The Share of Systematic Variation in Bilateral Exchange Rates *

Adrien Verdelhan

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Abstract

Changes in exchange rates are not random. Two factors account for 20% to 90% of the monthly exchange rate movements in developed countries. If these two factors were known one period in advance, mean squared errors would be a fraction of those obtained assuming that exchange rates are random walks. Across countries, the more integrated the equity and bond markets, the higher the share of systematic currency variation. These results have direct implications for asset managers, motivate further work on exchange rates, and offer new insights into international economics and finance models.

Keywords: Exchange rates, common factors, risk.

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*Verdelhan: MIT Sloan and NBER. Address: Department of Finance, MIT Sloan School of Management, E62-621, 77 Massachusetts Avenue, Cambridge, MA 02139; adrienv@mit.edu; Phone: (617) 253-5123; http://web.mit.edu/adrienv/www/. The author thanks Nittai Bergman, John Campbell, Emmanuel Farhi, Thomas Knox, Leonid Kogan, David Laibson, Hanno Lustig, Jun Pan, Nick Roussanov, and Jiang Wang for helpful comments and discussions.

1 Introduction

Changes in exchange rates appear random to most investors, central bankers, and researchers alike, except perhaps at very high or very low frequencies. Hundreds of studies report low R^2s in regressions of changes in exchange rates on lagged or contemporaneous interest rate differences or other macroeconomic variables at monthly, quarterly, and annual frequencies. No model has been consistently able to predict exchange rates better than a simple random walk. As a result, accounting for the time-series or cross-sectional variation in exchange rates is still a challenge, and each bilateral exchange rate movement appears mostly idiosyncratic.

Recent research, however, has uncovered common risk factors in *portfolios* of currency excess returns sorted on interest rates. Portfolios of currencies average out idiosyncratic components and allow researchers to focus on risk factors. Unfortunately, average excess returns on currency portfolios do not tell us much about the share of systematic versus idiosyncratic variation in *each* currency pair. The key question now is: What share of individual bilateral exchange rate variances do common factors account for? In other words, do common factors explain much of the changes in the U.S. dollar / U.K. pound exchange rate, for example? This is the question that this paper addresses.

Many economists would assume that common factors only account for a tiny share of the changes in bilateral exchange rates. Most previous research point in this direction. In the classic uncovered interest rate parity (UIP) tests, for example, monthly changes in bilateral exchange rates are regressed on a constant and the interest rate difference between two countries. R^2s on UIP regressions range from 0% to 2% on monthly series over the 1983–2010 period. Contemporaneous macroeconomic variables, like industrial production and inflation, generally do not fare better. As a result, the consensus is that each individual exchange rate variation is close to random.

In this paper, to the contrary, I find that two factors — the dollar and the carry factors — account for a substantial share of individual exchange rate time-series in developed countries. These two factors are constructed from portfolios of currencies. The dollar factor corresponds to the average change in the exchange rate between the U.S. dollar and all other currencies, while the carry risk factor corresponds to the change in exchange rates between baskets of high and low interest rate currencies. I augment the UIP regressions with additional, contemporaneous, explanatory variables, first adding the carry factor, and the same carry factor multiplied by the country-specific lagged interest rate difference; the latter is referred to as the "conditional carry" factor. The dollar factor is the last additional explanatory variable. Importantly, these carry and dollar factors do not include the bilateral exchange rate that is the dependent variable.

The augmented-UIP regressions offer a novel picture of bilateral exchange rate movements. U.S.-based exchange rates tend to move in sync, and thus the dollar factor accounts for a large share of their time-series. Exchange rates also respond to the unconditional and conditional carry risk factors: the higher the interest rate, the higher the loading on the carry risk factor. Each of these factors raises the adjusted R^2s of the usual UIP regressions by an order of magnitude. Adding the carry factors to the standard UIP regressions, the adjusted R^2s increases to 3% to 18%. With the dollar factor, R^2s increase further to between 18% and 90%. As an example, the augmented-UIP regression for the U.S. dollar / U.K. pound exchange rate has an R^2 of 57%. If exchange rate movements were independent, the R^2s on the augmented-UIP regressions would be zero. In the data, they are statistically significant.

The substantial R^2s of the augmented-UIP regressions do not imply that bilateral exchange rates are easy to forecast: the corresponding regressions use contemporaneous variables, not predictive ones. But they pave the way towards future predictability tests because the share of systematic risk and the factor loadings appear robust and persistent. The stability of the factor structure is best illustrated by a simple experiment, akin to a *pseudo* out-of-sample predictability test. The slope coefficients of the common factors are estimated up to date t and used to predict the changes in exchange rates between t and $t+1$. To do so, let us assume that we know the future values of the dollar and carry factors one period in advance (hence the *pseudo* characteristic). One can then easily compare the square root of the mean squared errors (RMSE) obtained with the factors to those of a simple random walk with drift. Currency factors deliver RMSE that are between 10% to 70% lower than those implied by random walks. Classic out-of-sample tests rarely beat the random walk, and if they do so in some samples, the decrease in RMSE is of a few percentage points — even when the *realized* values of the predictors are used, as here and as in Meese and Rogoff (1983). It is quite unlikely that one will ever obtain actual (i.e., not pseudo) decreases in RMSE of more than the values reported here. Doing so would require uncovering new sources of systematic risk and the ability to predict them accurately. Predicting factors, however, is not the object of this paper. Instead, this paper links the share of systematic variation in currency markets to other markets and to the properties of pricing kernels.

I find that the share of systematic risk in currency markets is related to world asset market integration. This finding comes from cross-country comparisons. The augmented-UIP regressions uncover large differences among countries in their shares of systematic currency risk. In the class of no-arbitrage models, such cross-sectional variation comes ultimately from differences in stochastic discount factors, and thus should appear in other markets. This is indeed the case: the results show that, over the last ten years, countries with a high share of systematic equity risk also have a high share of systematic currency risk. Shares of systematic currency risk thus appear related to equity market integration. Similarly, higher shares of systematic currency risk correspond to higher shares of fixed income risk.

Finally, the reduced form model of Lustig, Roussanov, and Verdelhan (forthcoming) offers a simple risk-based interpretation of the carry and dollar factors. In their no-arbitrage model, pricing kernels depend on country-specific and world shocks. The carry factor accounts for world shocks. The dollar factor captures both U.S.-specific and world shocks. Comparing UIP regressions with and without the carry factors is thus informative about the relative volatility of the country-specific and world components of the pricing kernel. More generally, augmented-UIP regressions can help pin down hard-to-measure parameters (linked to, for example, the long run risk component of stochastic discount factors or the time-varying disaster probabilities).

The findings in this paper are of importance for academics and practitioners alike. For researchers, they motivate the study of systematic components in exchange rates, since those components account for a large share of bilateral exchange rate movements. The augmented-UIP regressions are also of importance for international economists who want to link the deep characteristics of each economy to the behavior of its exchange rate. The heterogeneity and time-variation in loadings, along with the cross-country differences in predictability, offer new potential targets for future models in international economics. Finally, for macroeconomists, the augmented-UIP regressions suggest revisiting the links between monetary and fiscal policies and exchange rates.

For practitioners, the results of the augmented-UIP regressions stress the need for currency risk management at the aggregate level. It would clearly be suboptimal to measure and hedge the risk of each individual currency in a world with large common variations across currencies. As an example, the results imply a clear difference between a basket of currency options and an option on a basket of currencies. The results are also relevant for asset managers of international stocks and bonds who do not hedge their returns for currency risk or who want to design the optimal currency hedge to their portfolios (see Campbell, de Medeiros, and Viceira, 2010). Many asset managers assume that changes in exchange rates are independent and random: under this assumption, then buying stocks in many different currencies would offer a simple diversification mechanism of currency risk. This paper, however, shows that such diversification is wishful thinking. Diversification only helps to accommodate a fraction of exchange rate variations. By considering the effect of the dollar, carry, and conditional carry factors on their portfolios, asset managers can better hedge their investments.

