomposes long term government bond yields into term premia and expectations hypothesis components.[11] More specifically, to obtain the forecasts, we estimate a survey-data augmented VAR described in Section A of the Appendix that can be interpreted as a way to interpolate and extrapolate the average professional forecaster's expectations to horizons for which survey-based forecasts are not available. The VAR is fairly rich and contains standard macroeconomic variables used to forecast exchange rates, yields and inflation. What is novel is that we impose additional constraints ensuring that the VAR-based forecasts closely match consensus professional forecasts. More precisely, in addition to minimizing the sum of squared residuals from the VAR, we also minimize the sum of squared differences between the survey data expectations and the VAR-implied expectations. For more details, see Section A of the Appendix.

[11] Kim and Wright (2005), Kim and Orphanides (2012), Piazzesi, Salomao, and Schneider (2015), and Crump, Eusepi, and Moench (2018) use US survey data to estimate US term premia while Wright (2011) uses survey data to estimate term premia for a set of developed countries that largely overlaps with the ones considered in this study.

## 3.2 Fit of the Estimated VAR-Based Expectations

To assess the VAR model's ability to fit the survey forecasts, Table 1 presents the ratios of root-mean-square errors (RMSEs) between our baseline model-implied forecasts and actual survey measures to the same measure for a simple OLS estimation of the VAR without the additional survey-matching equations. These relative RMSEs are presented for 3-month interest rates, nominal exchange rates, and inflation.[12] Of course, the model augmented with survey data should, by definition, produce a better fit of the survey data expectations, indicated by values below 1 in this table. The measures of fit in this table serve to illustrate that the improvement is sometimes quite substantial.

In general, the results in this table show that a standard estimate of the VAR, without including survey data, does a poor job of mimicking the behavior of private sector forecasts, particularly for horizons longer than one quarter or the current year.[13] For horizons of a year or longer, our baseline estimates fit the survey data with RMSEs that are only about a third of the RMSEs of an estimation without survey data or often even smaller.

Figures 6 through 11 plot survey forecasts against model-implied fits for a few select countries both for the VAR with and without survey data, where we refer to the latter specification as the OLS specification. One can clearly see how augmenting the VAR model with survey data improves a number of qualitative aspects of the model-implied forecasts. One notable feature seen in Figure 6 is that including survey forecasts in the estimation results in no violations of the ZLB in 12-month-ahead 3-month bill rate forecasts unlike the estimation without forecast data. Figure 7 shows that the model without forecast data produces long-horizon 3-month interest rate forecasts that are unrealistically smooth and low for the US and Germany/Eurozone. In contrast, by using survey data in the estimation, our model is able to better mimic the variation in long-horizon survey forecasts.

The 1-year ahead inflation forecasts seen in Figure 8 are realistically less volatile when we add survey data to the estimation, particularly for the UK and Germany/Eurozone. Figure 9 shows that the estimation with survey data is able to match the slow-moving downward trend in long-horizon inflation forecasts over this sample. An estimation without survey data produces counterfactual long-horizon forecasts which actually trend up for Germany/Eurozone over time.

[12]Note that although we match relative interest rates in the estimation, this table presents statistics of the fit of country-specific interest rates.

[13]When evaluating these fits, it's important to keep in mind that the number of observations decreases with the forecast horizon with the longest forecast horizons suffering the most. For example, due to the timing of the survey, data for the 2Y horizon are generally only available annually and can have as few as 10-20 observations, depending on the country.

Lastly, Figures 10 and 11 shows that our VAR specification is capable of producing a very close fit of exchange rate level forecasts, even at a 24-month horizon, and currency premia based on survey data for a variety of currencies.

# 4 The Exchange Rate Change Sub-Components – Broad Overview

In this section, we first plot and discuss the sub-components of the exchange rate change decomposition and second we perform a variance covariance decomposition of the quarterly exchange rate change based on equation 6.

We start by plotting the country-specific sub-components of $\varphi_t^{EH,F}$=$\varphi_t^{EH,F,i}$-$\varphi_t^{EH,F,us}$ and $\varphi_t^{LR} = \varphi_t^{LR,i} - \varphi_t^{LR,us}$. Figure A1 plots $\varphi_t^{EH,F,i}$ against the quarterly change of the 10-year government yield. We find a very strong positive correlation ranging from .6 to .8. This correlation implies that upward revisions of expectations over the entire future path of short-term rates in the US coincide with increases in US 10-year yields. This is reassuring since 10-year yields themselves consist of the change of future short rate expectations and term premia where the former should correlate very strongly with our $\varphi_t^{EH,F,i}$ measure if our measure correctly captures market expectations. Figure A2 in the Appendix plots $\varphi_t^{LR,i}$ against actual quarterly inflation. The correlation between the two series ranges from .3 to .7 where higher inflation is associated with upward revisions of the expected future inflation path of the given country, as one might expect.

Delving deeper in the exchange rate change sub-components, Figures A3, A4 and A5 plot $\Delta s_t$ against the currency risk premia components (both lagged and forward-looking), the interest rate differential components (both lagged and forward-looking), and the inflation forward-looking component, respectively. One can clearly see that the lagged components are much less volatile than the forward-looking components with changes in expected future currency risk premia being the most volatile component.

To explore this more formally, we perform a variance covariance decomposition over the entire sample of the exchange rate change based on our estimated components in equations (6). The purpose of the decomposition is to assess how much the different components of the nominal exchange rate change and the interactions (covariances) between them contribute to the overall variation in exchange rates over the whole sample.

Notice that using our decomposition, the variance of the exchange rate change can be expressed as the sum of variances and the covariances of all the exchange rate change components as follows:

$$\begin{aligned} Var\left(\Delta s_t\right) =& Var\left(\varphi_t^{EH}\right) + Var\left(\varphi_t^{\lambda}\right) + Var\left(\varphi_t^{LR}\right) \\ &+ 2Cov\left(\varphi_t^{EH}, \varphi_t^{\lambda}\right) + 2Cov\left(\varphi_t^{EH}, \varphi_t^{LR}\right) + 2Cov\left(\varphi_t^{LR}, \varphi_t^{\lambda}\right). \end{aligned} \tag{7}$$

The estimates of these variances and covariances for each currency against the USD are reported in Table 2.

Over the entire sample, the ratios of variances, averaged across all currencies against the USD—$\frac{Var\left(\varphi_t^{EH}\right)}{Var(\Delta s_t)}$, $\frac{Var\left(\varphi_t^{LR}\right)}{Var(\Delta s_t)}$, and $\frac{Var\left(\varphi_t^{\lambda}\right)}{Var(\Delta s_t)}$—are .27, .17, and 1.08, respectively. Importantly, we note that the forward-looking components that reflect new information received in period $t$ ($-\varphi_t^{EH,F} - \varphi_t^{\lambda,F} + \varphi_t^{LR}$) are generally as volatile as the exchange rate change itself.

We observe the following patterns regarding the covariance terms in equation (7). The term $Cov\left(\varphi_t^{EH}, \varphi_t^{\lambda}\right)$ is negative, on average, over our sample and contributes to a lower exchange rate variance. A negative value of $Cov\left(\varphi_t^{EH}, \varphi_t^{\lambda}\right)$ means that higher expected future interest rates in country $i$ relative to the US (higher $\varphi_t^{EH,F}$) are associated with higher expected future excess returns from being long the 3-month government bond of country $i$ and short the US 3-month government bond (lower $\varphi_t^{\lambda,F}$). Magnitude-wise it can be a very important component of the exchange rate change variance covariance decomposition where $2\frac{Cov\left(\varphi_t^{EH}, \varphi_t^{\lambda}\right))}{Var(\Delta s_t)}$ ranges from -0.58 to 0.03 with an average value across all currency pairs of -0.24.

This result is consistent with the Fama puzzle (see Fama (1984)); namely that a higher realized excess return from being long currency $i$ and short the USD is associated with a higher interest rate differential in country $i$ relative to the US. It also supports the carry trade literature's finding that portfolios that are long high interest rate currencies and short low interest rate currencies tend to have high excess returns and Sharpe ratios on average (see the references in Brunnermeier, Nagel, and Pedersen (2009) and Burnside (2019)).

The negative $Cov\left(\varphi_t^{EH}, \varphi_t^{LR}\right)$ term also contributes to lower exchange rate change volatility and implies that higher expected future interest rates in country $i$ relative to the US (higher $\varphi_t^{EH,F}$) are associated with higher expected future inflation in country $i$ relative to the US (higher $\varphi_t^{LR}$). This is consistent with short-term rates being predominantly driven by monetary policy that raises rates when inflation is high. This component can be also a very important driver of the overall variation of the exchange rate change. $2\frac{Cov\left(\varphi_t^{EH}, \varphi_t^{LR}\right))}{Var(\Delta s_t)}$ ranges from -0.49 to -0.06 with an average value across all currency pairs of -0.18.

Finally, $Cov\left(\varphi_t^{LR}, \varphi_t^{\lambda}\right)$ tends to be negative but fairly small for many currency pairs with the exception of JPY and CHF. A negative value implies that a higher expected inflation path in country $i$ relative to the US is associated with higher expected excess returns from being long the USD and short currency $i$ going forward ($\varphi_t^{\lambda,F}$). $2\frac{Cov\left(\varphi_t^{LR},\varphi_t^{\lambda}\right))}{Var(\Delta s_t)}$ ranges from -0.35 to 0.08 with an average value across all currency pairs of -0.1.

To summarize, we find that the most volatile component of exchange rate changes is the component related to the expected future excess returns, where we use subjective beliefs. This result highlights the importance of allowing for sizable subjective currency risk premium in our exchange rate models. Moreover, the volatility of the interest rate and inflation components are still sizable. However, what's even more notable is the importance of the covariance terms across the various exchange rate sub-components. As we will discuss in the next sections, these covariance terms play an important role in explaining the Great Moderation exchange rate volatility puzzle for some currencies.

# 5 Decomposing Exchange Rate Volatility Trends

In this section, we use our decomposition to analyze the drivers of trends in exchange rate volatility. To do so, we construct estimates of the rolling variance covariance decomposition given by equation (7) with rolling windows of 20 quarters, the same 5-year window used in Section 2.

We present the results from this rolling variance covariance decomposition in Figures 12–17. In each figure, we also include the rolling variance of the exchange rate change itself so that the contribution of each component of the variance decomposition can be easily seen. The estimated time trends are shown as a dashed line in each figure and the estimated trend coefficients are presented in Table 3.[14] The sum of the trends of the rolling volatility of the sub-components equals the trend of the rolling volatility of the exchange rate change.

Notice that the sample that we use in this section is shorter than in Section 2 due to survey data availability and roughly covers the last 25 years.[15] Relative to the longer sample, the exchange rate change volatility trends remain the same, with the exception of GBP where over the last 25 years or so we have observed an increase in exchange rate change volatility of the GBP/USD currency cross.

Some echos of the Great Moderation are visible even in this more recent sample in the declining volatility of the overall interest rate component, $\varphi_t^{EH}$, of exchange rate changes for almost all currencies, with the exception of the DEM/EUR and JPY. Given that in Section 2, we showed that the Great Moderation volatility factor captures mostly the volatility of

[14]We do not control for either the GFC or COVID period in estimating these time trends, but the results are robust to including dummies for either or both of those periods.

[15]For details see the Data Appendix.

long term realized yield changes we will disentangle this result further.

There are three potential explanations as to why the volatility of $\varphi_t^{EH}$ has decreased. First, as Ilzetzki, Reinhart, and Rogoff (2020) argue, the lower volatility of revisions in expectations over relative monetary policy rates can be potentially explained by the decline in policy rates towards the ZLB and the subsequent ZLB period.[16] When interest rates are close to or at the ZLB, the amount of downward revisions in expectations over policy rates in the short and medium run is limited, which will mechanically lower the variance of $\varphi_t^{EH}$. Second, the increased transparency of central banks regarding how policy rates are set has further contributed to better policy rate forecasts, and, thus, smaller revisions of policy rate expectations [see Middeldorp (2011)]. Finally, realized interest rates and revisions in expectations over policy rate paths might comove more over time.

Table 4 and the corresponding Figure 18 explore each of these possible explanations by breaking down the volatility of $\varphi_t^{EH}$.[17] The table shows that the rolling volatilities of realized short term rates, $i_{t-1}^i$, have fallen for all countries, capturing the Great Moderation factor. However, in contrast, the component capturing the revisions in expectations over the infinite short term rate path, $\varphi_t^{EH,F,i}$, has become more volatile for a lot of countries including the US, perhaps reflecting the increasing use of forward guidance policies by central banks around the world or a greater weight placed on macroeconomic news by market practitioners when forming policy rate expectations. As a result the volatility of $\varphi_t^{EH,i}$ has increased for most countries. From Table 4 we can see that it is the last channel, a stronger covariance of $\varphi_t^{EH,i}$ and $\varphi_t^{EH,us}$ over time, potentially due to a greater coordination in monetary policy, that has driven a declining trend in the overall volatility of the *relative* past and expected future interest rates, $\varphi_t^{EH}$, for most countries against the US.

Going back to Table 3, the Great Moderation puzzle emerges here as a disconnect between the volatility trends in the interest rate component and the trends in overall exchange rate volatility. As seen before, we observe a negative trend in the estimated variance of the exchange rate primarily for the financial center currencies, CHF, DEM/EUR, and JPY. However, volatility has increased for the currencies of commodity producers (AUD, CAD and NZD) as well as for the GBP. Looking at the trends in the interest rate component, we see that the currencies that saw the greatest decreases in interest rate component volatility, AUD and NZD, actually experienced the greatest increases in exchange rate volatility. Similarly, while the DEM/EUR and JPY saw flat or even slight increases in the volatility of the

[16] Ilzetzki, Reinhart, and Rogoff (2020) conjecture that the lower volatility of monetary policy rates is an important reason as to why we observe a downward trend in the volatility of USDJPY and USDEUR.

[17] For the US-specific components, the trend estimates still differ slightly across currencies because of differences in sample ranges.

interest rate components of exchange rate changes, overall exchange rate volatility for these two currencies decreased by a fair amount over this sample.

With the exception of the AUD, the volatility of the forward looking relative inflation expectations component, $\varphi_t^{LR}$ has actually increased over time, due to the ZLB when monetary policy was constrained and inflation expectations across countries might have diverged and also due to the post-COVID high inflation period. The higher volatility trend $\varphi_t^{LR}$, together with a less negative co-movement between $\varphi_t^{LR}$ and $\varphi_t^{\lambda}$, is the main reason why the GBP exchange rate volatility has increased over the last 25 years – i.e. inflation expectations played a crucial role. The picture is quite different for other crosses.

Exchange rates of the other financial centers—CHF, DEM/EUR, and JPY—became less volatile, despite smaller declines (or even increases) of the volatility of the interest rate component, an increase in the volatility of the inflation component and a less negative co-movement between $\varphi_t^{LR}$ and $\varphi_t^{\lambda}$ (with the exception of JPY). This was the case due to declining volatility of past and expected future currency risk premia. There is also a small contribution from a decreasing covariance between the currency risk premia and interest rate components or a strengthening of the Fama puzzle for the CHF and the DEM/EUR.

The AUD and NZD, and to a lesser extent the CAD, actually saw increases in volatility, despite declines in the volatility of the interest rate components, primarily due to more positive covariances between $\varphi_t^{EH}$ and $\varphi_t^{LR}$ and between $\varphi_t^{EH}$ and $\varphi_t^{\lambda}$. The fact that $Cov(\varphi_t^{EH}, \varphi_t^{LR})$ became less negative implies that forecasters expected policy rates to be less reflective of inflation differential expectations. A slight reversal of this upward trend is visible in the high-inflation COVID period, as expected. This phenomena may be consistent with the fact that as inflation expectations have become better anchored, central banks have not needed to respond by as much to inflation in order to achieve their inflation targets. The more positive covariance between $\varphi_t^{EH}$ and $\varphi_t^{\lambda}$ indicates a weakening and even disappearing of the Fama puzzle for these commodity currencies. Baillie and Bollerslev (2000) and Burnside (2019) also find that the forward premium puzzle (i.e. the result that a currency appreciates when the interest rate of that country is relatively higher) has disappeared over time. Burnside (2019) argues that the observed trend in the estimated forward premium coefficients coincides with lower carry trade returns. Lastly, increased volatility of the currency risk premium component, $\varphi_t^{\lambda}$, also contributed to the increased volatility of the CAD, but not the AUD or NZD.

# 6 Conclusion

In this paper we explore the relationship between exchange rate volatility and *realized* and *expected* macroeconomic volatility over the last 50 and the last 25 years. We find significant heterogeneity in both the volatility trends of exchange rate changes and also the explanations for these trends.

As far as the contribution of *realized* macroeconomic volatility to exchange rate change volatility is concerned, we find that if one allows for a time varying relationship between macroeconomic variables and exchange rate changes, then the trend in exchange rate volatility tracks closely the volatility of the time varying contribution of the macroeconomic variables to the exchange rate movement. However, this co-movement is driven by the time varying coefficients and their interaction with the level of the macroeconomic variables rather than the lower macroeconomic volatility of the macroeconomic variables themselves. In other words, non linear effects are key.

