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Exchange rates, expected returns and risk

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Exchange rates, expected returns and risk[*]

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Abstract

According to theory, higher expected foreign risk-free returns and foreign currency risk both increase foreign yields, but have opposing effects on the value of the foreign currency. This paper exploits that relationship to jointly identify the unobserved risk-free return and risk premium components of exchange rates and expected relative returns. When risk and return are jointly modelled over a 10-year horizon, UIP cannot be rejected for any of the eight advanced country USD currency pairs examined. Innovations in the currency premium are correlated with 'speculative' positioning in foreign exchange markets, and for non-reserve currencies, with 'VIX' risk aversion. Innovations in the risk-free component are correlated with changes in nominal short-term interest rates. Both expected returns and risk play important roles in exchange rate dynamics.

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Non-technical summary

The uncovered interest parity (UIP) hypothesis is a key building block of open economy macroeconomics. It plays an important role in the transmission of shocks, it is a workhorse in models underlying studies of optimal monetary policy, and interest arbitrage is what makes the monetary policy trilemma bind. If UIP holds, then the expected returns to holding home assets and foreign assets should be equal. When expected home interest returns rise, the home currency should immediately appreciate (Dornbusch 1976) so that it can subsequently depreciate over the period of high home returns so there is no excess return to holding home currency assets.

There is a large literature that documents the empirical failure of UIP across advanced country currency pairs. Empirically, high interest rate currencies tend to be strong, as implied by theory, but tend to appreciate in the short term, rather than to depreciate as the theory implies. The standard UIP test makes important assumptions about expected future returns and risk. The standard test asks whether exchange rate changes offset, one-for-one, the difference between home and foreign short-term interest. By leaving out expected future returns and risk premia, that are difficult to measure, the standard test assumes that neither is correlated with short-term interest returns.

This paper seeks to model exchange rates, expected returns and risk together. The starting point is papers by Engel and West (2004, 2010) that employ asset price models of the exchange rate. Engel and West find that, by accounting for the expected future path of interest rates, the relationship between exchange rates and interest rates is closer to theory than is the standard test that considers only short-term returns. While the relationship is still weaker than theory predicts, it is generally correct in sign.

This paper extends Engel and West's approach in two ways. First, it constructs forecasts of future short-term returns from interest rate swap yields. The results based on those financial market forecasts of future returns are similar to Engel and West's results based on statistical model forecasts: the relationship between exchange rates and expected returns is generally of the correct sign, but is weak relative to what theory predicts.

Second, the paper extends the standard asset price model to include a currency risk premium. The risk-augmented model provides a framework for separating, statistically, the risk premium and risk-free components of expected returns and exchange rates. Intuitively, higher home risk-free returns raise observed home returns and appreciate the home currency. A higher home currency premium also increases observed home returns, but depreciates the home currency. The opposite-signed effects of risk-free returns and the currency premium on expected returns and on the exchange rate can be used to back out the two unobserved components.

When accounting for both expected future returns and risk, the relationship between exchange rates and returns is closer again to theory. We cannot reject full pricing of expected interest rate returns in exchange rates over a 5-10 year horizon. In the risk-augmented model, the risk-free component of expected returns accounts for just under half of exchange rate movement, on average, compared to less than 5% when currency risk is assumed to be uncorrelated with returns. Innovations in the risk-free component are correlated with changes in nominal short-term interest rates, a measure of monetary policy.

The currency risk premium component of expected returns accounts for just over half of exchange rate movements, on average. Innovations in the currency premium are correlated with 'speculative' positioning in foreign exchange markets, and for non-reserve currencies, with 'VIX' a standard measure of risk aversion. In contrast, "carry trade" returns (the return from borrowing in low return currencies and investing in high return currencies) tend not to be correlated with observed measures of risk.

Overall, the results suggest an additional channel for the transmission of foreign shocks in open economy macroeconomic models with sticky prices. In the standard model, the currency premium, the part of exchange rate movements not explained by expected future returns, affects the economy through demand for imports and exports. Through that channel, the currency premium generally affects the trade balance and the exchange rate, but has little effect on the economy. The results here show a significant effect of the currency premium in the risk premium component of expected returns. If the home currency premium eases, then the home exchange appreciates, restraining the tradable sectors; but the risk premium component of borrowing costs declines, stimulating interest-sensitive sectors of the economy. The relative size of those two opposing effects on the home economy is left for general equilibrium analysis.

1 Introduction

Uncovered interest parity (UIP) is a key building block of open economy macroeconomics. It plays an important role in the transmission of shocks, it is a workhorse in models underlying studies of optimal monetary policy, and interest arbitrage is what makes the monetary policy trilemma bind. The empirical failure of UIP -- high interest rate currencies tend to appreciate, rather than depreciate to offset higher interest returns -- has generated a large literature, both confirming that '*forward premium*' puzzle empirically and exploring potential resolutions.[1]

The standard interest parity test, that regresses exchange rate changes on ex-ante interest differentials, treats as exogenous both expectations of future returns and risk. An important strand of the literature, that endogenises expectations, treats the exchange rate as an asset price. In the presence of sticky prices, the exchange rate should reflect an infinite sum of expected relative home and foreign returns (Dornbusch 1976). Engel and West (2005) construct forecasts of expected future fundamentals and show that revisions to their forecasts of fundamentals are generally positively correlated with exchange rate changes, but that those correlations are well below the theoretical benchmark. Their findings suggest that expectations need to be treated endogenously.

Risk premia have been widely examined as an explanation of deviations from UIP.[2] Papers that relate UIP residuals to risk alone, however, treat changes in expected returns as exogenous.[3] Several influential papers jointly model risk and expected returns. Fama (1984) shows that the tendency of high interest rate currencies to appreciate implies that (i) the change in the rational exchange rate forecast is negatively correlated with a 'premium'; and (ii) the premium has the larger variance of the two. Backus et al (2001) characterise Fama's premium in the context of affine models of the term structure and relate it to differing discount factors, or incomplete risk sharing,

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[1] See Bilson (1981), Fama (1984). For literature reviews, see Engel (2013), Engel (2012), Engel (1996), and Flood and Rose (1996).

[2] See, for example, Chen and Gwati (2012), Burnside (2011), Farhi et al (2009), Lustig and Verdelhan (2007), Froot and Frankel (1989) and references therein.

[3] The standard risk-neutral no-arbitrage condition is: $q_t = -r_t^d + E_t(q_{t+1}) - \lambda_t$ where q_t is the real exchange rate (value of the foreign currency), r_t^d is the home-foreign interest differential, and λ_t is the foreign currency premium. Rearranging and adding $q_{t+1} = E_{t+1}(q_{t+1})$ to both sides, $\Delta q_{t+1} = r_t^d + [E_{t+1}q_{t+1} - E_t q_{t+1}] + \lambda_t$. The UIP residual, or carry trade return, is the premium, λ_t, plus the term is square brackets which is the change in expected returns from $t+1$ to ∞.

across currency areas. Lustig and Verdelhan (2007) extend that analysis and show that portfolios of high interest currencies depreciate when consumption is low, while portfolios of low interest currencies provide hedging of consumption risk. Those papers support the idea that risk needs to be endogenised. (Engel 2012) shows that, to account for empirical exchange rate regularities, there must be at least two driving factors.

This paper uses an asset price model that jointly identifies the contributions of expected risk-free returns and risk premia to exchange rates and to expected home and foreign interest returns. To do so, it exploits the opposite-signed effects of risk-free returns and the currency premium on the exchange rate and forecast yields. Higher home risk-free returns and a higher home currency premium both increase home yields, but the former appreciates the home currency while the latter depreciates the home currency. In the theoretical model, if risk sharing is incomplete, then single-equation estimates are biased and UIP holds with near-zero probability if innovations in the risk and risk-free factors are uncorrelated. The empirical model exploits the forecasts of nominal interest returns embedded in long-term interest rate swap yields.

The results support the idea that exchange rates, risk and expected returns need to be modeled jointly. The results contrast to the weak estimated role for expected returns when risk is assumed to be exogenous. When jointly modeled, rational pricing of expected returns (Dornbusch 1976) cannot be rejected, and expected returns account for a substantial share of exchange rate variance. The results also contrast to the difficulty in relating carry trade returns - which include changes in expectations - to common measures of risk (Burnside 2011). When risk and expected returns are jointly modeled, innovations in the risk premium are correlated with ‘speculative’ positioning in FX futures markets and, for non-reserve currencies, with changes in VIX ‘risk aversion’.[4] The results are robust eight advanced country USD currency pairs.

The next section sets out an asset price model of the exchange rate that incorporates consumption risk premia. It shows that with incomplete risk sharing, single equation estimates are biased and correlations between the exchange rate and forecast interest returns may be weak. Section 3 explains how forecasts of expected real returns are constructed empirically from interest rate swap and inflation data. Section 4 examines the properties of those forecasts for eight advanced country-USD currency pairs, confirms the identification problem in the data set, presents the joint estimation results.

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[4] The VIX index is the implied volatility of the S&P500 equity index, calculated from options prices.

Section 5 relates the unobserved risk-free factor to measures of monetary policy and relates the currency premium to measures of risk. The results are interpreted in the context of the forward premium puzzle and implications for empirical and structural modeling are discussed. Section 6 concludes.

2 Theory

2.1 The asset price model

UIP is derived from Euler equations that define no-arbitrage conditions for home and foreign bonds. Together they equate the expected returns to holding domestic and foreign short-term bonds (eg. Libor or government bills) with returns r_t and r_t^*. For simplicity, we will work with real interest rates and a real exchange rate, q_t defined as the value of the foreign currency in home currency terms (a rise in q_t is a depreciation of the home currency).[5]

The no-arbitrage condition that equates domestic and foreign returns, in home currency terms, is:

$$1 = E_t \left[M_{t+1} \frac{(1+r_t^*)}{(1+r_t)} \frac{Q_{t+1}}{Q_t} \right]$$

where M_{t+1} is the stochastic consumption discount factor[6] applied to returns received at $t+1$. Using $E(mx) = E(m)E(x) + cov(m, x)$, and a log approximation (lowercase variables are logs),

$$\hat{q}_t \;\; = \;\; -(r_t - r_t^*) + E_t \hat{q}_{t+1} - \lambda_t \tag{1}$$

where $\hat{q}_t = q_t - \bar{q}$, $\bar{q}$ is the long-run real exchange rate defined by purchasing power parity (PPP), and $\lambda_t \equiv E(\Delta q_{t+1} - (r_t - r_t^*))$ is the excess return to holding foreign currency using the standard notation in the literature (Engel and West 2010). The excess return, λ_t, can be written as a consumption-based

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[5] This relationship can be expressed in real or nominal terms. Engel and West (2005) and Nason and Rogers (2008) examine the assets price relationship between exchange rates and fundamentals in nominal terms. (Engel and West 2010) examine it in real terms.

[6] $M_t = \beta U'_{C_{t+1}} / U'_{C_t}$, where β is the subjective discount factor, and U'_{C_t} is the marginal utility of consumption.

risk premium:[7]

$$\lambda_t \;=\; \frac{cov(m_{t+1}, r_t) - cov(m_{t+1}, r_t^*) - cov(m_{t+1}, \hat{q}_{t+1})}{m_{t+1}}$$

The first two terms are the premia on home and foreign payoffs (credit risk, liquidity risk, interest rate risk, etc.). The final term is currency revaluation risk, which reduces the yield on currencies that perform well when consumption is low (safe haven currencies)[8] and raises the yield on currencies that depreciate when the marginal utility of consumption is high.