The paper is organized as follows. The rest of the introduction reviews the related literature. Section 2 presents the data and risk factors. Section 3 shows that the dollar and carry risk factors explain a large share of bilateral exchange rates and contrasts these findings with the usual UIP tests. Section 4 tests the persistence of the factor structure and reports pseudo out-of-sample predictability tests. Section 5 compares the shares of currency systematic variations to measures of world market integration. Section 6 relates the previous findings to recent models in international finance. Section 7 considers several robustness checks and extensions (the presence of a momentum factor and the power of macroeconomic variables; regression results at daily, quarterly, and annual frequencies; emerging and developing countries; changes in bid-ask spreads;

and other base currencies). Section 8 concludes and ends with some suggestions for future research, building on the heterogeneity in exchange rate responses. These suggestions echo Cochrane (2011) who notes the need to study asset pricing not only at the portfolio-level but also at the asset-level. The carry and dollar factors are available online and thus the results in this paper can be easily checked.

Related Literature Since the seminal work of Meese and Rogoff (1983), the standard view in international economics is that individual exchange rates follow random walks, with perhaps small departures from random walks at very high frequencies (Evans and Lyons, 2005). This consensus emerged from the failure of a large class of models to outperform the random walk in forecasting changes in exchange rates for individual currency pairs out-of-sample. Engel and West (2005) show that exchange rates are very close to random walks when fundamentals are not stationary and risk premia are constant. The random walk view of exchange rates is reinforced by the many tests of the UIP condition in the literature. The results in this paper show that all the previous UIP regressions in the literature are misspecified and suffer from an omitted variable bias because the conditional carry and dollar risk factors comove with interest rate differences. But the findings of this paper are not inconsistent with the random walk view of exchange rates: the common shocks that account for each currency pair could be random walks. In other words, each currency pair may follow a random walk whose shocks are highly correlated across countries, thus explaining the comovement among currencies.

This paper is related to principal component analyses of exchange rates: the dollar factor is close to the first principal component, although the carry factors are different from the other principal components. Early examples of principal component analyses include Diebold and Nerlove (1989) who propose a multivariate latent-variable model of seven currencies in which the common factor displays ARCH. Bollerslev (1990) estimate a GARCH model with constant conditional correlation on a set of five weekly exchange rates. More recently, Engel, Mark, and West (2009) propose a principal component decomposition of exchange rates and use the components to predict bilateral exchange rates. None of these papers reports the share of common variation of each currency pair.

This paper focuses instead on two economically motivated factors, which account for the cross-section of currency excess returns and have a natural interpretation in any no-arbitrage model.

Although this paper builds on Lustig, Roussanov and Verdelhan (forthcoming), it is clearly distinct from it: Lustig et al. (forthcoming) never report any R^2s on any time-series regressions of bilateral exchange rates. They focus mostly on the dynamics of *portfolios* of currencies. When they check their asset pricing results on bilateral exchange rates, they report only measures of cross-sectional, not time-series, fit. More generally, this paper is part of a growing literature that focuses on currency portfolios following Lustig and Verdelhan (2005, 2007). DeSantis and Fornari (2008), Jurek (2008), Menkhoff, Sarno, Schmeling, and Schrimpf (forthcoming), Farhi, Fraiberger, Gabaix, Ranciere, and Verdelhan (2009), Christiansen, Ranaldo, and Soderlind (2011), Gilmore and Hayashi (2011) study the properties of one-month interest rate-sorted portfolios of currency excess returns. Ang and Chen (2010), Kozak (2011), and Hu, Pan, and Wang (2010) consider new sorts, focusing on properties of the foreign yield curves at longer horizons or on liquidity risk. Lustig, Roussanov, and Verdelhan (2011) study the properties and predictability of the dollar risk factor.

Finally, the findings in this paper point to similar results obtained on equity and bond markets. Roll (1988) studies contemporaneous regressions of large individual U.S. stock returns on systematic risk factors and on the returns on other stocks in the same industry; he reports an average R^2 of about 35% on monthly data and 20% on daily data. Steeley (1990) and Litterman and Scheinkman (1991) uncover a clear factor structure in bond returns, where three factors account for more than 95% of the total return variance. Currency markets do not appear much different.

2 Data and Notation

I first describe the data set and introduce some notation before turning to the main result in the next section.

Data I start from daily spot and forward exchange rates in U.S. dollars and build end-of-month series from November 1983 to December 2010. These data are collected by Barclays and Reuters and available on Datastream. Spot and forward exchange rates correspond to midpoint quotes. The robustness section reports results on the changes in the bid-ask spreads.

The main data set contains at most 37 different currencies of the following countries: Australia, Austria, Belgium, Canada, Hong Kong, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Kuwait, Malaysia, Mexico, Netherlands, New Zealand, Norway, Philippines, Poland, Portugal, Saudi Arabia, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, United Kingdom, as well as the Euro. The euro series start in January 1999. Euro area countries are excluded after this date; only the euro series remains.

Some of these currencies have pegged their exchange rate partly or completely to the U.S. dollar over the course of the sample. They are in the sample because forward contracts were easily accessible to investors and their forward prices are not inconsistent with covered interest rate parity. Based on large failures of covered interest rate parity, however, the following observations are deleted from the sample: South Africa from the end of July 1985 to the end of August 1985; Malaysia from the end of August 1998 to the end of June 2005; Indonesia from the end of December 2000 to the end of May 2007; Turkey from the end of October 2000 to the end of November 2001; United Arab Emirates from the end of June 2006 to the end of November 2006.

Notation The lower letter s denotes the log of the nominal spot exchange rate in units of foreign currency per U.S. dollar, and f the log of the one-month forward exchange rate, also in units of foreign currency per U.S. dollar. An increase in s means an appreciation of the home currency. In normal times, forward rates satisfy the covered interest rate parity condition; the forward discount is equal to the interest rate differential: $f_t - s_t \approx i_t^\star - i_t$, where $i^\star$ and i denote the foreign and domestic nominal risk-free rates over the maturity of the contract. Akram, Rime and Sarno (2008) study high frequency deviations from covered interest rate parity (CIP). They conclude that CIP holds at daily and lower frequencies.[1]

Portfolios of Currencies Following Lustig and Verdelhan (2005, 2007), Lustig et al. (forthcoming) focus on six *portfolios* of currencies instead of individual exchange rates. They sort countries each month according to their interest rates. Their six portfolios are re-balanced monthly and currencies switch frequently from one portfolio to another. By averaging out idiosyncratic risk and conditioning on interest rates, these portfolios deliver a cross-section of exchange rates and currency risk premia. The reader is referred to Lustig et al. (forthcoming) for a detailed description of the portfolio statistics.

Carry and Dollar Factors Lustig et al. (forthcoming) show that average currency excess returns on these portfolios correspond to the covariances between currency returns and two risk factors, as implied by the arbitrage pricing theory of Ross (1976). The two risk factors are the average return across all portfolios and the difference in returns between the last and first portfolio. The changes in exchange rates of these two risk factors are their key components; Lustig et al. (forthcoming) obtain similar asset pricing results when ignoring their interest rate components and focusing on exchange rates. They call the two factors respectively the "Dollar" and "Carry" factors.

An alternative explanation of their findings is that the interest rate is simply one of the characteristics that determine returns. In this view, some currencies earn a lower risk premium than others because they have a lower interest rate, not because their exchange rates tend to comove with any risk factor. Based on the empirical evidence, Lustig et al. (forthcoming) cannot definitively rule out a characteristics-based explanation because interest rates and slope factor betas are very highly correlated in the data. However, they replicate their findings in the data simulated from a version of a model that is calibrated to match exchange rate and interest rate moments in the actual data. In the model-generated data, they cannot rule out a characteristics-based explanation either, even though the true data generating process has no priced characteristics.

[1] While this relation was violated during the extreme episodes of the financial crisis in the fall of 2008, including or excluding those observations does not have a major effect on the results.

The results in this paper do not depend on the outcome of the risk versus characteristics debate. I use the carry and dollar factors, focusing on their exchange rate component, but refraining from calling them *risk* factors: Section 6 offers a risk-based explanation of the empirical results in this paper, but leaves the door open to other, more behavioral, explanations.

