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***JEL Classification:*** G12, G15, F31.
***Keywords:*** Forward premium puzzle, currency variance risk premium, stock variance risk premium, unspanned currency uncertainty, forex return predictability.

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This paper presents evidence that the foreign exchange appreciation is predictable by the currency variance risk premium at a medium 6-month horizon and by the stock variance risk premium at a short 1-month horizon. Although currency variance risk premiums are highly correlated with each other over longer horizons, their correlations with stock variance risk premiums are quite low. Interestingly the currency variance risk premium has no predictive power for stock returns. We rationalize these findings in a consumption-based asset pricing model with orthogonal local and global economic uncertainties. In our model the market is incomplete in the sense that the global uncertainty is not priced by local stock markets and is therefore a forex-specific phenomenon—the currency uncertainty's effects on the expected stock return are offsetting between the cash flow channel and the volatility channel.

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# 1 Introduction

This paper joins the vast literature on the forward premium puzzle by relating exchange rate returns to the stock and currency variance premiums measured as the option-implied variance minus the expected or realized variance of stock and currency returns respectively.[1] First, we empirically show that the foreign exchange (forex) variance risk is indeed priced in forex markets—the currency variance risk premium is a useful predictor of the exchange rate return, especially at a medium 6-month horizon. Then, we document a finding that the stock variance risk premium can also predict the exchange rate return at a short 1-month horizon. Thus, currency and stock variance risk premiums seem to contain differential information content for the exchange rate return. This is confirmed by the fact that stock and currency variance premiums are poorly correlated with each other and by the evidence that the currency variance premium is not a useful predictor for local stock market returns.

To rationalize our new empirical findings, we introduce a two-country general equilibrium model with an uncertainty component common to both countries and incomplete local stock markets. Our model features differential information content of stock and currency variance premiums to explain the exchange rate appreciation under the following conditions: (i) the common uncertainty component is forex-specific and is therefore not priced in local stock markets, (ii) stock and currency variance premiums are imperfectly correlated (i.e., driven by different shocks), (iii) the currency variance risk premium isolates the forex-specific uncertainty, and (iv) both currency and stock variance premiums are useful predictors for forex return.

Our model entertains the possibility of market incompleteness in the sense that there are sources of risk orthogonal to any local or foreign stock market (Brandt and Santa-Clara, 2002). To be more precise, the forex-specific uncertainty appears to be a *hidden* or *unspanned* factor in local stock markets because its effect on the local consumption growth

[1] Zhou (2009) provides preliminary evidence that the U.S. stock variance risk premium predicts 1-month Dollar/Euro and Dollar/Pound returns.

is compensated by its effect on the conditional expectation of the country-specific economic volatility. In other words, forex-specific uncertainty's effects on the expected stock return are offsetting between the consumption growth channel and the consumption volatility channel.

To illustrate the ability of our model to reproduce the observed predictability patterns, we calibrate the parameters driving the economic growth process to mimic the U.S. and Germany as the local and the foreign economy respectively. We also calibrate the parameters driving the common uncertainty to match the observed dynamics of the Euro/Dollar appreciation rate and impose the market-incompleteness condition. We find that our model is able to qualitatively replicate the pattern for the predictive power of the currency variance premium for the exchange rate return while simultaneously matching the predictive power of the stock variance premium for stock returns previously documented in the literature.

There is a recent literature trying to assess explicitly or implicitly the role of the volatility risk premium in explaining the time variation in currency returns. Della Corte, Sarno, and Tsiakas (2011) provide empirical evidence that the volatility term premium, i.e., the relation between spot and forward-implied volatilities, is positive, time-varying, and predictable. In a related paper, Menkhoff, Sarno, Schmeling, and Schrimpf (2012) document the finding that global forex volatility risk measured as innovations to global forex volatility is priced in currency markets (also see Bakshi and Panayotov, 2012). Chernov, Graveline, and Zviadadze (2012) find evidence that jump risk in currency variance may be priced in forex markets, yet variance jumps seem to be unrelated to interest rates or macroeconomic news. Using different methodologies, Farhi, Fraiberger, Gabaix, Ranciere, and Verdelhan (2009), Jurek (2009), and Brunnermeier, Nagel, and Pedersen (2008) relate the high observed prices of currency options to the desire of agents to hedge rare and severe changes in exchange rate movements and find that crash-hedged carry trade strategies yield significantly lower returns than traditional carry trade strategies.[2] Finally, Mueller, Stathopolous, and Vedolin (2012)

[2]The rare disaster model in Farhi and Gabaix (2011) aims to rationalize this empirical finding. Burnside, Eichenbaum, Kleshchelski, and Rebelo (2011) provide a related interpretation based on the peso problem.

find that the forex correlation risk premium—inferred from currency option and spot prices—is also priced in currency markets. To the best of our knowledge, our paper is the first one to show that both stock and currency variance premiums have useful information to explain exchange rate returns at short and medium horizons and that the currency variance risk is not spanned by the local stock markets.

Our work is also intimately related to the early evidence that exchange rate volatility is time varying (Engle, 1982; Baillie and Bollerslev, 1989; Engel and Hamilton, 1990; Engle, Ito, and Lin, 1990; and Gagnon, 1993). However, we focus our attention on the additional information from the forex derivatives market not only to pin down the dynamics of forex volatility but also to show that the risk of this volatility is actually priced in forex markets. Graveline (2006) shows that the information from exchange rate options is valuable for the estimation of the exchange rate volatility that is much harder to identify only using time-series data. Bakshi, Carr, and Wu (2008) show that jumps are crucial in order to capture the currency return dynamics and to generate realistic currency option pricing behaviors. Finally, Bates (1996) and Guo (1998) provide evidence that the Dollar/German Mark variance risk premium is priced in the forex options market within a Heston (1993) type model. Our approach is consistent with these efforts trying to understand the exchange rate dynamics from the perspective of exchange rate options, yet we differ by offering an incomplete market interpretation—a framework that relies on currency and stock variance risk premiums to isolate different components of global and local economic uncertainties.

There is certainly a large literature focusing on the forward premium puzzle or the deviation from the uncovered interest parity (UIP). Early works by Hansen and Hodrick (1980), Fama (1984), Bansal (1997), and Backus, Foresi, and Telmer (2001), among others, find evidence that, as a consequence of this deviation, carry trade excess returns are large, on average positive, and predictable. Motivated by the recent finding that the stock variance premium can predict international stock market returns (Bollerslev, Marrone, Xu, and Zhou, 2012 and Londono, 2012), we investigate the role of currency and stock variance risk premiums in explaining this forward premium puzzle. Our contribution on this regard is twofold. First, we empirically document the different informational content of currency and stock variance risk premiums for explaining the predictable time-variation in the forward premium. Second, we provide an alternative incomplete-market interpretation of the forward premium puzzle in that the forex-specific global uncertainty is not priced in or spanned by the local stock markets.

The rest of the paper is organized as follows. In Section 2, we summarize the main empirical findings emphasizing the different informational content of stock and currency variance risk premiums for explaining the time variation in currency and stock returns. In Section 3, we propose a general equilibrium model with local and global consumption uncertainties and provide an interpretation of our empirical finding based on incomplete local stock markets. Finally, Section 4 concludes.

# 2 Currency returns and variance risk premiums

Motivated by the preliminary evidence in Zhou (2009) that the stock variance risk premium has forecasting power for 1-month Dollar/Euro and Dollar/Pound returns, we conduct a comprehensive analysis of currency return predictability from stock and currency variance risk premiums. Following the convention for the stock variance risk premium ($VP_t$) (Bollerslev, Tauchen, and Zhou, 2009; Drechsler and Yaron, 2011), we define the foreign exchange (forex) or currency variance risk premium of the returns in U.S. dollars per unit of foreign currency as

$$XVP_t \;\equiv\; E_t^Q\left(\sigma^2_{c,t+1}\right) - E_t^P\left(\sigma^2_{c,t+1}\right), \tag{1}$$

where the currency variance risk premium ($XVP_t$) equals the difference between the risk-neutral (Q) and the physical (P) expectations of the currency return variance ($\sigma^2_{c,t+1}$). For our empirical exercise below, we substitute the risk-neutral expectation with the currency option-implied variance ($h$)-months ahead, using the Black-Scholes at-the-money (ATM) options;

and we substitute the physical expectation with the sum of squared log daily currency returns.

More sophisticated approaches to calculate the variance risk premium include the model-free approach to measure risk-neutral expected variance (Britten-Jones and Neuberger, 2000), high-frequency return based measures of realized variance (Bollerslev, Tauchen, and Zhou, 2009), and VAR forecasted measures of the physical expectation of the variance (Drechsler and Yaron, 2011). We expect that the results reported here must hold true first for the simplest measures and should remain robust to more elaborate measures.

## 2.1 Data and summary statistics

Our sample runs from January 2000 to December 2011 and covers the exchange rate (with respect to the U.S. dollar) of the following countries' currencies: Japan (JPY), Great Britain (GBP), and the Euro Area (EUR). The ATM implied volatility for these currency pairs is obtained from JP Morgan's OTC currency options database while the spot rates are obtained from Bloomberg. We also use Bloomberg to obtain the daily price and the (model-free) implied volatility for each country's stock index. Finally, the $h$-month zero-coupon rates used to calculate the interest rate differentials are calculated by the Board of Governors of the Federal Reserve system using data from the local central banks.

Figure 1 displays the dollar exchange rates for the currencies in our sample and Table 1 reports the summary statistics and cross correlations for the 1-month currency depreciation rates. The mean appreciation of the JPY, GBP, and EUR against the U.S. dollar are between -0.02 and 0.19 percent with a relatively high volatility ranging from 2.29 to 2.59. Although the currency rates do not deviate significantly from the normal distribution, their AR(1) coefficients are significant, ranging between 0.17 and 0.31. It is particularly interesting to note that the currency pairs seem to have a common component, as the pairwise correlation ranges from 0.16 to 0.73.

Figure 2 displays the 1, 3, and 6-month horizon currency variance risk premiums (XVP) for the currencies in our sample while Table 2 reports their summary statistics and cross correlations. Overall, (annualized) XVPs are positive ranging from 2.44 to 17.95 (percentage squared) for 1-month, 4.14 to 19.96 for 3-month, and 6.95 to 22.64 for 6-month horizons. XVPs are also very volatile with unconditional standard deviations ranging from 40 to 53. In general, currency variance risk premiums are negatively skewed and have high kurtosis. 1-month XVPs are nearly serially uncorrelated, while the 6-month XVPs are somewhat persistent with statistically significant AR(1) coefficients ranging from 0.70 to 0.85.

A very important feature of currency variance risk premiums is their correlation structure. On the one hand, the stock and the currency variance risk premium do not show a consistent correlation pattern—e.g., XVPs' correlation with the U.S. VP ranges from -0.46 to 0.27. On the other hand, the correlation between XVP pairs increases with the horizon considered—ranging from 0.07 to 0.38 at 1-month, from 0.28 to 0.62 at 3-month, and from 0.60 to 0.86 at 6-month horizon. For the 1-month XVPs, the first principal component only explains 48 percent of the total variation. This percentage increases to 63 percent when we consider only 3-month XVPs and is as high as 83 percent for the 6-month XVPs.[3] Our empirical finding below will show that XVPs tend to forecast currency returns at a longer 6-month horizon, which may also be related to our theoretical model's implication that there is a common uncertainty factor unique to all currency pairs.

Figure 3 displays the stock variance risk premiums (VP) for the U.S. (US), Japan (JA), the U.K. (UK), and Germany (GE) while Table 3 reports their summary statistics and cross correlations. Annualized stock VPs are averaged around 77.59 to 150.09 (percentage squared), highly volatile with standard deviations between 375 and 445, negatively skewed about -2.25 to -5.55, and with high kurtosis between 15 and 52. Their AR(1) coefficients range from positive significant (U.S. and UK) to indifferent from zero (JA, and GE). In line with the preliminary evidence in Bollerslev, Marrone, Xu, and Zhou (2012) and Londono

[3] Results for the principal component analysis are omitted in order to save space and are available upon request from the authors.

(2012), stock variance risk premiums are highly correlated across countries with a correlation between 0.49 and 0.84. The first principal component of the VPs explains 76 percent of the total variation while the first and second components already explain 89 percent.

In the rest of this section, we investigate up to what extent exchange rate dynamics can be explained by currency and stock variance risk premiums.

## 2.2 The forward premium puzzle and variance risk premiums

The uncovered interest-rate parity (UIP) predicts that the expected *appreciation* of the foreign currency must equal the difference between domestic and foreign interest rates; such that an investor is indifferent between holding a domestic or a foreign bond. However, vast empirical evidence since Fama (1984) have found exactly the opposite—an increase in the domestic interest rate corresponds rather to a *depreciation* of the foreign currency. The UIP violation is especially challenging at short horizons (Hodrick, 1987), and here we provide evidence that the stock and currency variance risk premiums (VPs and XVPs) help explain the predictable time-variation in exchange rates. Our empirical regression setup is

$$s_{t+h} - s_t = b_{x,0}(h) + b_{x,IR}(h)[y_t(h) - y_t^*(h)] + b_{x,VP}(h)VP_t + b_{x,XVP}(h)XVP_t(h) + u_{t+h}, \quad (2)$$

where $s_t$ is the log of the exchange rate (in dollars over any of the foreign currencies considered), and $[y_t(h) - y_t^*(h)]$ is the interest rate differential for $h-$period zero-coupon bonds between the U.S. and the foreign country.