Turning to the link between exchange rate volatility and the volatility of *expected* macroeconomic variables, we find very heterogeneous drivers of exchange rate volatility trends across currency pairs. The currencies of three of the largest financial centers — namely CHF, DEM/EUR, and JPY against the USD—saw declines in volatility, which are larger than what can be explained by the relationships between these exchange rates and macro variables alone. Indeed, we find the decrease in exchange rate trend volatility for these currency crosses is due to a large decline in the volatility of expected future currency risk premia.

Currencies of commodity producers, particularly AUD, CAD, and NZD against the USD, actually saw increased volatility, despite the drop in macro volatility during the Great Moderation. The main explanation for the increase in trend volatility rests on the weakening of the Fama puzzle and also expectations of smaller policy rate responses to movements in inflation.

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# Tables and Figures

Figure 1: 60 Month Rolling Variance of the Quarterly Exchange Rate Change

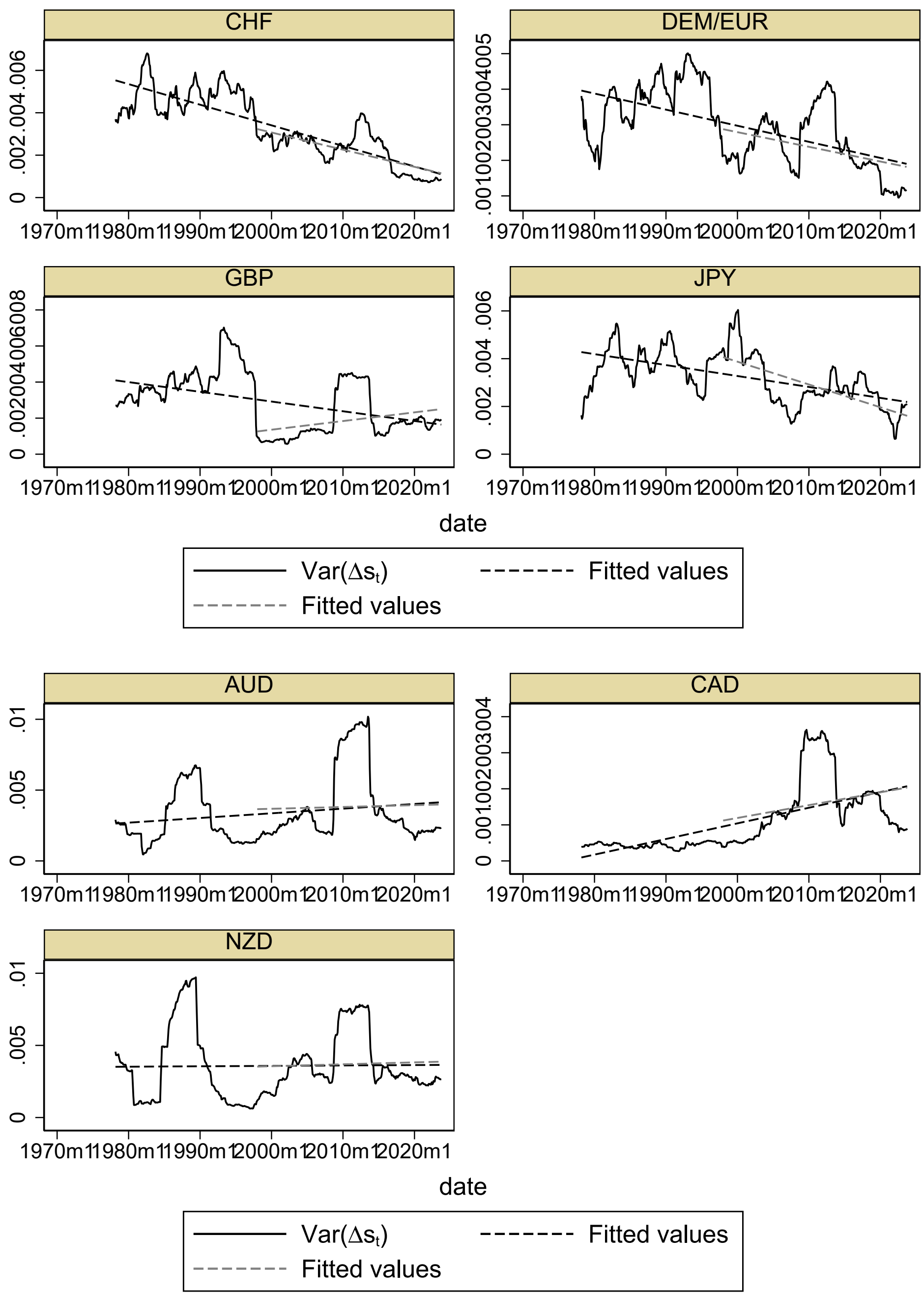
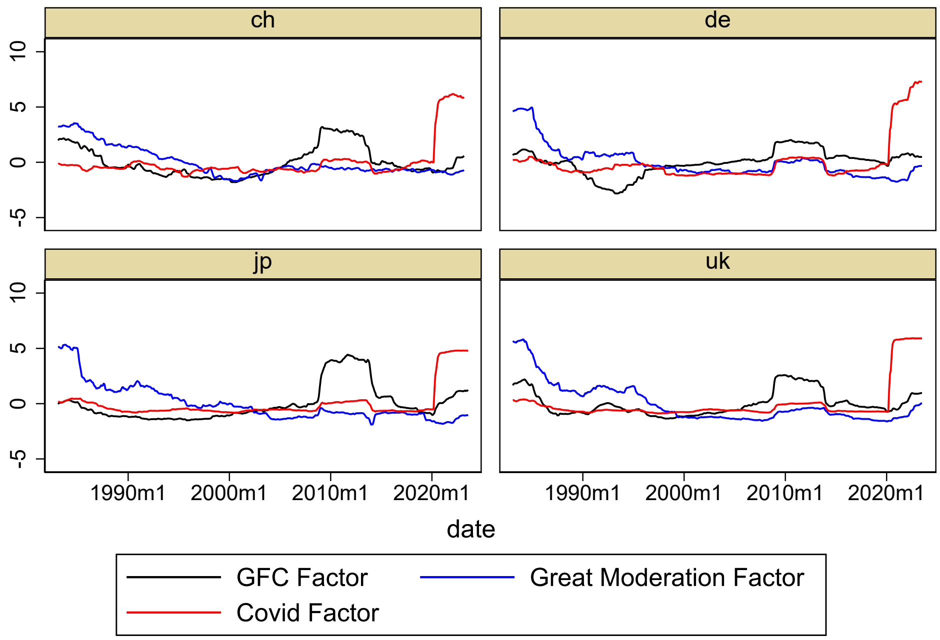
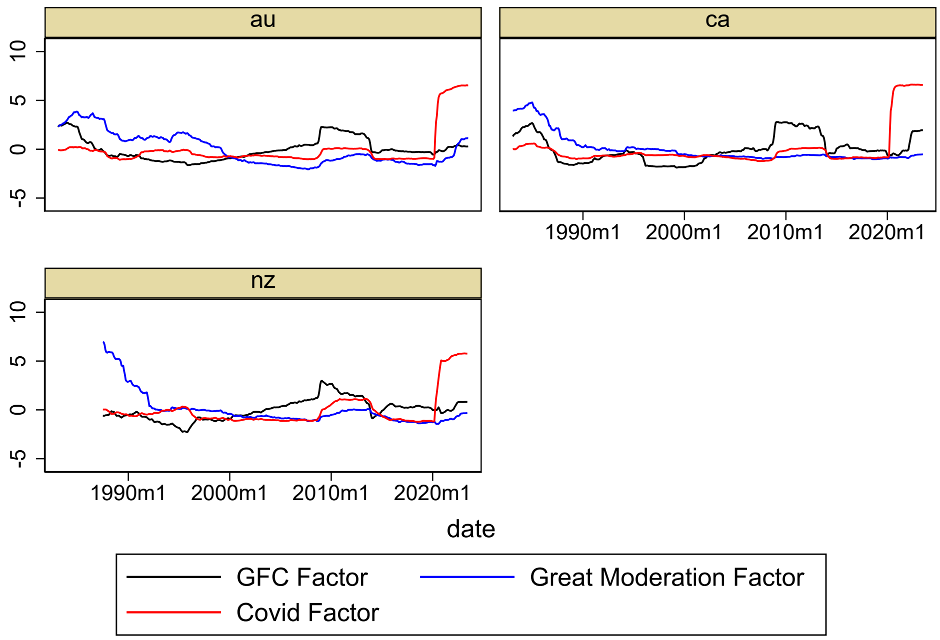


Figure 2: The Three Main Principal Components of the 60 Month Rolling Variance of Macroeconomic Variables




Overall variance explained by the three factors: ch: .79; jp: .9; uk: .9; de: .85




Overall variance explained by the three factors: au: .9; ca: .95; nz: .86

Figure 3: 60 Month Rolling Adj $R^2$ From Regressing the Exchange Rate Change on Macroeconomic Variables

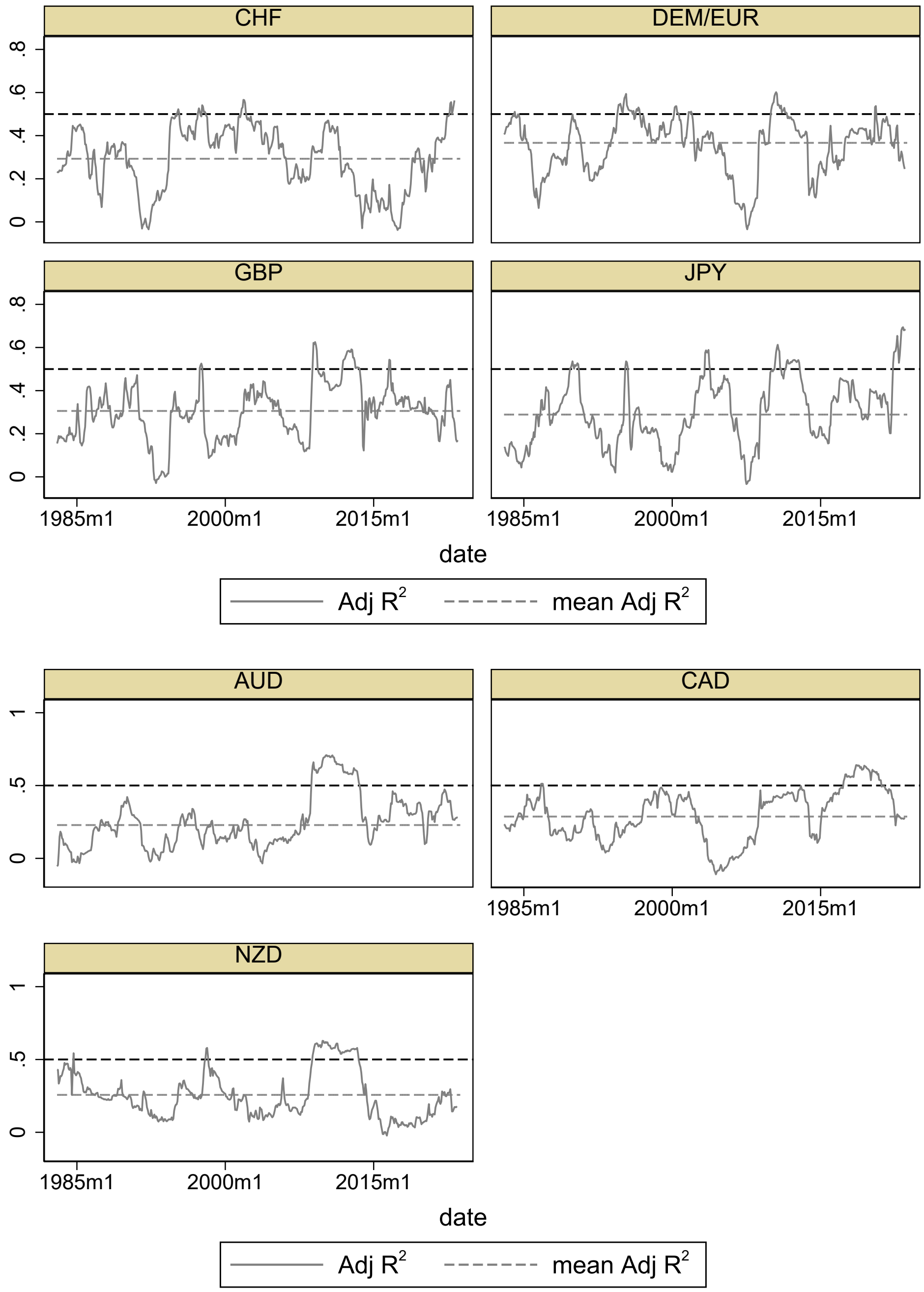


Figure 4: 60 Month Rolling Variance of the Quarterly Exchange Rate Change and the Fitted Values from Regressing the Exchange Rate Change on Macroeconomic Variables

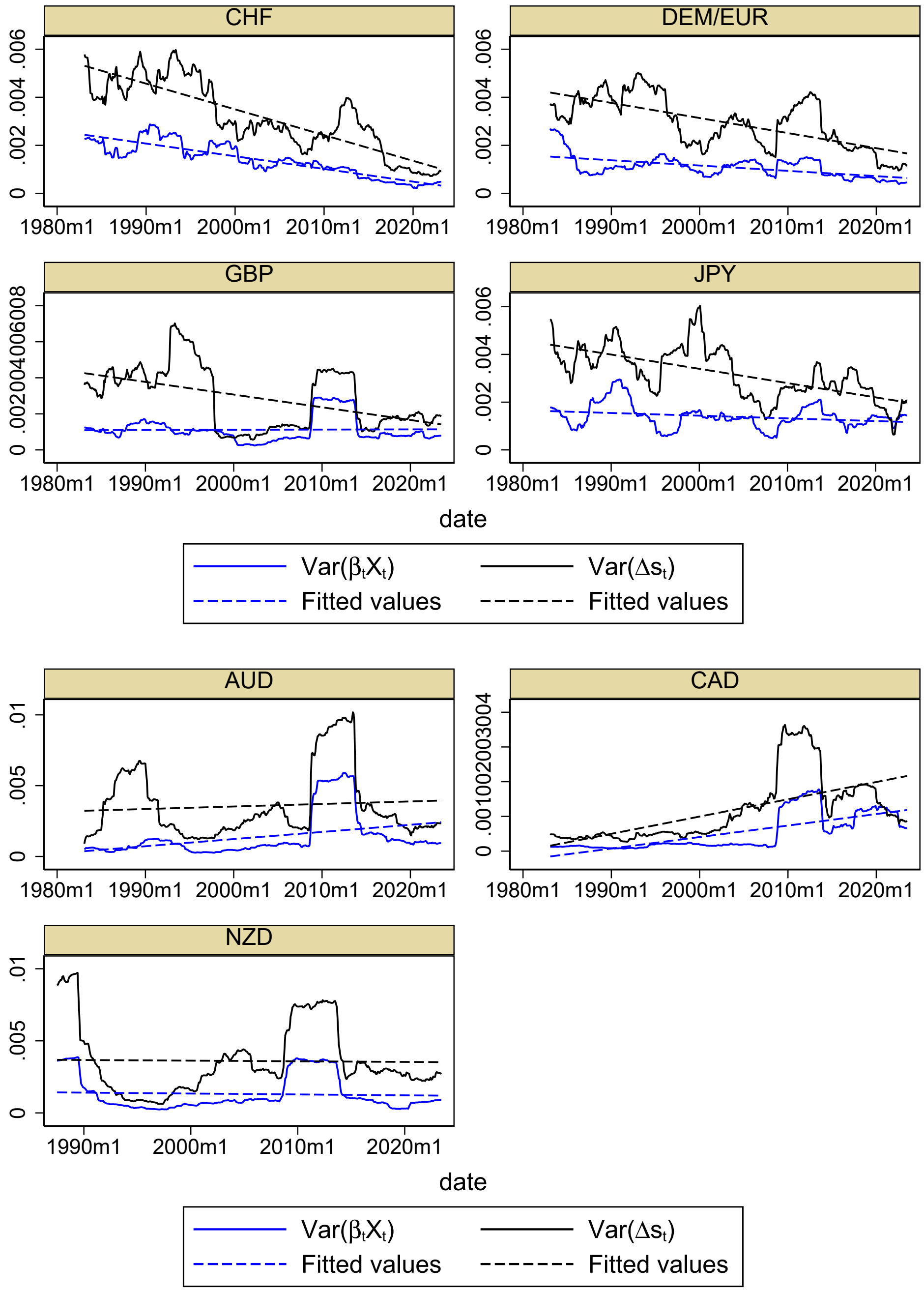


Figure 5: 60 Month Rolling Variance of $\beta_{avg}X_t$ against the Great Moderation Factor