To sum up, the dollar factor is the average change in the dollar versus all the other currencies; it corresponds to the average change in exchange rate across all six portfolios at each point in time. The carry factor is the average change in exchange rate between countries in the last portfolio (high interest rate countries) and those in the first portfolio (low interest rate countries). When built using all countries, the correlation between these two factors is less than 0.1.

Sample Most of the paper reports results for the following 13 developed countries: Australia, Canada, Denmark, Euro Area, France, Germany, Italy, Japan, New Zealand, Norway, Sweden, Switzerland, and United Kingdom. Finland, Portugal, and Spain are left out because there are only 22 months of data for these countries. Belgium and the Netherlands are also left out because the sample contains already many European countries (results on these countries are very similar to those of France and Germany). The robustness section considers emerging markets.

Preliminary Notes Three important points need to be highlighted. First, note that for each currency put on the left hand side of a regression, that currency is excluded from any portfolio that appears on the right hand side. The objective is to prevent some purely mechanical correlation to arise. This exclusion method is not perfect though: assume that two foreign countries A and B decide to peg their currency to each other, then excluding A from the dollar and carry portfolios does not matter much since the same information is available in the exchange rate between country B and the U.S. For this reason, all the countries in the euro area are excluded after January 1999, keeping only the Euro. But the objective of this paper is to highlight common components across currencies, so it is obviously not to exclude all the countries whose exchange rates might be correlated.

Second, the results do not differ much if the country under study is excluded or not from the portfolios. This is not surprising: 37 countries are used to build the factors. As a result, including or not a single currency pair has little impact on the properties of the factors. Likewise, similar results are obtained when using portfolios of currency excess returns instead of portfolios of changes in exchange rates. As a consequence, all the results reported in this paper can be easily checked and replicated using the portfolios of currency excess returns posted online.

Third, portfolios always use the largest available sample of countries. Even when studying the bilateral changes in exchange rates of developed countries, portfolios and thus risk factors are derived from the large sample of developed and emerging countries.

After this brief description of the data set, I turn now to the first test results.

3 UIP Redux

This section shows that the dollar and carry risk factors explain a large share of each currency pair variations. I start from the usual UIP regressions and progressively add risk factors as explanatory variables.

3.1 UIP and Augmented-UIP Tests

UIP According to the UIP condition, the expected change in exchange rates should be equal to the interest rate differential between foreign and domestic risk-free bonds. The UIP condition implies that a regression of exchange rate changes on interest rate differentials should produce a slope coefficient of one. Instead, empirical work following Hansen and Hodrick (1980) and Fama (1984) consistently reveals a slope coefficient that is smaller than one and very often negative. The international economics literature refers to these negative UIP slope coefficients as the UIP puzzle or forward premium anomaly.[2] Note that the UIP condition is equivalent to an Euler equation for

[2]The UIP condition appears to be a reasonable description of the data only in four cases. Bansal and Dahlquist (2000) show that UIP is not rejected at high inflation levels, and likewise Huisman, Koedijk, Kool and Nissen (1998) find that UIP holds for very large forward premia. Chaboud and Wright (2005) show that UIP is valid at very short horizons but is rejected for horizons above a few hours. Meredith and Chinn (2005) find that UIP cannot be rejected at horizons above 5 years. Lothian and Wu (2005) find positive UIP slope coefficients for France/U.K. and U.S./U.K. on annual data over 1800-1999, because of the 1914-1949 subsample.

risk-neutral investors.

Negative slope coefficients mean that currencies with higher than average interest rates tend to appreciate, not to depreciate as UIP would predict. Investors in foreign one-period discount bonds thus earn the interest rate spread, which is known at the time of their investment, plus the bonus from the currency appreciation during the holding period. As a result, the forward premium anomaly implies positive predictable excess returns for investments in high interest rate currencies and negative predictable excess returns for investments in low interest rate currencies. UIP regressions, however, do not uncover much predictability: R^2s are tiny and slope coefficients, although clearly different from one, are rarely statistically different from zero.

UIP Test Results The left panel of Table 1 reports country-level results from the usual UIP tests:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \varepsilon_{t+1},$$

where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, and $i_t^\star - i_t$ is the interest rate difference. As in the rest of the literature, βs are always below one, and most of them are negative. Out of 13 countries, only three lead to positive βs, none of which is statistically significant. The adjusted R^2s on these regressions are tiny, often negative, with a maximum of 1.9%, and an average of 1.3%. Note that every R^2 reported in this paper is adjusted for the degrees of freedom.

UIP and the Carry Factor Let us now add the information contained in the carry trade factor. The right panel of Table 1 reports country-level results from the following regression:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma(i_t^\star - i_t)Carry_{t+1} + \delta Carry_{t+1} + \varepsilon_{t+1},$$

where $Carry_{t+1}$ denotes the dollar-neutral average change in exchange rates obtained by going long a basket of high interest rate currencies and short a basket of low interest rate currencies. Each variable is expressed in percentage points; as a result, the slope coefficient on the conditional carry factor is 100 times larger than if all series were not in percentage points. Table 1 reports the constant α, the slope coefficients β, γ, and δ, as well as the R^2 of this regression (also in percentage points) and the number of observations. Standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). The standard errors for the R^2s are reported in parentheses; they are obtained by bootstrapping under the assumptions that changes in exchange rates are *i.i.d.*

All adjusted R^2s are positive. They are an order of magnitude higher than in classic UIP tests, ranging from 2% to 24%, with an average of 8.9% There is no clear pattern in the unconditional loadings (δ) on the carry trade factor: some are positive, some are negative, and only two of them are statistically significant. But there is a clear pattern in the conditional loadings (γ). The higher the interest rate, the higher the exposure to the carry factor: the coefficient γ is positive in all 13 cases, and significantly so in 8 cases. In other words, the higher the interest rate, the higher the likelihood that a currency will depreciate when other high interest rate currencies do so. The carry and conditional carry factors thus uncover strong comovement among exchange rates.

[Table 1 about here.]

UIP and the Carry and Dollar Factors I now turn to the main result of the paper, by introducing jointly the carry and dollar factors. Table 2 reports country-level results from the following regression:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma(i_t^\star - i_t)Carry_{t+1} + \delta Carry_{t+1} + \tau Dollar_{t+1} + \varepsilon_{t+1},$$

where $Dollar_{t+1}$ corresponds to the average change in exchange rates against the U.S. dollar. The previous results are robust to the inclusion of this variable. The conditional carry loadings (γ) remain positive for all countries, except for Canada and Japan. They are positive and statistically significant in 10 out of 13 countries. The carry loadings (δ) are now all negative except for Australia and Canada.

Let us turn now to the loadings on the dollar factor. They are positive and statistically significant in all 13 countries, with values ranging from 0.4 to 1.5. The loadings on the dollar factor reflect the existence of a clear principal component in the dollar exchange rates. When the dollar appreciates, it does so against all developed currencies. This common component explains a large share of the variation in bilateral exchange rates. The adjusted R^2s are now all between 22% and 90%. The average R^2 among the 13 developed countries is 66.8%.

Results do not change much by adding or not the interest rate differences, indicating that the bilateral interest rate differentials have little explanatory power for exchange rates once one accounts for the common sources of their variation captured by the systematic factors, consistent with the view of Meese and Rogoff (1988) that exchange rate changes are driven largely by real (or financial) shocks rather than nominal interest rates.

[Table 2 about here.]

3.2 Comparison to the Literature

The large R^2s and significant loadings on the dollar and carry factors on augmented-UIP regressions are the key, benchmark results of this paper. I now contrast these results to the previous literature on UIP test, currency portfolios, and principal components.

Omitted Variables The literature on exchange rates contains many estimations of the UIP condition. Twenty years ago, Froot and Thaler (1990) reported that, in a survey of 75 published estimates, the slope coefficient of the regression of changes in exchange rates on interest rate differences was always below unity (positive in a very few cases, and −0.88 on average). Many more papers have run similar tests since then and offered potential explanations. A simple search in *Scopus* returns 310 articles published since 1990 that mention "exchange rates" and either "uncovered interest rate parity" or "forward premium" or "carry trade" in their title, abstract or keywords. Engel (1996) and Chinn (2006) provide recent surveys.