In a multi-period setting, consider the following investment: borrow one unit of home currency at the short-term rate, r_t, invest it abroad at the foreign short-term rate, r_t^*, and keep rolling over the bonds for N periods. Defining $R_t = \sum_{k=1}^{N} r_{t+k-1}$ as the expected sum of observed short-term returns, and M_{t+N} as the N-step ahead stochastic discount factor, the real exchange rate can be written as:

$$\begin{aligned}\hat{q}_t &= -E_t R_t + E_t R_t^* - E_t \sum_{j=1}^{\infty} \lambda_{t+k-1} + \; E_t \hat{q}_{t+N} \\ &= -E_t \hat{R}_t - E_t \Lambda_t^q \qquad (2)\end{aligned}$$

where $\hat{R}_t \equiv R_t - R_t^*$, and the "level" excess return, $E_t \Lambda_t^q \equiv -(\hat{q}_t + \hat{R}_t)$, is the forward sum of future short-term excess returns, λ_ts, plus the expected level deviation of q_{t+N} from a constant long-run equilibrium exchange rate.[9] The term $-E_t \hat{R}_t$ in equation (2) is the standard risk-free asset price representation of the exchange rate as a sum of expected relative interest returns (Dornbusch 1976). If prices are sticky, then higher expected home returns, R_t, relative to the foreign currency returns, R_t^*, should lead to an immediate 'jump' appreciation of the home currency (fall in q_t) relative to purchasing power parity (PPP) to eliminate expected excess returns. The home currency can then depreciate over the period of high home interest rates, so that returns to holding home and foreign assets are expected to be equal.

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[7] The focus here is covariance measures of consumption risk. Risk premia can also be motivated by log-normality as in Backus et al (2001) and Lustig and Verdelhan (2007). This exposition abstracts from the variance terms associated with log-normality, without loss of generality.

[8] With perfect risk sharing, all countries' risk-free rates move together and the safe haven currency should be the one whose assets give the best hedge for consumption risk.

[9] The latter includes inflation risk: a high inflation currency should depreciate in nominal terms to restore real equilibrium. So the term $E_t q_{t+N}$ includes any deviation between relative inflation and nominal depreciation.

Expected interest rate returns, $\hat{R}_t$, can be divided into two parts: expected relative risk-free returns plus a risk premium. The N-period sum of observed short-term returns, R_t is related to the sum of 'risk-free' returns defined by the consumption discount factor $R_t^f = E_t(\sum_{j=1}^{\infty} m_{t+j})^{-1}$ as follows:[10]

$$
\begin{aligned}
E_t(R_t) &= E_t(R_t^f) - E_t \sum_{j=1}^{\infty} \frac{cov(m_{t+j}, r_{t+j-1})}{m_{t+j}} && (3) \\
E_t(R_t^*) &= E_t(R_t^{f*}) - E_t \sum_{j=1}^{\infty} \frac{cov(m^*_{t+j}, r^*_{t+j-1})}{m^*_{t+j}} && (4)
\end{aligned}
$$

Using (2), (3) and (4) we can write a two-equation system:

$$
\begin{aligned}
\hat{q}_t &= -E_t\hat{R}_t - E_t\Lambda_t^q && (5) \\
\hat{R} &= \hat{R}_t^f - E_t\Lambda_t^R && (6)
\end{aligned}
$$

where,

$$
\begin{aligned}
\Lambda_t^q &= E_t \sum_{j=1}^{\infty} \left(\frac{-cov(m_{t+j}, r_{t+j-1}) + cov(m_{t+j}, r^*_{t+j-1}) + cov(m_{t+j}, \hat{q}_{t+j})}{m_{t+j}} \right) \\
&\quad - E_t\hat{q}_{t+N} \\
\Lambda_t^R &= E_t \sum_{j=1}^{\infty} \left(-\frac{cov(m_{t+j}, r_{t+j-1})}{m_{t+j}} + \frac{cov(m^*_{t+j}, r^*_{t+j-1})}{m^*_{t+j}} \right)
\end{aligned}
$$

If the real exchange rate is stationary, ($lim_{k\rightarrow\infty}E_t q_{t+k} = \bar{q}$) and N is large, then $E_t\hat{q}_{t+N} \rightarrow 0$. That is, the risk of level shifts in the real exchange rate become unimportant. With identical preferences and complete markets in a one-good world economy, consumption in one country should be perfectly correlated with consumption in every other country so that consumption discount factors are equal (Backus and Smith 1993). In that case, $m_t = m_t^*$, and when returns R_t^* are priced according to m_t, in equation (4), then $\hat{R}_t = -\Lambda_t^q$ and $q_t = 0$. That is the standard setup used in flexible price macroeconomic models. In contrast, in the standard sticky price model, the premium does not affect expected returns, which are pinned down by expected monetary policy, but is fully priced into the exchange rate (equation 1).

In practice, we know that the real exchange rate is near-integrated and that empirical evidence for risk sharing is weak.[11] Moreover, we know from Engel

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[10] See Cochrane (2005), chapter 1.

[11] See Backus and Smith (1993). Kose et al (2003) find that, on average, consumption did not become more correlated across countries in the 1990s, despite financial integration.

and West (2005) that $cov(q_t, -R_t)$ is well below the theoretical value of one. Therefore it makes sense to estimate a general form of equations (5) and (6):

$$\begin{aligned} \hat{q}_t &= -\alpha \hat{R}_t - E_t\Lambda_t \qquad (7) \\ \hat{R} &= \hat{R}_t^f - \gamma E_t \Lambda_t \qquad (8) \end{aligned}$$

where the parameter, α, allows for incomplete pricing of expected returns, and the parameter, γ, allows for incomplete risk sharing. With complete markets, $\alpha = 1$ and $\gamma = 1$. This approach is consistent with that suggested by Baumeister and Hamilton (2013) for VARs with sign restrictions. Rather than imposing the structural parameters, $\alpha = \gamma = 1$, those parameters are estimated, conditioned on prior information.

Engel (2012) shows that, to account for the empirical regularities that a high interest currency is both strong and tends to appreciate in the short term, we need at least two driving factors. In the model represented in equations (7) and (8), there are two unobserved stochastic processes $\hat{R}_t^f$ and Λ_t that can be identified using sign restrictions. Those stochastic processes may be combinations of more fundamental shocks, such as shocks to productivity, consumption growth, consumption volatility, inter-temporal preferences, risk aversion, inflation etc.

2.2 The identification problem

Engel and West (2010) show that the correlation between the exchange rate and forecasts of fundamentals for a variety of exchange rate models is considerably weaker than expected, averaging 0.226 for five USD advanced-country exchange rates, compared to a theoretical value of one. In (7) and (8), risk-free returns and the currency premium have a within-period influence on both $\hat{R}_t$ and q_t. That structure implies that a single equation setup is subject to an identification problem and estimation bias, in the same way that demand and supply need to be jointly identified when prices and quantities are observed. The weak empirical correlations between movements in q_t and $-\hat{R}_t$ can be interpreted in terms of the parameters α and γ, the standard deviations of Λ_t and $\hat{R}_t^f$, and the covariance of the risk-free rate and the currency premium:

$$corr(q_t, -\hat{R}_t) = \frac{\sigma_{\hat{R}}}{\sigma_q}(\alpha + cov(R_t^f, \Lambda_t) - \gamma \frac{\sigma_\Lambda^2}{\sigma_{\hat{R}}^2}) \qquad (9)$$

where σ_{R^f} and σ_Λ are the standard deviations of observed returns and the premium, respectively. The term in round brackets is the single equation estimate for α.

Absent risk $\sigma_\Lambda = 0$, $\sigma_q = \sigma_{\hat{R}}$ and $cov(R^f_t, \Lambda_t) = 0$. In that case, the correlation between movements in the exchange rate and $-\hat{R}_t$ is α and the weak empirical correlation between exchange rates and fundamentals would be interpreted as partial adjustment.[12] Rather than a complete initial 'Dornbusch' jump response to a change in fundamentals, the high interest currency may only partly adjust on impact and continue to appreciate in the short term.

More generally, if $\Lambda^R_t = \gamma\Lambda^Q_t$, $\gamma > 0$, then the final term, $\gamma\sigma^2_{\Lambda^Q}/\sigma^2_{\hat{R}}$, is unambiguously positive. The estimated value of α falls from 1 as the variance of the premium rises relative to the variance of expected returns. An identification problem may arise for another, more fundamental reason: the consumption discount factor and the risk premium may be correlated. If $cov(\hat{R}^f_t, \Lambda^Q_t) < 0$ then $\hat{\alpha}$ will be biased further downward. Posterior estimates from the model can inform on α and γ as well as on the source of estimation bias.

3 Empirical strategy

3.1 Forecasts of returns in interest rate swaps

The interest rate swap market provides a useful market-based measure of expected future short-term (Libor or equivalent) nominal returns. The swap rate is the rate the market is willing to pay (receive) in exchange for floating-rate interest payments (receipts). A zero-coupon swap[13] equates the value of a single fixed payment at maturity to the expected compounded returns on floating interest rates up to the same maturity. Abstracting from risk, the ten-year zero-coupon swap rate (at an annual rate), multiplied by ten years incorporates a forecast of the sum of future short-term nominal interest rates

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[12] See footnote 32. See Engel (2012) for a critique of that view.

[13] Zero-coupon swap rates are derived from ordinary interest swap rates (see Hull (2000), p90-92). Both the exchange rate and the swap are priced under 'risk-neutral' probabilities, that is, they are arbitrage-free prices. Risk-neutral pricing does not assume that all market participants are risk neutral, but that the arbitrage-free price includes a premium that reflects a weighted combination of the premia of individual participants.

over a ten-year horizon:

$$(1 + i_t^Z)^N \;=\; E_t \prod_{k=1}^{N} (1 + i_{t+k-1})$$

taking logs,

$$N\, i_t^Z \;\simeq\; E_t \sum_{k=1}^{N} i_{t+k}$$

where i_t^Z is the N-period zero-coupon swap rate and i_t is the floating Libor interest rate. That is not quite the infinite un-discounted sum we would like, but it is a market-based forecast of short-term interest returns over a long horizon. Because it is based on transacted prices,[14] the swap-based forecast may be a better proxy for forward expectations than a regression-based forecast.

3.2 Nominal and real rates

Real returns, $\hat{R}_t$, are defined as relative nominal returns net of the forecast sums of relative inflation follows:

$$\begin{aligned} -\hat{R}_t &= -\sum_{k=0}^{119} (i_{t+k} - i^*_{t+k}) + E_t \sum_{k=1}^{\infty} (\pi_{t+k} - \pi^*_{t+k}) \\ &\approx -120\,(i_t^{Z10} - i_t^{*Z10}) + \frac{(\rho_\pi)^2 (\pi_{t-1} - \pi^*_{t-1})}{1 - \rho_\pi} \end{aligned} \qquad (10)$$

where i^{Z10} and i^{*Z10} are home and foreign ten-year zero-coupon swap rates (% per month). i^{Z10} and i^{*Z10} are multiplied by 120 months to proxy a 120 month sum of returns. As such, the forecasting horizon is 10 years. Five and fifteen-year forecast horizons are considered in the robustness section. The expected sum of future relative inflation from $t + 1$ to ∞ is proxied by a simple AR1 forecast.[15] The AR(1) coefficient for inflation is estimated jointly with other parameters.