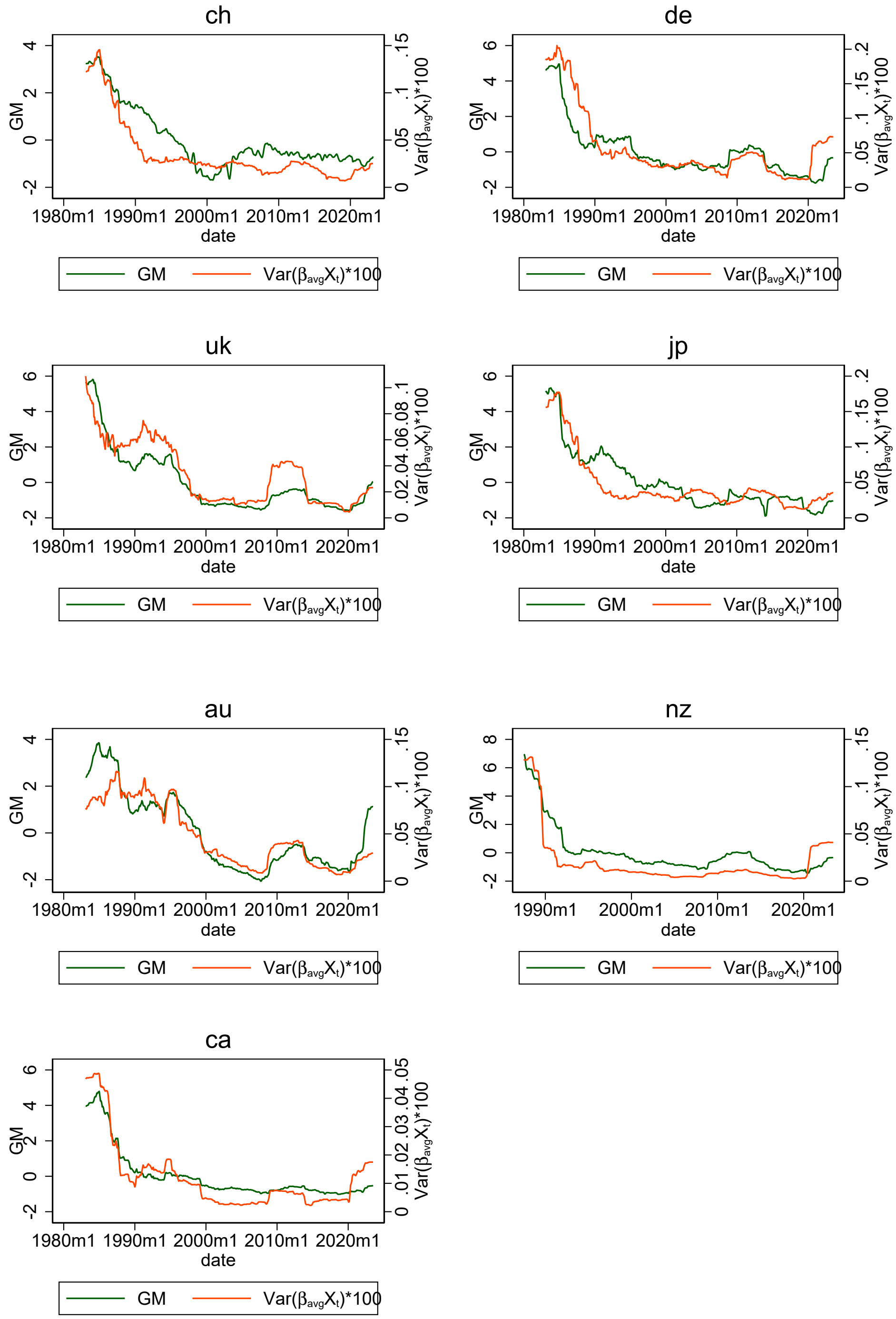


Table 1: Relative RMSEs of Survey Forecast Fit For Forecast-Augmented VAR Versus Standard OLS Estimation

| | | | AU | CA | CH | DE | JP | NZ | UK | US |
|---|---|---|---|---|---|---|---|---|---|---|
| Exch Rate | BC | 0Y | 0.50 | 0.52 | | 0.42 | 0.21 | | 0.34 | . |
| | | 1Y | 0.38 | 0.33 | | 0.34 | 0.19 | | 0.39 | . |
| | | 2Y | 0.32 | 0.25 | | 0.26 | 0.17 | | 0.31 | . |
| | BCF | 3M | 0.43 | 0.42 | 0.46 | 0.38 | 0.33 | | 0.44 | . |
| | | 6M | 0.38 | 0.34 | 0.39 | 0.31 | 0.21 | | 0.36 | . |
| | | 12M | 0.28 | 0.33 | 0.31 | 0.30 | 0.20 | | 0.38 | . |
| | CF | 3M | 0.40 | 0.29 | 0.35 | 0.31 | 0.27 | 0.39 | 0.40 | . |
| | | 12M | 0.25 | 0.19 | 0.25 | 0.20 | 0.16 | 0.27 | 0.29 | . |
| | | 24M | 0.25 | 0.14 | 0.22 | 0.16 | 0.18 | 0.22 | 0.26 | . |
| 3M Bill Rate | BC | 0Y | 0.43 | 0.42 | | 0.33 | 0.38 | | 0.37 | 0.46 |
| | | 1Y | 0.38 | 0.34 | | 0.26 | 0.35 | | 0.29 | 0.29 |
| | | 2Y | 0.33 | 0.26 | | 0.27 | 0.36 | | 0.25 | 0.30 |
| | | 7-11Y | | | | | | | | 0.15 |
| | BCF | 3M | 0.58 | 0.54 | 0.59 | 0.53 | 0.56 | | 0.45 | 0.45 |
| | | 6M | 0.44 | 0.40 | 0.48 | 0.37 | 0.41 | | 0.32 | 0.34 |
| | | 12M | 0.32 | 0.30 | 0.34 | 0.28 | 0.31 | | 0.25 | 0.30 |
| | CF | 3M | 0.59 | 0.79 | 0.59 | 0.56 | 0.55 | 0.81 | 0.46 | 0.59 |
| | | 12M | 0.21 | 0.39 | 0.34 | 0.27 | 0.37 | 0.42 | 0.25 | 0.32 |
| | | 6-10Y | 0.45 | 0.19 | 0.23 | 0.30 | 0.30 | 0.74 | 0.45 | 0.22 |
| Inflation | BC | 0Y | 0.63 | 0.66 | | 0.61 | 0.71 | | 0.60 | 0.63 |
| | | 1Y | 0.25 | 0.31 | | 0.21 | 0.34 | | 0.20 | 0.29 |
| | | 2Y | 0.18 | 0.25 | | 0.14 | 0.22 | | 0.12 | 0.19 |
| | CF | 0Y | 0.59 | 0.65 | 0.61 | 0.71 | 0.76 | 0.74 | 0.52 | 0.70 |
| | | 1Y | 0.29 | 0.36 | 0.31 | 0.23 | 0.38 | 0.44 | 0.24 | 0.28 |
| | | 2Y | 0.17 | 0.24 | 0.21 | 0.12 | 0.26 | 0.27 | 0.17 | 0.23 |
| | | 6-10Y | 0.34 | 0.36 | 0.33 | 0.28 | 0.25 | 0.36 | 0.25 | 0.28 |

Note: Each value in this table is the ratio of the RMSE of the fit of survey forecasts for the forecast-augmented VAR divided by the same RMSE for OLS estimation of only the VAR data-generating process in (10) subject to the restrictions in (11).

Figure 6: Model-Implied and Survey Forecasts: 3-Month Bill Rate (12 Months Ahead)

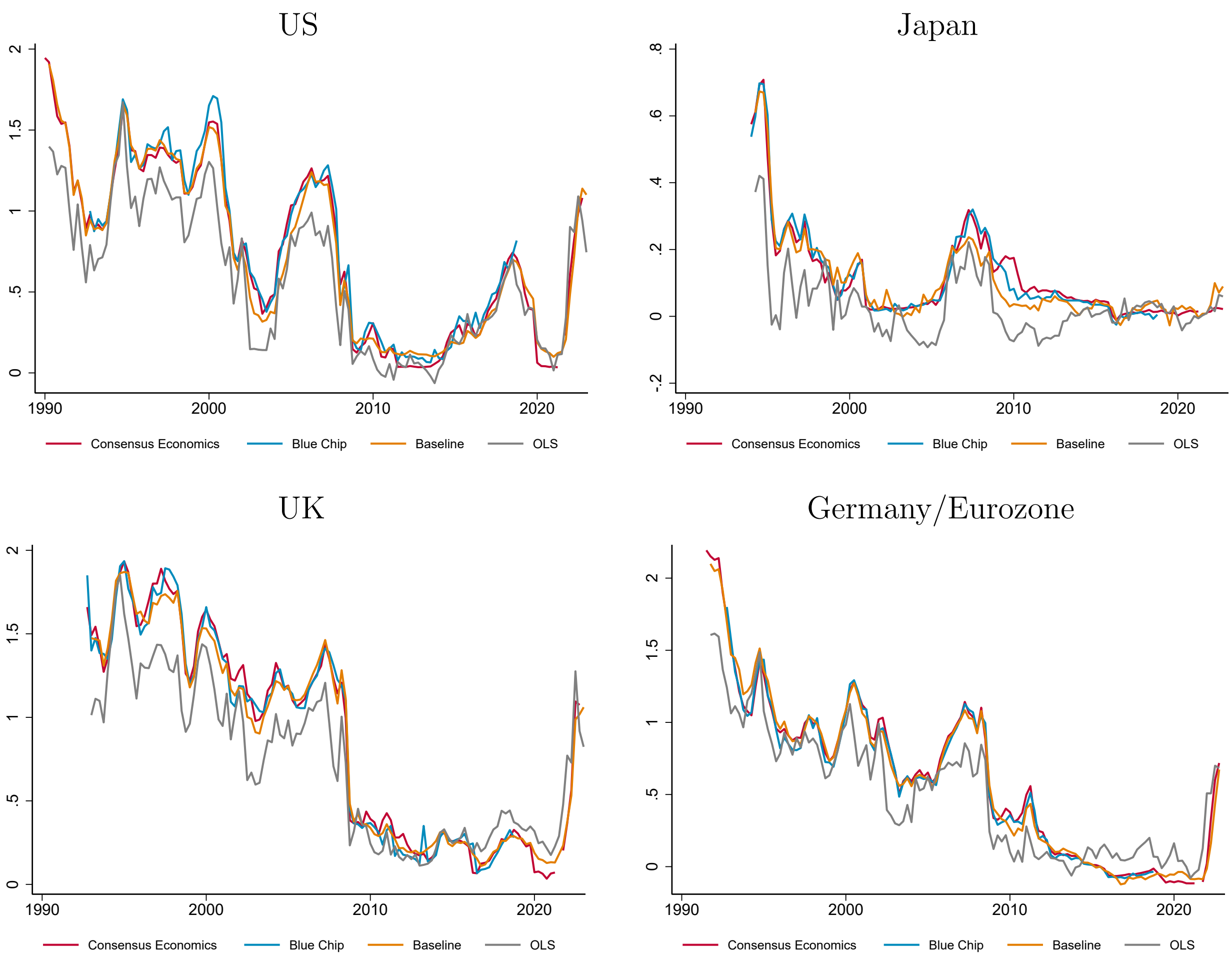



Figure 7: Model-Implied and Survey Forecasts: 3-Month Bill Rate (6-10 Years Ahead)

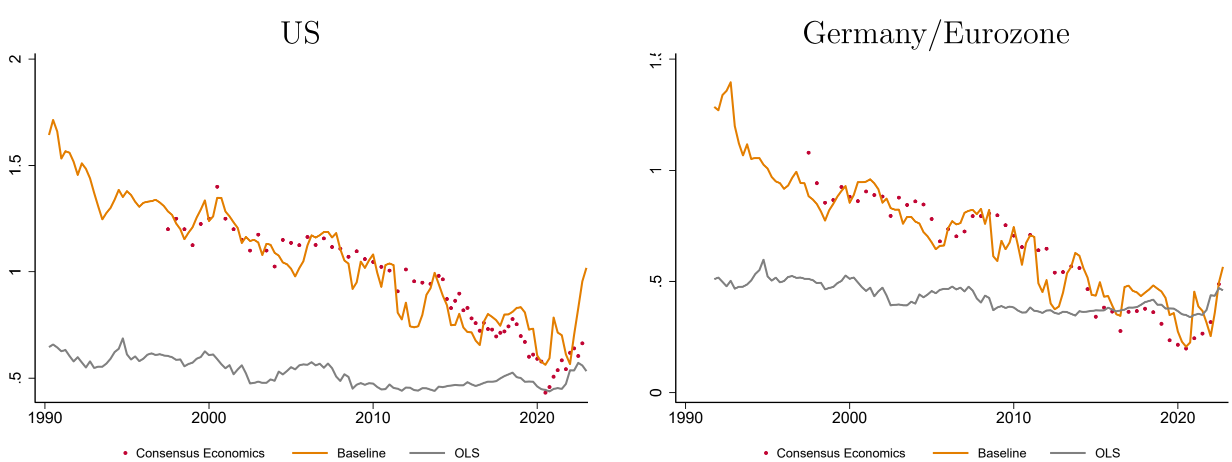


Figure 8: Model-Implied and Survey Forecasts: Inflation (1 Year Ahead)

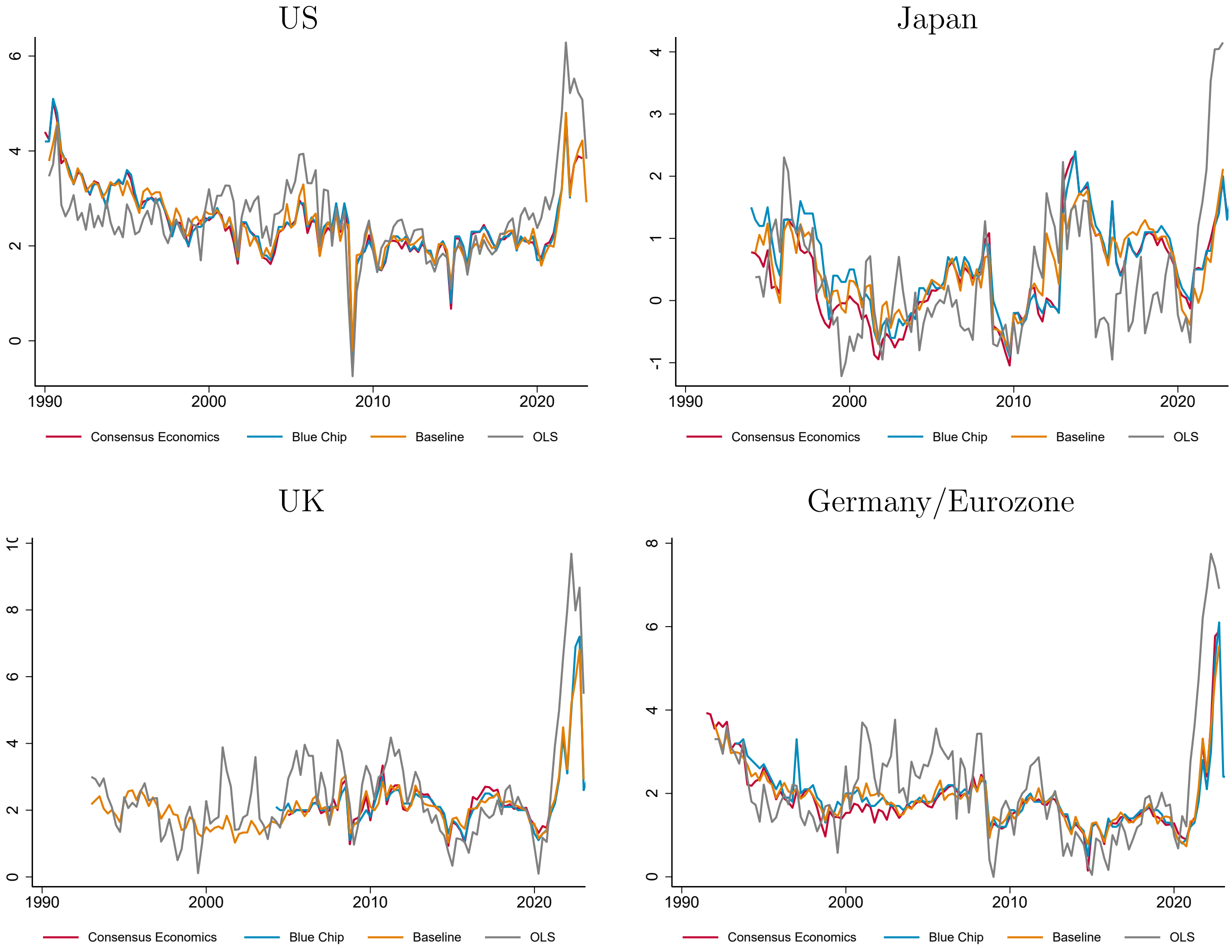



Figure 9: Model-Implied and Survey Forecasts: Inflation (6-10 Years Ahead)