This paper shows that all these UIP tests miss key explanatory variables. The conditional carry and dollar factors are statistically significant for almost all currencies; they are jointly significant in all countries. These findings imply that all classic UIP tests suffer from an omitted variable bias. Slope coefficients (β) on interest rate differences vary when the carry, conditional carry and dollar factors are added as explanatory variables. They tend to increase from an average of -0.62 in UIP regressions to an average of -0.17 in the augmented-UIP regressions. Neither the former not the latter are significant. The latter still do not measure the interest rate sensitivities of exchange rate because the conditional carry and the dollar factor also respond to interest rate differences.

As a result, in order to study the reaction of exchange rates to monetary and fiscal policy shocks, it is necessary to consider the role of the carry and dollar factors. Without them, key shares of systematic variations are ignored. Further research should thus focus on the impact of monetary and fiscal policy shocks on the systematic components of exchange rates.

Bilateral Exchange Rates versus Portfolios of Exchange Rates What do the augmented-UIP regressions teach us that we did not know from the principal component decomposition of currency portfolios? These regressions show the importance of idiosyncratic risk at the country level. Idiosyncratic risk is one of the main reasons portfolios are commonly used in finance: by building portfolios of assets, one hopes that idiosyncratic risk averages out inside each portfolio. On the one hand, if idiosyncratic risk were to drive all of bilateral exchange rates, R^2s would be extremely low in the augmented-UIP regressions. On the other hand, if idiosyncratic risk were nonexistent, R^2s would be one. The results in this paper show that exchange rates are far from independent random walks, but also that the share of idiosyncratic risk varies notably from one country to another.

These results seem to suggest that currency portfolios are unnecessary when studying exchange rates. This view is in general incorrect. Currency portfolios allow to extract risk premia in a simple and efficient way, reducing the dimension of any asset pricing test (let us think about the challenges of computing a spectral density matrix with many assets), and allowing for a very unbalanced panel as more and more spot and forward rates become tradable. Moreover, by appealing to the law of large numbers, portfolios offer a simple interpretation of the factors, as Section 6 later shows.

Principal Components Obtaining large R^2s *per se* does not require portfolios. Similar large R^2s are obtained by regressing each currency pair on exchange rates' first principal components, without forming any portfolio. I check this point rapidly, extracting principal components from a small set of countries (Canada, Germany, Japan, and UK) or a larger sample (Australia, Canada, Denmark, Germany, Hong-Kong, Japan, UK, New Zealand, Norway, Sweden, and Switzerland). In both cases, the Euro exchange rate extends the Deutsche Mark series. I pick these series because they are available on almost all the sample period, therefore simplifying the computation of their eigenvalues.

This experiment delivers three findings. First, the first principal component is, unsurprisingly, highly correlated with the dollar factor; the correlation is 0.95. The loadings on the first principal component (i.e., approximately the dollar factor) are quite similar when the principal component is obtained from a small or a large set of countries. The dollar factor seems thus to be generated by a small core of currencies. Second, the carry factor is different from the second principal component of unconditional changes in exchange rates. The correlation of the second principal component with the carry factor is only -0.38. Conditioning on interest rate levels (as portfolio do) matters. Third, R^2s on augmented-UIP regressions range from 40% to 95% when using the first two principal components (obtained on a large sample). With the first three components, the R^2s range from 43% to 95.5%. These R^2s are comparable (and even often higher) than those obtained with the simple carry and dollar factors.

I choose to focus on the benchmark carry and dollar factors (instead of the principal components) because they account for a large share of currency dynamics and are easily interpretable. They arise naturally in any no-arbitrage model of currency markets as Section section:models shows. Moreover, results obtained with the carry and dollar factors appear to be quite stable; they are not due to the lucky draw of a particular sample: I show in the next section that the factor structure is quite persistent.

4 Pseudo Out-of-Sample Predictability

This section focuses on the persistence of the loadings on the carry and dollar factors, first estimating these loadings on rolling windows of fixed or increasing sizes, and then comparing the one-step ahead prediction errors that these loadings imply.

4.1 Persistence of the Factor Structure

In order to study time-variation in currency R^2s and loadings, the same regressions as in Table 2 are run but on rolling windows of 60 months (5 years). For the purpose of reporting the results, this section focuses on six countries: Australia, Canada, Japan, New Zealand, Switzerland, and the United Kingdom, notably in order to avoid 13 tiny subplots in the following figures.

Time-Varying R^2s Figure 1 reports the time-varying R^2s, while Figure 2 reports the time-varying slope coefficients of the augmented-UIP regressions. The solid lines present the time-varying R^2s or slope coefficients (R_t^2 corresponds to an estimate over the sample from $t-60$ to t). The dotted lines correspond to the estimated R_t^2 or slope coefficients at date t plus or minus one standard deviation of the estimate. Standard deviations on R^2s are obtained by bootstrapping the augmented-UIP regressions, assuming that changes in exchange rates are *i.i.d.* Standard deviation thus take into account the small size of our rolling windows. The dash-dotted line reports the R^2s obtained on the full sample (as in Table 2).

In Figure Figure 1, there is no sign that the full sample corresponds to particularly high R^2s – higher values can be attained on shorter subsamples. Thus, the results reported in the previous tables do not appear to be particularly lucky. For Japan, Switzerland, and the United Kingdom, the adjusted R^2s remain significantly above 0 throughout the sample. For Australia and New Zealand, some samples ending in the second half of the 90s lead to zero or negative adjusted R^2s. For Canada, R^2s are significantly different from 0 only over samples ending in the last ten years.

Time-Varying Loadings For all countries in Figure 2, the carry and dollar slope coefficients are quite stable throughout the whole sample, while the conditional carry slope coefficient is much more volatile. The carry and dollar loadings appear as country-specific characteristics, rather constant through our sample. Further research should then try to link these coefficients to constant or slow moving country parameters, like country size (see Hassan (2010) for the impact of country size on the level of interest rates) or trade openness. The loadings on the conditional carry are different: they vary a lot and might depend on country-specific and world factors. Simple eyeballing on the six countries in Figure 2 does not detect clear co-movement across countries, but this question deserves further study.

[Figure 1 about here.]

[Figure 2 about here.]

Let us now check how quickly factor loadings reach their full sample values, starting with only 5 years of data (60 observations) and adding one period at a time in each estimation. After approximately 10 years, the carry and dollar slope coefficients have already reached their full sample values. This rapid convergence opens the door to a simple exercise in order to illustrate the persistence and key role of these factors.

Mean Squared Errors The following experiment exploits the persistence of factor loadings. Assume that the carry and dollar factors are known one period in advance. Then expected changes in exchange rates are derived using the loadings estimated on past observations. These are *not* true forecasts since they assume that the factors are known one period in advance and thus perfectly predictable. This is a strong assumption given that these two factors are actually hard to predict, hence the *pseudo* characteristic of the predictability test. The pseudo-predicted change in exchange rate is thus:

$$\widehat{\Delta s_{t+1}} = \alpha_t + \beta_t(i_t^\star - i_t) + \gamma_t(i_t^\star - i_t)Carry_{t+1} + \delta_t Carry_{t+1} + \tau_t Dollar_{t+1},$$

where α_t, β_t, γ_t, δ_t, and τ_t are estimated on samples that end at date t. This exercise is in the same spirit as that of Ferraro, Rossi and Rogoff (2011) who show that exchange rate changes can be predicted by *contemporaneous* changes in a fundamentals-related variable (in their case, oil prices). It extends the seminal Meese and Rogoff (1983) experiment, which also assumes that macroeconomic variables are know one period in advance.

Table 3 reports the standard deviation of log changes in spot exchange rates and the square root of mean squared errors (RMSE) obtained in the experiment above. These RMSE are compared to those obtained by assuming that exchange rates are random walks with drifts (i.e., when only α_t is estimated). Standard deviations and RMSE are annualized (i.e., multiplied by $\sqrt{12}$) and reported in percentages. Compared to the random walk, the decrease in RMSE is large: the ratios range from 0.3 to 0.9 for developed countries.[3]

A quick comparison with the predictive power of macroeconomic variables puts the results above into perspective. Cheung, Chinn and Pascual (2005) study five different models and test them on five currency pairs, two different samples, either in first-differences or in levels with cointegration, at one, four, and twenty-quarter horizons. Out of 216 estimations, only two outperforms significantly the random walk. Using the carry and dollar factors leads to large decreases in RMSE for the 13 developed countries in the sample.