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[14] Those forecasts are the basis for a vast volume of transactions: the Bank for International Settlements (2013) reports that the notional amount of interest rate swaps outstanding globally in December 2012 was $490 trillion.

[15] Break-even inflation rates from inflation-indexed bonds would provide a better measure of expected inflation than simple AR(1) forecasts. In practice, inflation-indexed bonds are only systematically issued in a few jurisdictions, markets are often not very liquid and data samples are short.

3.3 Accounting for risk premia

When accounting for risk, the real swap rate (the observed nominal swap rate adjusted for expected inflation) can be written:

$$E_t(R_t^z) = Nr_t^z \quad = \quad E_t(R_t^f) - E_t \sum_{j=1}^{\infty} \frac{cov(m_{t+j}, r_t^z)}{m_{t+j}}$$

Replacing $\hat{R}_t$ with $\hat{R}_t^z = N(r_t^z - r_t^{*z})$, equations (7) and (8) can be written,

$$\begin{aligned} \hat{q}_t &= -\alpha \hat{R}_t^z - E_t \Lambda_t' && (11) \\ \hat{R}^z &= \hat{R}_t^f + \gamma \Lambda_t' && (12) \end{aligned}$$

When using the observed zero-coupon swap as an observed variable rather than $\hat{R}_t$, in equations 11 and 12, the risk premium Λ_t' has less credit default risk and relatively more interest rate risk.[16] The interest rate risk is desirable for our purpose. Exposure to interest rate risk means that the swap market should provide good forecasts. In contrast, government or private bonds can carry a large risk premium or ‘‘specialness” discount if they are in short supply relative to requirements defined by investment mandates.[17] As before, under the assumptions of perfect risk sharing, stationarity of the real exchange rate, and large enough N, we expect $\alpha = 1$ and $\gamma = 1$. In the absence of complete risk sharing or if the real exchange rate is subject to a level shift then the nature of the identification problem is the same as before. For simplicity, from this point onwards $\hat{R}_t^z$ and Λ_t' will simply be referred to as $\hat{R}_t$ and Λ_t.

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[16] See Duffie and Singleton (1997).

[17] The credit risk embedded in a swap comes from two main sources. One is the risk that a counter-party becomes insolvent when the swap is out-of-the-money, due to movements in interest rates. Counter-party credit risk tends to be small because no principal is exchanged in the swap, and because counterparty credit risk is commonly mitigated by posting of collateral. The second source of credit risk is the credit default risk embodied in the underlying 90- or 180-day Libor, or equivalent, benchmark rate. The Libor-OIS premium is usually small, but reflected the large rise in counter-party risk during the Global Financial Crisis. *Relative* credit risk in the two currencies tends to be small because major participants in the home and foreign markets are financial institutions with similar risk profiles. There are still credit risk differences between the domestic and foreign interest rate series because of differences in reporting bank panels, unless a matched bank panel is used, and because of differences across jurisdictions in collateralisation, liquidity risk and currency revaluation risk, and quotes have, at times, been subject to manipulation.

3.4 The empirical model

We know from Engel and West (2005), that the level risk premium, Λ_t, and the sum of expected relative returns, $\hat{R}_t$, have near random walk properties. The baseline empirical model assumes that changes in those variables are random walk processes: $X_t = X_{t-1} + \eta_t^X, \ \ for X \in (R^f, \Lambda)$. Lagged observable variables are considered in the robustness section, but are expected to be small in keeping with the general inability to forecast exchange rates (Meese and Rogoff 1983) and the idea that changes in these forward-looking variables mainly reflect news.

Since the observed variables have near-random walk properties, the model is estimated in differences:

$$\begin{aligned} \Delta q_t &= -\alpha \Delta \hat{R}_t - \eta_t^{\Lambda} && (13) \\ \Delta \hat{R}_t &= \eta_t^{Rf} - \gamma\, \eta_t^{\Lambda} && (14) \end{aligned}$$

For estimation, the full model also includes an expression for the forecast of expected real returns $\hat{R}_t$ (equation 10), accounting identities that relate levels and differences, and an AR(1) process for the evolution of annual inflation $(\pi_t^{12} - \pi_t^{12*})$.

The model is estimated using Bayesian techniques[18] and demeaned observed data for q_t, the ten-year zero-coupon swap differential, and relative annual CPI inflation $(\pi_t^{12} - \pi_t^{12*})$. In a first step, the mode of the posterior distribution is estimated by maximizing the log posterior function, which combines the prior information on the parameters with the likelihood of the data. In a second step, the Metropolis-Hastings algorithm is used to sample the posterior space and build the posterior distributions. The posterior distributions are from a Metropolis Hastings chain of 200,000 draws, of which the first 50,000 are discarded. Acceptance rates are about 35%. Convergence is established using chi-squared statistics comparing the means of the beginning and end of the retained section of the Markov chain (Geweke 1992).[19]

By estimating α and γ, we allow for the possibilities that pricing is inefficient $\alpha \neq 1$, that risk is priced asymmetrically in the foreign exchange and fixed income markets $\gamma \neq 1$, and that relative risk-free returns and the premium are correlated $cov(R_t^f, \Lambda_t) \neq 0$. Priors restrict α, γ to be positive. Those restrictions provide the identifying restrictions for the structural interpretation

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[18] See (An and Schorfheide 2007) for a more elaborate description of this methodology. The estimation is implemented in Dynare (Adjemian et al 2011).

[19] See technical appendix

and allow joint identification of the unobserved risk-free and premium components of the exchange rate and expected returns. Thus, a purely empirical interpretation of R_t^f is factors that have opposite-signed effects on q_t and $\hat{R}_t$; while Λ_t includes factors that have same-signed effects on q_t and $\hat{R}_t$.

Priors also restrict the standard deviations to be to be positive, and the inflation AR(1) coefficient to be between 0 and 1. Priors are otherwise dispersed (see Table 1). Sensitivity to priors is considered in the robustness section.

For UIP to hold in equations(13) and (14), the exchange rate needs to, on average, move along the rational forecast path $q_t = -\hat{R}_t$ implying that $\Delta q_t = -\Delta\hat{R}_t$. Absent risk ($\eta_t^\Lambda = 0$), then $\alpha = 1$ ensures that UIP holds and the correlation between Δq_t and $-\Delta\hat{R}_t$ is unity. A more general solution for UIP to hold is: $\eta_t^\Lambda = \frac{1-\alpha}{1+\gamma-\alpha\gamma}\eta_t^R$. That is, *UIP is a special case, with very low probability if the two innovations are uncorrelated.*

3.5 Data

The data set covers eight US dollar (USD) currency pairs: the Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro (EUR), British pound (GBP), Japanese yen (JPY), New Zealand dollar (NZD) and Swedish krona (SEK). The data used are the nominal exchange rate, relative CPI prices and the nominal ten-year zero coupon swap rate differential. The start date of the sample is limited by the available period for zero-coupon swap data: on Bloomberg, the data are available from December 1989 for the yen and USD, from January 1999 for the euro, and from December 1994 for other currencies (223 observations). The end of the sample is July 2013. Exchange rate and interest rate data are end-month. Data sources are shown in Appendix A.

The real exchange rates and forecasts of undiscounted relative real interest rate returns are shown in Figure 1 for the eight USD currency pairs. Forecast revisions and exchange rate changes are shown graphically in Figure 2.

4 Results

4.1 Posterior parameter estimates

Summary posterior estimates are shown in Table 1.[20] The two parameters of greatest interest are α, which is the real exchange rate response to expected real interest returns, and γ, which measures the effect of the currency risk premium on the relative interest rate path. Prior and posterior distributions for those parameters are shown in Figure 3.

As a point of reference, the structural model is first estimated subject to the restriction $\gamma = 0$ so that the risk premium innovation η_t^{Λ} only enters the exchange rate equation. That special case, shown in the left hand panels of Figure 3, is equivalent to the standard, single equation, asset price model in which the currency risk premium affects the exchange rate, but not the relative yield curve. Estimating that 'single equation' case serves as a check on the influence of the estimation techniques on the results. When $\gamma = 0$, posterior mode estimates for α are well below the theoretical value of one, ranging from 0.12 for the CAD/USD to 0.50 for the EUR/USD, and averaging 0.32. One is outside the 90% confidence bands in all cases. The weak relationship between the exchange rate and expected returns is not resolved by the influence of the priors, nor by use of more volatile forecasts of future returns from interest rate swaps.

When risk is endogenous (right hand panels of Figure 3), the estimated posterior mode for γ, the effect of the currency risk premium on the relative yield curve, averages 0.36 and ranges from 0.28 for the AUD/USD to 0.45 for the GBP/USD. Those values are well below the theoretical value of one. Across the eight currency pairs, the 90% confidence bounds exclude values less than 0.14 and greater than 0.52. These values of γ between zero and one bias the correlation between q_t and $-\hat{R}_t$ downwards from 1 (final term in equation 9).

When the effects of the currency premium and risk-free returns on both the relative yield curve and the exchange rate are jointly modeled, the extent of the identification problem is apparent. The estimated relationships between exchange rates and returns are much closer to theory. The average posterior mode for α over the eight currencies is 0.95. One is inside the 90% confidence bounds for α in all cases, and the mode of the posterior distribution shifts towards the theoretical value of one. When the effects of risk and return

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[20] Detailed estimation results are provided in the Technical Appendix.

on the FX and the fixed-income markets are jointly modeled, the results are consistent with contemporaneous exchange rate adjustment to expected returns (Dornbusch 1976). The results do not support the idea that a high interest currency adjusts partially and then continues to appreciate.

The estimated AR(1) coefficient for the inflation differential ranges from 0.89 to 0.93. Consistent with Fama's interpretation of the tendency of high interest rate currencies to appreciate, the standard deviation of risk premium innovations is about 1.5 times that of innovations in the risk-free rate.

4.2 Exchange rate variance decomposition

When risk and return are jointly modeled, the risk-free factor accounts for about half of exchange rate variance, compared to about 5% when risk is assumed to be exogenous. The large role for expected risk-free returns arises for two reasons. First, the innovation η_t^{Rf} includes the endogenous monetary policy response to the economy, as well as the traditional monetary policy shock in New Keynesian models, and also expectations about future monetary policy that are not reflected in the short-term interest rate. Much of that variance would be attributed to other shocks in a general equilibrium setting. Second, the estimated exchange rate response to expected returns is near one, compared to the weak response in empirical models that treat risk as exogenous.

On average, the risk-free component of the yield curve, η_t^{Rf} accounts for about 80% of the variance of expected relative yields, $\hat{R}_t$. In this random walk model with iid innovations, the same shares hold in the forecast error variance decomposition at different horizons. Even if error correction terms or lagged observed variables are included, the shares are little changed because those terms are small. Historical decompositions of the exchange rates are shown in Figure 4. The blue bars show the contribution of innovations in the risk-free rate, and the yellow bars show the contribution of innovations in the currency premium.