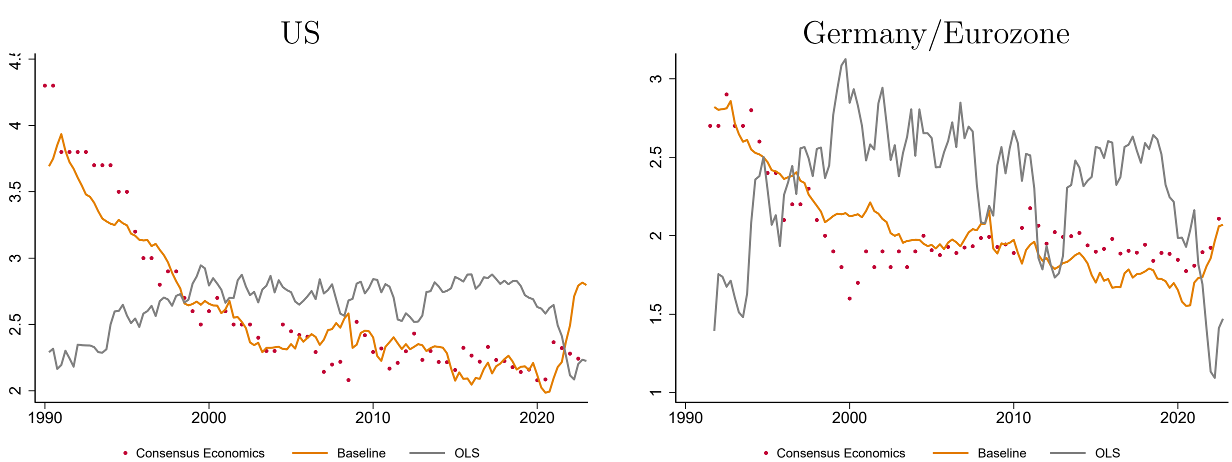


Figure 10: Model-Implied and Survey Forecasts: Exchange Rates (24 Months Ahead)

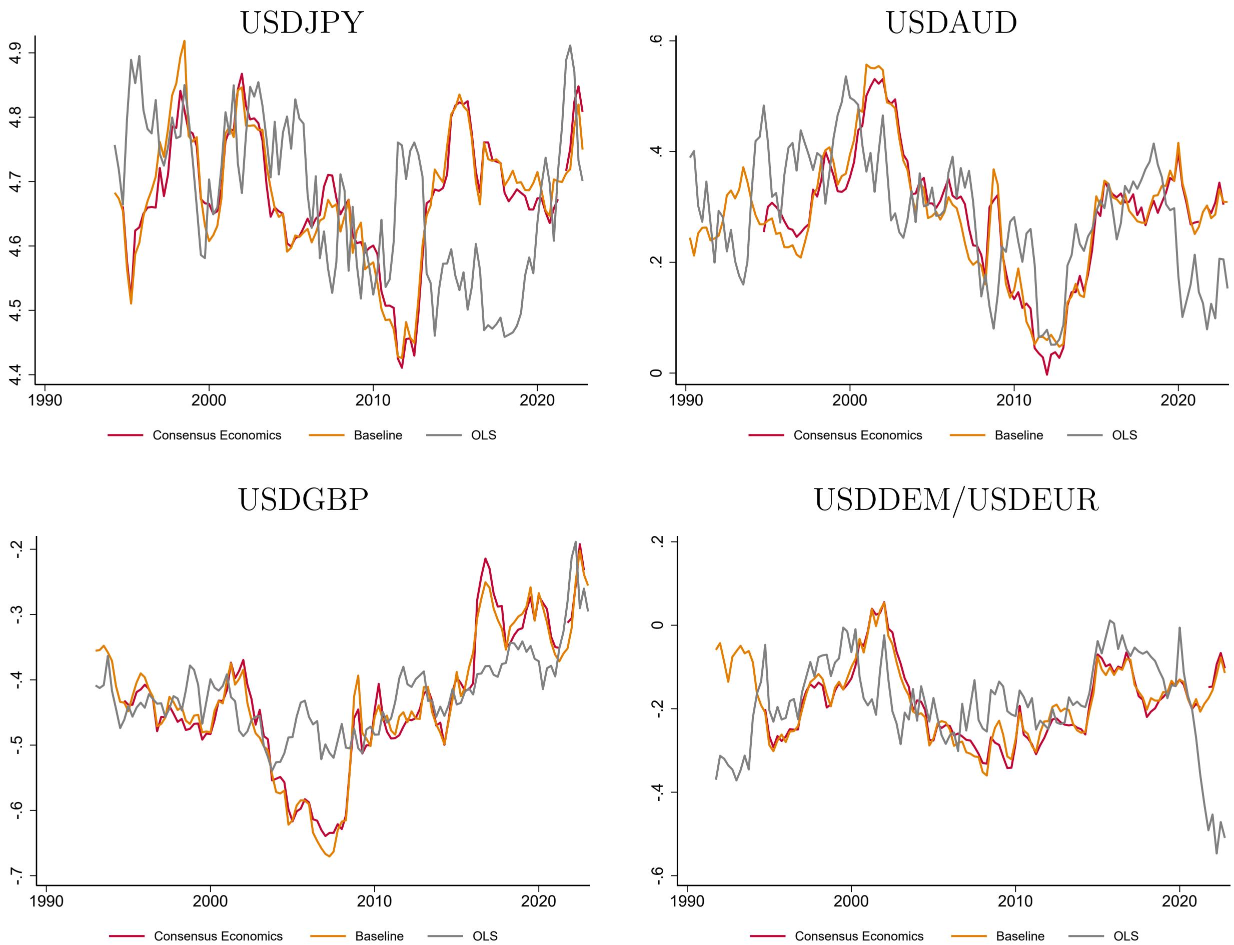



Figure 11: Model-Implied and Survey Currency Premia (3-Month Horizon)

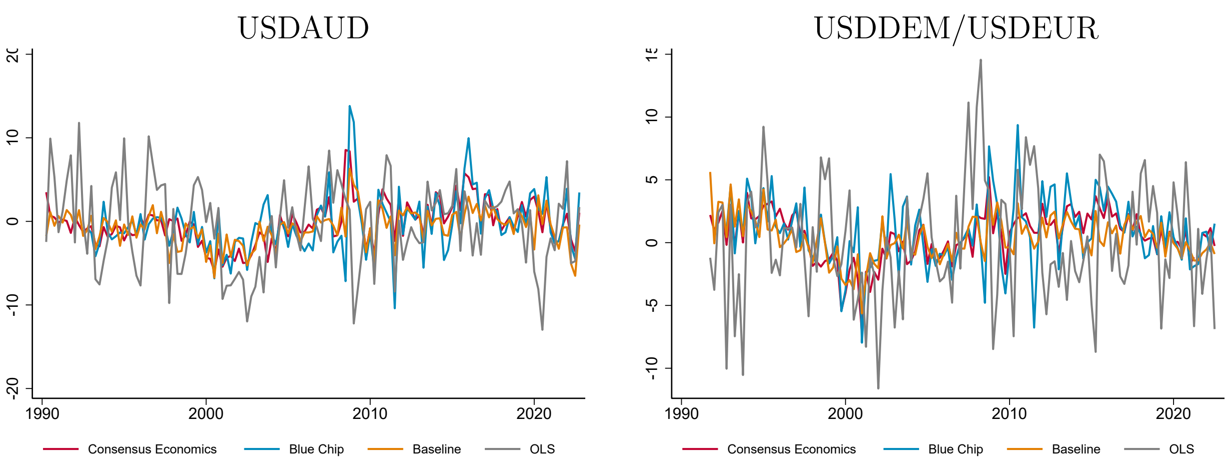


Table 2: Component Variances and Covariances US; Full Sample

| Base | AUD | CAD | CHF | DEM/EUR | GBP | JPY | NZD |
|---|---|---|---|---|---|---|---|
| $Var(\Delta s_t)$ | 32.57 | 13.93 | 27.48 | 25.88 | 18.61 | 34.56 | 31.71 |
| $Var(\varphi_t^{EH})$ | 8.35 | 2.05 | 4.05 | 4.38 | 8.45 | 6.51 | 17.45 |
| $Var(\varphi_t^{LR})$ | 1.89 | 3.30 | 2.29 | 1.64 | 8.28 | 5.43 | 5.54 |
| $Var(\varphi_t^{\lambda})$ | 31.89 | 15.79 | 27.49 | 29.89 | 19.52 | 36.60 | 37.40 |
| $2Cov(\varphi_t^{EH}, \varphi_t^{LR})$ | −5.20 | −1.06 | −2.47 | −1.57 | −9.10 | −2.73 | −9.79 |
| $2Cov(\varphi_t^{EH}, \varphi_t^{\lambda})$ | −7.08 | −5.40 | 2.21 | −6.82 | −6.51 | 0.95 | −18.49 |
| $2Cov(\varphi_t^{LR}, \varphi_t^{\lambda})$ | 2.74 | −0.76 | −6.09 | −1.64 | −2.03 | −12.20 | −0.39 |
| $Var(-\varphi_t^{EH,F} - \varphi_t^{\lambda,F} + \varphi_t^{LR})$ | 34.26 | 13.66 | 27.94 | 27.54 | 18.54 | 35.38 | 29.88 |

Note: Variance-covariance decomposition of the exchange rate change components based on the survey-data augmented VAR. Rows 2–7 sum up to the total variance of the one-quarter exchange rate change in row 1.

Table 3: Decomposing Trends in Exchange Rate Volatility

| | AUD | CAD | CHF | DEM/EUR | GBP | JPY | NZD |
|---|---|---|---|---|---|---|---|
| $Var(\Delta s_t)$ | 4.49*** | 3.59*** | −13.00*** | −4.06*** | 3.88*** | −11.16*** | 5.69*** |
| | (1.44) | (0.82) | (1.14) | (0.86) | (0.90) | (1.46) | (1.44) |
| $Var(\varphi_t^{\lambda})$ | 1.27 | 3.04*** | −10.77*** | −4.25*** | 1.15 | −11.80*** | −1.99 |
| | (0.96) | (0.59) | (0.92) | (1.01) | (0.96) | (1.35) | (1.34) |
| $Var(\varphi_t^{EH})$ | -3.35*** | −0.85*** | −1.66*** | 0.43** | −2.11*** | 0.09 | −8.67*** |
| | (0.37) | (0.13) | (0.29) | (0.21) | (0.45) | (0.33) | (0.92) |
| $Var(\varphi_t^{LR})$ | -0.49*** | 0.60*** | 0.42*** | 0.34*** | 1.13** | 1.49*** | 0.07 |
| | (0.08) | (0.13) | (0.11) | (0.07) | (0.43) | (0.22) | (0.16) |
| $2Cov(\varphi_t^{EH}, \varphi_t^{LR})$ | 3.28*** | 0.39** | 1.07*** | 0.48*** | 0.79 | −0.55** | 5.53*** |
| | (0.32) | (0.17) | (0.22) | (0.10) | (0.56) | (0.26) | (0.48) |
| $2Cov(\varphi_t^{EH}, \varphi_t^{\lambda})$ | 4.05*** | 1.21** | −3.54*** | −2.66*** | 0.72 | 0.70 | 16.93*** |
| | (0.89) | (0.49) | (0.42) | (0.60) | (0.98) | (0.78) | (1.58) |
| $2Cov(\varphi_t^{LR}, \varphi_t^{\lambda})$ | -0.27 | −0.80 | 1.48*** | 1.60*** | 2.20** | −1.09 | −6.18*** |
| | (0.47) | (0.62) | (0.26) | (0.47) | (0.85) | (1.07) | (0.59) |

Note: Each cell in this table reports the estimated coefficient from univariate regressions of each term in the exchange rate change variance decomposition on a time trend. The time trend is scaled such that the coefficient represents the average change in the term over a 10-year period. Note that the terms are scaled such that the coefficients in rows 2 through 7 sum up to the trend coefficient in the exchange rate change variance. Heteroskedasticity-robust standard errors are in parentheses.

Table 4: Decomposing Trends in Volatility of $\varphi_t^{EH}$

| | AUD | CAD | CHF | DEM/EUR | GBP | JPY | NZD |
|---|---|---|---|---|---|---|---|
| | $Var(\varphi_t^{EH}) = Var(\varphi_t^{EH,i}) + Var(\varphi_t^{EH,US}) - 2Cov(\varphi_t^{EH,i}, \varphi_t^{EH,US})$ | | | | | | |
| $Var(\varphi_t^{EH,i})$ | -5.15*** | 1.64** | 0.88* | 2.02*** | 0.28 | −2.31*** | −3.30*** |
| | (1.01) | (0.80) | (0.45) | (0.38) | (1.22) | (0.22) | (1.15) |
| $Var(\varphi_t^{EH,US})$ | 2.85*** | 3.60*** | 2.85*** | 3.17*** | 3.69*** | 3.55*** | 2.85*** |
| | (0.57) | (0.61) | (0.57) | (0.55) | (0.63) | (0.64) | (0.57) |
| $2Cov(\varphi_t^{EH,i}, \varphi_t^{EH,US})$ | 1.05 | 6.10*** | 5.39*** | 4.76*** | 6.08*** | 1.15** | 8.22*** |
| | (1.16) | (1.27) | (0.84) | (0.67) | (1.45) | (0.48) | (1.08) |
| | $Var(\varphi_t^{EH,i}) = Var(i_{t-1}^{i}) + Var(\varphi_t^{EH,F,i}) - 2Cov(i_{t-1}^{i}, \varphi_t^{EH,F,i})$ | | | | | | |
| $Var(i_{t-1}^{i})$ | -0.04*** | −0.04*** | −0.07*** | −0.04*** | −0.01** | −0.00*** | −0.05*** |
| | (0.01) | (0.00) | (0.01) | (0.01) | (0.01) | (0.00) | (0.01) |
| $Var(\varphi_t^{EH,F,i})$ | -4.94*** | 1.49* | 0.90* | 2.05*** | 0.50 | −2.27*** | −3.08*** |
| | (0.96) | (0.80) | (0.46) | (0.36) | (1.24) | (0.21) | (1.12) |
| $2Cov(i_{t-1}^{i}, \varphi_t^{EH,F,i})$ | 0.18* | −0.19*** | −0.05 | −0.01 | 0.21*** | 0.04*** | 0.17* |
| | (0.09) | (0.04) | (0.03) | (0.03) | (0.04) | (0.01) | (0.09) |
| | $Var(\varphi_t^{EH,US}) = Var(i_{t-1}^{US}) + Var(\varphi_t^{EH,F,US}) - 2Cov(i_{t-1}^{US}, \varphi_t^{EH,F,US})$ | | | | | | |
| $Var(i_{t-1}^{US})$ | -0.02*** | −0.03*** | −0.02*** | −0.02*** | −0.03*** | −0.04*** | −0.02*** |
| | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) |
| $Var(\varphi_t^{EH,F,US})$ | 2.87*** | 3.58*** | 2.87*** | 3.14*** | 3.66*** | 3.44*** | 2.87*** |
| | (0.56) | (0.61) | (0.56) | (0.55) | (0.63) | (0.64) | (0.56) |
| $2Cov(i_{t-1}^{US}, \varphi_t^{EH,F,US})$ | -0.00 | −0.05 | −0.00 | −0.06 | −0.06 | −0.16*** | −0.00 |
| | (0.04) | (0.05) | (0.04) | (0.05) | (0.06) | (0.06) | (0.04) |

Note: Each cell in this table reports the estimated coefficient from univariate regressions of each term in the $\varphi_t^{EH}$ variance decomposition on a time trend. The time trend is scaled such that the coefficient represents the average change in the term over a 10-year period. Heteroskedasticity-robust standard errors are in parentheses.