A very large literature attempts to predict changes in exchange rates at the bilateral level (see Rossi (2011) for a survey). The experiment in this paper offers two insights to this literature. First, it gives a new benchmark. Table 3 shows that models in international economics and finance should seek to reduce the RMSE by 10% to 70% (depending on the currency) compared to a prediction based on a random walk. Additional pseudo-predictability might come from better predictions of the factor loadings and the discovery of new factors. Second, efforts should be focused on predicting the dollar and carry components in order to move beyond pseudo-predictability. These two components average out idiosyncratic changes in exchange rates and thus constitute better test assets for any model in international finance than individual exchange rates.

[3]The literature relies on the Diebold and Mariano (1995) and Clark and West (2006) tests of equal predictive ability in order to assess small decreases in RMSEs.

[Table 3 about here.]

5 World Market Integration and Systematic Currency Variation

This paper reports high levels of systematic currency risk on average, and a large variation across countries in these levels. Since all exchange rates are defined with respect to the U.S. dollar, the absence of arbitrage implies that shares of systematic risk vary across countries because the properties of foreign stochastic discount factors vary too. Such variation should affect other asset prices, for example, equity and fixed income markets, and it does. This section compares the cross-sectional variation in shares of systematic currency risk to the cross-sectional variation in shares of systematic equity and fixed income risk.

Systematic Equity Risk The study of comovements between stock returns across countries is the object of a large literature that is too wide to survey here. The reader is referred to a recent survey article by Lewis (2011) and recent evidence at the industry level by Bekaert, Hodrick, and Zhang (2009).

I adopt a simple approach, focusing on the world capital asset pricing model (CAPM) and Fama and French (1993) factors. Equity indices correspond to country-level indices, and thus no additional local risk factor is used. The share of systematic equity risk at the country-level corresponds to the share of each country i's equity returns explained by world equity factors:

$$r_{t+1}^{m,i,\$} = \alpha + \beta r_{t+1}^{m,world,\$} + \gamma r_{t+1}^{hml,world,\$} + \varepsilon_{t+1},$$

where $r_{t+1}^{m,i,\$}$ denotes the returns on a given foreign country MSCI stock market index, $r_{t+1}^{m,world,\$}$ is the MSCI world return equity index, and $r_{t+1}^{hml,world,\$}$ is the difference between the returns on the world MSCI value equity index and the world MSCI growth equity index (i.e., high minus low book-to-market equity returns). Pukthuanthong and Roll (2009) argue in favor of similar R^2s to measure world market integration. As in Bekaert and Harvey (1995), Bekaert, Hodrick, and Zhang (2009), and Pukthuanthong and Roll (2009), all returns are expressed in U.S. dollars. Systematic equity risk is estimated on the same sample period as currency risk for each country. Adjusted R^2s range from 27% to 87% in developed countries, and from 26% to 67% in developing countries.

Equity versus Currency Figure 3 reports the share of systematic *currency* risk as a function of the share of systematic *equity* risk. Systematic risk is measured using the interest rate differences, carry, conditional carry, and dollar factors for exchange rates, and the world market and world value factors for equity. Standard errors on R^2s are obtained by bootstrapping, as in the rest of the paper. Figure 3 reports point estimates of R^2s as well as one-standard error confidence intervals on both sides of each point estimate. The estimation focuses on the 1999.1–2010.12 sub-sample, after the introduction of the euro. Over this sub-sample, the data set offers an (almost) balanced panel of both developed and emerging economies and one can thus compare countries over the same sample.[4] Over the last 10 years, the higher the share of systematic risk on equity markets, the higher the share of systematic risk on currency markets.

This result appears consistent with a simple risk-based definition of exchange rates. The intuition is as follows: the return on the world stock market depends only on world shocks, since country-specific shocks average out. The share of systematic equity risk thus increases with the relative volatility of world versus country-specific shocks to each stochastic discount factor: if all shocks were local (global), R^2s on equity returns would be zero (one). Likewise, the carry and conditional carry factors capture exposure to world shocks: if all shocks to the foreign stochastic discount factor were global (in addition to the U.S.-specific shocks), then the dollar and carry factors would account for them perfectly, and R^2s on exchange rates would be one. The currency R^2s are not one because changes in exchange rates also depend on foreign-specific shocks (e.g., shocks on the U.K. stochastic discount factor) that are not spanned by the currency factors. As a result, high shares of systematic equity and currency risk can be interpreted as reflecting a large

[4]The whole sample, starting in 1983, offers a fuzzier picture as it mixes currency forward contracts defined on different time periods. Before the introduction of the euro, many European currencies exhibited high share of systematic currency risk (as they comoved a lot), but lower shares of equity risk.

relative variance of world shocks in foreign stochastic discount factors.

Saudi Arabia (denoted SA) and Hong Kong (HK) appear as outliers on Figure 3: their share of systematic equity risk is much higher than their share of systematic currency risk, which are close to zero. This finding is not surprising: both countries have pegged their currencies to the U.S. Dollar throughout the sample.

Among the developed countries, Canada and the U.K. exhibit higher shares of systematic equity risk than their currencies would suggest. How to interpret this finding? In any no-arbitrage model, exchange rates are informative about SDFs and equity returns depend on both SDF and the properties of the dividend processes. Thus, one potential explanation is that Canadian and British firms (and thus their dividends) are more highly exposed to world shocks than their corresponding SDF would suggest, because of a higher leverage for example.

Overall, one cannot reject that the share of systematic currency risk increases across countries one for one with the share of systematic equity risk. Could this result be mechanical? If exchange rates drive most of the variation in equity betas, then both measures of systematic risk are equivalent. The literature on stock comovements use equity returns expressed in U.S. dollars: $r_{t+1}^{m,i,\$} = r_{t+1}^{m,i} - \Delta s^i$, where $r_{t+1}^{m,i}$ denotes the return on country i's stock market, expressed in foreign currency. As a first approximation, the world equity return correspond to the average of the country-specific returns; likewise, the dollar risk factor is approximately the average change in exchange rates of the U.S dollar (ignoring capitalization weights for equity indices and portfolios for currencies). Tests of stock return comovements thus correspond to:

$$r_{t+1}^{m,i} - \Delta s^i = \alpha + \beta(\frac{1}{N}\sum_{i=1}^{N} r_{t+1}^{m,i} + Dollar_{t+1}) + \gamma(\frac{1}{N}\sum_{i=1}^{N} r_{t+1}^{hml,i} + Dollar_{t+1}) + \varepsilon_{t+1}.$$

If equity returns in local currencies are much less volatile than currency movements, the tests above boil down to measures of systematic currency risk using the dollar risk factor. This is, however, not the case in the data. Equity returns in local currencies deliver measures of systematic risk that do not differ much from our main estimates; the pattern observed in Figure 3 remains the same.

Fixed Income versus Currency Finally, I compare the shares of systematic risk on currency and fixed income markets. Adjusted R^2s on bond markets are derived from:

$$r_{t+1}^{b,\star} = \alpha + \beta r_{t+1}^{m,world} + \gamma r_{t+1}^{b,world} + \varepsilon_{t+1},$$

where $r_{t+1}^{b,\star}$ denotes the returns in U.S. dollars on a given foreign country 10-year bond return index, $r_{t+1}^{m,world}$ corresponds to returns on the MSCI world equity index, and $r_{t+1}^{b,world}$ is the world bond return, obtained as the average of all the 10-year bond returns. Again, as Figure 4 shows, the more integrated the bond markets, the higher the share of systematic currency risk. Similar results appear with bond returns expressed in local currencies, except for three countries: the Czech Republic, Hungary, and Poland exhibit much lower R^2s in local currencies (in the 30% to 40% range instead of the 60% to 70% range reported in Figure 4). But, even measured in local currencies, R^2s in fixed income markets increase with their currency counterparts.