Table 4 reports the predictive power of the variance risk premium measures over the $h$-months ahead appreciation rates. Our results suggest that the U.S. stock variance premium plays the key role in explaining the future appreciation rate for all currencies considered especially at the short 1-month horizon (columns 1 to 3).[4] In particular, following an increase in the U.S. VP, the (1-month ahead) dollar tends to appreciate with respect to the Yen and depreciate with respect to European currencies. The statistical significance is above the 1

[4] Aloosh (2012) also finds some positive evidence of 1-month ahead currency return predictability from the stock variance premium differential between the U.S. and other countries.

percent level for all currencies at the 1-month horizon, above the 1 percent level for the Yen and Pound at the 3-month horizon, and above 1 percent level for the Pound at the 6-month horizon. The predictive power of the stock variance premium over $h$-months ahead appreciation rates remains significant, at almost the same levels, when we control for the foreign VP instead of the U.S. VP for all currencies but the Yen at the 1-month horizon (columns 4 to 6).[5]

The results in Table 4 also suggest that currency variance premiums play the key role in predicting future appreciation rates at a medium 6-month horizon for all currencies considered. The significance level is above 10 percent for the Yen and Euro, and above 1 percent for the Pound after controlling for the U.S. VP, and above the 5 percent for the Yen and Euro and 1 percent for the pound after controlling for the foreign stock variance premiums. Overall, our evidence suggests that stock and currency variance risk premiums are priced in currency markets. That is, they contain useful information to explain the time variation in the future exchange rate return, with the stock variance risk premium mainly in a short horizon and the currency variance risk premium in a medium horizon.

It should be pointed out that the interest rate differential is not significant for all currencies, except for the Yen where it is significant at the 1 percent level for all horizons but with a wrong negative sign—the UIP is violated. Also of note, the effect of the U.S. variance premium over the appreciation rate of the Yen is negative in contrast to its effect over the two other currencies considered. The highly idiosyncratic component of the Japanese stock market and as a consequence the high idiosyncrasy of the Japanese stock variance premium can help us understand this finding. In unreported results we show that the average correlation of the Japanese stock index with the stock indices of the other countries in our sample is as low as 22 percent (based on daily returns). For all other countries, the average pair-wise correlation is around 63 percent. Furthermore, our structural model featuring a country-

[5] Due to the high correlation between VPs reported in Table 3, estimation results for a regression including both the U.S. and the foreign VPs will be highly affected by multicollinearity.

specific uncertainty component offers a consistent explanation for the predictive power of the stock variance premium for exchange rate returns.

Table 5 reports the predictive power of both stock and currency variance premiums for $h$-months ahead stock returns,

$$r_{t+h} - r_{f,t} = b_{r,0}(h) + b_{r,VP}(h)VP_{US,t} + b_{r,XVP}(h)XVP_{i,t}(h) + u_{i,t+h}, \tag{3}$$

where $r_t$ is the local- or foreign-market stock index log return for each one of the four countries. The results in columns 1 to 3 suggest that except for the U.K. at the 6-month horizon (being significant at the 1 percent level and negative), the currency variance risk premiums seem to have no additional predictive power for U.S. stock returns. The results in column 4 to 6 suggest that the \$/GBP XVP (significant at the 1 percent level for the 6-month horizon) and the \$/EUR XVP (significant at the 10 percent level for the 3-month horizon) have additional predictive power for foreign stock stock returns.[6] Overall, our evidence suggests that the currency variance risk premium is not priced in local stock markets. Finally, it is important to note that consistent with the evidence reported by Bollerslev, Marrone, Xu, and Zhou (2012) and Londono (2012), the U.S. stock variance risk premium does have strong predictive power for all countries' stock returns, with the $t$-statistics and $R^2$'s maximized at the 3-month horizon.[7]

In summary, we provide new and relevant empirical evidence that stock and currency variance risk premiums predict short 1-month and mid 6-month exchange rate returns respectively, while for the local stock market returns, the currency variance risk premium has no additional predictive power. In the following section, we offer a structural economic model to rationalize these new empirical findings.[8]

[6]In unreported results we show that the currency variance risk premiums of the U.K. (significant at the 1 percent level for the 3-month horizon) and the Euro Area (significant at the 5 percent level for the 1- and 3-month horizons) have additional predictive power for non U.S. stock returns after controlling for the foreign instead of the US VP.

[7]Lustig, Roussanov, and Verdelhan (2012) also provide evidence for global sources of risk with predictive power for currency returns and orthogonal to global risks linked to financial markets.

[8]Our main empirical findings are robust to including the Swiss Franc (CHF) at least for a subsample

# 3 A two-country model with incomplete markets

In this section, we introduce a two-country consumption-based asset pricing model that allows us to rationalize our main empirical findings. In the first part of the section, we explain the model setup and its main implications. According to our model, each country's consumption growth is exposed to two types of economic uncertainty, a local and a global uncertainty. The representative agent in each country prefers an early resolution of uncertainties and the market is incomplete in the sense that the global uncertainty is not priced by the local stock markets and is therefore a forex-specific phenomenon. In the second part of the section, we introduce a general framework for our model and find the necessary conditions under which the stock and currency variance premiums contain differential information to explain the exchange rate appreciation. In the final part of the section, we calibrate the parameters in the model to illustrate the model's ability to qualitatively replicate the predictability patterns in our empirical evidence.

## 3.1 Incomplete markets and forex-specific uncertainty

Our model extends the domestic framework in Bollerslev, Tauchen, and Zhou (2009) (BTZ2009 hereafter) to include a source of uncertainty common to the two economies. We assume that the domestic economy evolves as follows:

$$g_{t+1} = \mu + \phi_l \sigma_{l,t} z_{g_l,t+1} + \phi_w \sigma_{w,t} z_{g_w,t+1}, \tag{4}$$

where the local macroeconomic uncertainty is characterized by

$$\sigma^2_{l,t+1} = \mu_l + \rho_l \sigma^2_{l,t} + \rho_{lw} \sigma^2_{w,t} + \phi_{\sigma_l} \sqrt{q_t} z_{\sigma_l,t+1},$$

before the introduction of the 1.20 CHF/EUR ceiling on September 6th, 2011. However, investigating the impact of central bank interventions on currency markets is out of the scope of this paper. Therefore, the results for a sample including the CHF are left unreported, and our model below does not explicitly consider the possibility of such interventions.

and

$$q_{t+1} = \mu_q + \rho_q q_t + \phi_q \sqrt{q_t} z_{q,t+1}.$$

The foreign economy follows a similar process and its state variables are labeled with star (*). We assume that there are neither within nor cross-country statistical correlations in the shocks. Each country's consumption growth process is also exposed to a global source of uncertainty characterized by

$$\sigma_{w,t+1}^2 = \mu_w + \rho_w \sigma_{w,t}^2 + \phi_{\sigma_w} \sigma_{w,t} z_{\sigma_w,t+1},$$

where the global shock, $z_{\sigma_w,t+1}$, is uncorrelated with the local shocks.

We assume that each country's representative agent is endowed with recursive preferences (Epstein and Zin, 1989, and Weil, 1990) with homogeneous parameters. Thus, the domestic stochastic discount factor (SDF hereafter) is given by

$$\begin{aligned} m_{t+1} &= \theta \log \delta - \frac{\theta}{\psi} g_{t+1} + (\theta - 1) r_{t+1} \qquad (5) \\ &= b_{mo} + b_{mg} g_{t+1} + b_{mr} r_{t+1}, \end{aligned}$$

where $r_t$ is the domestic stock market return. Finally, we follow the intuition in Brandt and Santa-Clara (2002) and assume that markets may be incomplete in the sense that the global uncertainty is orthogonal to any local or foreign stock price process and becomes priced once the forex market is added to the local stock markets.[9,10] Thus, the augmented SDF with respect to the local stock market is assumed to follow:

$$\widetilde{m}_{t+1} = m_{t+1} + \widetilde{\lambda} \sigma_{w,t+1}^2, \qquad (6)$$

where $\widetilde{\lambda}$ is the additional price of risk of $\sigma_{w,t}^2$ in the forex market. A similar expression is

[9]The idea of a forex-specific uncertainty, $\sigma_{w,t}^2$, is closely related to the unspanned volatility literature initiated by Collin-Dufresne and Goldstein (2002), and to the more general concept of a *hidden* risk factor (Duffee, 2011).

[10]The key components in our model: existence of a common factor and market incompleteness, are also related to the intuition in Zapatero (1995).

assumed for the augmented SDF with respect to the foreign stock market, $\widetilde{m}^*_{t+1}$.

In order to solve the model, as it is standard in the literature, we propose a process for the wealth-consumption ratio of the asset that pays the consumption endowment in terms of the state variables,

$$z_{t+1} = A_0 + A_{\sigma_l}\sigma^2_{l,t+1} + A_q q_{t+1} + A_{\sigma_w}\sigma^2_{w,t+1}. \tag{7}$$

The detailed solution of the model is presented in Appendix A. In this section, we are particularly interested in finding the conditions under which the global uncertainty is not priced in or unspanned by local stock markets—$A_{\sigma_w} = A^*_{\sigma_w} = 0$. The model solution yields

$$A_{\sigma_w} = \frac{(1-\kappa_1\rho_w) - \sqrt{(1-\kappa_1\rho_w)^2 - 2\kappa_1^2\phi^2_{\sigma_w}(\theta\kappa_1 A_{\sigma_l}\rho_{lw} + \frac{1}{2}(1-\gamma)^2\phi^2_w)}}{\theta\kappa_1^2\phi^2_{\sigma_w}}.$$

Therefore, the necessary condition for the incompleteness of the domestic stock market becomes

$$\phi^2_w = -\frac{\kappa_1\phi^2_l}{(1-\kappa_1\rho_l)}\rho_{lw}. \tag{8}$$

Eq. (8) implies that the effect of the global uncertainty on the local consumption growth, $\phi^2_w$, needs to be compensated by a decrease in the effect of this uncertainty on the conditional expectation of the country-specific uncertainty, $\rho_{lw}$, in order for the global uncertainty to be orthogonal to the domestic stock market.

If the condition in Eq. (8) holds, the model-implied domestic expected stock return is given by

$$E(r_{t+1}) - r_f = \gamma\sigma^2_{g,t} + (1-\theta)\kappa_1^2(A^2_{\sigma_l}\phi^2_{\sigma_l} + A^2_q\phi^2_q)q_t, \tag{9}$$

where $\sigma^2_{g,t} = (\phi^2_l\sigma^2_{l,t} + \phi^2_w\sigma^2_{w,t})$ is the total volatility of the domestic consumption growth, and $\gamma = -(b_{mr} + b_{mg})$.

The model-implied stock variance risk premium for the domestic market is given by

$$VP_t \;=\; Cov_t(\sigma^2_{r,t+1}, m_{t+1}),$$

where $\sigma_{r,t}^2 = Var_t(r_{t+1})$. Then,

$$VP_t \quad = \quad b_{vp,q} q_t + b_{vp,\sigma_w} \sigma_{w,t}^2, \tag{10}$$

where

$$b_{vp,q} = (\theta - 1)\kappa_1 (A_{\sigma_l} \phi_l^2 \phi_{\sigma_l}^2 + \kappa_1^2 A_q (A_{\sigma_l}^2 \phi_{\sigma_l}^2 + A_q^2 \phi_q^2) \phi_q^2),$$

and

$$b_{vp,\sigma_w} = (\theta - 1)\kappa_1 A_{\sigma_w} (\kappa_1^2 A_{\sigma_w}^2 \phi_{\sigma_w}^2 + \phi_w^2) \phi_{\sigma_w}^2.$$

Thus, in line with the intuition in BTZ2009, Eq. (10) implies that the domestic stock variance risk premium isolates the domestic economy's volatility of volatility (VoV), $q_t$. A similar expression can be found for $VP_t^*$ in terms of $q_t^*$. Together with Eq. (9), the expressions for the domestic and foreign stock variance premiums also imply that the local stock variance premiums should be useful predictors for the local stock returns.

The model-implied expected variation in exchange rate returns can be found as follows:

$$E_t(s_{t+1}) - s_t = (y_{t,1} - y_{t,1}^*) + \frac{1}{2}[Var_t(m_{t+1}) - Var_t(m_{t+1}^*)], \tag{11}$$

where $y_{t+1} = E_t(m_{t+1})$. The components of Eq. (11) can be rewritten as

$$\begin{aligned} y_{t,1} - y_{t,1}^* \quad = \quad & C_s + (\theta - 1)(A_{\sigma_l}(\kappa_1 \rho_l - 1)\sigma_{l,t}^2 - A_{\sigma_l}^*(\kappa_1^* \rho_l^* - 1)\sigma_{l,t}^{*2}) \\ & +(\theta - 1)(A_q(\kappa_1 \rho_q - 1)q_t - A_q^*(\kappa_1^* \rho_q^* - 1)q_t^*) \\ & +(\theta - 1)((\kappa_1 A_{\sigma_l} \rho_{lw} + A_{\sigma_w}(\kappa_1 \rho_w - 1)) - (\kappa_1^* A_{\sigma_l}^* \rho_{lw}^* + A_{\sigma_w}^*(\kappa_1^* \rho_w^* - 1)))\sigma_{w,t}^2, \end{aligned}$$

where $C_s$ is a constant, and

$$\begin{aligned} Var_t(m_{t+1}) - Var_t(m_{t+1}^*) \quad = \quad & \gamma^2(\phi_l^2 \sigma_{l,t}^2 - \phi_l^{*2} \sigma_{l,t}^{*2}) \\ & +(\theta - 1)^2(\kappa_1^2(A_{\sigma_l}^2 \phi_{\sigma_l}^2 + A_q^2 \phi_q^2)q_t - \kappa_1^{*2}(A_{\sigma_l}^{*2} \phi_{\sigma_l}^{*2} + A_q^{*2} \phi_q^{*2})q_t^*) \\ & +\gamma^2((\phi_w^2 + (\theta - 1)^2 \kappa_1^2 A_{\sigma_w}^2 \phi_{\sigma_w}^2) - (\phi_w^{*2} + (\theta - 1)^2 \kappa_1^{*2} A_{\sigma_w}^{*2} \phi_{\sigma_w}^2))\sigma_{w,t}^2. \end{aligned}$$

In order to find the model-implied currency variance risk premium, we proceed in a similar way to the stock variance risk premium. First, we define the one-period log forex return as $c_{t+1} = \ln(S_{t+1}/S_t) = m_{t+1} - m^*_{t+1}$, or alternatively, as $c^*_{t+1} = \ln(S^*_{t+1}/S^*_t) = m^*_{t+1} - m_{t+1}$. Then, from the point of view of the forex-augmented domestic market, the currency variance risk premium would be given by

$$XVP_t = Cov_t(\sigma^2_{c,t+1}, \widetilde{m}_{t+1}),$$

where $\sigma^2_{c,t} = Var_t(c_{t+1})$ and $\widetilde{m}_{t+1}$ is the forex-market augmented SDF defined in Eq. (6). Therefore,

$$XVP_t \;=\; b_{xvp,q} q_t + b_{xvp,\sigma_w} \sigma^2_{w,t}, \tag{12}$$

where

$$b_{xvp,q} = (\theta - 1)\kappa_1 (A_{\sigma_l} \gamma^2 \phi_l^2 \phi_{\sigma_l}^2 + A_q (\theta - 1)^2 \kappa_1^2 (A^2_{\sigma_l} \phi^2_{\sigma_l} + A_q^2 \phi_q^2) \phi_q^2),$$

and

$$b_{xvp,\sigma_w} = ((\theta - 1)\kappa_1 A_{\sigma_w} + \widetilde{\lambda})((\theta - 1)^2 (\kappa_1 A_{\sigma_w} - \kappa_1^* A^*_{\sigma_w})^2 \phi^2_{\sigma_w} + \gamma^2 (\phi_w - \phi^*_w)^2) \phi^2_{\sigma_w}.$$

Together with Eqs. (12) and (10), Eq. (11) implies that the stock and currency variance risk premiums contain useful but differential information to explain the exchange rate appreciation.[11] However, if the condition in Eq. (8) holds, the global uncertainty is strictly a forex-specific phenomenon, and the currency variance risk premium should not contain additional information to explain the time variation in stock returns once you control for the stock variance premium (Eq. (9)).