Figure 12: $Var(\varphi_t^{EH})$

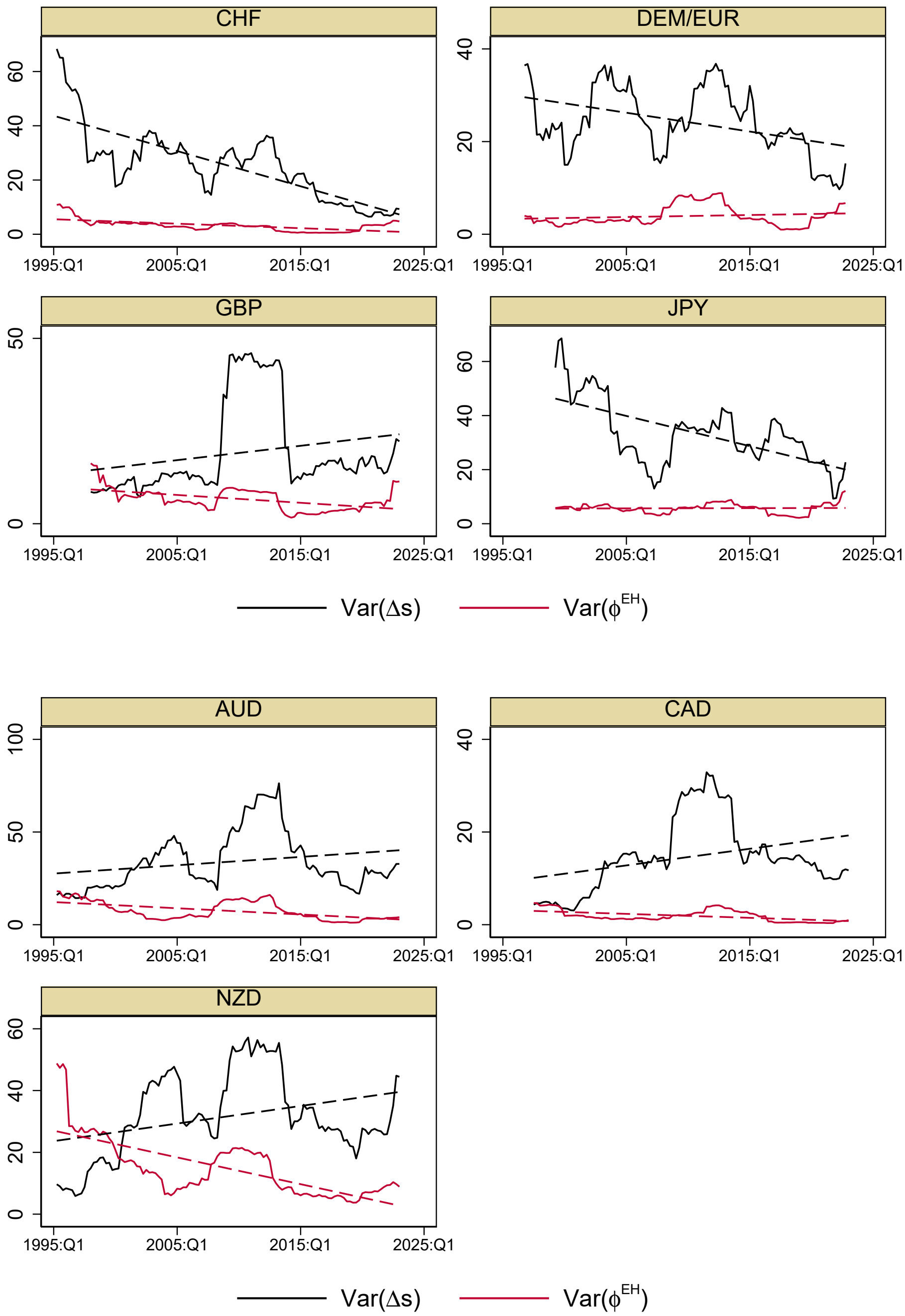


Figure 13: $Var(\varphi_t^{LR})$

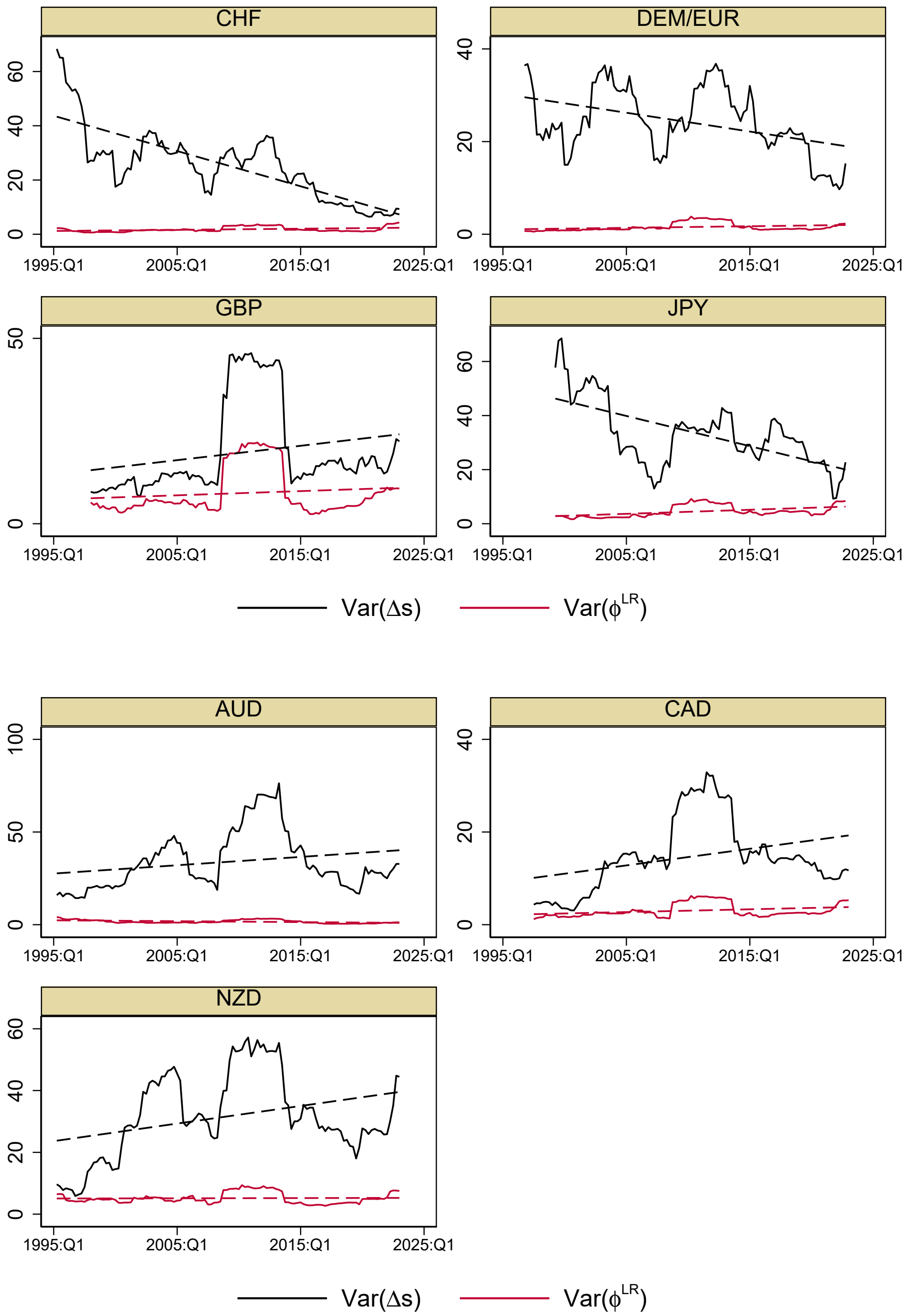


Figure 14: $Var(\varphi_t^\lambda)$

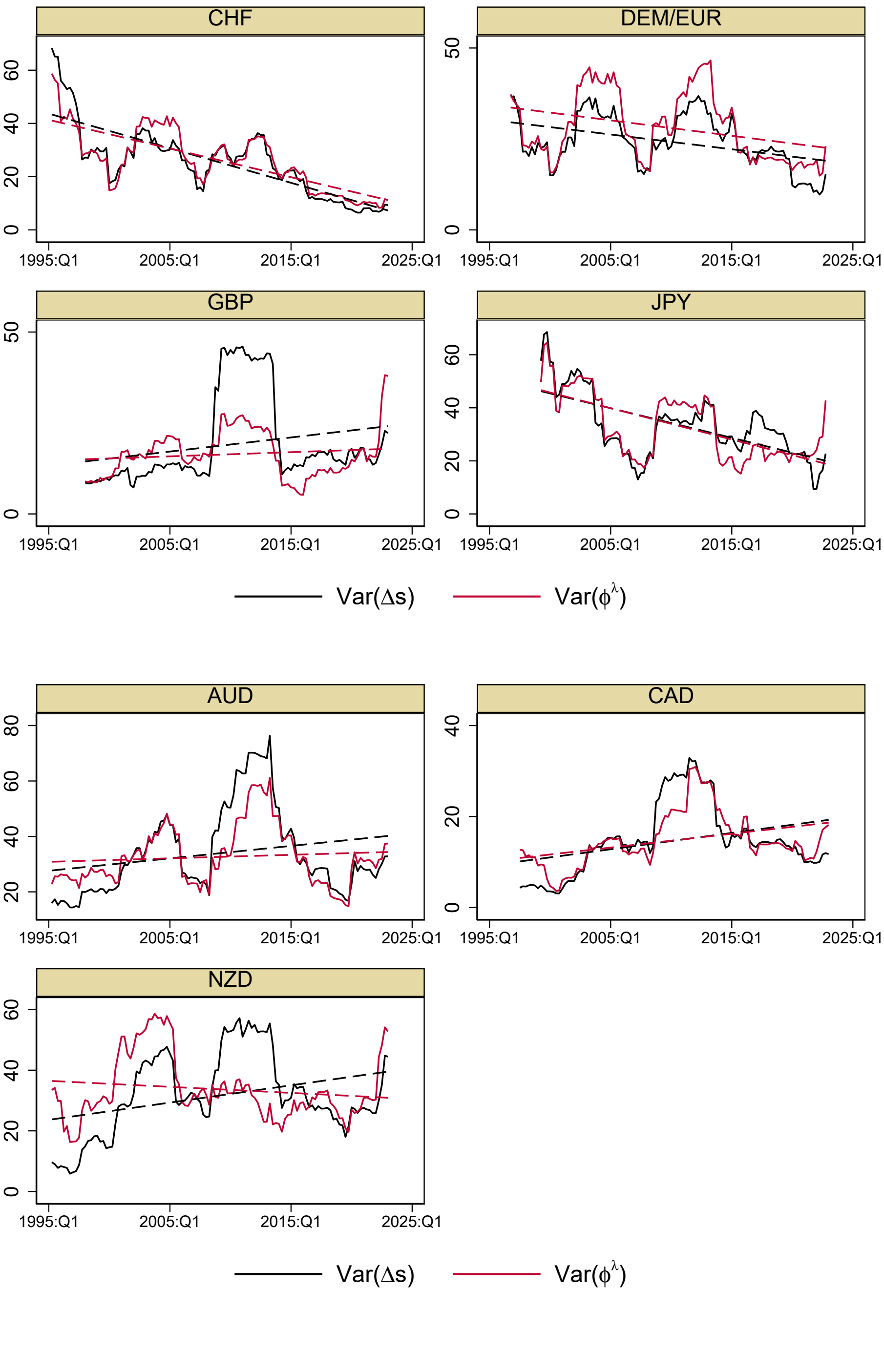


Figure 15: $2Cov(\varphi_t^{EH}, \varphi_t^{LR})$

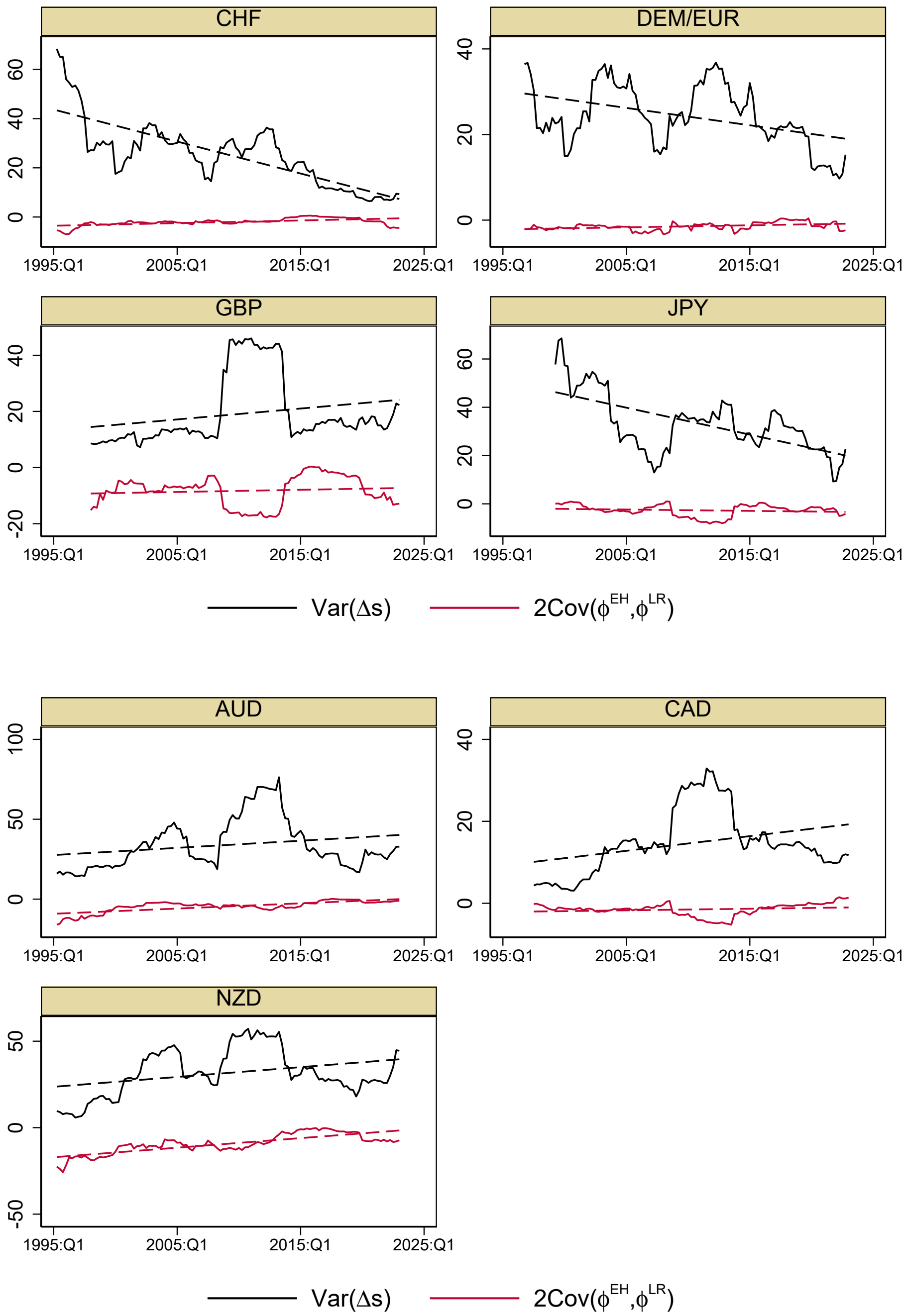
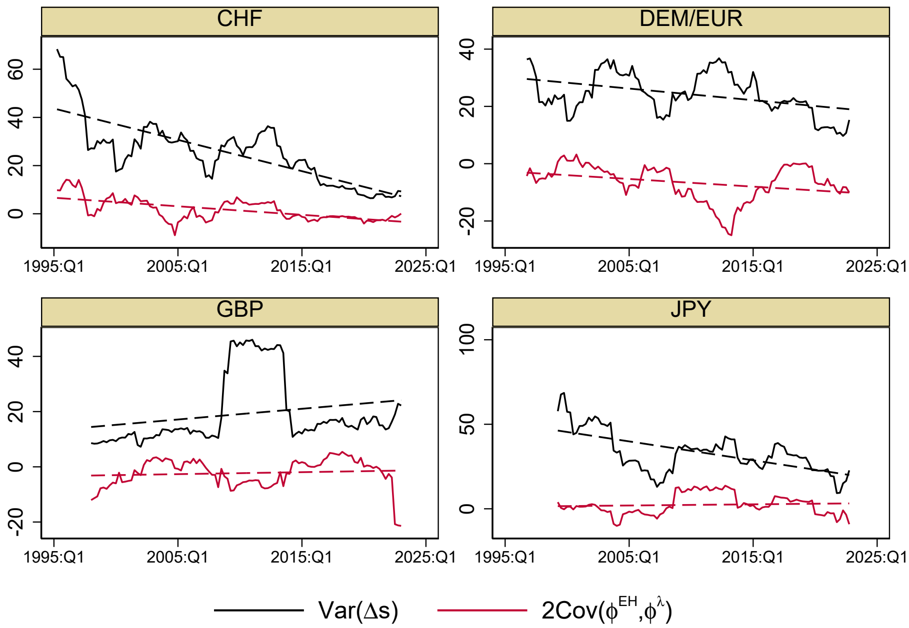


Figure 16: $2Cov(\varphi_t^{EH}, \varphi_t^{\lambda})$



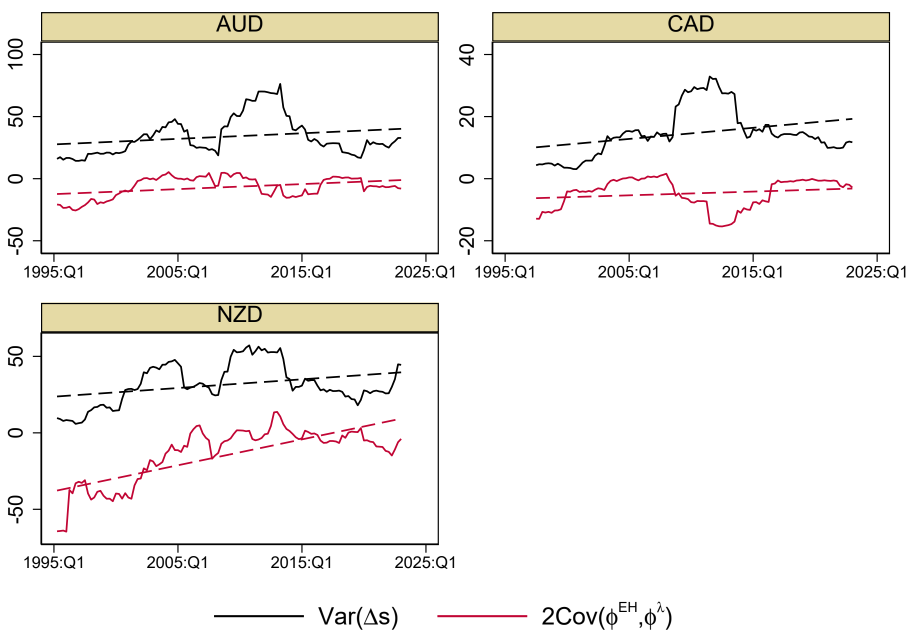
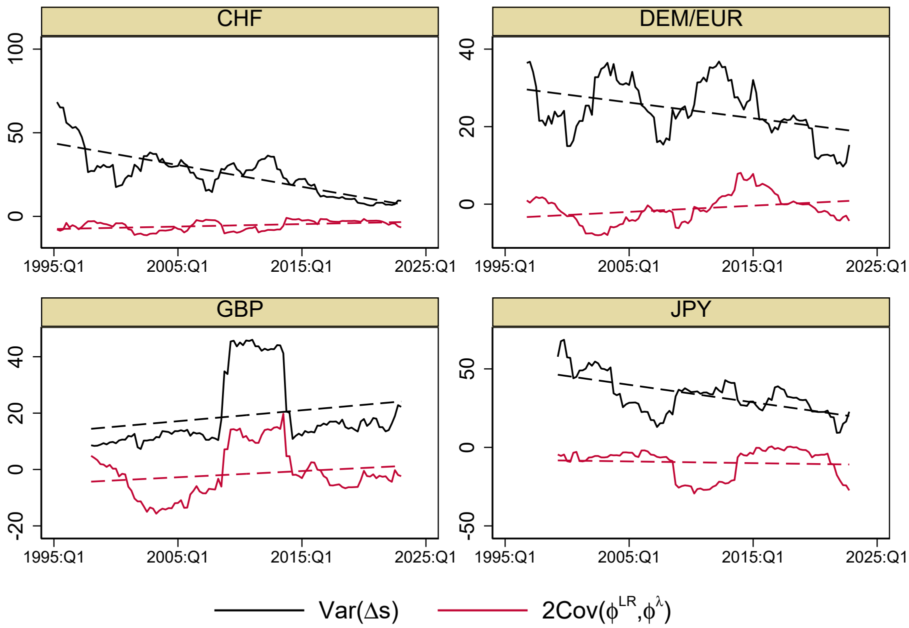