4.3 Properties of $\hat{R}_t$ and Λ_t

Table 3 shows the correlations and standard deviations of q_t $\hat{R}_t$ and Λ_t akin to those in Engel and West (2010).[21] As in Engel and West (2010), the correlations of exchange rates, q_t, and expected returns, $\hat{R}_t$, are weak. For the five USD currency pairs in Engel and West (2010), Table 1 (CAD, CHF, EUR, GBP and JPY), $corr(q_t, \hat{R}_t)$ for the swap-based forecasts averages -0.28 (ranging from -0.59 to -0.01) compared to an average -0.24 (with a range of -0.86 to 0.35) for Engel and West's VAR forecasts, and compared to a theoretical value of -1.

The market-based forecasts of $\hat{R}_t$ are more volatile than Engel and West's forecasts.[22] As shown in Table 3, for the same five currency pairs, the standard deviation of the market-based forecasts of $\hat{R}_t$ have standard deviations averaging 0.57 times that of q_t, and 0.6 times that of Λ_t, compared to 0.32 times the standard deviation of q_t and 0.33 times the standard deviation of Λ_t for Engel and West's forecasts. As a result the constructed level risk premium $\Lambda_t = -(q_t + \hat{R}_t)$ is substantially different to that in (Engel and West 2010). The higher variance of the premium relative to the sum of expected returns is one source of single equation estimation bias (final term in equation 9).

As shown in Table 4, $corr(\hat{R}^f_t, \Lambda_t)$ is consistently negative for the eight currency pairs. That negative covariance is a second source of the weak empirical correlations between q_t and $\hat{R}_t$ (covariance term in equation 9) so further biases single equation estimates of α downwards from one. These results are consistent with Fama (1984)'s interpretation of the failure of the forward premium puzzle. The the rational forecast of expected returns is time varying, and systematically correlated with the premium $\hat{R}_t = \hat{R}^f_t - \gamma\Lambda_t,\ \gamma \neq 0$ and the variance of the premium is greater than the variance of rational forecast revisions ($\sigma^{\Lambda} > \sigma^{\hat{R}}$).

4.4 Robustness

The first point to note is the robustness of the results across currencies. The consistency of the parameter estimates across currency pairs suggests a similar data generating process, characterised by immediate and near-complete

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[21] The level risk premium is constructed as $\Lambda_t = -(q_t + \hat{R}_t)$. That implies a long-run assumption $\alpha = 1$ in our model, while the short-run exchange rate response to expected returns is estimated. The long-run assumption $\alpha = 1$ is lifted in a robustness check and the estimated long run value of α is close to one (section 4.4).

[22] The results are not directly comparable because of differences in the sample periods.

exchange rate adjustment to fundamentals, and by asymmetric pricing of risk in the FX and fixed income markets.

Second, several variations in data and structure were estimated to assess robustness. These included the following, with average posterior estimates for (α, γ) shown in parentheses:

- Flat priors for α to assess bias from the prior distributions: (1.12,0.36) compared to (0.95,0.36) in the baseline estimation. That result implies that the posterior for α is biased downwards by the priors;
- separate estimation of the exchange rate response to the nominal and inflation components of expected real returns: $(\alpha_i, \alpha_\pi, \gamma)$ averaged (0.97, 0.81, 0.35), where α_i is the exchange rate response to nominal returns and α_π is the exchange rate response to expected relative inflation. The weaker response to the inflation component is consistent with a monetary policy response to inflation of more than one (Taylor principle), so that real rates rise, partly offsetting the the effect of inflation on the nominal PPP equilibrium in the short term (Clarida and Waldman 2007);
- the long-run relationship $q = -\hat{R} - \Lambda$ was changed to include an estimated long-run exchange rate response to expected returns: α_L where $\Lambda_t = -(q_t + \alpha_L \hat{R}_t)$. In that case, $(\alpha, \alpha_L, \gamma)$ = (0.97, 0.77, 0.36);
- the long-run exchange rate response to expected returns is constrained to equal the contemporaneous response: $(\alpha = \alpha_L, \gamma)$ = (0.95, 0.36);
- $\hat{R}_t$ constructed as a discounted 10-year sum using plain vanilla swaps (1.01,0.35) instead of an un-discounted sum from zero-coupon swaps;
- the inflation forecast is constructed from inflation-indexed bonds for the GBP/USD: (α, γ) =(0.84,0.38) compared to (0.85, 0.29) for the benchmark formulation estimated over the shorter 2004-2013 period;
- the innovations η_t^{Rf} and η_t^{Λ} were modeled as AR(1) processes (0.94, 0.36). The estimated AR(1) coefficients were small, averaging 0.021 and 0.023 respectively, in keeping with the idea that the innovations represent news;
- the variables $\hat{R}_t^f$ and Λ_t were modeled as AR(1) processes (0.76, 0.41). One is still inside the 90% confidence bounds for all currencies except the CAD/USD pair for which the

upper boundary is 0.998. The AR(1) coefficients averaged 0.78 and 0.97 respectively. The higher AR(1) coefficient for the level premium, across all currency pairs, implies that the near-random walk behavior of the exchange rate is associated with the premium rather than relative risk-free returns;

Further discussion and posterior distributions are shown in the Technical Appendix. To summarise, the results are qualitatively similar for all formulations above and across all eight currency pairs: the currency premium is priced into the relative yield curve with a weight γ well below one; and a complete contemporaneous exchange rate response to expected returns is within the 90% confidence bounds in all cases, in contrast to being outside those confidence bounds for all single equation estimates.

The results are more variable as the forecast horizon changes. When $\hat{R}_t$ is constructed as a 5-year sum from 5-year zero-coupon swaps, (α, γ)=(1.80,0.13). That result suggest that 5 years is too short a forecast horizon to proxy the infinite sum.[23]

When $\hat{R}_t$ is constructed as a 15-year sum, the exchange rate response is less than one: (α, γ)=(0.78,0.49). The estimated value of α is expected to converge on one from above as the forecast horizon increases. To explore that result further, the 15-year un-discounted sum was divided into three 5-year components: 0-5 year returns, 5-10 year returns and 10-15 year returns. Compared to a benchmark AR(1) model, the estimated values for α imply that forecast returns for the first 5-year period are, on average, fully priced into the exchange rate; five- to 10-year returns are discounted slightly, while 10- to 15-year returns are discounted substantially. To some extent the average value below one can be attributed to the downward bias from the prior. Another potential explanation is uncertainty. Higher estimates for γ for the longer-horizon sums suggest that risk premia are more prevalent in longer-horizon returns. That is consistent with the idea that risk premia dominate the long end of the yield curve (Piazzesi and Cochrane 2009).

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[23] For a simple AR(1) forecast of relative returns, we would expect the coefficient α to be $(1 - \rho)/(1 - \rho_r^N)$ where ρ_r is the AR(1) coefficient on the 1-period relative returns and N is the forecast horizon. As the forecast horizon increases, the estimated coefficient $\hat{\alpha}$ should converge on one from above.

5 Discussion

5.1 The risk-free rate

How does the unobserved risk-free factor relate to measured monetary policy? In the model defined by equations (11) and (12) the risk-free rate is defined by the consumption discount factor. The risk-free rate is not the observed short-term interest rate, but is the observed rate net of the unobserved premium. Empirically, innovations in relative expected returns are positively correlated with changes in the relative nominal 30-day interest rate, as shown in Table 5 (first column). That correlation comes from the correlation of the risk-free innovation with changes in the relative 30-day rate (second column). In contrast, correlations between innovations in the premium and changes in the relative 30-day rate are weak and generally insignificant (final column). Those correlations support a role for monetary policy in expected risk-free returns. Empirically, short-term interest rates are persistent, so are expected to be informative about expected future short-term interest rates.

In a sticky-price macroeconomic model, the risk-free rate is typically equal to the monetary policy interest rate. If interpreted as monetary policy, expected relative interest returns, $\hat{R}_t$, represent a forward-looking measure of monetary policy that encompasses the endogenous monetary policy rule, deviations of the short-term rate from that rule, and also market expectations about future short-term rates that are not reflected in the model-consistent path of short-term rates.

5.2 The currency risk premium

How does the unobserved risk premium compare to observed measures of risk? Table 6 shows correlations of innovations in the currency premium and the risk-free factor with changes in the 'VIX' index. When the VIX index rises, the risk premium on non-reserve currencies relative to the USD rises (eg. rising risk aversion is correlated with, withdrawal from risky assets, including equities and non-reserve currencies). The correlations between the VIX index and currency premia are consistent with the idea that occasional periods of financial stress are important for exchange rate dynamics (Burnside 2011).

As shown in Table 7, when 'speculative positioning' in a currency rises relative to the USD in FX futures markets.[24] the premium on that currency falls. That correlation ranges from -0.25 to -0.46 for the seven USD currency pairs for which it is available and is significant to the 1% level in all cases.

Large changes in Λ_t often coincide with known episodes of financial stress. For example, Figure 5 relates large negative values of η_t^Λ for the NZD/USD exchange rate to known financial stress episodes.[25]

In this paper, Λ_t is interpreted as a foreign currency risk premium, however we cannot rule out a role for the supply and demand effects of cross-border capital flows. A capital outflow has the same sign properties as the foreign currency risk premium. A capital outflow from the foreign country implies a fall in demand for the foreign currency - a depreciation of the foreign currency; a fall in the supply of funding in the foreign fixed-income market - pushing up foreign yields; and a rise in the supply of funding in the home currency fixed income markets - pushing down home yields. Speculative positioning in FX markets could reflect transitory supply/demand influences in FX markets, or a response to currency risk. Empirically, cross-currency flows are large and volatile,[26] so may have significant short-term effects on prices.[27] Capital flows may reflect a variety of influences including portfolio shifts, 'carry trade', trade flows, and central bank intervention.

In practice, risk premia and capital flows are often closely related. Empirically, stress events are often associated with large capital flows. Changes in risk may generate large capital flows such as safe-haven flows, or a retreat from risky assets during periods of uncertainty; and expectation of flows in/out of asset markets, in turn, affect the risk of holding assets in those markets. In principle, assets can be repriced without actual flows (Fama 1965), so a lasting role for flows (the innovations, η_t^Λ, have lasting effects because Λ_t is near-integrated) would imply some sort of limit to capital free arbitrage (Shleifer and Vishny 1997).

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[24] Non-commercial positioning in FX futures in the Chicago Mercantile Exchange International Money Market (IMM). Positioning of non-commercial investors in FX futures is often used as a measure of speculative capital flows (Goldstein 1983).

[25] Since New Zealand has a net external debt, nonresident flows tend to dominate those of residents. One interpretation of Figure 5 is that investment in NZD assets by nonresidents, who do not have NZD liabilities, so bear currency risk, is subject to withdrawal during periods of uncertainty.

[26] For advanced countries, gross current account credits and debits typically account for less than 1% of foreign exchange market turnover reported in the BIS Triennial Central Bank Survey of Foreign Exchange and Derivatives Market Activity.

[27] Evans and Lyons (2002) and Evans and Lyons (2006) show that flows through foreign currency markets have strong explanatory power for exchange rate movements

5.3 The UIP puzzle

Engel (2012) shows that it is difficult to reconcile risk premia with empirical exchange rate behaviour in two respects. First, when a country's real interest rate is high (relative to the foreign real interest rate, relative to average), its currency tends to be strong in real terms (relative to average). Moreover, the strength of the currency cannot be attributed entirely to $\hat{R}$ as it would be in the absence of risk (Dornbusch 1976). If the home interest rate is high because of a high risk premium, then the home currency should be weak, not strong as we observe empirically.