Our model's implications help understand the empirical evidence in Section 2. First, our empirical evidence suggests that the stock and currency variance risk premiums are imperfectly correlated since they are driven by different shocks. Thus, according to our

[11] See how, since $\sigma^2_{w,t}$ also appears in the expression for the interest rate differential, $y_{t,1} - y^*_{t,1}$, the currency variance premium might also contain useful information to explain the returns of carry trade strategies. We intend to address this issue in future research.

model, the stock variance premium isolates the local uncertainty (Eq. (10)) while the currency variance premium is a function of the local and global/forex-specific uncertainties (Eq. (12)). Therefore, in line with the possibility of market incompleteness, our evidence reveals that the currency variance premium contains no additional useful information, after controlling for the stock variance premium, to explain the time variation in domestic stock returns. Also in line with our model's implications, our empirical evidence suggests that both the currency and the stock variance premiums contain useful but differential information to explain the exchange rate appreciation. Our empirical evidence suggests that while the local uncertainty seems to be an important source of variation especially at the short 1-month horizon, the forex-specific uncertainty is especially useful at the medium 6-month horizon.

## 3.2 Necessary conditions in a general setting

In this part of the section, we propose a more general setting of our model above and find the necessary conditions for the currency variance risk to be priced in currency markets and imperfectly correlated with the stock variance risk premium. Our general model extends the model in Bansal and Shaliastovich (2010) to account for the potential incompleteness of local stock markets. Within this general setting, each country's economy evolves as follows:

$$Y_{t+1} = \mu + FY_t + G_{l,t}z_{l.t+1} + G_{w,t}z_{w,t+1}, \tag{13}$$

where $Y_t = [g_t, x_t, \sigma^2_{l,t}, q_t, \sigma^2_{w,t}]'$. While the long-run risk, $x_t$, and $\sigma^2_{w,t}$ are assumed to be common risk factors, $\sigma^2_{l,t}$ and $q_t$ are strictly domestic state variables.[12] We maintain the affine nature of the model by assuming $G_{l,t}G'_{l,t} = h_{\sigma_l} + H_{\sigma_l}\sigma^2_{l,t} + H_q q_t$, and $G_{w,t}G'_{w,t} = h_{\sigma_w} +$

[12]The model in Colacito and Croce (2012) also builds on the relevance of the preference specification of Epstein and Zin (1989), and Weil (1990), and the assumption of correlated long-run growth perspectives for understanding the forward premium puzzle. However, in contrast to our model, theirs does not model directly the consumption growth volatility. Instead, their model relies on consumption volatility endogenously generated due to risk-sharing when markets become integrated.

$H_{\sigma_w}\sigma^2_{w,t}$.[13,14] For simplicity, and without loss of generality, we assume that $h_{\sigma_l} = h_{\sigma_w} = 0$. We also assume that $H_{\sigma_l}$ and $H_{\sigma_w}$ are diagonal matrices with elements $\varphi^2_{y,\sigma_l}$ and $\varphi^2_{y,\sigma_w}$ for all $y \in Y$. The pricing kernel and the augmented pricing kernel are exactly those in Eqs. (5) and (6) respectively. Finally, the general version of the wealth-consumption ratio in Eq. (7) is given by

$$z_t = A_0 + A'Y_t.$$

Propositions 1 to 4 describe the conditions under which a general version of our model yields the main qualitative implications suggested by our empirical evidence. That is, the stock and currency variance premiums contain useful but differential information to explain the exchange rate appreciation and the currency variance premium is not a useful predictor for local stock market returns.[15]

*Proposition 1.* The global uncertainty is strictly a forex-specific source of risk if $\varphi_{x,\sigma_w} = \varphi_{\sigma_l,\sigma_w} = \varphi_{q,\sigma_w} = 0$ unless $x_t$, $\sigma^2_{l,t}$ and $q_t$ are all simultaneously not priced in the domestic stock market—$A_x = A_{\sigma_l} = A_q = 0$. This condition implies that, in order to be coherent with the assumption of market incompleteness, the effect of the global uncertainty on the volatility of the long-run component, the domestic economy's volatility or the domestic economy's VoV should be null in order for the global uncertainty not to contain additional useful information for stock returns.

*Proposition 2.* If the condition in proposition 1 holds, the stock variance risk premium is a function solely of domestic state variables. Moreover, in our setting, the stock variance risk premium would isolate the VoV if $\varphi_{\sigma_l,\sigma_l} = \varphi_{q,\sigma_l} = \varphi_{\sigma_w,\sigma_l} = 0$. In other words, if the local volatility does not affect the volatility of $\sigma^2_{l,t}$, $q_t$ or $\sigma^2_{w,t}$, the stock variance risk premium can not only be differentiated from the traditional risk-return trade-off ($\gamma\sigma^2_{g,t}$ in Eq. (9)) but is

[13] One can easily show that including the VoV in the process for the global uncertainty increases significantly the complexity of the equations but is not relevant to rationalize our empirical findings.

[14] Later on, we formally find the conditions under which $\sigma^2_{w,t}$ is not only a global source of risk, but one strictly related to the forex market. In other words, an even more general version of the model in Eq. (13) would feature both global and forex-specific uncertainty.

[15] The proofs to the propositions in this section are presented in Appendix B.

also not driven by the global uncertainty.

*Proposition 3.* Given propositions 1 and 2, the forex-specific uncertainty is a source of risk imperfectly correlated with the local stock variance risk premiums if $\widetilde{\lambda} \neq 0$.

*Proposition 4.* The forex-specific uncertainty is a useful predictor for the exchange rate appreciation if $\varphi^2_{c,\sigma_w} \neq \varphi^{*2}_{c,\sigma_w}$. This condition implies that, under the assumption of homogenous preference function parameters, the impact of the global uncertainty over the local consumption growth processes should be heterogeneous in order for this source of risk to be priced in forex markets.[16]

## 3.3 Model-implied predictability patterns

In the last part of this section, we calibrate our model to illustrate its ability to yield predictability patterns qualitatively comparable to those suggested by the empirical evidence in Section 2. In particular, we show that the model-implied slope coefficient for the predictive power of the currency variance premium for exchange rate returns, the model counterpart of $b_{x,XVP}$ in Eq. (2), and the coefficient of determination linked to this coefficient, $R^2_{x,XVP}$, follow similar patterns to those reported in Table 4. The $h$-horizon model-implied slope coefficient would be given by

$$\beta_{x,XVP}(h) = \frac{Cov(\frac{1}{h}(s_{t+h} - s_t), XVP_t(h))}{Var(XVP_t(h))}, \tag{14}$$

while the coefficient of determination, for a regression where only the currency variance premium is considered, is given by

$$R^2_{x,XVP}(h) = \frac{Cov(\frac{1}{h}(s_{t+h} - s_t), XVP_t(h))^2}{Var(XVP_t(h))Var(\frac{1}{h}(s_{t+h} - s_t))}. \tag{15}$$

[16]See how, the common component in Bansal and Shaliastovich (2010) and Du (2011) cancels out in the expression for the expected appreciation rate precisely because of the homogeneous exposure of both countries to this factor. The relevance of having heterogeneous exposures to the common factor is acknowledged in Gourio, Siemer, and Verdelhan (2012); Farhi, Fraiberger, Gabaix, Ranciere, and Verdelhan (2009); Backus, Foresi, and Telmer (2001) and Lustig, Roussanov, and Verdelhan (2011); and in a no-arbitrage setting in Lustig, Roussanov, and Verdelhan (2012).

We also verify if our calibrated model fits the pattern previously documented in the literature for the predictive power of the stock variance premium for stock returns. The $h$-horizon slope coefficient for the predictive power of the stock variance risk premium for future stock returns is given by

$$\beta_{r,VP}(h) = \frac{Cov(\frac{1}{h}(r_{t+h} - r_{f,t}), VP_t)}{Var(VP_t)}, \tag{16}$$

and the coefficient of determination is in this case

$$R^2_{r,VP}(h) = \frac{Cov(\frac{1}{h}(r_{t+h} - r_{f,t}), VP_t)^2}{Var(VP_t)Var(\frac{1}{h}(r_{t+h} - r_{f,t}))}. \tag{17}$$

The expressions for the components of Eqs. (14) to (17) can be found in Appendix C.

The numerical values for the components of the model-implied slope coefficients and coefficients of determination depend upon the values of the parameters that characterize the local and foreign economic growth processes (Eq. (4)) and the parameters of the preference function (Eqs. (5) and (6)). We calibrate the parameters for the consumption growth process to mimic the U.S. as the local economy and Germany as the foreign economy. Thus, we assume $\mu = 0.18\%$ and $\mu^* = 0.125\%$ equivalent to the average monthly IP growth for the US and Germany respectively for a sample period running from 1970 and 2011. For simplicity, we assume that the components of the consumption growth volatility in the two countries move proportional to each other. But to focus the attention on the effect of the global uncertainty, we set $\phi_l = \phi_l^*$=0.5 and assume that $\phi_w$ and $\phi_w^*$ are proportional to each other with $\phi_w = 1$ and $\phi_w^* = w\phi_w$. Thus, parameter $w$ controls the heterogeneous exposure to the global uncertainty, and therefore the difference between the two countries' total consumption growth volatilities. To calibrate the parameters driving the dynamics of the local uncertainties, we follow BTZ2009 and set $\rho_l = \rho_l^* = 0.979$. We calibrate $\rho_{\sigma_l}$ and $\rho_{\sigma_l}^*$ so that the condition for the global uncertainty to be unspanned by the two countries' stock markets (Eq. (8)) holds. We also set $\phi_{\sigma_l} = \phi_{\sigma_l}^* = 0.2 < 1$ to reduce the chance of finding non-real solutions for the model. To calibrate the parameters driving the dynamics of the volatility of volatility, we also follow BTZ2009, assume homogeneous parameters for the two countries, and set $\rho_q = 0.80$, $\mu_q = 1\text{x}10^{-6}(1-\rho_q)$ and $\phi_q = 0.001$. We calibrate the parameters driving the process for the global uncertainty, $\mu_w$, $\rho_w$ and $\phi_{\sigma_w}$, to match three basic unconditional moments for the Dollar/EUR exchange rate appreciation: its unconditional mean, $E(c_t)$, its average first difference, $E(c_{t+1} - c_t)$, and its unconditional volatility, $Var(c_t)$. Thus, we find $\mu_w$, $\rho_w$ and $\phi_{\sigma_w}$ that minimize the average of the squared moment conditions defined as the difference between the observed moments in our sample and those implied by our model. Following this simple procedure, we obtain the following calibrated values: $\mu_w = 5\text{x}10^{-13}$, $\rho_w = 0.9855$, and $\phi_{\sigma_w} = 0.6332$. Finally, to calibrate the preference-function parameters, we follow Bansal and Yaron (2004) and BTZ2009 and set $\delta = 0.997$, $\gamma = 10$, and $\psi = 1.5$. For this set of parameters, we investigate the impact of the additional price of risk of the global uncertainty in the forex market, $\widetilde{\lambda}$, on the model-implied coefficients.[17,18]

The model-implied slope coefficient, $\beta_{x,XVP}$, and the coefficient of determination, $R^2_{x,XVP}$, for a benchmark scenario where $\widetilde{\lambda} = -150$ and $w = 1.5$ are displayed in panel A and B of Figure 4 respectively. The model-implied predictive power of the currency variance risk premium for forex returns is qualitatively similar to that in Table 4. That is, the slope coefficient becomes more negative while its predictive power increases for longer horizons. Moreover, the slope coefficient implied by our calibration is within the confidence intervals of the estimated parameter from an individual regression for the predictive power of the currency variance premium over the future Dollar/EUR appreciation rate. In contrast, we obtain a model-implied coefficient of determination considerably lower than the one observed (plotted in a different axis). The model-implied coefficient of determination is below 1% for

[17] Calibrating $\widetilde{\lambda}$ to match the first or second order moment of the currency variance risk premium yields $\widetilde{\lambda} \neq 0$ for all specifications considered. This result is in line with the intuition in our model that the global economic volatility is only priced in currency markets. However, the calibrated $\widetilde{\lambda}$ turns out to be extremely high, positive or negative, in all cases.

[18] Following Londono (2012), we calibrate the Campbell and Shiller's constants to match the unconditional mean of the price-dividend ratios for these two countries. Thus, we fix $\kappa_0 = 0.13$, $\kappa_1 = 0.97$, $\kappa_0^* = 0.12$, and $\kappa_1^* = 0.97$.

the 6-month horizon—the horizon at which the observed predictive power of the currency variance risk premium for forex returns is the highest, slightly below 6%.