Figure 17: $2Cov(\varphi_t^{LR}, \varphi_t^{\lambda})$



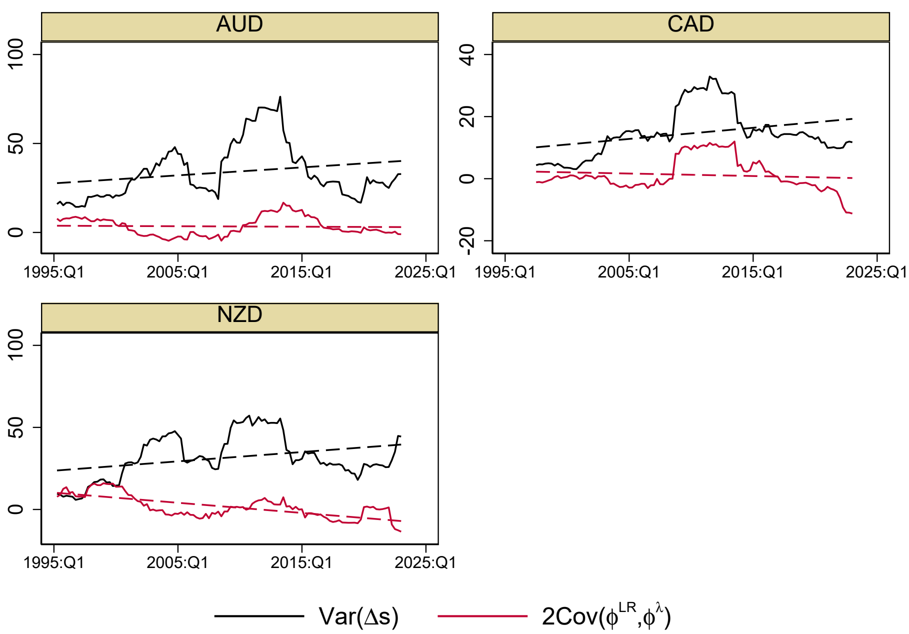
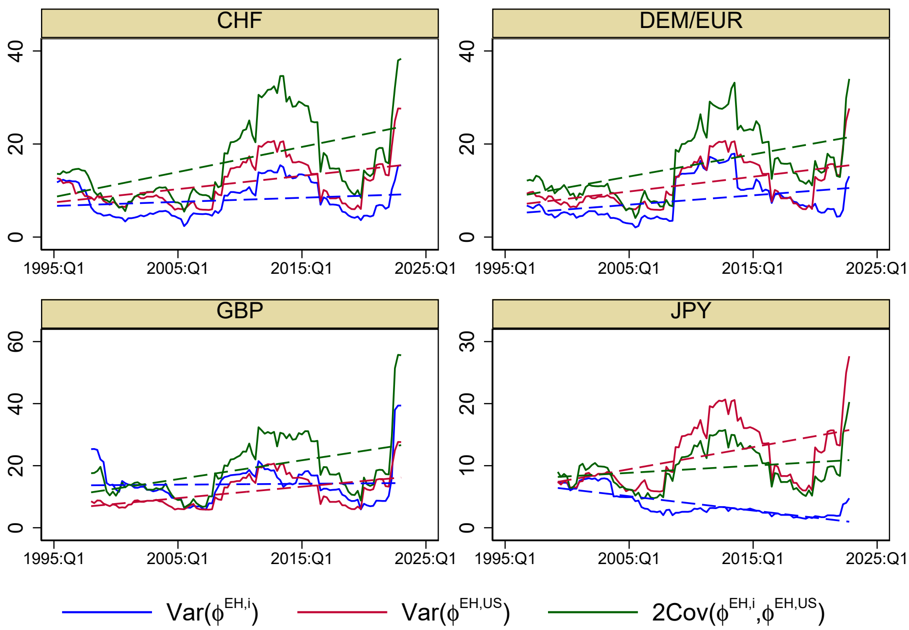
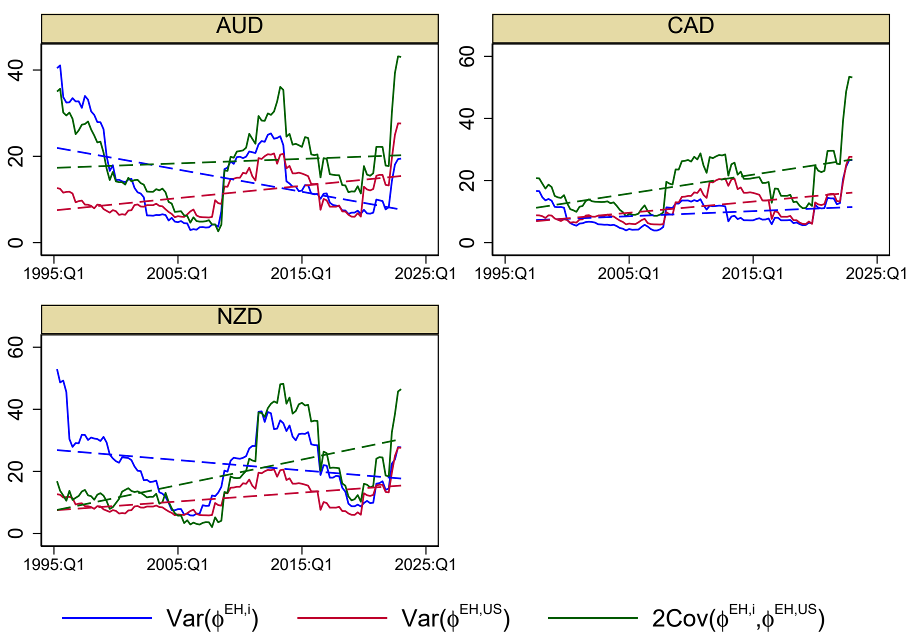



Figure 18: Further Decomposition of $Var(\varphi_t^{EH})$




Note: The components displayed here are those in the decomposition: $Var(\varphi_t^{EH}) = Var(\varphi_t^{EH,i}) + Var(\varphi_t^{EH,US}) - 2Cov(\varphi_t^{EH,i}, \varphi_t^{EH,US})$.

# Appendix

## A Forecast-Augmented VAR

We model exchange rates and short-term interest rates for each country $i$ using the following reduced-form quarterly VAR($p$) process:

$$
\begin{aligned}
F_t &= \bar{F} + \gamma(L) F_{t-1} + \varepsilon_{F,t} && (8)\\
\text{where } \gamma(L) &\equiv \gamma_1 + \gamma_2 L + ... + \gamma_p L^{p-1} \\
\text{and } F_t &\equiv [q_t^{i,US}, \tilde{x}_t^i, z_t^i, x_t^{US}, z_t^{US}]'. && (9)
\end{aligned}
$$

Here, $q_t$ is the level of the real exchange rate defined as units of currency $i$ per US dollar. By including the real exchange rate in levels, we are estimating a specification where a stable estimate of the VAR implies that long-run PPP holds and VAR-based expectations of the long-run real exchange rate are constant. The vector $x_t^{US}$ is a set of variables describing the US yield curve, including the 3-month bill rate as well as the empirical term structure slope and curvature factors defined as:

$$
\begin{aligned}
sl_t^{US} &= y_t^{40,US} - i_t^{US} \\
c_t^{US} &= 2y_t^{8,US} - \left(y_t^{40,US} + i_t^{US}\right).
\end{aligned}
$$

The vector $\tilde{x}_{t+1}^i$ is a set of variables describing the yield curve *differentials* between country $i$ and the US. More specifically, it includes the relative 3-month bill rate as well as the relative slope and curvature factors defined as, $\tilde{sl}_t^i = sl_t^i - sl_t^{US}$ and $\tilde{c}_t^i = c_t^i - c_t^{US}$. The country-specific vector $z_t^j$ for $j \in \{i, US\}$ represents other variables that may be useful for forecasting either short-term interest rates or changes in the exchange rate. Importantly, we always include a quarterly inflation rate (measured using CPI inflation) in $z_t^j$. This allows us to compute VAR-based expectations of nominal exchange rate changes from our estimates of the real exchange rate and inflation equations. The other variables in $z_t^j$ include the GDP gap and the current-account-to-GDP ratio.

In addition to these variables, we include a number of other US macroeconomic variables in $z_t^{US}$. First, we capture global financial conditions using the US VIX index and the spread between the 3-month US LIBOR and Treasury bill rates (the TED spread). While the yield curve variables do capture aspects of financial conditions that affect markets for sovereign debt, the VIX and TED spread can reflect financial conditions in other markets such as equity and interbank lending markets, which may be relevant to financial market participants for forecasting interest rates, inflation, or exchange rates. Secondly, to improve our fit of long-horizon inflation forecasts, we include an exponentially weighted average of lagged US inflation which is constructed as

$$\pi_t^{avg,US} = \rho \pi_{t-1}^{avg,US} + (1-\rho)\pi_{t-p}^{US},$$

where we choose $\rho = 0.95$. When we include $\{\pi_{t-1}^{avg,US}, ..., \pi_{t-p}^{avg,US}\}$ in the VAR in equation (8), this will contain information on US inflation for lags beyond $p$. Note also that the coefficients in the VAR equation for this variable can be fixed at their known values, allowing us to include information in the VAR from further lags of US inflation in a way that minimizes the number of additional coefficients to be estimated.

This variable improves our fit of long-horizon inflation forecasts by capturing the declining trend in inflation expectations as most central banks in our countries of interest began targeting inflation during our sample. Since this decline is common to most countries in our sample, an alternative would've been to use an average or principal component of country-specific exponentially weighted averages rather than only the one for the United States. The issue with such a measure is that the true data-generating process for this variable would be a function of all our countries' inflation rates. To avoid estimating a misspecified equation for this variable, we would have to estimate a large VAR with all countries' variables simultaneously, which is infeasible. Since the US exponentially weighted average inflation has a correlation of .95 with the first principal component estimated from the set of analogous measures for each country, we believe that it is a sufficiently good proxy of the common declining trend in inflation across all the countries in our study.

This reduced-form VAR($p$) in equation (8) can be written in a VAR(1) companion form:

$$\underbrace{\begin{bmatrix} F_t \\ \vdots \\ F_{t-p+1} \end{bmatrix}}_{\mathbf{X}_t} = \underbrace{\begin{bmatrix} \bar{F} \\ 0 \\ 0 \end{bmatrix}}_{\bar{\mathbf{X}}} + \underbrace{\begin{bmatrix} \gamma_1 & \gamma_2 & \cdots & \gamma_p \\ & \mathbf{I} & & \mathbf{0} \end{bmatrix}}_{\mathbf{\Gamma}} \underbrace{\begin{bmatrix} F_{t-1} \\ \vdots \\ F_{t-p} \end{bmatrix}}_{\mathbf{X}_{t-1}} + \underbrace{\begin{bmatrix} \varepsilon_{F,t} \\ 0 \\ \vdots \end{bmatrix}}_{\mathbf{\Xi}_t}. \qquad (10)$$

To ameliorate the problem of overparameterization in unrestricted VARs, we follow Cushman and Zha (1997) in restricting both the contemporaneous and the lagged relationships between the variables in the VAR, i.e., imposing zero restrictions on the elements of $\{\gamma_1, ..., \gamma_p\}$. More specifically, we consider a specification where each country's financial variables follow a smaller three-variable VAR.[18] This can be interpreted as a version of a three-factor affine term structure model where we directly measure, rather than estimate, the factors and where

[18] One caveat is that we do not impose a zero lower bound (ZLB) in the VAR. However, once the estimation is disciplined by survey data, we estimate negative 3-month bill rate forecasts mainly only for countries and time periods where actual short-term interest rates were negative.

we do not further impose no-arbitrage restrictions. One advantage of this specification versus one that models the short-term interest rate as a function of macroeconomic variables (such as a Taylor rule) is that it uses information from long-term yields in a parsimonious way. This allows the estimates to better capture the effects of forward guidance, among other things, on expectations and is therefore more appropriate for a sample that includes ZLB episodes.

Our next set of restrictions concerns the macroeconomic variables. We assume that changing economic conditions in the United States affect expectations over macro variables in other countries through spillovers from the United States into the macroeconomy of these other countries. See Miranda-Agrippino and Rey (2015) for VAR-based evidence of such spillovers. At the same time, we restrict US macroeconomic variables to depend only on lags of themselves and US financial variables. Lastly, we allow the real exchange rate to enter as a lag only in its own equation. We impose this restriction so that information from lagged exchange rates themselves will not enter the nominal interest rate or long-term exchange rate terms. This distinction becomes relevant when we consider the importance of movements in these terms in driving variation exchange rate changes. As will be seen below, the model is still able to produce forecasts that closely mimic survey forecasts even with this restriction.

To summarize, if we partition each matrix $\{\gamma_1, ..., \gamma_p\}$ into five blocks corresponding to the partitioning of $F_t$ given in (9), then the above restrictions imply the following zero restrictions on the matrix of VAR coefficients:

$$\gamma_l = \begin{bmatrix} \bullet & \bullet & \bullet & \bullet & \bullet \\ 0 & \bullet & 0 & 0 & 0 \\ 0 & \bullet & \bullet & \bullet & \bullet \\ 0 & 0 & 0 & \bullet & 0 \\ 0 & 0 & 0 & \bullet & \bullet \end{bmatrix} \quad \text{for } l = 1, ..., p. \tag{11}$$

Our main innovation to the existing literature on exchange rate decompositions is that we estimate not only (10) subject to (11), but that we further discipline the estimation using survey forecasts of exchange rates, interest rates, and inflation to ensure that our model-implied estimates capture private sector expectations well.

More specifically, we add the following set of equations relating survey forecasts to VAR-implied forecasts:

$$\mathbf{Y}_t^S = H_t\left(\bar{\mathbf{X}}, \mathbf{\Gamma}\right)\mathbf{X}_t + H_t^Z \mathbf{Z}_t + \mathbf{\Xi}_{h,t}^S \tag{12}$$

where $\mathbf{Y}_t^S$ is a vector of survey forecasts. The right-hand-side of the above equation maps current and lagged data $\{F_{t-l}\}_{l=0}^P$ into model-implied forecasts that correspond to this vector of survey forecasts. $H_t\left(\bar{\mathbf{X}}, \mathbf{\Gamma}\right)$ is the matrix of coefficients on the VAR variables $\mathbf{X}_t$, which contains up to $p$ lags of VAR variables. It's a function of the coefficient matrices in (10) as well as $t$ through the quarter of the year that period $t$ falls in. The dependence on the quarter is a result of the forecast horizons and variable definitions in our survey data. For the same reason, the mapping is also a function of additional variables $\mathbf{Z}_t$ which contains further lags of the VAR variables and data on price levels. The error $\Xi^S_{h,t}$ can be interpreted as capturing measurement error due to the discrepancy between forecasters' observations of real-time macroeconomic data versus our use of current vintage data as well as small differences between the timing of the surveys and our data observations. See the Appendix for further details on this mapping.

Taken together, the system of equations given by (10) and (12) can be interpreted as a way to interpolate and extrapolate the survey data available in $\mathbf{Y}^S_t$ to other horizons in a way that's consistent with the data-generating process in (10) and the behavior of actual realized one-period ahead data. Without making any further assumptions regarding the errors, we can consistently estimate the coefficients $\bar{\mathbf{X}}$ and $\mathbf{\Gamma}$ subject to the restrictions in (11) by minimizing the sum of squared errors from all equations in (10) and (12).[19] Since the decomposition given in equations (3) and (5) relies heavily on forecast revisions, we also include differences between model-implied and survey forecast revisions as additional errors in this estimation.[20] We estimate this system using quarterly data with a lag length of two quarters for the following nine economies against the US: Australia, Canada, Germany/Euro area, Japan, New Zealand, Switzerland, and the United Kingdom. For all financial variables, we use end-of-quarter values when possible. The overall sample time period is 1990–2023 but we exclude periods of currency pegging, prior to 1992:Q4 for the GBP and 2011:Q3–2015:Q1 for the CHF, and samples for individual countries may also differ slightly due to data unavailability.