Table 8 confirms the observation that a high interest currency is a strong currency, relative to average. When the home currency is strong (q_t is low), the short-term interest differential (home-foreign) tends to be high in both real and nominal terms.

The correlations of the innovations in expected risk-free returns with changes in risk aversion (VIX) and speculative positioning (IMM) in Tables 6 and 7 provide some evidence that a strong currency tends to be associated with both a low currency premium and high relative risk-free returns. When VIX rises, the correlations show that the USD appreciates relative to 'risky' non-reserve currencies. In the context of the model (11) and (12), there are two channels through which the exchange rate and expected relative returns are affected. For non-reserve currencies, the higher foreign currency premium - 'flight to quality' - appreciates the USD and increases foreign currency yields relative to USD yields. However, correlations with the risk-free factor show that foreign risk-free returns fall relative to USD risk-free returns. The relative fall in foreign risk-free returns further appreciates the USD and roughly offsets the effect of the higher foreign currency premium on the relative yield curve ($|\gamma corr(\Delta VIX, \eta^{\Lambda})| \sim |corr(\Delta VIX, \eta^{R^f})|$). As a result, a high risk premium currency is not necessarily a high interest rate currency.

The correlations with 'speculative positioning' relative to the USD show a similar pattern but, in that case, the movement in risk-free returns dominates the effect of the premium on the relative yield curve. When speculative positions in a foreign currency relative to the USD rise, that currency appreciates relative to the USD for two reasons. First, the correlation with η_t^{Λ} averaging -0.37, implies an appreciation of the foreign currency. Second, the correlation with $\eta_t^{R^f}$, averaging -0.35, implies that USD risk-free returns fall relative to foreign currency risk-free returns. For example, foreign monetary policy tightens - or is expected to tighten - relative to US monetary policy. The fall in the foreign currency premium reduces expected foreign currency yields relative to USD yields, but the relative rise in foreign risk-free returns has a larger effect on expected relative yields ($|\gamma corr(\Delta VIX, \eta^{\Lambda})| < |corr(\Delta VIX, \eta^{R^f}|)$). So when positioning in the foreign currency is high, that currency has high expected returns (relative to the foreign real rate and relative to average) and a low currency risk premium. These results are consistent with Engel (2012)'s observation that when a currency is strong, its strength cannot be attributed entirely to expected returns, $\hat{R}$, as it would be in the absence of risk (Dornbusch 1976).

The second empirical regularity highlighted by Engel (2012) is that a high interest currency has excess returns in the short term (the 'forward premium' puzzle). If the home interest rate is high because of a risk premium, it is unclear why a the home currency should continue to appreciate. Table 9 confirms that $corr(\Delta s_t, \hat{i}_{t-1})$ and $corr(\Delta q_t, \hat{r}_{t-1})$ are well below one for this data set, ie. high interest rate currencies have excess returns in the short term ($cov(\hat{r}_{t-1}, \lambda_t) < 0$).

Even if a high interest currency is a low risk currency (relative to others relative to average), as discussed above, it is not obvious why a low risk currency should continue to appreciate in a forward-looking framework. As shown in Table 4, $cov(\hat{R}^f_t, \Lambda_t)$ and $cov(\Delta\hat{R}^f_t, \Delta\Lambda_t)$ are systematically negative.[28] From a causal point of view, that systematic correlation could arise because risk-free rates and risk premia respond to common factors,[29] because risk responds to the state of the economy, or because the economy, and so monetary policy, respond to risk premia. Whatever the mechanism, the systematic correlation between expected risk-free returns and the premium, and between changes in expectations and changes in the premium, suggest that exchange rates, risk and return need to be modeled jointly, as implied by the analysis of Fama (1984).

What mechanisms can explain the systematic $cov(\Lambda_t, \hat{R}^f_t) < 0$? One potential explanation is that, when the home economic outlook is good (high $\hat{R}^f_t$), home investors have greater appetite for risk, including investment in foreign currency assets. Higher home risk appetite lowers the foreign currency premium, so that $cov(\Lambda_t, R_t) < 0$. Since, $\gamma < 1$, the lower premium is not fully priced into the relative yield curve, so the foreign currency continues to have higher relative returns in the short term.

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[28] In contrast, gross returns $\hat{R}_t$ and the premium Λ_t are not systematically correlated as shown in Table 3 and in Engel and West (2010).

[29] For example, if volatility increases, then increased precautionary savings can be expected to depress risk-free rates, while variance and covariance-based measures of risk can be expected to rise.

A related explanation can be made in the context of convergence between high and low return-to-capital economies and a role for capital flows. Absent risk, capital should flow to high return currencies to equalise the return on capital. When home risk tolerance allows (Λ_t is low), capital flows to the foreign country, driving down foreign currency yields ($\hat{R}_t^f$ rises). While prices can adjust without actual flows (Fama 1965), the equalisation of returns to capital requires a rise in the capital stock of the high-return-to-capital country, and so sustained capital inflows. That convergence may take decades in the absence of either very high savings or large current account deficits, and the speed of convergence may be further constrained by the capacity of the foreign economy to absorb high rates of investment. Moreover, if capital flows to high-return countries are very persistent, they may overwhelm arbitrageurs' exposure limits (Shleifer and Vishny 1997). In that case, capital inflows may have lasting supply-demand effects in the FX markets so that $cov(\hat{R}_t^f, \Lambda_t),\ cov(\Delta\hat{R}_t^f, \Delta\Lambda_t) < 0$.

5.4 Relationship to the literature

This paper relates to several strands of the literature. It builds on the asset price framework of Engel and West (2005)[30] in two ways: by employing the forecasts of interest returns embedded in long-term interest rate swaps; and by jointly modeling the unobserved risk and return components of relative yields and the exchange rate. Interest rate swaps provide a market-based, long-horizon forecasts of short-term interest returns.[31] The swap-based forecasts have moments that bring expected returns empirically closer to exchange rates but, like Engel and West (2005)'s AR(1) and VAR(2) forecasts, the correlations between forecast returns and exchange rates are well below the theoretical value. In contrast, the joint modeling of risk and return appears to partly resolve an identification problem weakens the relationship between exchange rates and returns in a single equation setup.

The nature of expectations has been an important issue in the exchange rate

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[30] See also Engel and West (2010) and Nason and Rogers (2008).

[31] The approach here is conceptually different to Chinn and Quayyum (2012) and Chinn and Meredith (2004) who relate multi-year exchange rate changes to multi-year bond differentials. Here long-term swaps are used as a proxy for expected future short-term returns, and are related to monthly exchange rate movements.

literature[32]. The results in this paper support the idea that expectations are important. Empirically, this paper exploits the market-based forecasts of expected returns in interest rate swap pricing. Theoretically, it admits a role for risk in those forecasts. Doing so requires joint identification of risk and risk-free returns and appears to overcome an identification problem that leads to a weak estimated exchange rate response when either risk or expectations is treated as exogenous.

Many papers in the VAR literature seek to identify the exchange rate response to changes in interest rates. If the currency premium affects both the exchange rate and expected returns, then identification based on a Cholesky factorisation cannot identify the exchange rate response to a monetary policy shock. It precludes the contemporaneous and correlated responses of expected returns and risk in the data.[33] Moreover, the short-term interest rate is a weak proxy for the sum of future returns, which is considerably more volatile. Some VAR studies identify a strong immediate exchange rate response to monetary policy shocks, including Scholl and Uhlig (2008) using sign restrictions. Bjørnland (2009) uses long-run restrictions that allow for a contemporaneous relationship between interest rates and the exchange rate, and identifies a Dornbusch 'jump' response for a range of advanced small open economy currencies. None of those papers explicitly addresses the role of risk.

Papers that relate latent yield curve factors to exchange rates[34] potentially capture both risk and return. Piazzesi and Cochrane (2009) associate the market price of risk exclusively with the level factor which dominates longer-term returns in affine yield curve models. Therefore a decomposition into yield curve factors likely captures both risk and return. The approach here differs from affine yield curve models by decomposing the yield curve into the risk-free return and premium components exploiting their opposite-signed effects on the exchange rate and expected future returns, rather than into factors informed by the cross-sectional shape of the yield curve.

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[32] The weak empirical relationship between exchange rates and expected returns has generated a large literature with distorted expectations that generate slow or partial adjustment such as incomplete information, learning, the presence of noise traders and transactions costs. See Froot and Thaler (1990), Eichenbaum and Evans (1995), Gourinchas and Tornell (2004), Sarno et al (2006), van Wincoop and Bacchetta (2007) and Bacchetta and van Wincoop (2010).

[33] Faust and Rogers (2003) show that the timing of the exchange rate response to monetary policy is sensitive to identifying assumptions.

[34] Backus et al 2001, Krippner 2006, De Los Rios 2009, Chen and Tsang 2011, Bauer and de los Rios 2012 and Chen and Tsang 2013.

Event studies provide a potential means of addressing the identification problem by focusing on periods dominated by changes in expected risk-free returns rather than risk. Zettelmeyer (2006) and Kearns and Manners (2006) find relatively strong exchange rate response to monetary policy and Coleman and Karagedikli (2008) find a strong exchange rate response to yield curve shocks, using swap rates as a proxy for the expected returns.

Backus et al (2001) and Lustig and Verdelhan (2007) associate deviations from UIP with incomplete risk sharing. In those papers, consumption risk is motivated by log-normality. In the theoretical model presented here, deviations from UIP are also associated with also associated with incomplete risk sharing. Here the risk premia are derived as covariance-based measures of risk. If derived as variance-based premia associated with log-normality, the empirical model in this paper would be identical, but subject to a slightly different interpretation. In practice, both types of premia likely play a role. In the framework here, incomplete risk sharing leads to asymmetric pricing of risk in the FX market and the fixed income markets, and creates an identification problem that obscures the relationship between the exchange rate and expected returns in a single-equation setup where risk is treated as exogenous.

In open economy New Keynesian models, the exchange rate functions as an asset price subject to an exogenous shock to the asset price equation, or 'UIP shock'.[35] The UIP shock is generally found to have a significant effect on the exchange rate and the current account, but a relatively small effect on the economy. The results here confirm a key role for an asset price view of the exchange rate, but point to a potentially important effect of the UIP shock on expected yields and, in turn, on the risk-free rate. In the standard model, the UIP shock stimulates the home economy by depreciating the home currency. The results here imply that the premium also restrains the home economy by driving up the premium component of home yields, providing a potentially powerful channel for the transmission of foreign shocks, with important implications for monetary policy. While the mechanism here is set in partial equilibrium to provide a parsimonious framework to examine the exchange rate identification problem, it can easily be extended to a general equilibrium setting.

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[35] For recent examples, see Adolfson et al (2008), Bergin (2006), Jacob and Peersman (2013), Justiniano and Preston (2010).

6 Conclusion

The results presented here support the idea that exchange rates, risk and expected returns need to be modeled jointly. When jointly modeled, rational pricing of expected returns (Dornbusch 1976) cannot be rejected, and expected returns account for a substantial share of exchange rate variance. The bulk of that contribution is associated with the immediate Dornbusch 'jump' response to changes in expected returns. Those results are in sharp contrast to the weak estimated role for expected returns in exchange rate dynamics when risk is assumed to be exogenous. The results are robust eight advanced country USD currency pairs.