Panel C and D of Figure 4 show the model-implied predictive power of the stock variance premium for stock returns. For our benchmark calibration ($\widetilde{\lambda} = -150$, $w = 1.5$), the predictive pattern of the stock variance premium coincides with that suggested by our empirical evidence. Moreover, our model yields a predictive pattern qualitatively similar to that previously found in the literature. That is, we also find that the slope coefficient decreases with the horizon, although the numerical values of the calibrated slope coefficients are significantly higher than those observed for an individual regression for the predictive power of the stock variance premium for stock returns. The results from our calibration also replicate the hump-shaped pattern for the coefficient of determination suggesting that the predictive power of the stock variance premium for stock returns reaches its maximum around the quarterly horizon. However the model-implied coefficients of determination are again considerably lower than those suggested by our empirical evidence (plotted in a different axis).

In sum, the results in this section suggest that our model is able to replicate the pattern for the predictive power of the currency variance premium for forex returns suggested by our empirical evidence. At the same time, our model replicates the pattern for the predictive power of the stock variance premium for stock returns previously documented in the literature.

To assess the magnitude of the predictability patterns implied by our model, we investigate the values of parameters $\widetilde{\lambda}$ and $w$ that yield quantitatively comparable patterns to those observed in the data. Panel A and B of Figure 5 display the numerical values for $\beta_{x,XVP}$ and $R^2_{x,XVP}$ respectively for alternative values of the parameter driving the additional price of risk of the global uncertainty in the forex market, $\widetilde{\lambda}$. This parameter seems to have an important effect for the slope coefficient as suggested by Panel A. In particular, as $\widetilde{\lambda}$ becomes more negative, the slope coefficient approaches to zero for any horizon considered. In contrast, the results in Panel B suggest that the coefficient of determination increases as $\widetilde{\lambda}$ becomes more negative. Similarly, Panel C and D display the numerical values of $\beta_{x,XVP}$ and $R^2_{x,XVP}$ respectively for alternative values of the parameter driving the heterogeneous exposure to the global uncertainty, $w$. This parameters turns out to have a significant effect for both, the slope coefficient and the coefficient of determination. In particular, the slope coefficient becomes more negative as $w$ gets closer to 1—the scenario with homogeneous exposures to the global uncertainty. In contrast, as $w$ gets closer to 1, $R^2_{x,XVP}$ gets closer to 0. In sum, the information in Figure 5 suggests that although our calibration of the model's parameter yields qualitatively similar predictive patterns for all parameter combinations considered, it would be hard to find a parameter combination that matches simultaneously the numerical values in our empirical evidence.

# 4 Conclusion

The forward premium puzzle or the violation of the uncovered interest parity in exchange rates is one of the leading challenges in international finance and asset pricing. At the same time, the implied-realized variance difference can be viewed as a measure of variance risk premium and as a proxy for economic uncertainty. In this paper, we provide empirical evidence that the currency variance risk is priced in currency markets—the currency variance risk premium predicts currency depreciation against the U.S. dollar significantly at the 6-month horizon. We also document a finding that the stock variance premium can predict 1-month ahead appreciation rates. However, the stock and currency variance premiums seem to contain information of a different nature, in that they are poorly correlated and that the currency variance premium is not a useful predictor for local stock returns.

We offer a structural interpretation of these new findings by introducing a two-country general equilibrium model with forex-specific uncertainty and incomplete local stock markets. Under some specific conditions, the stock and currency variance premiums contain differential information for future exchange rate movements. Our model entertains the possibility of market incompleteness. That is, there are sources of risk orthogonal to (unspanned by) any local or foreign stock market (Brandt and Santa-Clara, 2002). In particular, the global/forex-specific uncertainty, revealed by the currency variance risk premium, is a *hidden* factor in local stock markets. More precisely, the effect of the forex-specific uncertainty on the local consumption growth is compensated by its effect on the conditional expectation of the country-specific uncertainty. In other words, forex-specific uncertainty's effects on the expected stock return are offsetting exactly between the consumption growth channel and the consumption volatility channel.

We calibrate the parameters in our model to illustrate its ability to replicate the short- and medium-term return predictability of the exchange rates from variance risk premiums in our empirical evidence. We find qualitatively comparable predictability patterns for the predictive power of the currency variance risk premium for exchange rate returns. However, we find the magnitudes of these patterns to depend mainly on the additional price of risk of the forex-uncertainty and the heterogeneous exposure of the economies to this source of uncertainty.

Finally, the time-series predictability of the variance risk premiums for currency returns documented here may need to be reconciled with the cross-sectional evidence of carry trade strategies of large portfolios (Lustig and Verdelhan, 2007; and Lustig, Roussanov, and Verdelhan, 2011). We leave this challenging task for further research.

# APPENDIX

## A Detailed solution of the model in Section 3.1

As it is standard in the literature, we solve the model in Section 3.1 by log-linearizing the domestic stock returns following Campbell and Shiller (1988) as follows:

$$r_{t+1} = \kappa_0 + \kappa_1 z_{t+1} - z_t + g_{t+1}. \tag{18}$$

We then propose a process for the log of the wealth-consumption ratio of the asset that pays the consumption endowment in terms of the state variables such as the one in Eq. (7) (written here again for completeness). That is,

$$z_{t+1} = A_0 + A_{\sigma_l}\sigma^2_{l,t+1} + A_q q_{t+1} + A_{\sigma_w}\sigma^2_{w,t+1}.$$

Finally, we impose the general equilibrium condition $E_t(r_{t+1}+m_{t+1})+\frac{1}{2}Var_t(r_{t+1}+m_{t+1}) = 0$. The solution yields

$$A_0 = \frac{\theta\log\delta + \theta\kappa_0 + (1-\gamma)\mu + \theta\kappa_1(A_{\sigma_l}\mu_l + A_q\mu_q + A_{\sigma_w}\mu_w)}{\theta(1-\kappa_1)},$$

$$A_{\sigma_l} = \frac{(1-\gamma)^2\phi_l^2}{2\theta(1-\kappa_1\rho_l)},$$

$$A_q^{\pm} = \frac{(1-\kappa_1\rho_q) \pm \sqrt{(1-\kappa_1\rho_q)^2 - \theta^2\kappa_1^4\phi_q^2\phi_{\sigma_l}^2 A_{\sigma_l}^2}}{\theta\kappa_1^2\phi_q^2},$$

and

$$A_{\sigma_w}^{\pm} = \frac{(1-\kappa_1\rho_w) \pm \sqrt{(1-\kappa_1\rho_w)^2 - 2\kappa_1^2\phi_{\sigma_w}^2(\theta\kappa_1 A_{\sigma_l}\rho_{lw} + \frac{1}{2}(1-\gamma)^2\phi_w^2)}}{\theta\kappa_1^2\phi_{\sigma_w}^2}.$$

In order to avoid the load of time-varying domestic VoV, $q_t$, and common volatility, $\sigma_{w,t}$, from growing without bounds, it only makes sense to keep $A_q^-$ and $A_{\sigma_w}^-$ respectively. Positive roots are discarded as they are explosive in $\phi_q$ and $\phi_{\sigma_w}$ respectively. That is, $\lim_{\phi_q\to 0} A_q^+\phi_q \neq 0$ and $\lim_{\phi_{\sigma_w}\to 0} A_{\sigma_w}^+\phi_{\sigma_w} \neq 0$. $A_q^-$ and $A_{\sigma_w}^-$ will be solutions to the model as long as $(1-\kappa_1\rho_q)^2 \geq \theta^2\kappa_1^4\phi_q^2\phi_{\sigma_l}^2A_{\sigma_l}^2$ and $(1-\kappa_1\rho_w)^2 \geq 2\kappa_1^2\phi_{\sigma_w}^2(\theta\kappa_1 A_{\sigma_l}\rho_{lw} + \frac{1}{2}(1-\gamma)^2\phi_w^2)$

respectively. It is easy to show from these expressions that $A_{\sigma_l}$, $A_q$, $A_{\sigma_w} \leq 0$ as long as $\theta < 1$.

# B Proof of the propositions in Section 3.2.

In order to prove the propositions in Section 3.2, we first find the expressions for the domestic expected stock returns, the domestic stock variance risk premium, the expected forex returns and the currency variance risk premium for the model in Eq. (13). In order to do so, we solve this model as it is standard in the literature. For this setting, the general version of the wealth-consumption ratio is given by

$$v_t = A_0 + A'Y_t,$$

where $A = [A_c, A_x, A_{\sigma_l}, A_q, A_{\sigma_w}]'$, and the return of the asset that pays the consumption as dividend is

$$\begin{aligned} r_{t+1} &= \kappa_0 + \kappa_1 v_{t+1} - v_t + g_{t+1} \\ &= r_0 + (B_r'F - A')Y_t + B_r' G_{l,t} z_{l.t+1} + B_r' G_{w,t} z_{w,t+1}, \end{aligned}$$

where $B_r = (\kappa_1 A + e_g)$, and $e_g = (1, 0, 0, 0, 0)'$ is a selector vector for $g_t$.

The pricing kernel is the same as in Eq. (5). For illustrative purposes, we follow the notation in Drechsler and Yaron (2011) and rewrite this pricing kernel in terms of the price of risk as follows:

$$m_{t+1} = b_{mo} + b_{mr}\kappa_0 + b_{mr}(\kappa_1 - 1)A_0 - \Lambda'\mu - (b_{mr}A' + \Lambda'F)Y_t - \Lambda' G_{l,t} z_{l.t+1} - \Lambda' G_{w,t} z_{w,t+1},$$

where $\Lambda = -[(b_{mr} + b_{mg})e_g + b_{mr}\kappa_1 A]$.[19] The forex-augmented pricing kernel is given by Eq. (6).

[19] In our global and domestic uncertainties setting, $\Lambda$ is the price of risk of the shocks since $m_{t+1} - E_t(m_{t+1}) = -\Lambda(Y_{t+1} - E_t(Y_{t+1})) = -\Lambda(G_{l,t} z_{l,t+1} + G_{w,t} z_{w,t+1})$

The expression for the model-implied domestic expected stock returns is

$$\begin{aligned} E_t(r_{t+1} - r_f) &= -Cov_t(m_{t+1}, r_{t+1}) \\ &= B_r' G_{l,t} G_{l,t}' \Lambda + B_r' G_{w,t} G_{w,t}' \Lambda, \end{aligned} \tag{19}$$

and the domestic stock variance risk premium can be found as follows:

$$\begin{aligned} E_t^Q[Var_{t+1}(r_{t+2})] - E_t^P[Var_{t+1}(r_{t+2})] &= B_r' H_{\sigma_l} B_r [E_t^Q(\sigma_{l,t+1}^2) - E_t^P(\sigma_{l,t+1}^2)] + \\ &\quad + B_r' H_q B_r [E_t^Q(q_{t+1}) - E_t^P(q_{t+1})] + \\ &\quad + B_r' H_{\sigma_w} B_r [E_t^Q(\sigma_{w,t+1}^2) - E_t^P(\sigma_{w,t+1}^2)]. \end{aligned} \tag{20}$$

The model-implied variation in expected forex returns is given by

$$\begin{aligned} E_t(s_{t+1}) - s_t &= -[E_t(M_{t+1}^*) - E_t(M_{t+1})] \\ &= (y_{t,1} - y_{t,1}^*) + \frac{1}{2} Var_t(m_{t+1}) - \frac{1}{2} Var_t(m_{t+1}^*), \end{aligned} \tag{21}$$

where, as noted in the main text, the terms labeled with a star ($^*$) correspond to the foreign economy. Eq. (21) can be rewritten as

$$\begin{aligned} E_t(s_{t+1}) - s_t &= s_0 + (b_{mr} A' + \Lambda' F) diag(e_l) Y_t \\ &\quad - (b_{mr}^* A^{*\prime} + \Lambda^{*\prime} F^*) diag(e_l) Y_t^* \\ &\quad + (b_{mr} A' - b_{mr}^* A^{*\prime} + \Lambda' F - \Lambda^{*\prime} F^*) diag(e_w) Y_t \\ &\quad + \frac{1}{2}[\Lambda' G_{l,t} G_{l,t}' \Lambda - \Lambda^{*\prime} G_{l,t}^* G_{l,t}^{*\prime} \Lambda^*] \\ &\quad + \frac{1}{2}[\Lambda' H_{\sigma_w} \Lambda - \Lambda^{*\prime} H_{\sigma_w}^* \Lambda^*] \sigma_{w,t}^2, \end{aligned} \tag{22}$$

where the vector $e_l = (1, 0, 1, 1, 0)'$ is the selector vector for the local variables and $diag(e_l)$ is the diagonal matrix whose elements are those of $e_l$. Similarly, $e_w = (0, 1, 0, 0, 1)'$ is the selector vector for the global variables. This notation allows us to conveniently write the local and foreign consumption growth as $Y_t = diag(e_l) Y_t + diag(e_w) Y_t$ and $Y_t^* = diag(e_l) Y_t^* + diag(e_w) Y_t$ respectively.

The volatility of the forex rate implied by the general version of our model is given by

$$
\begin{aligned}
\sigma^2_{c,t} &= \Lambda^{*\prime} h^* \Lambda^* + \Lambda^{*\prime} H^*_{\sigma_l} \Lambda^* \sigma^{*2}_{l,t} \\
&\quad + \Lambda^{*\prime} H^*_q \Lambda^* q^*_t + \Lambda' H_{\sigma_l} \Lambda' \sigma^2_{l,t} + \Lambda' H_q \Lambda' q_t \\
&\quad + (\Lambda^{*\prime} H^*_{\sigma_w} - \Lambda' H_{\sigma_w})(\Lambda^{*\prime} H^*_{\sigma_w} - \Lambda' H_{\sigma_w})' \sigma^2_{w,t}.
\end{aligned}
$$

Therefore, the model-implied currency variance risk premium can be found as follows:

$$
\begin{aligned}
E^{\widetilde{Q}}[\sigma^2_{c,t+1}] - E^P_t[\sigma^2_{c,t+1}] &= \Lambda' H_{\sigma_l} \Lambda' [E^{\widetilde{Q}}(\sigma^2_{l,t+1}) - E^P(\sigma^2_{l,t+1})] \\
&\quad + \Lambda' H_q \Lambda' [E^{\widetilde{Q}}(q_{t+1}) - E^P(q_{t+1})] \\
&\quad + (\Lambda^{*\prime} H^*_{\sigma_w} - \Lambda' H_{\sigma_w})(\Lambda^{*\prime} H^*_{\sigma_w} - \Lambda' H_{\sigma_w})' [E^{\widetilde{Q}}(\sigma^2_{w,t+1}) - E^P(\sigma^2_{w,t+1})],
\end{aligned} \tag{23}
$$

where $E^{\widetilde{Q}}[.]$ denotes expectations under the risk-neutral distribution of the forex-augmented market.