To ensure consistency of the coefficients in the data-generating process of the US variables, we estimate the equations for US variables separately over the full sample of data available for the US and then hold these coefficients fixed when estimating country $i$ equations for each country in our sample.

[19]This can be alternatively interpreted as estimating the regressions implied by (10) and (12) with cross-equation coefficient restrictions generated by the fact that $\bar{\mathbf{X}}$ and $\mathbf{\Gamma}$ show up in both sets of equations. Under this interpretation, the equations in (12) represent an estimation of data-generating processes for survey expectations as a function of observable variables in our VAR.

[20]For cases where the available forecast horizons do not allow us to construct revisions, we use changes in forecasts.

## A.1 Calculating the Components of the Exchange Rate Decomposition

Using the estimated VARs, the five components of exchange rate changes listed in equation (6) can be easily obtained. First, to represent the expected excess return, $\lambda_t$, in terms of VAR variables, note that the exchange rate change and lagged short-term interest rate differential can be expressed as

$$\begin{aligned} \Delta s_t &\equiv \Delta q_t + \tilde{\pi}_t = \left(e_q + e_\pi^i - e_\pi^j\right) \mathbf{X}_t - e_q \mathbf{X}_{t-1} \\ \tilde{\imath}_{t-1} &= e_{\tilde{\imath}} \mathbf{X}_{t-1}, \end{aligned}$$

where $e_q$ is a row vector that selects $q_t$ from $\mathbf{X}_t$. That is, it has the same number of elements as $\mathbf{X}_t$ with an entry of 1 corresponding to the position of $q_t$ in $\mathbf{X}_t$ and zeros elsewhere. Likewise, $e_{\tilde{\imath}}$ is the selection vector corresponding to the short-term interest rate of countries $i$ relative to the US and $e_\pi^i$ and $e_\pi^j$ are the selection vectors for inflation in country $i$ and the US, respectively. Thus, denoting VAR-implied expectations at time $t$ by $\hat{E}_t$, we have the following expression for the lagged currency premium:[21]

$$\lambda_{t-1} = \hat{E}_{t-1}[\Delta s_t] - \tilde{\imath}_{t-1} = \left(e_q + e_\pi^i - e_\pi^j\right)\left(\bar{\mathbf{X}} + \mathbf{\Gamma} \mathbf{X}_{t-1}\right) - \left(e_q + e_{\tilde{\imath}}\right) \mathbf{X}_{t-1}.$$

The final three terms in equation (6) are infinite sums of changes in expectations. Note that the VAR-implied change in expectations over future $\mathbf{X}_{t+k}$ can be written simply as a linear combination of the time $t$ reduced-form residuals:

$$\hat{E}_t \mathbf{X}_{t+k} - \hat{E}_{t-1} \mathbf{X}_{t+k} = \mathbf{\Gamma}^k \mathbf{\Xi}_t.$$

Using this fact, the remaining three VAR-implied exchange rate change components can be constructed as follows, as long as estimates of the VAR are stationary, which is true for all

[21] The $\hat{E}_t$ operator denotes expectations based on the linear projections performed in the VAR estimation. Although not explicitly delineated, the operator conditions only on the set of regressors included in the estimation of each equation. Due to the restrictions set out above, this means that the relevant information set differs across variables.

our currency pairs:[22]

$$
\begin{aligned}
\varphi_t^{EH,F} &= e_{\tilde{i}} \left( \mathbf{I} - \mathbf{\Gamma} \right)^{-1} \mathbf{\Xi}_t \\
\varphi_t^{\lambda,F} &= \left[ \left( e_q + e_\pi^i - e_\pi^j \right) \mathbf{\Gamma} - \left( e_q + e_{\tilde{i}} \right) \right] \; \left( \mathbf{I} - \mathbf{\Gamma} \right)^{-1} \mathbf{\Xi}_t \\
\varphi_t^{LR} &= \left( e_\pi^i - e_\pi^j \right) \left( \mathbf{I} - \mathbf{\Gamma} \right)^{-1} \mathbf{\Xi}_t .
\end{aligned} \tag{13}
$$

Note that none of the terms in this decomposition are a residual in the traditional sense since each of the terms can be directly computed from the variables and coefficient estimates in the reduced-form VAR model. These five terms sum to the exchange rate change without any other residual in the equation because the decomposition is based on a definition of the expected excess return that holds exactly by assumption.

## A.2 Details on Mapping VAR to Survey Forecasts

The VAR augmented with survey data given by equations (10) and (12) in the main text can be written in the following more compact state-space form:

$$
Z_t = \bar{\mathbf{\Gamma}} Z_{t-1} + \bar{\mathbf{\Xi}}_t
$$

$$
\begin{bmatrix} Y_t^A \\ Y_t^S \end{bmatrix} = \underbrace{\begin{bmatrix} E^A \\ E_t^S \end{bmatrix}}_{\mathbf{E}_t} Z_t + \begin{bmatrix} 0 \\ \Xi_t^s \end{bmatrix}
$$

where $Z$ includes a constant, the elements in $X$ as described in Section 3.1, and the additional lags of $X$ that appear in equation (12). $\bar{\mathbf{\Gamma}}$ thus includes the coefficients in $\bar{\mathbf{X}}$ and $\mathbf{\Gamma}$ as well as additional ones and zeros. $\bar{\mathbf{\Xi}}_t$ contains $\mathbf{\Xi}_t$ and zeros. $Y_t^A$ contains observed actuals which are mapped using a selection matrix $E^A$ to the elements in the state vector $Z_t$. $Y_t^S$ contains survey forecasts which are a linear function of $Z_t$ where $E_t^S$ is a product of selection matrices and powers of $\bar{\Gamma}$, as shown below. The time variation in $E_{t+1}^S$ results from the nature of the survey forecasts, which will be detailed below. $\Xi_t^s$ are i.i.d. Gaussian errors whose variances are, for parsimony, parameterized by country-variable-horizon groups (following Crump, Eusepi, and Moench (2018)). Within each country and survey variable, forecasts for horizons up to two quarters out form one group, those for horizons three quarters to two years out form another and those for long-run averages of the 3-month interest rates form

[22] While no restrictions were imposed on the residuals when estimating the VAR, in order to derive the analytical results in (13) and also to define the VAR based expectations in equation (12) we assume that $\check{E}_t \mathbf{\Xi}_{t+k} = 0$. Given that the approach we take here is similar to estimating the parameters of a pre-specified data generating process for the consensus forecast data, as long as we are consistent and match the survey data well, it is inconsequential whether we allow for persistence in the VAR residuals. The VAR should be interpreted simply as a way to interpolate and extrapolate survey data for horizons for which it's unavailable.

the final group.

The mapping between actual data and the survey forecasts is given by the matrix:

$$E_t^S = H_t^S \underbrace{\begin{bmatrix} I \\ \bar{\Gamma} \\ \vdots \\ \bar{\Gamma}^{h_{\max}} \end{bmatrix}}_{\tilde{\bar{\Gamma}}},$$

where $h_{\max}$ is the longest available horizon for our set of survey variables. Right-multiplying $\widetilde{\Gamma}$ by the state vector $Z_t$ results in a large matrix containing model-implied forecasts for horizons 0 to $h_{\max}$. Each row of $H_t^S$ corresponds to the mapping for a single survey forecast. Most rows of $H_t^S$ are selection vectors selecting the relevant forecast horizon and variable. There are a few notable exceptions discussed below:

1. Mapping annualized quarterly log growth rate actuals to annual average percent growth rates (e.g., 0-2 years ahead inflation forecasts):

   Let $z_{j,t}$ be an annualized quarterly log growth rate of some variable $X_t$ so that we have

$$\begin{aligned} z_{j,t} &\approx 400\Delta x_t \\ \text{where } x_t &\equiv \ln X_t \end{aligned}$$

   Let $y_{i,t}^S$ be a forecast of the annual average percent growth rate of $X_t$ between years $h-1$ and $h$ ahead of the current year. Then we have,

$$\begin{aligned} y_{i,t}^S &= 100E_t\left[\frac{X_{t-q}+X_{t-q+1}+X_{t-q+2}+X_{t-q+3}}{X_{t-q-1}+X_{t-q-2}+X_{t-q-3}+X_{t-q-4}}-1\right] \quad \text{where } q = Q(t)-4h-1 \\ &= 100E_t\left[\Delta x_{t-q+3}+2\Delta x_{t-q+2}+3\Delta x_{t-q+1}+4\Delta x_{t-q}+3\Delta x_{t-q-1}+2\Delta x_{t-q-2}+\Delta x_{t-q-3}\right] \\ &= \sum_{l=-3}^{3}\underbrace{\frac{4-|l|}{4}}_{w_l}E_t[z_{j,t-q+l}] \end{aligned}$$

   In the above expression, $Q(t)$ gives the quarter of the year that $t$ falls in. In the context of the framework above, the relevant row of $H_{t+1}^S$ would contain a vector of zeros and the elements of $\{w_l\}$ in a way that results in the weighted average shown above.

2. Mapping real exchange rate forecasts to nominal exchange rate forecasts:

   Our model contains real exchange rates $q_t$ while the survey participants forecast the nominal exchange rate $s_t$. We use the relationship below to obtain model-implied forecasts of $s_t$ which we map to the survey data.

$$\hat{E}_t s_{t+h} = \hat{E}_t q_{t+h} + \sum_{i=1}^{h} \hat{E}_t \tilde{\pi}_{t+i} + \tilde{p}_t$$

where $E_t^S s_{t+h}$ is the observed $h$-period ahead forecast, $E_t^M s_{t+h}$ is the model-implied forecast and $\tilde{p}_t$ is the actual relative price level.

# B Data Details

## B.1 Macroeconomic Variables Used in Section 2

Section 2 utilizes a longer monthly data sample starting in 1973. Variables that had only quarterly data are carried forward to monthly.

- 10 year yields – Global Financial Data
- Unemployment rate – Global Financial Data
- Total CPI – OECD (NZL quarterly only)
- Industrial Production (Total IP for all countries but Japan, Manufacturing IP for Japan, quarterly for NZL and part of the CHE sample)
- Exchange rates – Global Financial Data

| | Start | End |
|---|---|---|
| AU | 1973:M1 | 2023:M7 |
| CA | 1973:M1 | 2023:M7 |
| CH | 1973:M1 | 2023:M3 |
| DE | 1973:M1 | 2023:M7 |
| JP | 1973:M1 | 2023:M8 |
| NZ | 1973:M1 | 2023:M6 |
| UK | 1973:M1 | 2023:M7 |
| US | 1973:M1 | 2023:M8 |

## B.2 Macroeconomic and Financial Variables used for the Exchange Rate change Decomposition

- *Exchange rates*: End-of-quarter exchange rates are computed using daily data from Global Financial Data.

- *Short-term rates*: End-of-quarter three-month bill rates are obtained from the following sources:
  - Australia, Canada, New Zealand, Switzerland, United Kingdom, and United States: Central bank data obtained through Haver Analytics.
  - Germany: Reuters data obtained through Haver Analytics. German three-month bill rates are replaced with three-month EONIA OIS swap rates starting in 1999:Q1.
  - Japan: Bloomberg
- *Zero-coupon yields:* End-of-quarter zero-coupon yields are obtained from the following sources:
  - Canada, Germany, Switzerland, and United Kingdom: Central banks. German zero-coupon bond yields are replaced with estimates of zero-coupon yields on AAA-rated euro area sovereign debt provided by the European Central Bank (ECB).
  - Australia, New Zealand: Data from Wright (2011) extended with data from central banks
  - Japan: Bloomberg.
  - United States: Gürkaynak, Sack, and Wright (2007)
- *Output gap and current account-to-GDP ratio:* All macro data are from the OECD Main Economic Indicators and Economic Outlook databases. The GDP gap is computed using the OECD's annual estimates of potential GDP, which were log-linearly interpolated to the quarterly frequency. German data are replaced with euro-area data starting in 1999:Q1.
- *CPI inflation:* Government statistical agencies.
- *US VIX and TED spread:* Haver Analytics.
- *Market-based interest rate surprises and expected changes:* These are computed using prices of futures on 3-month interest rates on the last trading day of each quarter. These expectations refer to the 3-month rates on each contract's last trading day, which typically falls within the second-to-last week of each quarter. When computing the surprises and expected changes in these interest rates, the actual rate used is the underlying rate of each futures contract. The futures data are all obtained from Bloomberg and are based on the following underlying rates:
  - Australia: Australian 90-day bank accepted bills.
  - Canada: Canadian three-month bankers' acceptance.

– Switzerland: Three-month Euroswiss.

– Germany/EU: ICE three-month Euribor.

– New Zealand: New Zealand 90-day bank accepted bills.

– United Kingdom: Three-month Sterling LIBOR.

– United States: Three-month Eurodollar.

The following table shows the start and end of our data samples for each currency. For the CHF, we also exclude the period of fixed exchange rates (2011:Q3–2015:Q1) from the estimation of the VAR coefficients though we still compute exchange rate change components over this period.

| | Start | End |
|---|---|---|
| AU | 1990:Q3 | 2023:Q1 |
| CA | 1992:Q4 | 2023:Q1 |
| CH | 1990:Q3 | 2023:Q1 |
| DE | 1992:Q1 | 2022:Q4 |
| JP | 1994:Q3 | 2022:Q4 |
| NZ | 1990:Q3 | 2023:Q1 |
| UK | 1993:Q2 | 2023:Q1 |
| US | 1990:Q3 | 2023:Q1 |

## B.3 Survey data details

In the VAR, we include the following survey data for three-month interest rates, CPI inflation and exchange rates:

*Blue Chip Economic Indicators*

- Countries: Australia, Canada, Germany/Eurozone, Japan, United Kingdom, United States
- Non-US variables: Current, 1, and 2 years ahead forecasts of three-month interest rates, CPI inflation and exchange rates.
- US variables: 7-11 year ahead average three-month bill rate (starting in 1990:Q1).
- Other details: Forecasts for German three-month interest rates and CPI inflation are replaced with Eurozone forecasts starting in January 2000, when they become available.

*Blue Chip Financial Forecasts*

- Countries: Australia, Canada, Germany/Eurozone, Japan, Switzerland, United Kingdom, United States
- Variables: 3, 6 and 12 month ahead three-month interest rate and exchange rate forecasts.
- Other details: Forecasts for German three-month interest rates and exchange rates are replaced with Eurozone forecasts starting in January 1999.

*Consensus Economics*

- Country coverage: Australia, Canada, Germany/Eurozone, Japan, New Zealand, Switzerland, United Kingdom, United States
- Variables: Current, 1, and 2 years ahead and 6-10 year ahead average for CPI inflation; 3, 12, and 24 month ahead for exchange rates. 6-10 year ahead average GDP growth forecasts are used to impute long-horizon non-US three-month bill rate forecasts, but are not directly included in the VAR estimation.
- Other details: Forecasts for Germany are replaced with Eurozone forecasts as they become available. Short-horizon CPI inflation and three-month interest rate forecasts switch from Germany to Eurozone in December 2002 and January 2005, respectively. Long-horizon CPI inflation and GDP growth forecasts switch from Germany to Eurozone in April 2003.

Other details:

- The *Blue Chip* publications contain forecasts from around 50 survey respondents while *Consensus Economics* polls approximately 200 forecasters while each publication contains responses from about 10–30 participants for any given variable.
- For interest rates, we have long-horizon forecasts for the U.S (6-10 or 7-11 year ahead averages), but not other countries. Instead, we impute long-horizon 3-month interest rates using a procedure akin to the one employed in Wright (2011). More specifically, Wright (2011) fits US long-horizon 3-month interest rate forecasts to US long-horizon inflation and GDP growth forecasts and then uses the estimated coefficients to impute long-horizon 3-month interest rate forecasts for other countries. We adopt this method but also include 5-year-ahead 5-year forward rates in the regression as we found that this greatly improved our fit of US long-horizon interest rate forecasts. Table A1 below shows the regression of US long-horizon rates whose estimates are used to impute long-horizon interest rate forecasts for other countries. Compared to the original Wright (2011) specification, adding 5-year-ahead 5-year forward rates to the regression raises the adjusted $R^2$ from 81 to 88 percent over our sample.
- All inflation forecasts are for an annual-average (price index) over annual-average basis. Annual interest rate and exchange rate forecasts are for end-of-year values. Months-ahead forecasts are for end-of-month values.
- Surveys are usually published within the first two weeks of the month and contain responses from survey participants from the end of the prior month. To map the survey data to our model, we backdate the survey variables (for example, a January publication is mapped to model-implied forecasts as of the end of Q4).
- CPI forecasts for the U.K. begin in 2004:Q2 in all databases. Previous inflation forecasts for the U.K. were for the retail price index.
- Three-month interest rate forecasts, for certain countries, are explicitly for interbank rather than bill rates. There are also cases where the survey does not specify the particular rate that respondents forecast. To account for this, we allow data-source-specific constants in the rows of equation ( 12) that correspond to three-month interest rate forecast data. Though sometimes statistically significant, the estimated constants are small and consistent with average spreads between interbank and bill rates. When assessing model fit, we include this additional constant in the model-implied counterpart to forecasts of the *surveyed variable*. However, this additional constant is not considered to be part of the model-implied three-month *bill rate* forecasts.