The different shares of systematic currency risk across countries are thus quite unlikely to be random; they are clearly related to measures of world equity and fixed income market integration.

[Figure 3 about here.]

[Figure 4 about here.]

6 A Risk-Based Interpretation of the Findings

In this section, I compare the key empirical results of this paper to existing models in international finance, starting with a rapid review of the reduced-form model of Lustig et al. (forthcoming), which provides a simple interpretation of the dollar and carry factors. More generally, in the class of no arbitrage models of currency markets, the R^2s of augmented-UIP regressions are informative on the relative volatilities of the country-specific and world components of the pricing kernels. The results in this paper thus provide useful additional moments to match.

6.1 A Reduced-Form Model

Complete Markets Lustig et al. (forthcoming) assume that financial markets are complete, but that some frictions in the goods markets prevent perfect risk-sharing across countries. As a result, the change in the real exchange rate Δq^i between the home country and country i is $\Delta q^i_{t+1} = m_{t+1} - m^i_{t+1}$, where q^i is measured in country i goods per home country good and m denotes the log stochastic discount factor (SDF) or pricing kernel. An increase in q^i means a real appreciation of the home currency. For any variable that pertains to the home country (the U.S.), the superscript is dropped.

Stochastic Discount Factors In this model, there are two sources of priced risk: country-specific and world shocks. Each type of risk has a different price. Lustig et al. (forthcoming) assume that the risk prices of country-specific shocks depend only on the country-specific factors, and that the risk prices of world shocks depend on world and country-specific factors. Let us consider a world with N countries and currencies. Lustig et al. (forthcoming) do not specify a full economy complete with preferences and technologies; instead they posit a law of motion for the SDFs directly. Following Backus, Foresi and Telmer (2001), they assume that in each country i, the logarithm of the real SDF m^i follows a two-factor conditionally-Gaussian process:

$$-m^i_{t+1} = \alpha + \chi z^i_t + \sqrt{\gamma z^i_t} u^i_{t+1} + \chi z^w_t + \sqrt{\delta^i z^w_t + \kappa z^i_t} u^w_{t+1}.$$

To be parsimonious, they limit the heterogeneity in the SDF parameters to the different loadings, denoted δ^i, on world shocks (denoted u^w); all the other parameters are identical for all countries. Lustig et al. (forthcoming) show that the cross-sectional variation in δ is key to understanding the carry trade. The SDFs are heteroscedastic because, as Bekaert (1996), Bansal (1997), and Backus et al. (2001) have shown, expected currency log excess returns depend on the conditional variances of the home and foreign (lognormal) SDFs. If SDFs were homoscedastic, expected excess returns would be constant and the UIP condition would be valid.

Two minor comments are in order. First, all variables in the model are real: a law of motion for inflation can easily added, or the SDF can be reinterpreted as nominal variables. Second, there is no direct relation between the symbols in the model and the symbols previously used to describe the slope coefficients in the regressions of the previous sections. I choose to keep the same notation as in Lustig et al. (forthcoming) to help the reader familiar with their work.

In this model, there is a common global factor z_t^w and a country-specific factor z_t^i. The currency-specific innovations u_{t+1}^i (uncorrelated across countries) and global innovations u_{t+1}^w are $i.i.d$ gaussian, with zero mean and unit variance; u_{t+1}^w is a world shock, common across countries, while u_{t+1}^i is country-specific. The country-specific and world volatility components are governed by autoregressive square root processes:

$$
\begin{aligned}
z_{t+1}^i &= (1-\phi)\theta + \phi z_t^i - \sigma\sqrt{z_t^i}u_{t+1}^i, \\
z_{t+1}^w &= (1-\phi)\theta + \phi z_t^w - \sigma\sqrt{z_t^w}u_{t+1}^w.
\end{aligned}
$$

Interest Rate Difference Let us now define in the model the same variables used in the augmented-UIP regressions, starting with the forward discount between currency i and the U.S. In this model, it is equal to:

$$
r_t^i - r_t = \left(\chi - \frac{1}{2}(\gamma+\kappa)\right)(z_t^i - z_t) - \frac{1}{2}\left(\delta^i - \delta\right) z_t^w.
$$

If $\chi = 0$, the Meese-Rogoff hypothesis holds: the log of real exchange rates follows a random walk, and the expected log excess return is simply proportional to the real interest rate difference. This case is not supported by the data. In order to reproduce the UIP puzzle, Lustig et al. (forthcoming) and Verdelhan (2010) show that the precautionary savings effect must dominate on real interest rates. Here it means that interest rates decrease when volatility increases: $\chi - \frac{1}{2}(\gamma+\kappa) < 0$ and $\chi - \frac{1}{2}\delta^i < 0$. High interest rate currencies tend to have low loadings δ^i on common innovations, while low interest rate currencies tend to have high loadings δ^i.

Dollar Factor The dollar factor is also obtained in closed form. Recall that it corresponds to the average change in all exchange rates versus the U.S dollar. In the following, a bar superscript ($\overline{x}$) denotes the average of any variable or parameter x across all countries. To build intuition, let us first focus on expected changes in exchange rates. As Lustig et al. (forthcoming) show, the expected dollar change in exchange rate is:

$$E_t[Dollar_{t+1}] = E_t[\overline{\Delta q}_{t+1}] = \chi\left(\overline{z_t} - z_t\right).$$

They assume that country-specific shocks average out within each portfolio. In this case, $\overline{z}$ is constant in the limit (when N is infinitely large, i.e., $N \to \infty$) by the law of large numbers. As a result, the expected dollar change in exchange rates only depends on the U.S.-specific market price of risk z_t. Hence its name as the dollar factor.

The realized dollar factor corresponds to the expected dollar factor above plus U.S specific and world shocks:

$$Dollar_{t+1} = \chi\left(\overline{z_t} - z_t\right) - \sqrt{\gamma z_t}u_{t+1} + (\overline{\sqrt{\delta^i z_t^w + \kappa z_t^i}} - \sqrt{\delta z_t^w + \kappa z_t})u_{t+1}^w.$$

If one assumes that the average country's SDF has the same exposure to global innovations as the U.S, then the dollar factor only depends on the U.S specific market price of risk z_t and U.S shocks u_{t+1}. In this special case, $Dollar_{t+1} = \chi\left(\overline{z_t} - z_t\right) - \sqrt{\gamma z_t}u_{t+1}$.

Carry Factor The carry factor corresponds to the average change in exchange rates between high and low interest rate countries. Its expected value is:

$$E_t[Carry_{t+1}] = E_t[\Delta q_{t+1}^H - \Delta q_{t+1}^L] = \chi\left(\frac{1}{N_H}\sum_{i\in H} z_t^i - \frac{1}{N_L}\sum_{i\in L} z_t^i\right),$$

where N_H and N_L denote the number of currencies in the high (H) and low (L) interest rate portfolios. Again, with an infinite number of currencies per portfolio, the average z^i would be zero. But here sorting matters. The countries that end up in the first or last portfolios are not randomly chosen. As the closed form expression for interest rate differences show, these countries belong to those portfolios partially because of the values of their market prices of risk z^i. The realized carry factor corresponds to:

$$Carry_{t+1} = \chi \left(\frac{1}{N_H} \sum_{i \in H} z_t^i - \frac{1}{N_L} \sum_{i \in L} z_t^i \right) + \left(\frac{1}{N_H} \sum_{i \in H} \sqrt{\delta^i z_t^w + \kappa z_t^i} - \frac{1}{N_L} \sum_{i \in L} \sqrt{\delta^i z_t^w + \kappa z_t^i} \right) u_{t+1}^w.$$

Lustig et al. (forthcoming) present similar results on currency excess returns. The carry factor captures world shocks.