*Proof of Proposition 1.* According to our model, the global uncertainty is unspanned by local stock markets—$A_{\sigma_w} = 0$. Therefore, and in order to maintain the coherence, $\sigma^2_{w,t}$ should not be a useful predictor for local stock market returns. From Eq. (19), imposing this condition yields

$$
-b_{mr} \kappa_1^2 A' H_{\sigma w} A = 0,
$$

which only holds when $\varphi^2_{x,\sigma_w} = \varphi^2_{\sigma_l,\sigma_w} = \varphi^2_{q,\sigma_w} = 0$ unless $x_t$, $\sigma^2_{l,t}$ and $q_t$ are all simultaneously not priced.

*Proof of Proposition 2.* Eq. (20) can be rewritten as follows:

$$
\begin{aligned}
E^Q_t[Var_{t+1}(r_{t+2})] - E^P_t[Var_{t+1}(r_{t+2})] &= B'_r H_{\sigma_l} B_r [-(\varphi_{\sigma_l,\sigma_l} \sigma^2_{l,t} + \varphi_{\sigma_l,q} q_t)\Lambda_{\sigma_l} - (\varphi_{\sigma_l,\sigma w} \sigma^2_{w,t})\Lambda_{\sigma_l}] \\
&\quad + B'_r H_q B_r [-(\varphi_{q,\sigma_l} \sigma^2_{l,t} + \varphi_{q,q} q_t)\Lambda_q - (\varphi_{q,\sigma w} \sigma^2_{w,t})\Lambda_q] \\
&\quad + B'_r H_{\sigma_w} B_r [-(\varphi_{\sigma_w,\sigma_l} \sigma^2_{l,t} + \varphi_{\sigma_w,q} q_t)\Lambda_{\sigma_w} - (\varphi_{\sigma_w,\sigma w} \sigma^2_{w,t})\Lambda_{\sigma_w}],
\end{aligned}
$$

where $\Lambda_y = -b_{mr} \kappa_1 A_y$ for all $(y \neq g) \in Y$. Thus, on the one hand, the condition for the stock variance risk premium to isolate the VoV, $q_t$, becomes $\varphi_{\sigma_l,\sigma_l} = \varphi_{q,\sigma_l} = \varphi_{\sigma_w,\sigma_l} = 0$.

On the other hand, the condition for the domestic stock variance risk premium not to be a function of the common uncertainty, $\sigma^2_{w,t}$, becomes $\varphi_{\sigma_l,\sigma w} = \varphi_{q,\sigma w} = 0$. The latter condition implies that the common uncertainty does not affect the volatility of $\sigma^2_{l,t}$ nor that of $q_t$.

*Proof of Proposition 3.* Imposing the conditions in Propositions 1 and 2 in Eq. (23) yields

$$E^{\widetilde{Q}}[\sigma^2_{c,t+1}] - E^P_t[\sigma^2_{c,t+1}] = \Lambda' H_{\sigma_l} \Lambda' \varphi_{q,q} b_{mr} \kappa_1 A_q q_t + (\gamma^* \varphi^*_{g,\sigma_w} - \gamma \varphi_{g,\sigma_w})^2 \widetilde{\lambda}^2 \sigma^2_{w,t}.$$

Thus, it becomes obvious that shocks to the global uncertainty do not drive the variation in the stock variance premium, therefore making the stock and currency variance risk premiums imperfectly correlated, only if $\widetilde{\lambda} \neq 0$.

*Proof of Proposition 4.* Given propositions 1 to 3, and assuming for simplicity and without loss of generality that $A_x = 0$, the following condition needs to be imposed to Eq. (22) in order for $\sigma^2_{w,t}$ to be a useful predictor of the time variation in future forex returns:

$$\frac{1}{2}[\Lambda' H_{\sigma w} \Lambda - \Lambda^{*\prime} H^*_{\sigma w} \Lambda^*] \sigma^2_{w,t} = \frac{1}{2}[\gamma^2 \varphi^2_{c,\sigma_w} - \gamma^{*2} \varphi^{*2}_{c,\sigma_w}] \neq 0.$$

Under the assumption of homogeneous preference function parameters. This condition necessarily implies $\varphi^2_{c,\sigma_w} \neq \varphi^{*2}_{c,\sigma_w}$.

# C Model-implied regression coefficients

This appendix provides the expressions for the slope coefficients and the coefficients of determination in Section 3.3.

The regression slope coefficients in Eqs. (2) and (3) implied by our model can be found as $\beta_{y,x} = \frac{Cov(x,y)}{Var(x)}$. Similarly, the (individual regression) coefficients of determination are given by $R^2 = \frac{(Cov(x,y))^2}{Var(x)Var(y)}$. Due to the complex nature of the components of these expressions, we first simplify the notation. Thus, we define $b_{V,z}$ to be the 1-period ahead variable $V$ load on the state variable $z_t$ (for the local state variables $\sigma^2_{l,t}, q_t$, the foreign state variables $\sigma^{*2}_{l,t}, q^*_t$ and the global state variable $\sigma^2_{w,t}$). For instance, according to this notation, the 1-month ahead stock return can be expressed as follows:

$$r_{t+1} = c_r + b_{r,q}q_t + b_{r,\sigma_l}\sigma_{l,t}^2 + b_{r,\sigma_w}\sigma_{w,t}^2 + f_{r,1}(z_{y,t+1}),$$

where $f_r(.)$ is a function of error terms,

$$b_{r,q} = (\kappa_1\rho_q - 1)A_q,$$

$$b_{r,\sigma_l} = (\kappa_1\rho_l - 1)A_{\sigma_l},$$

and

$$b_{r,\sigma_w} = (\kappa_1\rho_{lw}A_{\sigma_l} + (\kappa_1\rho_w - 1)A_{\sigma_w}).$$

Also following this notation, the $h-$period ahead compound stock return is given by

$$\begin{aligned} r_{t,t+h} &\simeq \frac{1}{h}\sum_{j=1}^{h} r_{t+j} \qquad (24)\\ &= \frac{1}{h}[c_{r,h} + b_{r,q}q_t(\frac{1-\rho_q^h}{1-\rho_q}) + b_{r,\sigma_l}\sigma_{l,t}^2(\frac{1-\rho_l^h}{1-\rho_l})\\ &\quad +(b_{r,\sigma_w}(\frac{1-\rho_w^h}{1-\rho_w}) + \frac{b_{r,\sigma_l}\rho_{lw}}{\rho_l-\rho_w}(\frac{1-\rho_l^h}{1-\rho_l} - \frac{1-\rho_w^h}{1-\rho_w}))\sigma_{w,t}^2\\ &\quad +f_r(z_{y,t+1},..,z_{y,t+h})], \end{aligned}$$

where $c_{r,h}$ is a constant term.

The model-implied $h$-period ahead exchange rate return is given by the compound return

$$\begin{aligned} \frac{1}{h}(s_{t+h} - s_t) &\simeq \frac{1}{h}\sum_{j=1}^{h}(s_{t+h} - s_t) \qquad (25)\\ &= \frac{1}{h}[b_{x,\sigma_l}(\frac{1-\rho_l^h}{1-\rho_l})\sigma_{l,t}^2 + b_{x,\sigma_l^*}(\frac{1-\rho_l^{*h}}{1-\rho_l^*})\sigma_{l,t}^{*2}\\ &\quad +b_{x,q}(\frac{1-\rho_q^h}{1-\rho_q})q_t + b_{x,q^*}(\frac{1-\rho_q^{*h}}{1-\rho_q^*})q_t^* \end{aligned}$$

$$+(\frac{b_{x,\sigma_l}\rho_{lw}}{\rho_l-\rho_w}(\frac{1-\rho_l^h}{1-\rho_l}-\frac{1-\rho_w^h}{1-\rho_w})+\frac{b_{x,\sigma_l^*}\rho_{lw}^*}{\rho_l^*-\rho_w}(\frac{1-\rho_l^{*h}}{1-\rho_l^*}-\frac{1-\rho_w^h}{1-\rho_w})+b_{x,\sigma_w}(\frac{1-\rho_w^h}{1-\rho_w}))\sigma_{w,t}^2$$
$$+f_c(z_{y,t+1},..z_{y,t+h})],$$

where $c_{c,h}$ is a constant term, and

$$b_{x,\sigma_l}=(\theta-1)b_{r,\sigma_l},$$

$$b_{x,\sigma_l^*}=-(\theta-1)b_{r^*,\sigma_l^*},$$

$$b_{x,q}=(\theta-1)b_{r,q},$$

$$b_{x,q^*}=-(\theta-1)b_{r^*,q^*},$$

and

$$b_{x,\sigma_w}=(\theta-1)(b_{r,\sigma_w}-b_{r^*,\sigma_w})$$

Similarly, and to maintain the equations interpretable, the $h$-month ahead currency variance risk premium is proxyed by the compound return from 1-period currency variance premiums as follows:

$$\begin{aligned} XVP_t(h) &\approx \frac{1}{h}\sum_{j=1}^{h}XVP_{t+j} \\ &= \frac{1}{h}[b_{xvp,q}q_t(\frac{1-\rho_q^h}{1-\rho_q})+b_{xvp,\sigma_w}\sigma_{w,t}^2(\frac{1-\rho_w^h}{1-\rho_q})+f_{xvp}(z_{t+1,..}z_{t+h})], \end{aligned} \tag{26}$$

where $b_{xvp,q}$ and $b_{xvp,\sigma_w}$ are defined in Eq. (12).

Following this simplified notation, the components of $\beta_{x,XVP}$ and $R^2_{x,XVP}$ are given by the following expressions:[20]

[20]The components of $\beta_{x,VP}$, $\beta_{r,XVP}$, $R^2_{x,VP}$, and $R^2_{r,XVP}$ are available upon request from the authors.

$$
\begin{aligned}
Cov(\frac{1}{h}\sum_{j=1}^{h} c_{t+j}, \frac{1}{h}\sum_{j=1}^{h} XVP_{t+j}) &= hCov(c_{t+1}, XVP_{t+1}) \\
&+ \sum_{j=1}^{h-1}(h-j)Cov(c_{t+1}, XVP_{t+j+1}) + \sum_{j=1}^{h-1}(h-j)Cov(c_{t+1+j}, XVP_{t+1}),
\end{aligned}
$$

where

$$
Cov(c_{t+1}, XVP_{t+1}) = b_{xvp,q}b_{x,q}Var(q_t) + b_{xvp,\sigma_w}b_{x,\sigma_w}Var(\sigma_{w,t}^2),
$$

$$
\begin{aligned}
Cov(c_{t+1}, XVP_{t+j+1}) &= b_{xvp,q}b_{x,q}\rho_q^j Var(q_t) + b_{xvp,\sigma_w}b_{x,\sigma_w}\rho_w^j Var(\sigma_{w,t}^2) \\
&+ b_{xvp,q}\rho_q^{j-1}b_{mr}\kappa_1 A_q \phi_q^2 E(q_t) + b_{xvp,\sigma_w}\rho_w^{j-1}b_{mr}(\kappa_1 A_{\sigma_w} - \kappa_1^* A_{\sigma_w}^*)\phi_{\sigma_w}^2 E(\sigma_{w,t}^2),
\end{aligned}
$$

and

$$
\begin{aligned}
Cov(c_{t+1+j}, XVP_{t+1}) &= b_{xvp,q}b_{x,q}\rho_q^j Var(q_t) \\
&+ b_{xvp,\sigma_w}(b_{x,\sigma_l}\rho_{lw}(\frac{\rho_l^j - \rho_w^j}{\rho_l - \rho_w}) + b_{x,\sigma_l^*}\rho_{lw}^*(\frac{\rho_l^{*j} - \rho_w^j}{\rho_l^* - \rho_w}) + b_{x,\sigma_w}\rho_w^j)Var(\sigma_{w,t}^2);
\end{aligned}
$$

$$
\begin{aligned}
Var(\frac{1}{h}\sum_{j=1}^{h} XVP_{t+j}) &= \frac{1}{h^2}Var(\sum_{j=1}^{h} XVP_{t+j}) \\
&= \frac{1}{h^2}[hVar(XVP_{t+1}) + 2\sum_{j=1}^{h-1}(h-j)Cov(XVP_{t+1}, XVP_{t+1+j})],
\end{aligned}
$$

where

$$
Var(XVP_{t+1}) = b_{xvp,q}^2 Var(q_t) + b_{xvp,\sigma_w}^2 Var(\sigma_{w,t}^2),
$$

and

$$
Cov(XVP_{t+1}, XVP_{t+1+j}) = b_{xvp,q}^2\rho_q^{h-1}Var(q_t) + b_{xvp,\sigma_w}^2\rho_w^{h-1}Var(\sigma_{w,t}^2);
$$

$$
\begin{aligned}
Var(\frac{1}{h}\sum_{j=1}^{h}c_{t+j}) &= \frac{1}{h^2}Var(\sum_{j=1}^{h}c_{t+j}) \\
&= \frac{1}{h^2}[hVar(c_{t+1})+2\sum_{j=1}^{h-1}(h-j)Cov(c_{t+1},c_{t+1+j})],
\end{aligned}
$$