The results also contrast to the difficulty in relating carry trade returns to common measures of risk (Burnside 2011). Carry trade returns include changes in expectations and risk premia. Here, innovations in the risk premium, that exclude changes in expectations, are correlated with 'speculative' positioning in FX futures markets and, for non-reserve currencies, with changes in VIX 'risk aversion'.

Jointly modeling risk and return has implications for both empirical and structural modeling. The results imply that, in VAR models, identifying restrictions need to allow for contemporaneous two-way causality between expected returns and risk. In general equilibrium macroeconomic models, the results imply that the standard 'UIP' residual should affect the premium component of expected yields as well as the exchange rate. Introducing that common risk factor, which is well identified in the data, provides a potentially powerful mechanism for the transmission of foreign shocks to the domestic economy, with implications for monetary policy.

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Table 1: Prior and posterior estimates for endogenous risk and exogenous risk formulations

	α	γ	ρ^{π}	σ^{R}	σ^{P}	σ^{π}
Distribution	γ	γ	β	γ^{-1}	γ^{-1}	γ^{-1}
Prior mean	1	1	0.8	0.020	0.020	0.0003
Prior mode	0.76	0.76	0.85	0.009	0.009	0.0001
Prior stdev	0.5	0.5	0.1	0.500	0.500	0.0050

Risk treated as exogenous ($\gamma = 0$)
('Single equation' estimate)

AUD	0.46	0	0.89	0.02	0.04	0.0005
CAD	0.12	0	0.92	0.02	0.02	0.0003
CHF	0.35	0	0.90	0.02	0.03	0.0003
EUR	0.50	0	0.89	0.02	0.03	0.0003
GBP	0.28	0	0.93	0.02	0.02	0.0003
JPY	0.24	0	0.92	0.03	0.03	0.0004
NZD	0.30	0	0.89	0.02	0.04	0.0005
SEK	0.32	0	0.92	0.03	0.03	0.0003
average	0.32	-	0.91	0.023	0.030	0.0004

Risk and return jointly modeled

AUD	1.10	0.27	0.90	0.019	0.038	0.0005
CAD	0.80	0.35	0.91	0.015	0.028	0.0003
CHF	0.94	0.36	0.90	0.021	0.035	0.0003
EUR	1.10	0.33	0.89	0.020	0.033	0.0003
GBP	0.82	0.45	0.93	0.019	0.026	0.0003
JPY	0.84	0.43	0.91	0.025	0.036	0.0004
NZD	1.03	0.28	0.88	0.020	0.040	0.0005
SEK	0.98	0.38	0.91	0.022	0.036	0.0003
average	0.95	0.36	0.90	0.020	0.034	0.0004

The posterior mode is the maximum of posterior distribution. The standard asset price model is subject to the restriction $\alpha > 0$ and Bayesian priors. See Technical Appendix for detailed estimation tables. α is the exchange rate response to expected interest returns. γ is the weight of the currency premium on expected relative interest returns. ρ_{π} is the AR(1) coefficients of relative inflation. σ_{Λ}, σ_{R^f} and σ_{π} are the standard deviations of risk-free relative returns, the currency premium and relative inflation.

Table 2: Unconditional variance decomposition

variable →	Exchange rate changes Δq_t		Expected returns $\Delta \hat{R}_t$	
shock →	risk-free factor η_t^{Rf}	risk factor η_t^{Λ}	risk-free factor η_t^{Rf}	risk factor η_t^{Λ}
Risk treated as exogenous ($\gamma = 0$) ('Single equation' estimate)				
AUD	8.7	91.3	100.0	-
CAD	0.7	99.3	100.0	-
CHF	4.8	95.3	100.0	-
EUR	10.7	89.3	100.0	-
GBP	3.6	96.4	100.0	-
JPY	2.7	97.3	100.0	-
NZD	3.6	96.4	100.0	-
SEK	4.9	95.1	100.0	-
average	5.0	95.0	100.0	-
Risk and return jointly modeled				
AUD	48.4	51.6	88.8	11.2
CAD	37.9	62.1	78.7	21.4
CHF	38.1	61.9	82.6	17.4
EUR	61.9	38.1	80.2	19.8
GBP	53.7	46.3	69.6	30.4
JPY	56.6	43.5	70.4	29.6
NZD	42.8	57.2	77.7	22.3
SEK	45.7	54.3	79.4	20.7
average	48.1	51.9	78.4	21.6

The standard asset price model is subject to the restriction $\alpha > 0$ and Bayesian priors.

Table 3: Estimated standard deviations and correlations of q, R, and Λ

		Levels						Differences				
		q	R		Λ			q	R		Λ	
AUD	q	22.11	-0.73	***	-0.92	***	Δq	3.61	-0.25	***	-0.84	***
	$\hat{R}$		9.43		0.40	***	$\Delta\hat{R}$		2.06		-0.32	***
	Λ				16.59		$\Delta\Lambda$				3.69	
CAD	q	14.23	-0.01		-0.91	***	Δq	2.44	0.04		-0.82	***
	$\hat{R}$		6.40		-0.40	***	$\Delta\hat{R}$		1.77		-0.61	***
	Λ				15.52		$\Delta\Lambda$				3.07	
CHF	q	14.24	-0.60	***	-0.86	***	Δq	3.22	-0.22	***	-0.76	***
	$\hat{R}$		7.31		0.10		$\Delta\hat{R}$		2.37		-0.47	***
	Λ				11.48		$\Delta\Lambda$				3.55	
EUR	q	15.24	-0.42	***	-0.91	***	Δq	3.16	-0.32	***	-0.77	***
	$\hat{R}$		6.16		0.02		$\Delta\hat{R}$		2.14		-0.35	***
	Λ				13.81		$\Delta\Lambda$				3.19	
GBP	q	8.02	-0.23	***	-0.73	***	Δq	2.41	-0.21	***	-0.68	***
	$\hat{R}$		6.37		-0.50	***	$\Delta\hat{R}$		2.18		-0.58	***
	Λ				9.05		$\Delta\Lambda$				2.89	
JPY	q	13.97	-0.17	***	-0.74	***	Δq	3.22	-0.19	***	-0.70	***
	$\hat{R}$		11.07		-0.54	***	$\Delta\hat{R}$		2.83		-0.58	***
	Λ				16.31		$\Delta\Lambda$				3.87	
NZD	q	20.54	-0.58	***	-0.93	***	Δq	3.67	-0.13	*	-0.84	***
	$\hat{R}$		7.55		0.25	***	$\Delta\hat{R}$		2.20		-0.43	***
	Λ				17.30		$\Delta\Lambda$				4.03	
SEK	q	13.41	-0.53	***	-0.62	***	Δq	3.29	-0.22	***	-0.75	***
	$\hat{R}$		11.20		-0.34	***	$\Delta\hat{R}$		2.50		-0.48	***
	Λ				12.13		$\Delta\Lambda$				3.66	
averages	q	15.22	-0.41		-0.83		Δq	3.13	-0.19		-0.77	
	$\hat{R}$		8.19		-0.13		$\Delta\hat{R}$		2.26		-0.48	
	Λ				14.02		$\Delta\Lambda$				3.49	

Diagonal elements are standard deviations; off-diagonal elements are correlations. Expected relative returns, $\hat{R}_t$, are the 10-year zero-coupon interest rate swap differential, net of an AR(1) forecast of relative inflation. $\Lambda_t = -(q_t + \hat{R}_t)$. The left panel of this table is comparable to Table 1 in Engel and West (2010), which is based on VAR forecasts of $\hat{R}_t$, but covers a different sample period.

*** indicates significance to the 1% level; ** indicates significance to the 5% level, * indicates significance to the 10% level.

Table 4: Correlations of unobserved components

	$corr(R^f, \Lambda)$		$corr(\Delta R^f, \Delta\Lambda)$		$corr(\eta^{R^f}, \eta^{\Lambda})$
AUD	0.07		-0.57	***	0.03
CAD	-0.79	***	-0.83	***	0.02
CHF	-0.35	***	-0.72	***	0.02
EUR	-0.48	***	-0.61	***	0.03
GBP	-0.78	***	-0.81	***	0.02
JPY	-0.80	***	-0.80	***	0.01
NZD	-0.27	***	-0.68	***	0.02
SEK	-0.59	***	-0.74	***	0.02
average	-0.50		-0.72		0.02

*** indicates significance to the 1% level; ** indicates significance to the 5% level, * indicates significance to the 10% level.

Table 5: Correlations with short-term interest rate changes

	$corr(\Delta R, \Delta i_t)$		$corr(\eta^{R^f}, \Delta i_t)$		$corr(\eta_t^{\Lambda}, \Delta\hat{i}_t)$	
AUD	0.22	***	0.27	***	0.11	
CAD	0.24	***	0.20	***	-0.12	*
CHF	0.15	**	0.14	**	-0.05	
EUR	0.12		0.15	**	0.05	
GBP	0.12	*	0.12	*	-0.03	
JPY	0.21	***	0.21	***	-0.06	
NZD	0.25	***	0.25	***	-0.05	
SEK	0.24	***	0.25	***	-0.04	
average	0.19		0.20		-0.02	

*** indicates significance to the 1% level; ** indicates significance to the 5% level, * indicates significance to the 10% level. η^{Λ} is not significantly correlated with $\Delta\hat{i}_t$ for any currency pair.

Table 6: Correlations of real exchange rates and innovations with VIX

	real exchange rate		risk-free factor, η^{Rf}		risk factor, η^{Λ}	
AUD	-0.54	***	0.23	***	0.50	***
CAD	-0.48	***	0.13	*	0.48	***
CHF	-0.11		0.01		0.13	*
EUR	-0.36	***	0.14	*	0.36	***
GBP	-0.07		-0.03		0.12	*
JPY	0.07		-0.06		-0.04	
NZD	-0.42	***	0.12	*	0.42	***
SEK	-0.32	***	0.17	**	0.28	***
average	-0.28		0.09		0.28	

*** indicates significance to the 1% level; ** indicates significance to the 5% level, * indicates significance to the 10% level. The VIX index is the implied volatility of the S&P500 equity index, and is commonly used as a measure of risk aversion. A rise in the exchange rate is a depreciation of the USD. Relative interest returns are US minus foreign. A rise in VIX is correlated with appreciation of the USD relative to non-reserve currencies (except the yen) for two reasons: the foreign currency premium rises and foreign risk-free returns fall relative to USD returns. Risk-free returns and the premium reinforce each other in their effect on the currency but offset each other in their effect on observed yields.

Table 7: Correlations of real exchange rates and innovations with IMM positioning

	real exchange rate		risk-free factor, η^{Rf}		risk factor, η^{Λ}	
AUD	0.52	***	-0.32	***	-0.42	***
CAD	0.49	***	-0.22	***	-0.45	***
CHF	0.51	***	-0.35	***	-0.38	***
EUR	0.52	***	-0.29	***	-0.45	***
GBP	0.55	***	-0.40	***	-0.39	***
JPY	0.45	***	-0.37	***	-0.28	***
NZD	0.51	***	-0.33	***	-0.44	***
SEK	na		na		na	
average	0.51		-0.32		-0.40	

IMM positioning is non-commercial positioning in FX futures in the Chicago Mercantile Exchange International Money Market (IMM). A rise in the exchange rate is a depreciation of the USD. Relative interest returns are US minus foreign. A rise in non-commercial positioning in a foreign currency relative to the USD is correlated with appreciation of the foreign currency for two reasons: the foreign currency premium falls and foreign risk-free returns rise relative to USD returns. The effects of the lower foreign currency premium on the relative yield curve is dominated by higher foreign risk-free returns relative to USD returns. Therefore a low risk currency is not necessarily a low interest rate currency.