Table A1: Relationship Between US Long-Horizon Interest Rate Forecasts, Macroeconomic Forecasts, and Forward Rates

| | Baseline | Wright(2011) |
|---|---|---|
| 6Y-10Y Ahead Inflation Forecast | 0.75** | 1.76*** |
| | (0.30) | (0.34) |
| 6Y-10Y Ahead GDP Growth Forecast | 0.86*** | 1.60*** |
| | (0.16) | (0.15) |
| 5Y Ahead 5Y Forward Rate | 0.32*** | |
| | (0.05) | |
| Constant | -1.45** | -4.40*** |
| | (0.65) | (0.65) |
| Adj. $R^2$ | 0.88 | 0.81 |
| # of Observations | 69 | 69 |

Note: The dependent variable is the 6Y-10Y ahead 3-month interest rate forecast. All dependent and independent variables in this regression are specific to the US and are contemporaneous in timing. All forecast data used is from *Consensus Economics*. The sample is semi-annual observations over 1997:Q3–2013:Q4 and quarterly observations thereafter until 2022:Q4. Heteroskedasticity-robust standard errors are reported in parentheses.

# C Additional Figures

Figure A1: $\varphi_t^{EH,F,i}$ and Changes in 10-year Yields

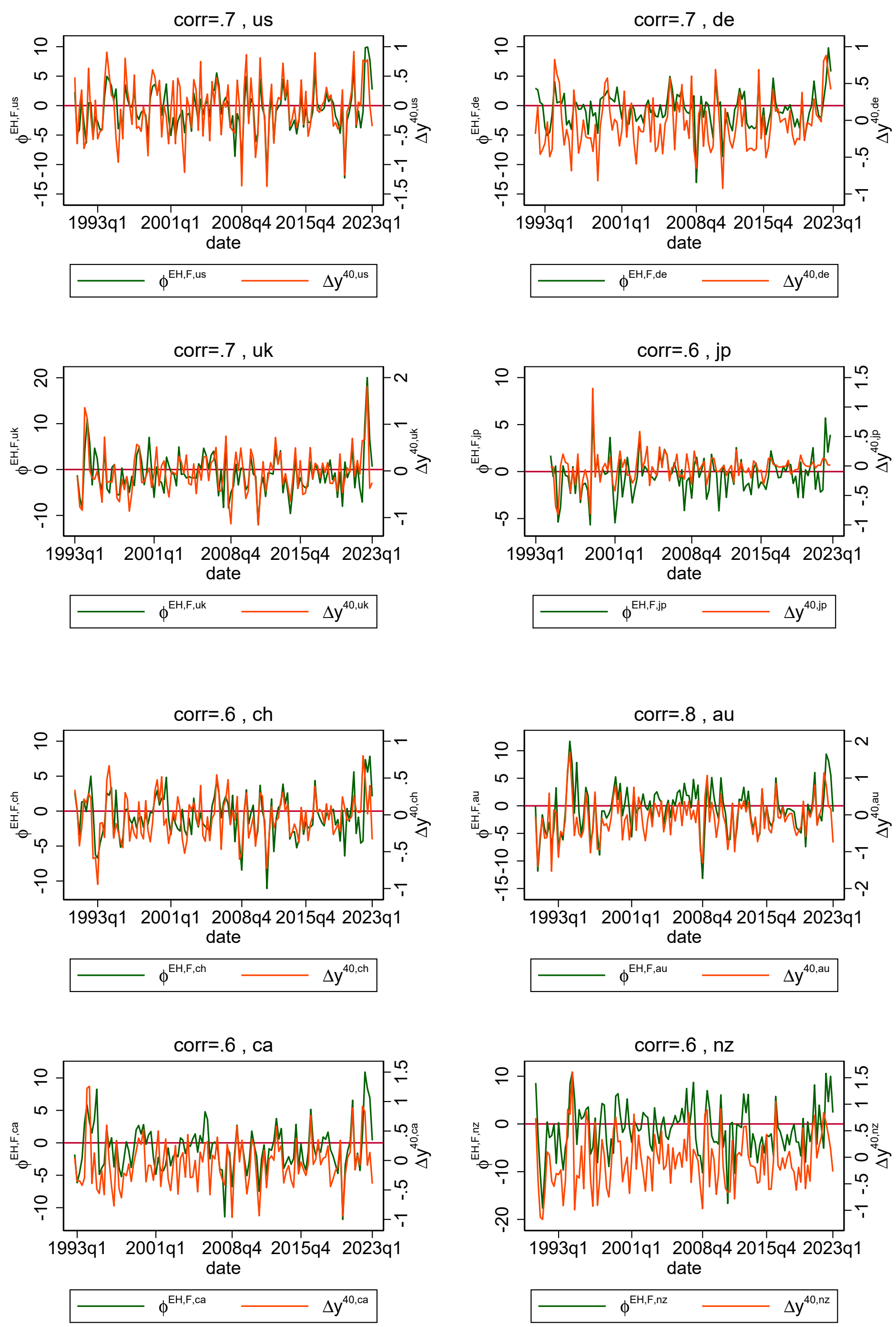


Figure A2: $\varphi_t^{LR,i}$ and Inflation

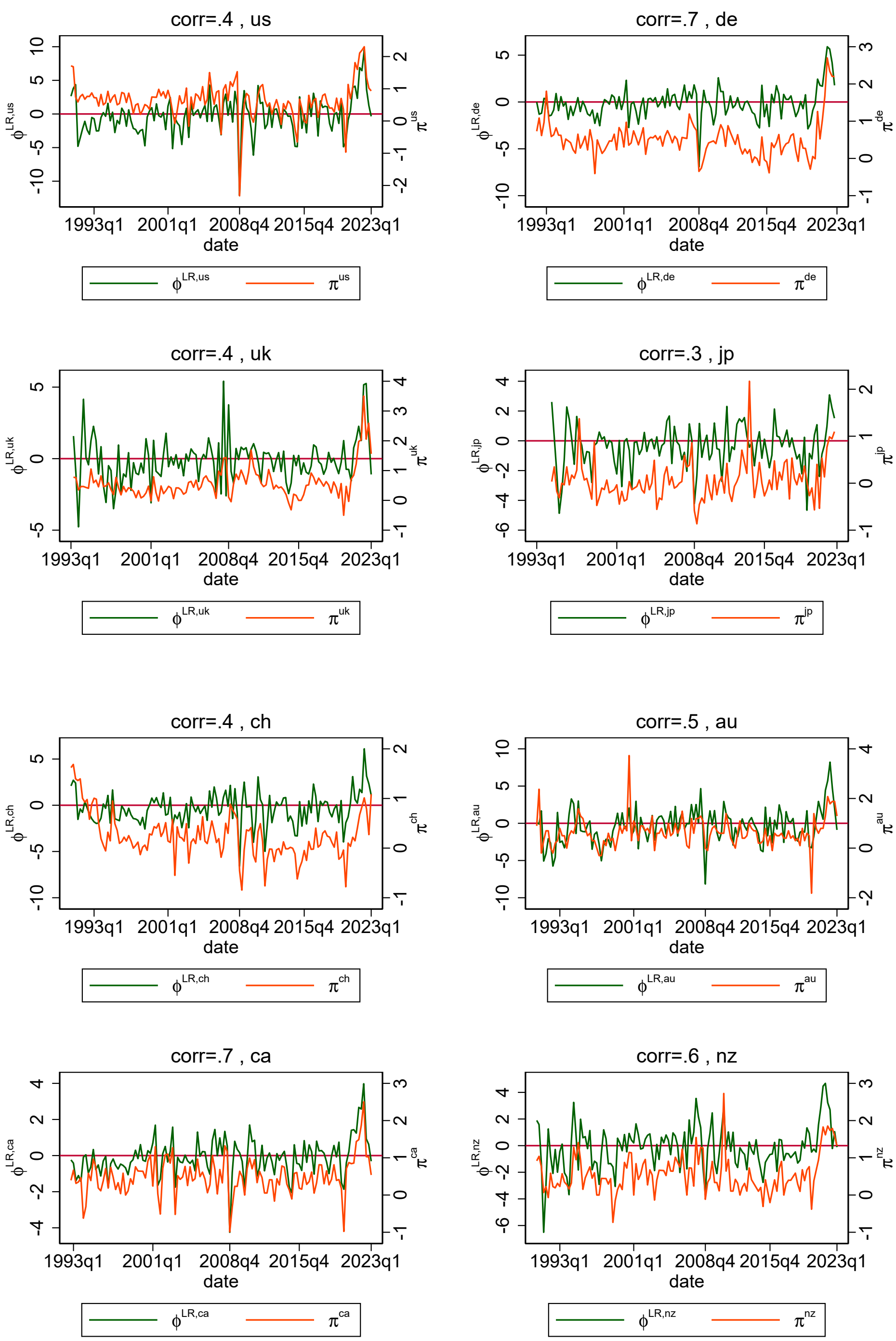
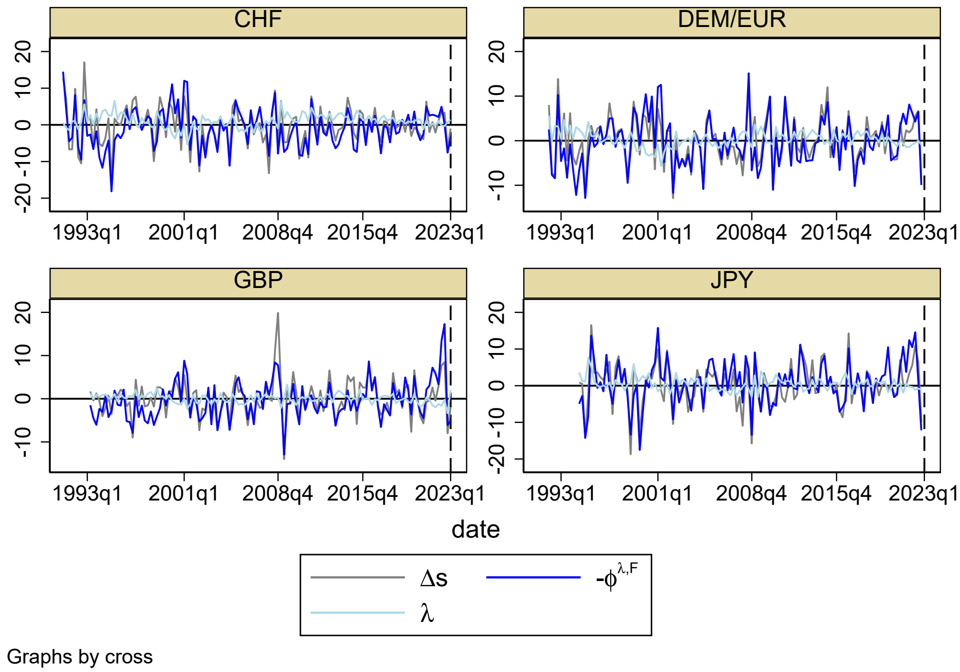


Figure A3: Lagged and Expected Future Currency Premia Components



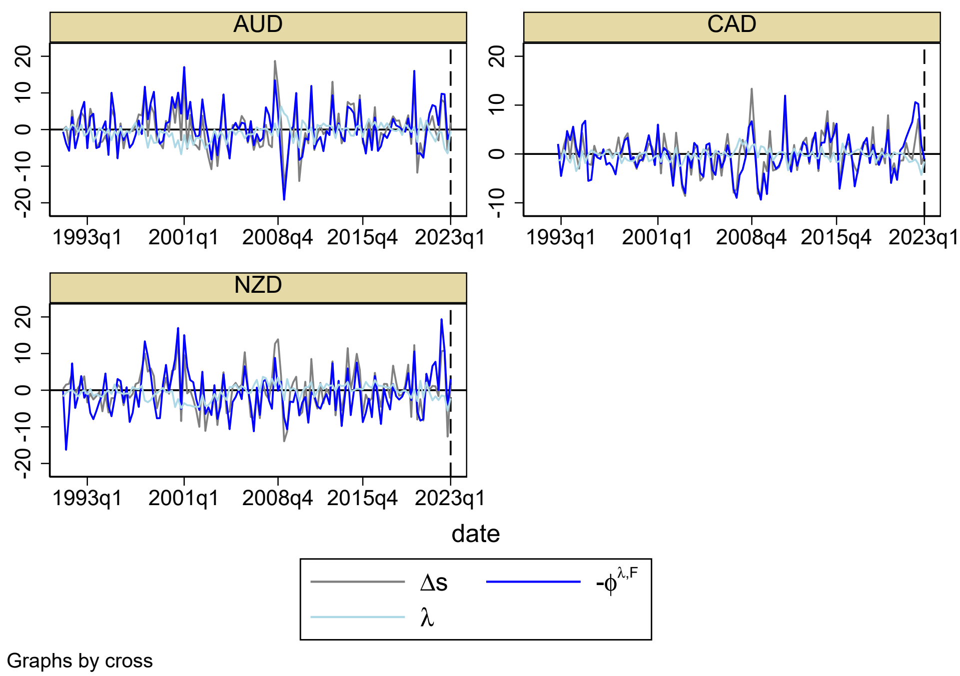



Figure A4: Lagged and Expected Future Interest Rate Differential Components

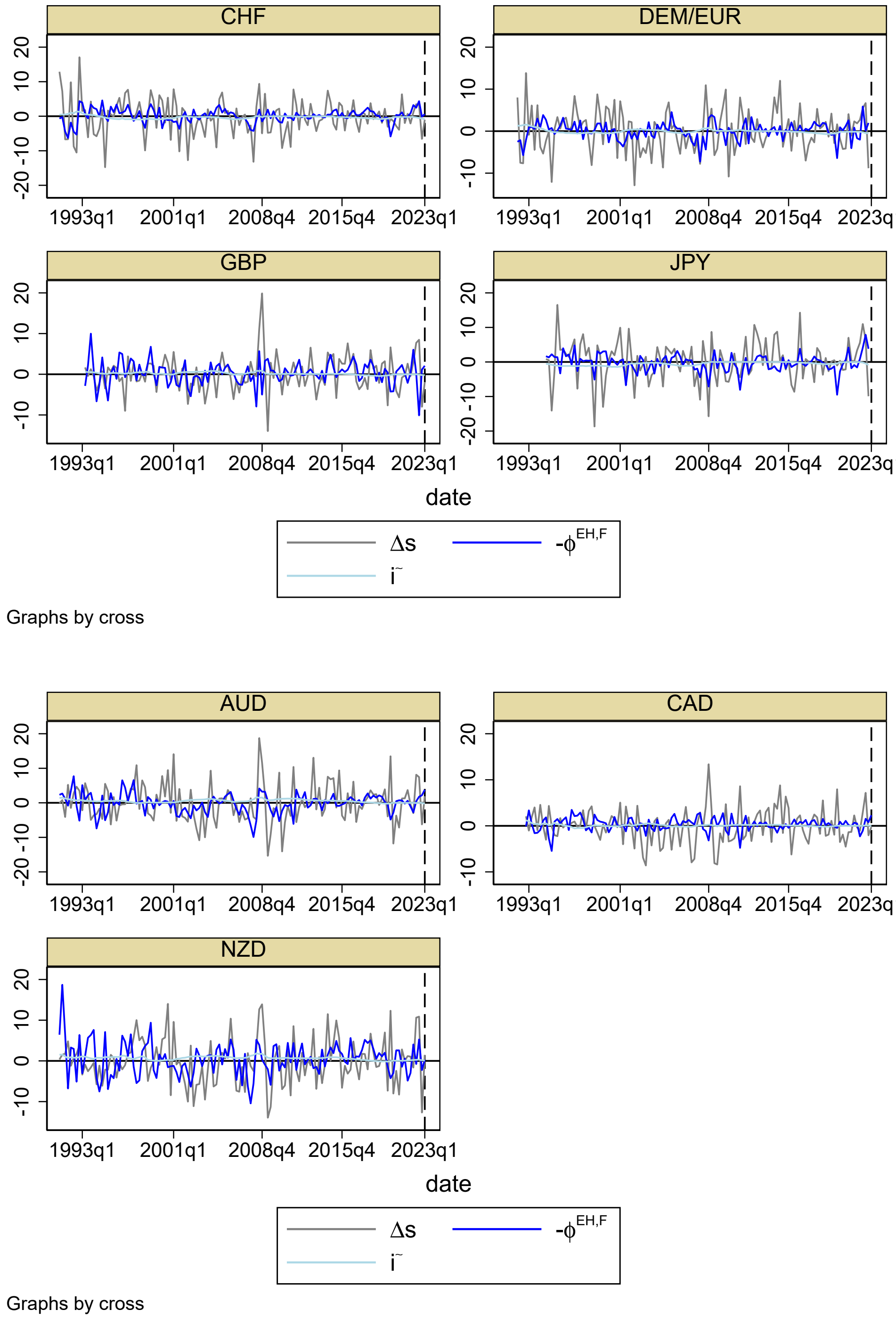


Figure A5: Expected Future Inflation Component