where

$$
\begin{aligned}
Var(c_{t+1}) &= b_{x,\sigma_l}^2 Var(\sigma_{l,t}^2)+b_{x,\sigma_l^*}^2 Var(\sigma_{l,t}^{*2}) \\
&+b_{x,q}^2 Var(q_t)+b_{x,q^*}^2 Var(q_t^*)+b_{x,\sigma_w}^2 Var(\sigma_{w,t}^2) \\
&+\gamma^2\phi_l^2 E(\sigma_{l,t}^2)+(\theta-1)^2\kappa_1^2(A_{\sigma_l}^2\phi_{\sigma_l}^2+A_q^2\phi_q^2)E(q_t) \\
&+\gamma^2\phi_l^{*2}E(\sigma_{l,t}^{*2})+(\theta-1)^2\kappa_1^{*2}(A_{\sigma_l}^{*2}\phi_{\sigma_l}^{*2}+A_q^{*2}\phi_q^{*2})E(q_t^*) \\
&+(\theta-1)^2(\kappa_1 A_{\sigma_w}-\kappa_1^* A_{\sigma_w}^*)^2\phi_{\sigma_w}^2 E(\sigma_{w,t}),
\end{aligned}
$$

and

$$
\begin{aligned}
Cov(c_{t+1},c_{t+1+j}) &= b_{x,\sigma_l}^2\rho_l^j Var(\sigma_{l,t}^2)+b_{x,\sigma_l^*}^2\rho_l^{*j}Var(\sigma_{l,t}^{*2})+b_{x,q}^2\rho_q^j Var(q_t)+b_{x,q^*}^2\rho_q^{*j}Var(q_t^*) \\
&+b_{x,\sigma_w}(b_{x,\sigma_l}\rho_{lw}(\frac{\rho_l^j-\rho_w^j}{\rho_l-\rho_w})+b_{x,\sigma_l^*}\rho_{lw}^*(\frac{\rho_l^{*j}-\rho_w^j}{\rho_l^*-\rho_w})+b_{x,\sigma_w}\rho_w^j)Var(\sigma_{w,t}^2) \\
&+(\theta-1)\kappa_1 A_{\sigma_l}b_{x,\sigma_l}\phi_{\sigma_l}^2\rho_l^{j-1}E(q_t)+b_{mr}\kappa_1 A_q b_{x,q}\phi_q^2\rho_q^{j-1}E(q_t) \\
&-(\theta-1)^*\kappa_1^* A_{\sigma_l}^* b_{x,\sigma_l^*}\phi_{\sigma_l}^{*2}\rho_l^{*j-1}E(q_t^*)-(\theta-1)^*\kappa_1^* A_q^* b_{x,q^*}\phi_q^{*2}\rho_q^{*j-1}E(q_t^*) \\
&+(\theta-1)(\kappa_1 A_{\sigma_w}-\kappa_1^* A_{\sigma_w}^*)(b_{x,\sigma_l}\rho_{lw}(\frac{\rho_l^{j-1}-\rho_w^{j-1}}{\rho_l-\rho_w})+b_{x,\sigma_w}\rho_w^{j-1}+\ldots \\
&b_{x,\sigma_l^*}\rho_{lw}^*(\frac{\rho_l^{*j-1}-\rho_w^{j-1}}{\rho_l^*-\rho_w}))\phi_{\sigma_w}^2 E(\sigma_{w,t}^2).
\end{aligned}
$$

The additional components of $\beta_{r,VP}$ and $R_{r,VP}^2$ are given by

$$
\begin{aligned}
Cov(\frac{1}{h}\sum_{j=1}^{h}r_{t+j},VP_t) &= \frac{1}{h}(\sum_{j=1}^{h}r_{t+j},VP_t) \\
&= \frac{1}{h}b_{vp,q}b_{r,q}(\frac{1-\rho_q^h}{1-\rho_q})Var(q_t)
\end{aligned}
$$

$$+\frac{1}{h}b_{vp,\sigma_w}(b_{r,\sigma_w}(\frac{1-\rho_w^h}{1-\rho_w})+\frac{b_{r,\sigma_l}\rho_{lw}}{\rho_l-\rho_w}(\frac{1-\rho_l^h}{1-\rho_l}-\frac{1-\rho_w^h}{1-\rho_w})Var(\sigma_{w,t}^2)];$$

$$Var(VP_t)=b_{vp,q}^2Var(q_t)+b_{vp,\sigma_w}^2Var(\sigma_{w,t}^2);$$

and

$$\begin{aligned}Var(\frac{1}{h}\sum_{j=1}^{h}r_{t+j}) &= \frac{1}{h^2}Var(\sum_{j=1}^{h}r_{t+j}) \\ &= \frac{1}{h^2}[hVar(r_{t+1})+2\sum_{j=1}^{h-1}(h-j)Cov(r_{t+1},r_{t+1+j})],\end{aligned}$$

where

$$\begin{aligned}Var(r_{t+1}) &= b_{r,q}^2Var(q_t)+b_{r,\sigma_l}^2Var(\sigma_{l,t}^2)+b_{r,\sigma_w}^2Var(\sigma_{w,t}^2) \\ &\quad +\phi_l^2E(\sigma_{l,t}^2)+\kappa_1^2(A_{\sigma_l}^2\phi_{\sigma_l}^2+A_q^2\phi_q^2)E(q_t)+(\phi_w^2+\kappa_1^2A_{\sigma_w}^2\phi_{\sigma_w}^2)E(\sigma_{w,t}^2),\end{aligned}$$

and

$$\begin{aligned}Cov(r_{t+1},r_{t+1+h}) &= b_{r,q}^2\rho_q^hVar(q_t)+b_{r,\sigma_l}^2\rho_l^hVar(\sigma_{l,t}^2) \\ &\quad +b_{r,\sigma_w}(b_{r,\sigma_w}\rho_w^h+b_{r,\sigma_l}\rho_{lw}(\frac{\rho_l^h-\rho_w^h}{\rho_l-\rho_w}))Var(\sigma_{w,t}^2) \\ &\quad +\kappa_1(A_{\sigma_l}b_{r,\sigma_l}\phi_{\sigma_l}^2\rho_l^{h-1}+A_qb_{r,q}\phi_q^2\rho_q^{h-1})E(q_t) \\ &\quad +\kappa_1A_{\sigma_w}(b_{r,\sigma_w}\rho_w^{h-1}+b_{r,\sigma_l}\rho_{lw}(\frac{\rho_l^{h-1}-\rho_w^{h-1}}{\rho_l-\rho_w}))\phi_{\sigma_w}^2E(\sigma_{w,t}^2);\end{aligned}$$

$$\begin{aligned}Cov(\frac{1}{h}\sum_{j=1}^{h}c_{t+j},VP_t) &= b_{vp,q}b_{x,q}(\frac{1-\rho_q^h}{1-\rho_q})Var(q_t) \\ &\quad +b_{vp,\sigma_w}(\frac{b_{x,\sigma_l}\rho_{lw}}{\rho_l-\rho_w}(\frac{1-\rho_l^h}{1-\rho_l}-\frac{1-\rho_w^h}{1-\rho_w})+...\end{aligned}$$

$$\frac{b_{x,\sigma_l^*}\rho_{lw}^*}{\rho_l^* - \rho_w}(\frac{1-\rho_l^{*h}}{1-\rho_l^*} - \frac{1-\rho_w^h}{1-\rho_w}) + b_{x,\sigma_w}(\frac{1-\rho_w^h}{1-\rho_w}))Var(\sigma_{w,t}^2).$$

Finally, the unconditional first and second order moments of the state variables can be found as follows:

$E(q_t) = \frac{\mu_q}{1-\rho_q}$; $E(q_t^*) = \frac{\mu_q^*}{1-\rho_q^*}$; $E(\sigma_{w,t}^2) = \frac{\mu_w}{1-\rho_w}$; $E(\sigma_{l,t+1}^2) = \frac{\mu_l+\rho_{lw}E(\sigma_{w,t}^2)}{1-\rho_l}$; $E(\sigma_{l,t+1}^{*2}) = \frac{\mu_l^*+\rho_{lw}^*E(\sigma_{w,t}^2)}{1-\rho_l^*}$;

$Var(q_t) = \frac{\phi_q^2 E(q_t)}{1-\rho_q^2}$; $Var(q_t^*) = \frac{\phi_q^{*2}E(q_t^*)}{1-\rho_q^{*2}}$; $Var(\sigma_{l,t+1}^2) = \frac{\rho_{lw}^2 Var(\sigma_{w,t}^2)+\phi_{\sigma_l}^2 E(q_t)}{1-\rho_l^2}$; $Var(\sigma_{l,t+1}^{*2}) = \frac{\rho_{lw}^{*2}Var(\sigma_{w,t}^2)+\phi_{\sigma_l}^{*2}E(q_t^*)}{1-\rho_l^{*2}}$;

$Var(\sigma_{w,t}^2) = \frac{\phi_{\sigma_w}^2 E(\sigma_{w,t}^2)}{1-\rho_w^2}$.

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Table 1: 1-month depreciation rates. Summary statistics

This table reports the summary statistics for the 1-month depreciation rate between each currency and the U.S. dollar.

| | **\$/JPY** | **\$/GBP** | **\$/EUR** |
|---|---|---|---|
| **Mean** | 0.19 | −0.02 | 0.18 |
| **Median** | 0.05 | 0.02 | 0.24 |
| **St. Dev.** | 2.29 | 2.30 | 2.59 |
| **Skew.** | 0.27 | −0.47 | −0.08 |
| **Kurt.** | 2.89 | 4.68 | 3.03 |
| **AR(1)** | $0.17^{**}$ | $0.31^{***}$ | $0.30^{***}$ |

| **Correlation Matrix** | **\$/JPY** | **\$/GBP** | **\$/EUR** |
|---|---|---|---|
| **\$/JPY** | 1 | | |
| **\$/CHF** | 0.47 | | |
| **\$/GBP** | 0.16 | 1 | |
| **\$/EUR** | 0.33 | 0.73 | 1 |

Table 2: Currency variance risk premiums. Summary Statistics

This table reports the summary statistics for the currency variance premiums, $XVP_t(h)$, for the sample period running from January 2000 to December 2011. $XVP_t(h)$ is measured as the difference between the squared of the $h$-month (ATM) forex option implied volatility and the expected realized variance of the exchange rate appreciation. The expected realized variance is assumed to be $E_t(XRV_{t+h}^2) = XRV_t(h)^2$, where $XRV_t(h)^2$ is the realized variance calculated using $h$-month non-overlapping rolling windows of daily (log) appreciation rates between each currency and the U.S. dollar (martingale assumption). $^{*}$,$^{**}$ and $^{***}$ represent the usual 10, 5 and 1% significance levels. In order to assess the significance of the mean $XVP_t(h)$, the standard errors are corrected by Newey-West with 3 lags. The correlations are only reported within the same horizon category.

| $h$ | **1** | | | **3** | | | **6** | | |
|---|---|---|---|---|---|---|---|---|---|
| (months) | **\$/JPY** | **\$/GBP** | **\$/EUR** | **\$/JPY** | **\$/GBP** | **\$/EUR** | **\$/JPY** | **\$/GBP** | **\$/EUR** |
| **Mean** | 15.19$^{***}$ | 2.44 | 17.95$^{***}$ | 10.49$^{**}$ | 4.14 | 19.96$^{***}$ | 9.32$^{*}$ | 6.95 | 22.64$^{***}$ |
| **Median** | 13.55 | 5.77 | 14.08 | 9.88 | 11.23 | 12.61 | 6.35 | 11.83 | 17.84 |
| **St. Dev.** | 46.59 | 42.26 | 46.81 | 45.52 | 43.14 | 40.34 | 40.03 | 52.68 | 45.82 |
| **Skew.** | 0.07 | −2.83 | 2.16 | −0.76 | −2.38 | 1.87 | −0.43 | −2.62 | 0.33 |
| **Kurt.** | 4.34 | 21.82 | 14.49 | 7.50 | 11.76 | 15.78 | 5.86 | 14.92 | 8.79 |
| **AR(1)** | 0.01 | −0.09 | 0.08 | 0.37$^{***}$ | 0.74$^{***}$ | 0.51$^{***}$ | 0.70$^{***}$ | 0.85$^{***}$ | 0.74$^{***}$ |

**Correlation Matrix (including the U.S. VP)**

| $h$ | **1** | | | **3** | | | **6** | | |
|---|---|---|---|---|---|---|---|---|---|
| (months) | **\$/JPY** | **\$/GBP** | **\$/EUR** | **\$/JPY** | **\$/GBP** | **\$/EUR** | **\$/JPY** | **\$/GBP** | **\$/EUR** |
| $VP_{US,t}$ | 0.27 | 0.16 | −0.29 | 0.13 | −0.08 | −0.46 | −0.06 | −0.27 | −0.39 |
| **\$/JPY** | 1.00 | | | 1.00 | | | 1.00 | | |
| **\$/GBP** | 0.07 | 1.00 | | 0.45 | 1.00 | | 0.66 | 1.00 | |
| **\$/EUR** | 0.18 | 0.38 | 1.00 | 0.28 | 0.62 | 1.00 | 0.60 | 0.86 | 1.00 |

Table 3: Stock variance risk premiums. Summary statistics

This table reports the summary statistics for the countries' stock variance premiums, $VP_t$, measured as the difference between the squared (model-free) implied volatility index (IV) and the expected realized variance for the underlying index in each country. As for the currency variance risk premium, we assume that the expected stock realized variance is given by $E_t(RV_{t+1}^2) = RV_t^2$, where $RV_t^2$ is the realized variance of each country's index calculated using one-month non-overlapping rolling windows of daily (log) stock returns.

| | **US** | **JA** | **UK** | **GE** |
|---|---|---|---|---|
| **Mean** | 108.70** | 150.09*** | 107.33*** | 77.59** |
| **Median** | 125.61 | 169.93 | 116.58 | 116.46 |
| **St. Dev.** | 431.75 | 445.03 | 375.30 | 404.36 |
| **Skew.** | −3.87 | −4.47 | −5.55 | −2.25 |
| **Kurt.** | 30.26 | 39.43 | 52.45 | 14.53 |
| **AR(1)** | 0.32*** | 0.00 | 0.28*** | 0.10 |

| **Correlation Matrix** | **US** | **JA** | **UK** | **GE** |
|---|---|---|---|---|
| **US** | 1 | | | |
| **JA** | 0.62 | 1 | | |
| **SWI** | 0.67 | 0.63 | | |
| **UK** | 0.84 | 0.69 | 1 | |
| **GE** | 0.66 | 0.49 | 0.78 | 1. |