Table 8: Correlation between the exchange rate and interest differentials

	$corr(q_t, \hat{r}_{t-1})$		$corr(s_t, \hat{i}_{t-1})$	
AUD	-0.57	***	-0.54	***
CAD	-0.28	***	-0.16	**
CHF	-0.30	***	-0.53	***
EUR	-0.12		-0.18	**
GBP	-0.23	***	-0.21	***
JPY	-0.01		-0.18	***
NZD	-0.16	**	-0.37	***
SEK	-0.33	***	-0.19	***
average	-0.25		-0.30	

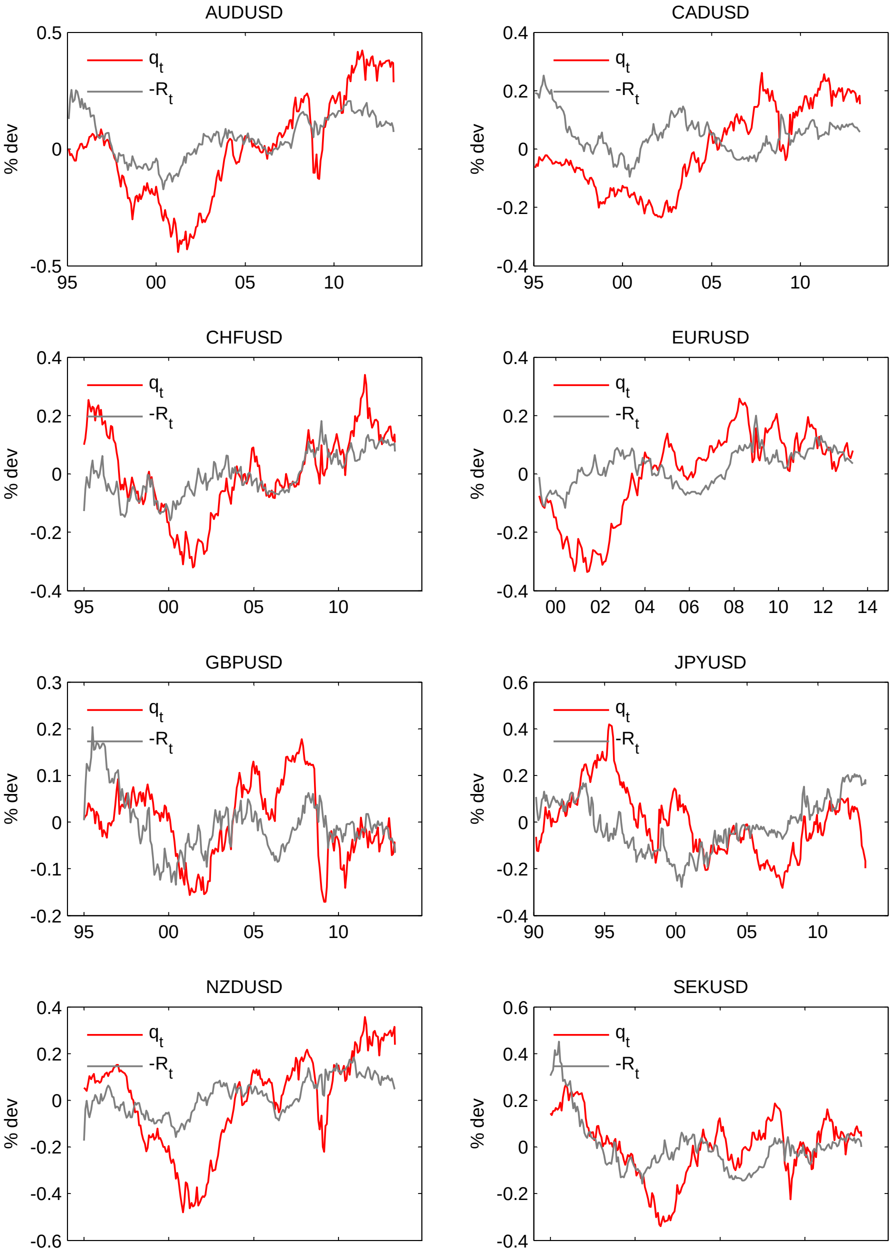
Note: Real interest rate calculated from ex-ante, observed inflation. For Australia and NZ, inflation is lagged by an additional 2 months to account for quarterly inflation reporting. *** indicates significance to the 1% level; ** indicates significance to the 5% level, * indicates significance to the 10% level. These results confirm (Engel 2013)'s observation that a high interest rate currency is a strong currency.

Table 9: Correlation between exchange rate changes and interest differentials

	$corr(\Delta q_t, \hat{r}_{t-1})$		$corr(\Delta s_t, \hat{i}_{t-1})$
AUD	0.07		-0.08
CAD	0.13	*	-0.05
CHF	-0.05		-0.10
EUR	0.08		-0.05
GBP	0.10		0.05
JPY	-0.09		-0.08
NZD	0.16	**	-0.02
SEK	0.08		-0.08
average	0.06		-0.05

Note: Real interest rate calculated from ex-ante, observed inflation. For Australia and NZ, inflation is lagged by an additional 2 months to account for quarterly inflation reporting. *** indicates significance to the 1% level; ** indicates significance to the 5% level, * indicates significance to the 10% level. These correlations confirm the forward premium puzzle in this data set: the correlations are well below the theoretical value of one, if risk is exogenous.

Figure 1: Real exchange rates and forecast sums of future relative returns



Real exchange rates (red lines) are % deviation from sample mean so are subject to a level shift if the sample mean (see Appendix A for sample periods) differs from the long-run real equilibrium. Dashed grey lines show UIP-constant PPP consistent exchange rates ($-\hat{R}_t$) constructed as 120 times the ten-year nominal zero-coupon swap differential (monthly rate), net of an AR(1) forecast of the relative inflation paths.

Figure 2: Forecast revisions ($-\Delta \hat{R}_t$) and exchange rate changes (Δq_t)

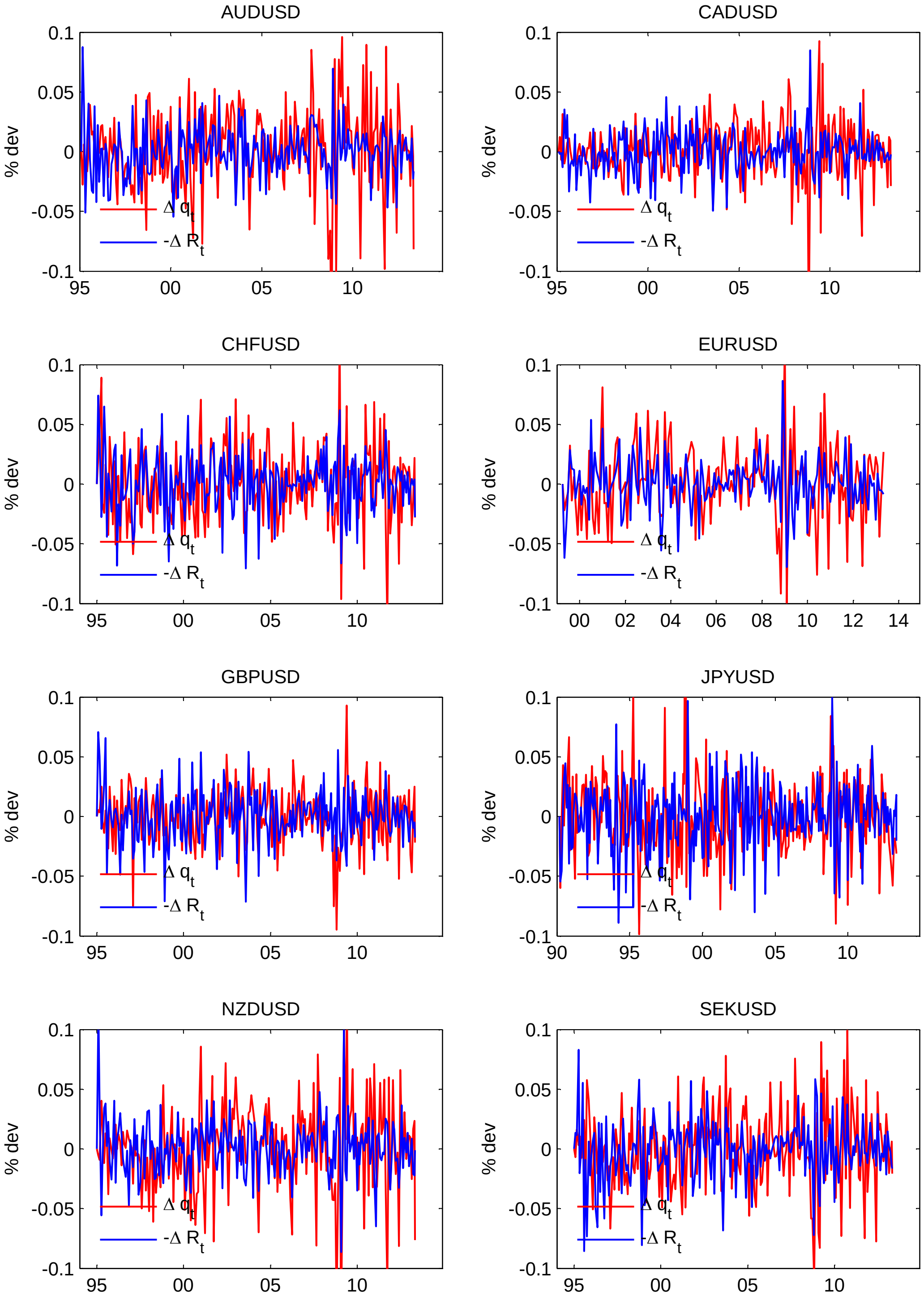
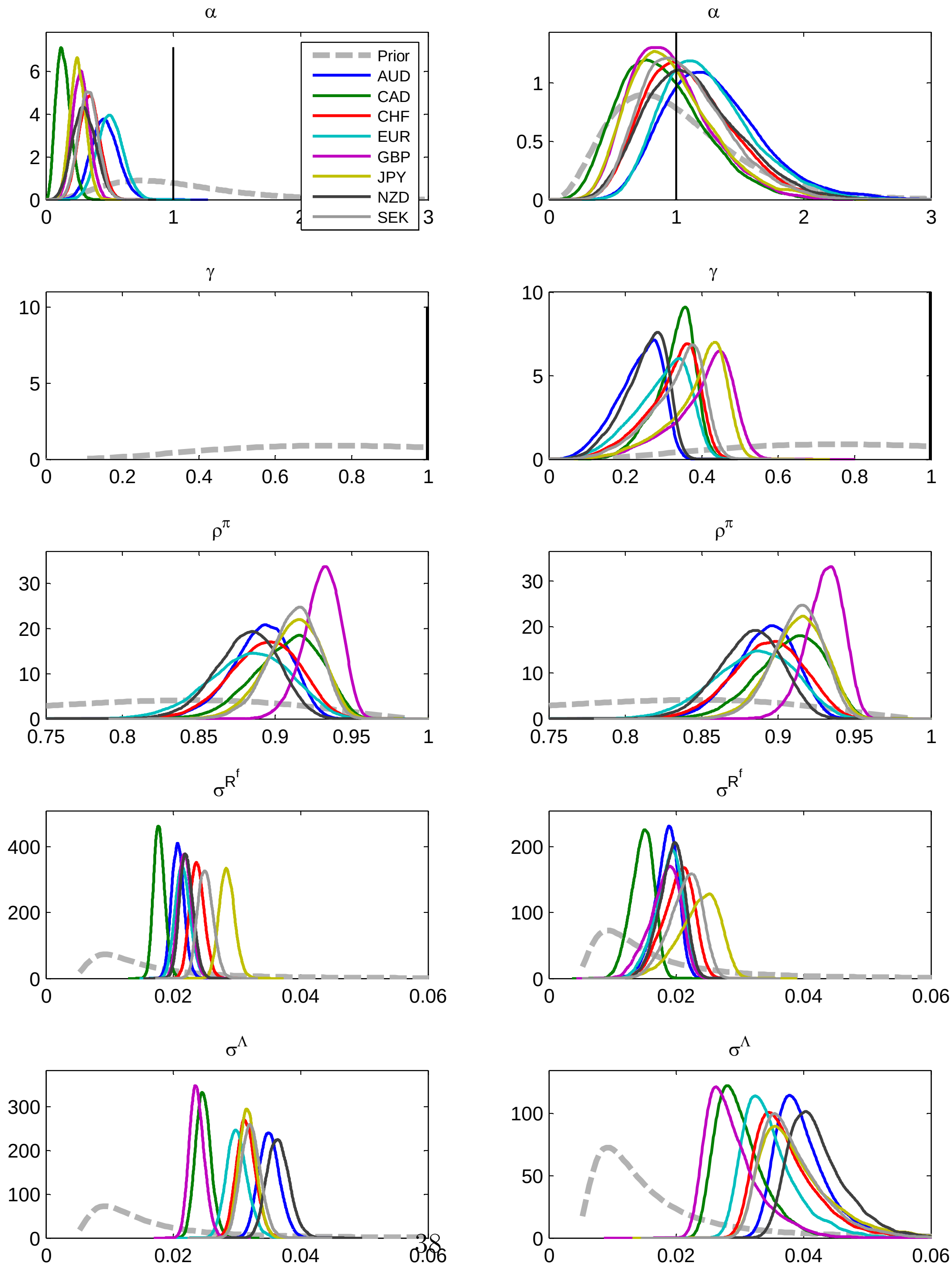