Finally, the change in bilateral exchange rates is:

$$\Delta q_{t+1}^i = \chi(z_t^i - z_t) + \sqrt{\gamma z_t^i} u_{t+1}^i - \sqrt{\gamma z_t} u_{t+1} + (\sqrt{\delta^i z_t^w + \kappa z_t^i} - \sqrt{\delta z_t^w + \kappa z_t}) u_{t+1}^w.$$

Augmented-UIP Regressions In contemporaneous regressions, the dollar factor picks up the U.S-specific shocks u_{t+1}, and possibly (if the U.S. does not have the average exposure to world shocks) part of the world shocks u_{t+1}^w. The carry factor picks up the remaining world shocks. Interest rate differences at date t proxy for the spread in market prices of risk $z_t^i - z_t$. The augmented-UIP regression tests are thus quite natural in this framework.

The empirical findings in this paper show that the market price of global risk in each country must depend on country-specific variables. In the language of the Lustig, Roussanov, and Verdelhan's model, the coefficient κ must be nonzero. If κ were zero, then the model would imply that slope coefficients on the conditional carry factor are zero. If $\kappa = 0$, the carry factor and changes in exchange rates are:

$$\begin{aligned} Carry_{t+1} &= \chi \left(\frac{1}{N_H} \sum_{i \in H} z_t^i - \frac{1}{N_L} \sum_{i \in L} z_t^i \right) + \left(\frac{1}{N_H} \sum_{i \in H} \sqrt{\delta^i} - \frac{1}{N_L} \sum_{i \in L} \sqrt{\delta^i} \right) \sqrt{z_t^w} u_{t+1}^w, \\ \Delta q_{t+1}^i &= \chi(z_t^i - z_t) + \sqrt{\gamma z_t^i} u_{t+1}^i - \sqrt{\gamma z_t} u_{t+1} + (\sqrt{\delta^i} - \sqrt{\delta}) \sqrt{z_t^w} u_{t+1}^w. \end{aligned}$$

There is clearly no need for a conditional carry factor to capture the role of global shocks in the bilateral exchange rates. In the data, however, most slope coefficients on the conditional carry factor are statistically different from zero, and thus κ must be different from zero. Exchange rates do not respond to the carry factor simply because of some country's fixed effects; they respond more to the carry factor the higher their interest rates.

The model offers an interpretation to the simple augmented-UIP regressions reported in the first sections of this paper, but the regressions do not correspond exactly to this particular model. Two differences are worth pointing out. First, the model does not imply that the conditional carry factor should be the product of the interest rate difference times the carry factor: this is simply a convenient approximation. Likewise, the model suggests that a better description of the change in exchange rates would come from a conditional dollar factor. If the U.S. had the average exposure to world shocks, then the average forward discount would be the perfect measure of the U.S. market price of risk (see Lustig, Roussanov and Verdelhan (2011) along this line). A more model-consistent regression would then use the average forward discount multiplied by the dollar factor as explanatory variable. Second, in the augmented-UIP regressions, no variable captures the foreign country-specific shock u^i_{t+1}. Thus, augmented-UIP regressions should not deliver R^2s of 100%. The model suggests adding the foreign equivalent of the dollar factor to each regression (e.g., the pound factor for the U.S./U.K exchange rate, or more generally a basis factor). Replacing the dollar factor by a foreign basis factor delivers similar results (with an opposite sign on the basis factor).

There are clearly many potential variations around the augmented-UIP regressions; they are left out for future research. The goal is here to provide an interpretation to the empirical results in this paper and to highlight the usefulness of such tests for model assessments and calibrations.

Simulation I use this model to run on simulated data the same regressions as in the first part of this paper. The model is simulated at monthly frequency using the calibration proposed in Lustig et al. (forthcoming) and the last 300 observations to build a sample of the same length as in the actual data. Table 4 reports the results.

Panel A focuses on standard UIP regressions. As in the data, UIP slope coefficients are negative. They are significantly negative in a long, but not in a short sample. The Wald test cannot reject the null hypothesis that slope coefficients are zero. As in the data, adjusted R^2s are small and less than 2%.

Panel B introduces the carry and conditional carry risk factors. As in the data, the higher the interest rate, the higher the exposure to the carry factor. This effect is highly significant, even in a short sample. The unconditional loading on the carry is negative for low delta countries and positive for high delta countries, but not always significant. The conditional loading, however, is so significant that the Wald test easily rejects the null hypothesis that all slope coefficients are zero. The adjusted R^2s of these regressions are much higher than for the standard UIP tests: R^2s are now in the 60% to 80% range. These R^2s are higher than in the data: the model implies that a too large share of bilateral exchange rates variations is explained by the carry factor and its interaction with interest rates.

Panel C uses the carry trade and dollar risk factors. The dollar slope coefficient is highly statistically significant and adjusted R^2s raise to the 80% to 90% range. In the actual data, R^2s are between 20% and 90%.

Overall, the model does a good job matching the UIP regressions. Its most glaring shortcoming resides in the R^2s of the augmented-UIP regressions. In the model, world shocks drive most of the variance in exchange rates. As a result, the carry factor, which captures those world shocks, accounts for a very large share of the changes in exchange rates. Its role is less proeminent in the data.

This finding does not imply a deep flaw in the model but highlights the usefulness of looking at new moments. Without them, one cannot pin down the share of systematic versus idiosyncratic risk. In order to match the share of exchange rates accounted for by the carry factor, one needs to increase the share of idiosyncratic shocks in the exchange rate volatility. Multiplying γ tenfold, for example, increases the volatility of exchange rates from 8.4% to 14% and reduces the R^2 in panel B to the 11% to 40% range, i.e., to levels closer to the data. A new complete calibration would require lowering slightly the exchange rate volatility.

[Table 4 about here.]

I turn now to recent advances in international finance and briefly sketch the use of augmented-UIP regressions.

6.2 Recent Macro-Finance Explanations of the UIP Puzzle

In order to account for the empirical findings in this paper, models need to deliver currency excess returns in the first place, and thus must be consistent with the failure of UIP. This is not an easy task, but a recent literature offers several potential explanations of the UIP puzzle. This literature can be divided into two groups that differ by their departure or not from rational expectations.

In the class of rational expectation frameworks, three general equilibrium models, through volatile stochastic discount factors, can replicate the UIP puzzle and are thus consistent with the most well-known stylized facts on exchange rates. I review them here rapidly in their chronological order of appearance and discuss their potential extensions. Verdelhan (2010), in a Campbell and Cochrane (1999) habit model, offers the first rational expectation model of the UIP puzzle. Bansal and Shaliastovich (2008), Colacito (2008), and Colacito and Croce (2011a) explain the UIP puzzle in a Bansal and Yaron (2004)'s long run risk model. Farhi and Gabaix (2008) build on the disaster risk model of Rietz (1988), Barro (2006), and Gabaix (2008). These models start from endowment economies. See Gourio, Siemer and Verdelhan (2010) for an international real business cycle version of the disaster risk model.

These papers feature two-country models. They first need to be extended to several countries, while featuring a common risk factor. In the habit model, this necessary condition could be satisfied by the definition of habits over a global consumption growth rates. In the long-run risk model, the slow moving mean of consumption growth (i.e., its long-run risk component) is a natural candidate for the common component. Along this line, Colacito and Croce (2011b) show that highly correlated long-run risk components across countries deliver exchange rates that are as volatile as their empirical counterparts. They thus offer a solution to the puzzle described by Brandt, Cochrane and Santa-Clara (2006). In the disaster risk model, a world disaster whose probability is time-varying delivers a common source of risk (if the disaster characteristics were constant, risk premia would also be constant, and the model could not replicate the UIP puzzle). The findings in this paper imply restrictions in the calibrations of these models.

For long run risk models, augmented-UIP regressions are informative about the relative variance of the long run component of consumption growth relative to its temporary part. This is an interesting additional moment to consider because the long run component is difficult to pin down in the data. For disaster risk models, augmented-UIP regressions speak to the volatility of the world disaster probability, which is another component that is difficult to measure directly in the data.

There is a second set of potential explanations for the failure of UIP. Following Froot and Thaler (1990) and Lyons (2001), some authors depart from rational expectations in order to account for the forward premium puzzle. They assume that agents' expectations or beliefs are systematically distorted. See notably Gourinchas and Tornell (2004), Bacchetta and van Wincoop (2010) and Ilut (2010). It remains to be shown how these models could deliver the properties of currency portfolios (common factors across portfolios and large drops in carry trade excess returns when global volatility increases). Their extension to many countries seems also a worthwhile endeavor, left out for future research.