Table 4: The predictive power of the stock and currency variance risk premiums for exchange rate returns

This table reports the estimated coefficients for the following regressions:

$$s_{t+h} - s_t = b_{x,0}(h) + b_{x,IR}(h)[y_t(h) - y_t^*(h)] + b_{x,VP}(h)VP_t + b_{x,XVP}(h)XVP_t(h) + u_{t+h},$$

where $s_t$ is the dollar exchange rate, $[y_t(h) - y_t^*(h)]$ is the interest rate differential for $h-$month zero-coupon bond rates between the U.S. and the foreign country, $XVP$ is the currency variance premium and $VP$ is the local/foreign stock variance premium. The standard errors are corrected by Newey-West with 12 lags and the standard deviations are reported in parenthesis. $^{*}$,$^{**}$ and $^{***}$ represent the usual 10, 5 and 1% significance levels. The sample period runs from January 2000 to December 2011. The estimated regression constants are left unreported in order to save space.

| | | $VP_{US}$ | | | $VP_i$ | | |
|---|---|---|---|---|---|---|---|
| $h$ | | **\$/JPY** | **\$/GBP** | **\$/EUR** | **\$/JPY** | **\$/UK** | **\$/EUR** |
| 1 | $[y_t(h) - y_t^*(h)]$ | $-2.69^{***}$ | 0.87 | $-2.41$ | $-2.84^{***}$ | 1.08 | $-2.47$ |
| | | $(-2.79)$ | (0.34) | $(-0.98)$ | $(-3.10)$ | (0.40) | $(-0.97)$ |
| | $VP_{us}/VP_i$ | $-1.74^{***}$ | $2.58^{***}$ | $1.73^{***}$ | $-0.96$ | $2.62^{***}$ | $1.10^{***}$ |
| | | $(-4.48)$ | (5.36) | (4.06) | $(-1.41)$ | (5.32) | (2.82) |
| | $XVP_i$ | $12.23^{**}$ | $-2.53$ | 2.93 | $11.78^{*}$ | $-2.04$ | $-0.62$ |
| | | (2.41) | $(-0.45)$ | (0.58) | (1.76) | $(-0.37)$ | $(-0.15)$ |
| | $R^2$ | 12.69 | 16.61 | 6.16 | 7.60 | 13.18 | 2.87 |
| 3 | $[y_t(h) - y_t^*(h)]$ | $-2.93^{***}$ | 3.24 | $-0.76$ | $-3.05^{***}$ | 3.77 | $-0.78$ |
| | | $(-3.57)$ | (1.08) | $(-0.26)$ | $(-3.76)$ | (1.13) | $(-0.26)$ |
| | $VP_{us}/VP_i$ | $-0.98^{***}$ | $1.30^{***}$ | 0.31 | $-0.65^{**}$ | $0.95^{***}$ | 0.12 |
| | | $(-3.57)$ | (4.49) | (0.78) | $(-2.28)$ | (2.73) | (0.30) |
| | $XVP_i$ | 1.88 | $-12.26^{***}$ | $-4.00$ | 0.42 | $-11.62^{**}$ | $-5.20$ |
| | | (0.54) | $(-3.07)$ | $(-0.63)$ | (0.13) | $(-2.54)$ | $(-1.04)$ |
| | $R^2$ | 14.56 | 22.43 | 1.59 | 11.50 | 17.96 | 1.32 |
| 6 | $[y_t(h) - y_t^*(h)]$ | $-2.98^{***}$ | 2.55 | $-0.56$ | $-3.02^{***}$ | 2.55 | $-0.54$ |
| | | $(-3.68)$ | (0.66) | $(-0.19)$ | $(-3.78)$ | (0.66) | $(-0.19)$ |
| | $VP_{us}/VP_i$ | $-0.23$ | $0.65^{***}$ | $-0.11$ | $-0.32^{*}$ | $0.65^{***}$ | $-0.14$ |
| | | $(-1.29)$ | (2.63) | $(-0.31)$ | $(-1.85)$ | (2.92) | $(-0.42)$ |
| | $XVP_i$ | $-4.84^{*}$ | $-5.87^{***}$ | $-8.31^{*}$ | $-5.81^{**}$ | $-5.99^{***}$ | $-8.17^{**}$ |
| | | $(-1.81)$ | $(-3.19)$ | $(-1.80)$ | $(-2.11)$ | $(-3.19)$ | $(-2.20)$ |
| | $R^2$ | 21.57 | 12.01 | 5.50 | 22.14 | 11.62 | 5.54 |

Table 5: The predictive power of the stock and currency variance risk premiums for stock returns

This table reports the estimated coefficients for the following regressions:

$$r_{t+h} - r_{f,t} = b_{r,0}(h) + b_{r,VP_{US}}(h)VP_{US,t} + b_{r,XVP}(h)XVP_{i,t}(h) + u_{US,i,t+h},$$

where $r_t$ is the local- or foreign-market stock index log return. The standard errors are corrected by Newey-West with 12 lags and the standard deviations are reported in parenthesis. *,** and *** represent the usual 10, 5 and 1% significance levels. The sample period runs from January 2000 to December 2011. The estimated regression constants are left unreported in order to save space.

| | | $r_{us}$ | | | $r_i$ | | |
|---|---|---|---|---|---|---|---|
| $h$ | | **JA** | **UK** | **EU** | **JA** | **UK** | **EU** |
| 1 | $VP_{US}$ | 4.56*** | 4.14*** | 4.28*** | 3.50*** | 1.99*** | 2.39*** |
| | | (6.39) | (4.96) | (4.89) | (3.32) | (2.60) | (2.59) |
| | $XVP_i$ | −11.63 | 5.08 | 1.92 | −24.64* | −3.04 | −15.28 |
| | | (−0.80) | (0.35) | (0.16) | (−1.76) | (−0.30) | (−1.08) |
| | $R^2$ | 11.03 | 10.33 | 10.22 | 5.19 | 2.67 | 2.92 |
| 2 | $VP_{US}$ | 3.17*** | 3.21*** | 2.82*** | 2.07*** | 1.83*** | 2.12*** |
| | | (7.56) | (7.22) | (4.25) | (5.25) | (4.56) | (2.79) |
| | $XVP_i$ | 9.53 | −10.95 | −11.16 | 5.19 | −6.56 | −22.21* |
| | | (1.64) | (−1.64) | (−1.06) | (0.53) | (−1.24) | (−1.79) |
| | $R^2$ | 16.41 | 16.68 | 16.20 | 4.06 | 7.50 | 8.75 |
| 3 | $VP_{US}$ | 1.79*** | 1.29** | 1.51** | 1.07 | 0.57 | 1.45 |
| | | (4.21) | (2.04) | (2.22) | (1.59) | (0.99) | (1.51) |
| | $XVP_i$ | −2.42 | −13.83*** | −6.24 | −4.94 | −14.99*** | −8.17 |
| | | (−0.16) | (−2.84) | (−0.67) | (−0.29) | (−4.02) | (−0.81) |
| | $R^2$ | 5.92 | 10.91 | 6.48 | 1.73 | 12.63 | 3.78 |

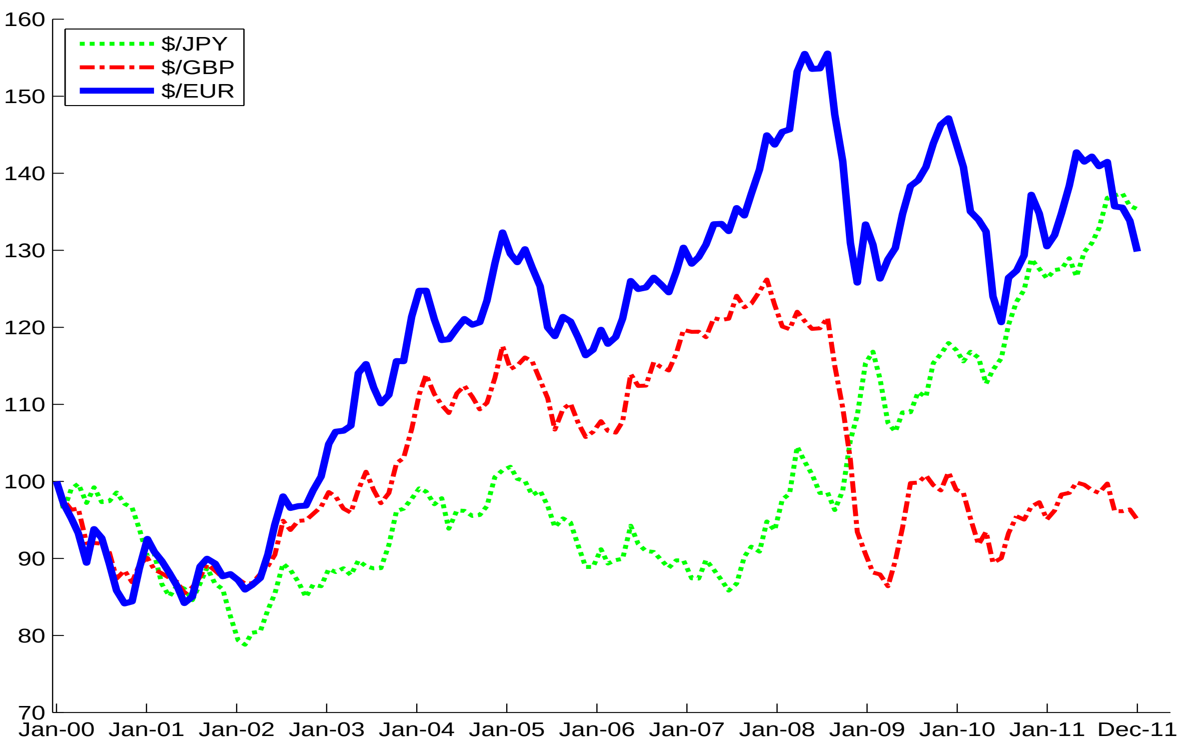
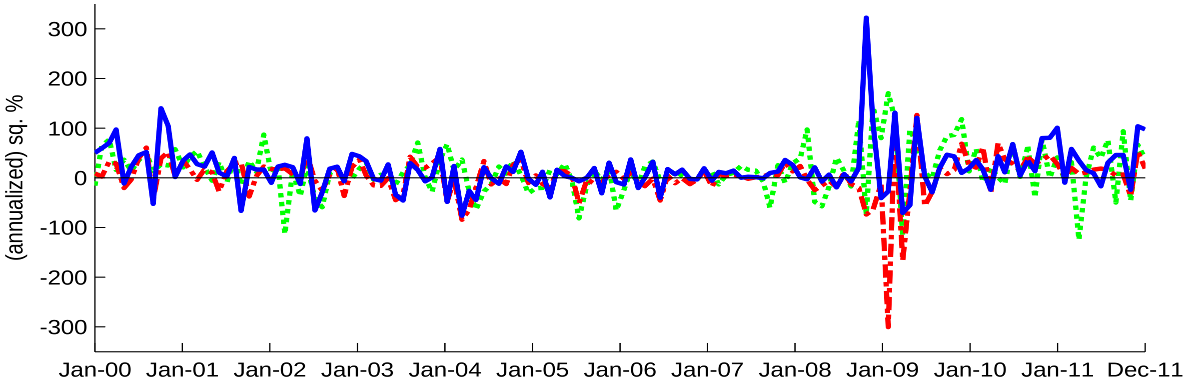


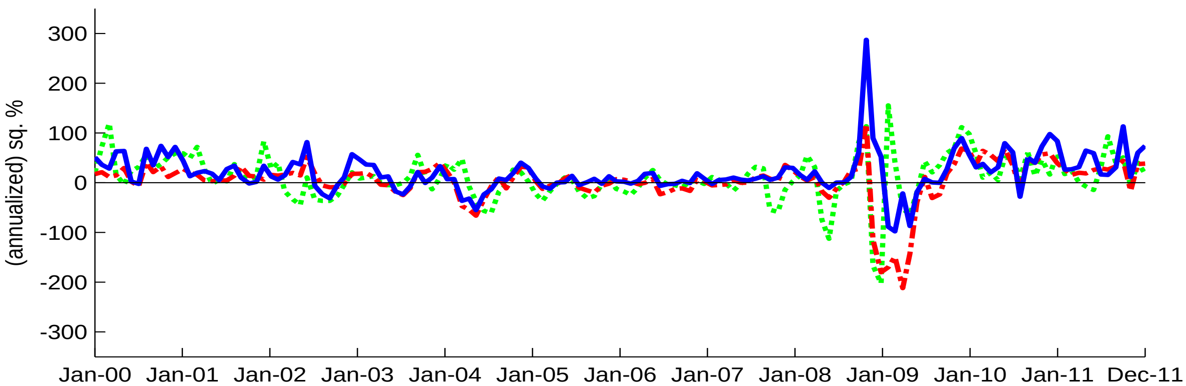

Figure 1: Exchange rates

The figure displays the spot exchange rate of each country's currency with respect to the U.S. dollar as a monthly index (Jan-2000=100).