Figure 3: Posterior Densities



(a)
Currency risk treated as exogenous
($\gamma = 0$)

(b)
Risk and expected returns
jointly modeled

Figure 4: Historical decompositions of real exchange rates

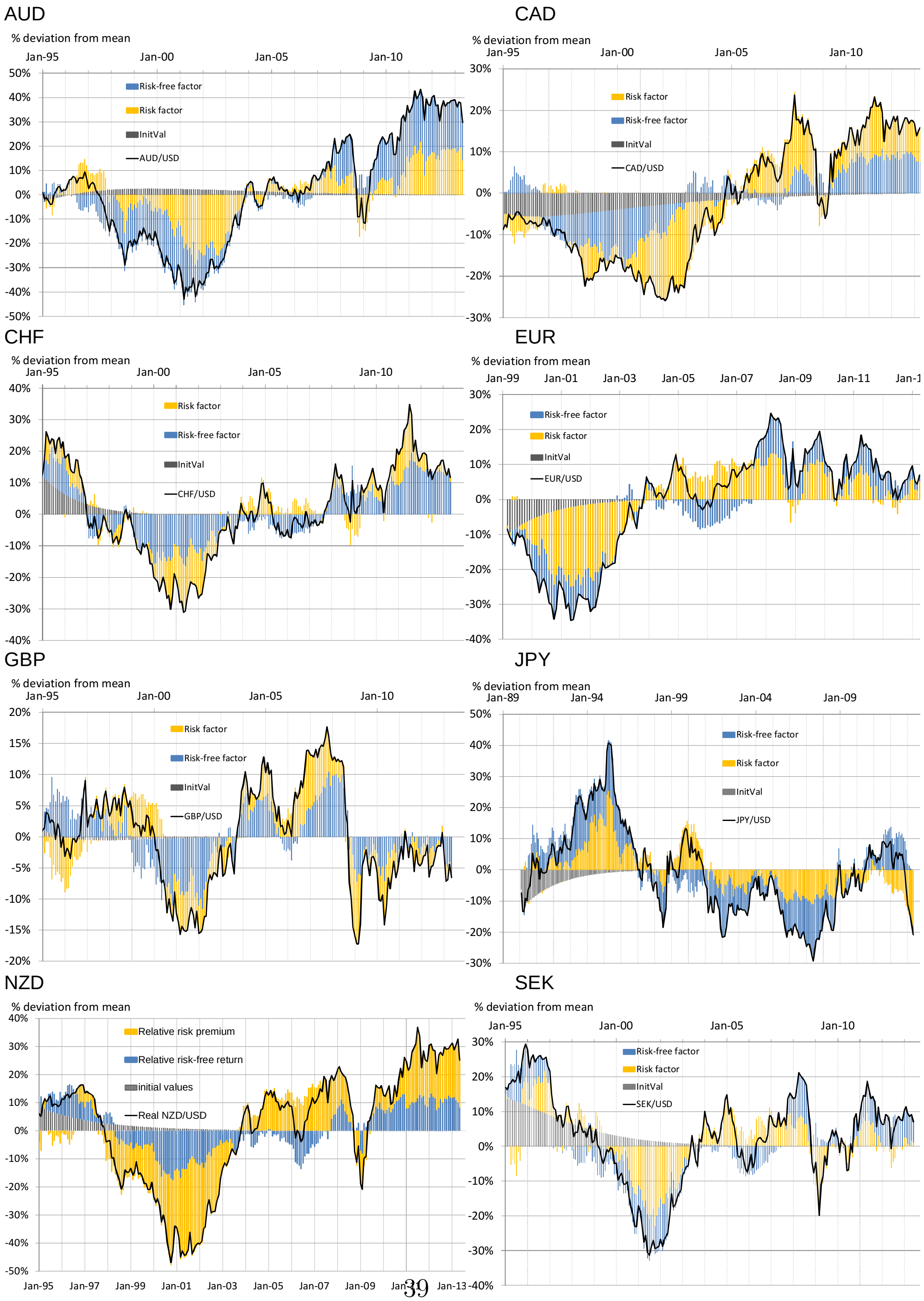
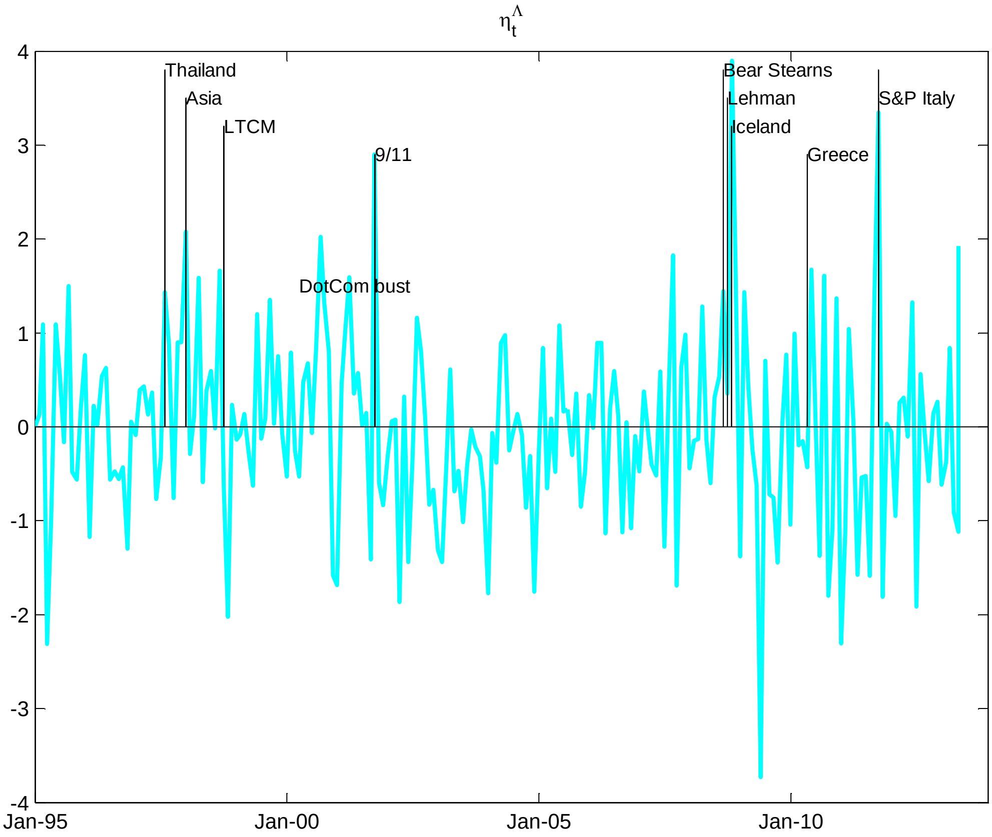


Figure 5: NZD/USD risk premium innovations, η_t^{Λ}



Appendices

A Data Appendix

Exchange rates and nominal interest rates are end-month rates. Real exchange rates are measured ex-post. The inflation component of real interest rates is forecast on the basis of distributed lag equations. CPI data is assumed to be released with in a month. Nominal 30-day interest rates, zero-coupon swap rates and spot exchange rates are end-month rates from Bloomberg:

Bloomberg codes

currency	90-day interest rate	10-year interest rate swap	10-year zero-coupon swap	exchange rate
AUD	ADBB1M Curncy	ADSW10 Curncy	I00110y index	AUD Curncy
CAD	CD001M Curncy	CDSW10 Curncy	I00710Y Index	CAD Curncy
CHF	SF001M Curncy	SFSW10 Curncy	I05710y index	CHF Curncy
EUR	EU001M Curncy	EUSa10 Curncy	I05310Y Index	EUR Curncy
GBP	BP001M Curncy	BPSW10 Curncy	I05510Y Index	GBP Curncy
JPY	JY001M Curncy	JYSW10 Curncy	I05610Y Index	JPY Curncy
NZD	NDBB1M Curncy	NDSW10 Curncy	I04910y index	NZD Curncy
SEK	SK001M Curncy	SKSW10 Curncy	I08710y index	SEK Curncy
USD	US0001M Index	USSW10 Curncy	I05210Y Index	1

For 5-year and 15-year swaps used in the robustness section, the codes are as above except that ”10” is replaced with ”5” or ”15”. Nominal 30-day interest rates are Libor rates or a local equivalent rate where the local benchmark rate is more heavily traded (e.g., Australia and New Zealand bank bill rates). Ten year zero-coupon swap rates are available from December 1989 for the JPY/USD pair, from December 1994 for all other currency pairs except the euro which is available from January 1999. Consumer price indices and import and export price indices are from the IMF International Financial Statistics. For Australia and New Zealand, quarterly price indices are interpolated so that inflation is the same for the three months of the quarter.