**A. 1-month**




**B. 3-month**




**C. 6-month**

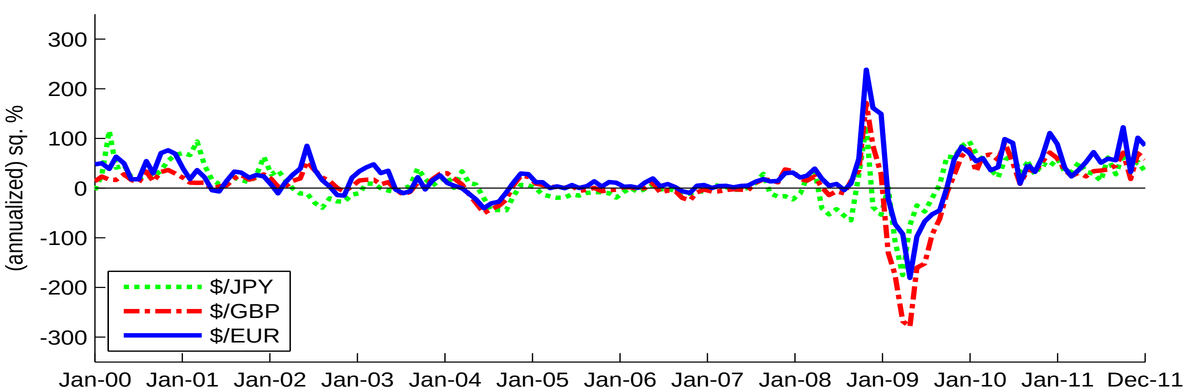



Figure 2: Currency variance risk premiums

The figure displays the currency variance risk premiums measured as described in Table 2.

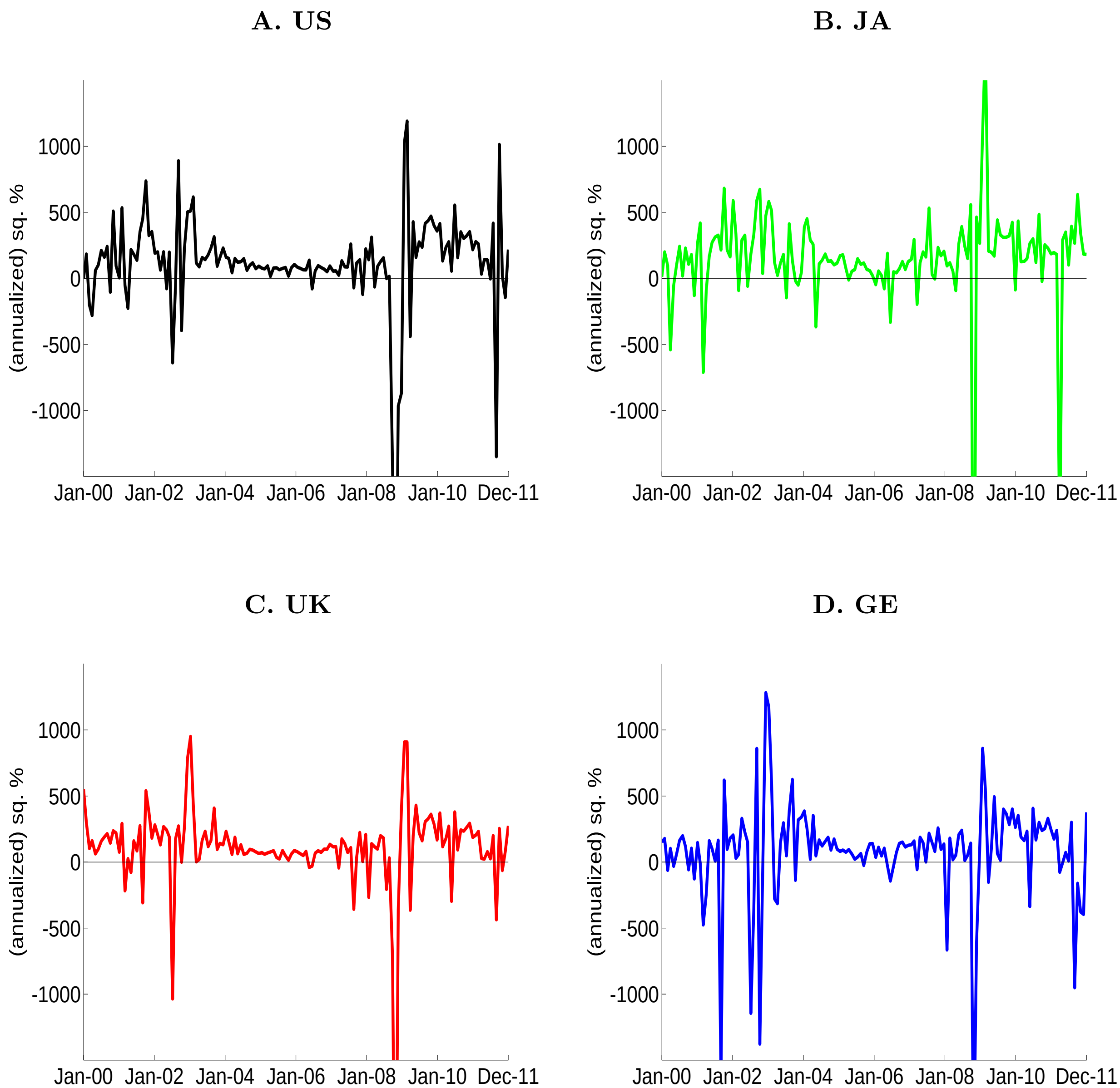



Figure 3: Stock variance risk premiums

The figure displays the stock variance risk premiums, $VP_t$, measured as the difference between the squared of the (model-free) implied volatility index (IV) and the expected realized variance for the underlying index in each country (see Table 3).

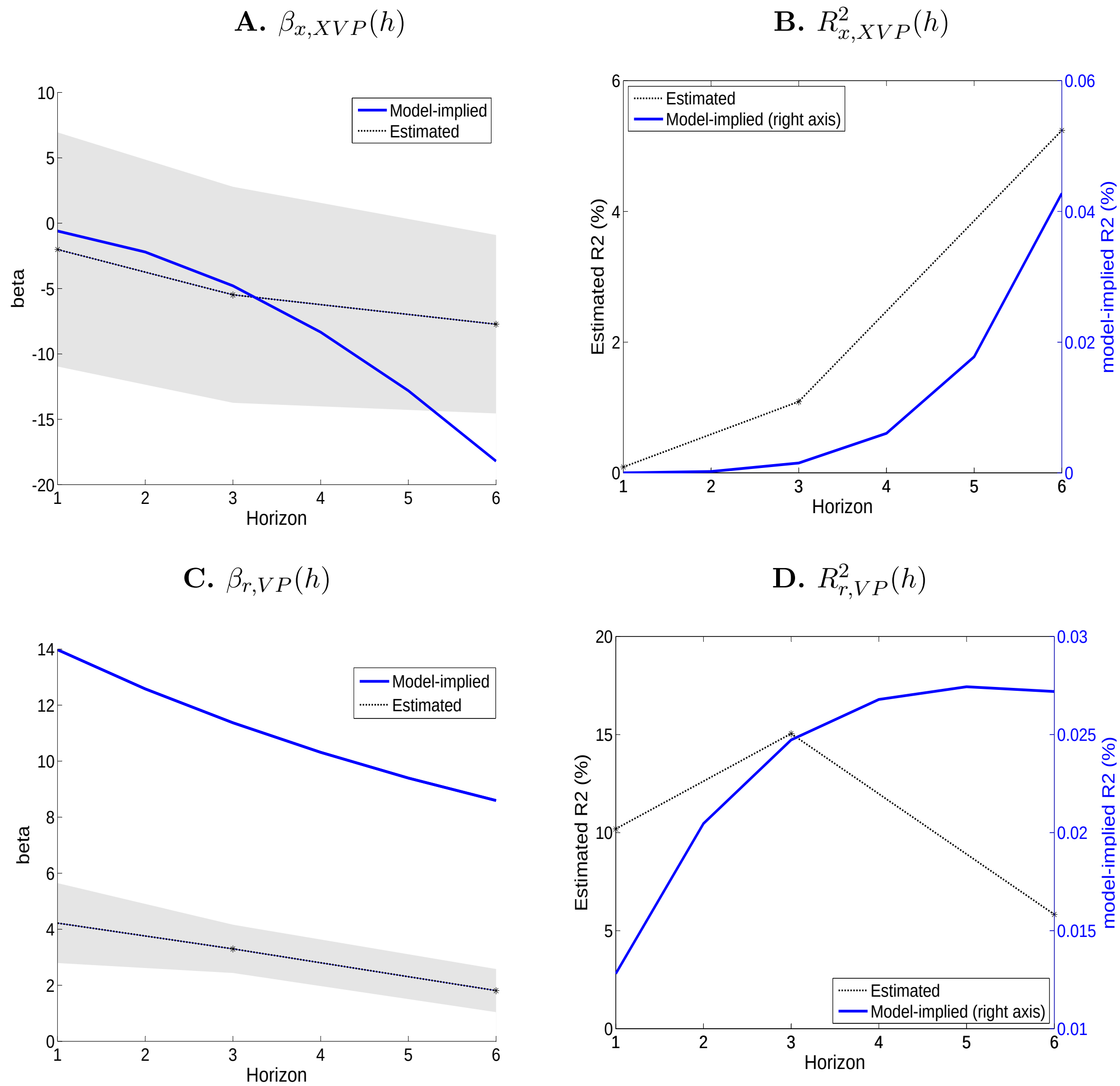



Figure 4: Calibrated model. Predictability patterns

Panel A shows the slope coefficient for the predictive power of the currency variance risk premium for the $h$-month ahead forex appreciation rate implied by our model (the bold line). The dotted line is a linear interpolation of the estimated regression coefficients, $b_{x,XVP}(h)$, for an individual regression, and the shaded area its corresponding 5% confidence interval. Panel B shows, in bold and in the right axis, the model-implied coefficient of determination for this regression. The estimated coefficient of determination is plotted as a dotted line in the left axis. Similarly, Panel C and D display the slope coefficient and coefficient of determination for the predictive power of the stock variance risk premium for $h$-month ahead stock returns. The calibration of the model parameters is discussed in detail in Section 3.3, and the model-implied slope coefficients and coefficients of determination are explained in Appendix C.

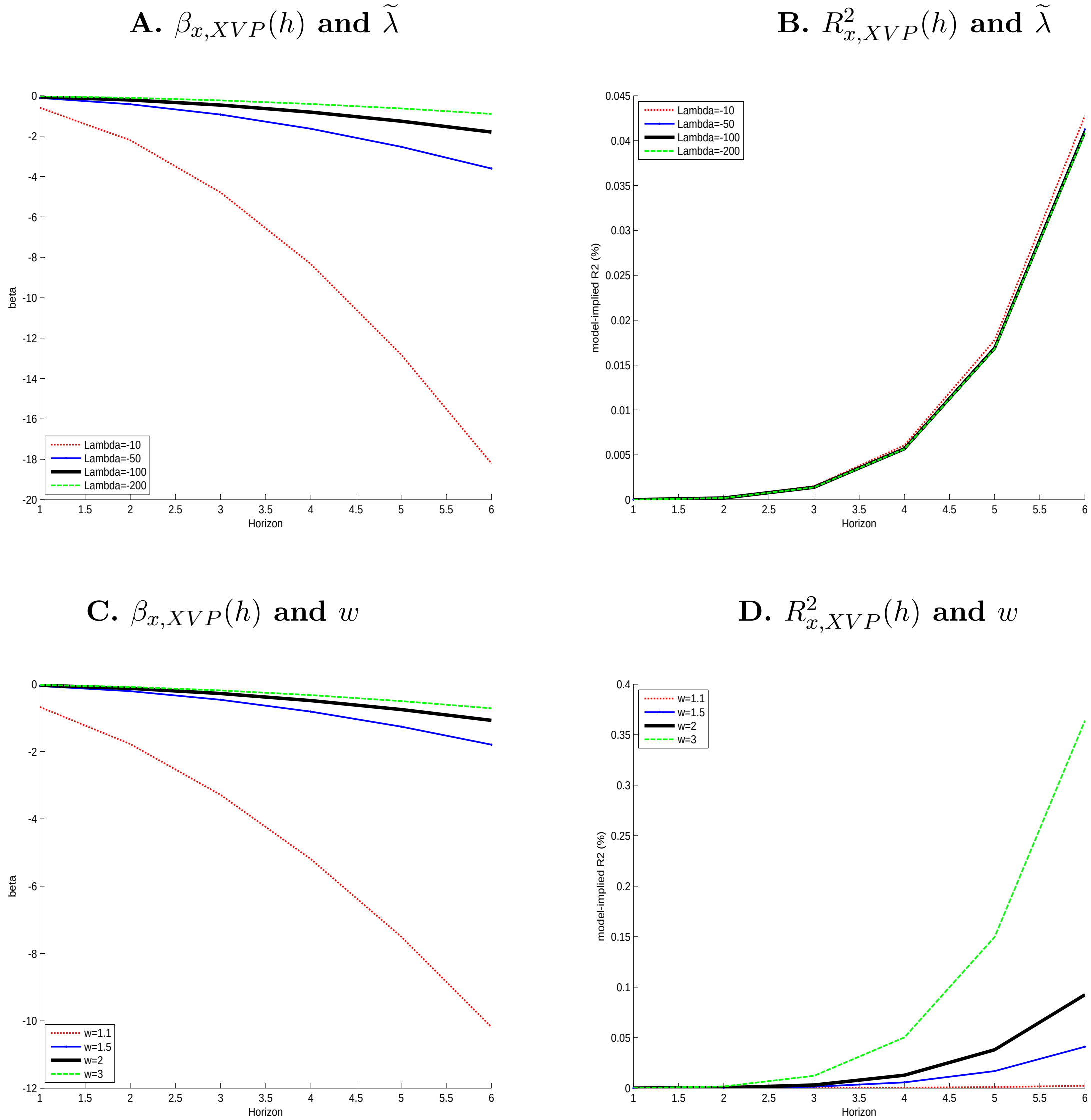



Figure 5: Effect of $\widetilde{\lambda}$ and $w$ on the predictability patterns

The figure shows the model-implied slope coefficients and coefficients of determination for alternative values of $\widetilde{\lambda}$ (Panel A and B respectively), the parameter driving the additional price of risk of the global uncertainty in the forex market, and $w$ (Panel C and D respectively), the parameter driving the heterogeneous exposure to the global uncertainty. We report the effect of these two parameters on the predictive power of the currency variance risk premium for forex appreciation rates. The calibration of the model parameters is discussed in detail in Section 3.3, and the model-implied slope coefficients and coefficients of determination are explained in Appendix C.