7 Robustness Checks and Extensions

I now consider several robustness checks to the main result. This section reports results obtained with other factors (like momentum, subsection 7.1), at daily, quarterly, and annual frequencies (subsection 7.2), with macroeconomic variables (subsection 7.3), in emerging and developing countries (subsection 7.4), and the dynamics of bid-ask spreads (subsection 7.5). Finally, I redo similar tests using different base currencies (subsection 7.6).

7.1 Other Factors

Momentum appears as a pervasive phenomenon in equity markets and seems also present in currency markets (see Asness, Moskowitz, and Pedersen, 2008). The equity literature has proposed many different ways to pick past winners and losers: for example, measuring returns over 1 to 12 months before sorting stocks, or adding lags of 1 to n months between the time stocks are sorted and the date portfolios are formed. I do not explore all the potential definitions, but conduct a simple experiment.

Momentum portfolios are formed by sorting countries on their past currency excess returns (measured over the previous month). The obtained cross-section of excess returns is partly explained by the carry and dollar factors. But a third potential factor emerges; it corresponds to the third component of the momentum-sorted portfolios. This momentum factor, however, does not add much explanatory power beyond the carry and dollar factors. It appears significant only for the U.K, but never in the other 12 countries. Similar results appear by sorting countries on their past three-month returns (instead of one-month returns). These negative results do not rule out the existence of an independent momentum factor in bilateral exchange rates as many other definitions of momentum can be tested.

Focusing on the currency market literature, another potential factor emerges: Ang and Chen (2010) show that sorting countries on the *changes* in short term interest rates also leads to a cross-section of currency excess returns. A potential factor could correspond to the following long-short strategy: long the last portfolio (larges changes in foreign interest rates) and short the first portfolio (small changes in foreign interest rates). This strategy delivers positive currency excess returns. As for the carry factor, the focus is on the exchange rate components of these portfolios. In a similar set of augmented-UIP regressions, the additional factor appears significant for Denmark, Germany, Switzerland, and the U.K. but does not deliver significant increases in R^2s.

Again, these findings do not rule out the existence of other factors that account for bilateral changes in exchange rates. Future research will certainly uncover some new factors, but this study is limited to the potential factors already established by previous empirical and theoretical literature.

7.2 Daily, Quarterly, and Annual Changes in Exchange Rates

I now check the robustness of the main results at different frequencies, starting with daily data and then moving to quarterly and annual series.

Daily Data The carry and dollar factors are built from portfolios of daily changes in exchange rates by sorting countries on their one-month forward discounts. Although the forward rates are observed at daily frequencies, interest rate differences are quite persistent and thus the portfolio sorts are also persistent. Table 5 is the counterpart to Table 2: it reports similar regression results but at a daily frequency. The time windows are the same but the number of observations jumps from a maximum of 324 months to a maximum of 7047 days.

The similarity with monthly estimates is obvious. The adjusted R^2 still range from 20% to almost 90% even when looking at daily changes in exchange rates. The average adjusted R^2 is 61%. The carry loadings are still negative for 9 out of 13 countries (and positive for Australia, Canada, New Zealand, and Sweden). The conditional carry loadings are positive in 11 out of 13 countries. They are negative for Japan and Canada (the two countries that did not have significantly positive loadings at the monthly frequency). They are now significantly different from zero for 11 out of 13 countries. The dollar loadings are quite similar to the monthly estimates too. They range from 0.5 (Canada, as on monthly data) to almost 1.5 (mostly scandinavian countries, again as on monthly data). R^2s and loading estimates thus appear very consistent across these two different frequencies.

[Table 5 about here.]

Quarterly and Annual Data A similar conclusion emerges at a quarterly frequency. The samples contain less observations than in the benchmark tables because of the focus on non-overlapping series and the standard errors are now higher. But the basic insights do not change. At annual frequencies, the factor structure appears less clearly. Again, note that using non-overlapping series limits the sample size drastically: UIP augmented tests are run if series have at least 20 observations: this constraint is binding for several countries in the sample. Loadings on the dollar factor are still around one and significant, but loadings on the carry and conditional carry factors are not always significant. This result speaks to the difficulties of many papers in international economics that attempt to link changes in exchange rates to macroeconomic variables, often measured at quarterly or annual frequencies. At an annual frequency, the dollar factor appears significant for bilateral exchange rates, but the carry factor does not.

7.3 Comparison to Macroeconomic Variables

For macroeconomic variables, capturing currency variations is even harder: while changes in exchange rates that drive the dollar and carry factors are measured precisely, growth rates of macroeconomic variables are not. I turn now to this issue, providing a quick comparison of the benchmark results to those obtained using macroeconomic variables.

At a monthly frequency, industrial production growth rates and the foreign minus domestic growth rates of the consumer price index appear as natural candidates in order to measure currency risk. Table 6 reports the results. Many adjusted R^2s are negative, and the highest value is 2.5%. As with the usual UIP tests, such low R^2s led many people to think of exchange rates as independent random walks. Moreover, these macroeconomic variables are almost never significant. Even if one were to predict them perfectly, one would not beat the random walk at a monthly frequency.

This experiment does not mean that exchange rates are unrelated to macroeconomic variables. It simply highlights how difficult to uncover such links are. Yet, these links exist: they tend to appear more clearly at low frequencies (with quarterly, and mostly annual series), and on portfolios of currencies (instead of individual currency pairs). Lustig and Verdelhan (2007, 2011), for example, report that high (low) interest rate currencies tend to depreciate (appreciate) when annual and quarterly consumption growth is low. Further research will certainly explore many more potentially interesting macroeconomic series (notably the principal components of large data sets) in order to account for exchange rate comovements.

[Table 6 about here.]

7.4 Emerging Markets

Having shown that the main results remain valid at different frequencies, I now turn to a set of 12 developing countries (using the same factors as for developed countries): Hong Kong, Czech Republic, Hungary, India, Kuwait, Malaysia, Mexico, Philippines, Poland, Saudi Arabia, Singapore, South Korea, Taiwan, and Thailand. Turkey, Indonesia, and South Africa are left out because of their short samples (respectively 46, 48, and 21 months): these countries, however, are in the dataset and part of the carry and dollar factors.

Panel B of Table 3 reports RMSEs obtained on developing countries. The two factors fail to beat the random walk for currencies that are pegged during a large fraction of the time window. This is the case of Hong Kong, Malaysia, Thailand and the United Arab Emirates.[5] But for the other developing countries, results are quite similar to those obtained for developed countries. The carry and dollar factors decrease considerably the RMSEs.

These results are partly consistent with the augmented-UIP regressions reported in Table 7. Adjusted R^2s tend to be higher for floating currencies. They are low for two pegged currencies: Hong Kong and the United Arab Emirates (5.1% and -1.4% respectively). Thailand and Malaysia, although they also experienced currency pegs, do not appear that much different from the other developing countries. Except for Hong Kong and the United Arab Emirates, R^2s range from 14% to 77%, almost as high as for developed countries. Loadings on the dollar are significantly positive for all countries, except the United Arab Emirates. But loadings on the carry and conditional carry factors vary a lot and are much less precisely estimated as those on developed countries. Note that this lack of significance might come from the much smaller samples available. Overall, developing countries with floating currencies seem to share the same factors as developed countries.

[Table 7 about here.]

[5]Kuwait also pegged its currency to the dollar from 2003 to 2007, but the carry and dollar factors still beat the random walk.

7.5 Principal Components of Bid-Ask Spreads

Some authors argue that price pressure or other informational frictions (like moral hazard) are key mechanisms on currency markets. There is no formal empirical test of these mechanisms on currency markets, but the intuition suggests that they should affect the dynamics of bid-ask spreads.

Is there systematic variation in bid-ask spreads? Certainly, and the recent crisis offers a clear example, as many bid-ask spreads increased at the same time. But these bid-ask spreads are not strongly correlated with currency factors. In the data, the dollar and carry factors only explain a small fraction of the changes in bid-asks spreads. The average R^2 is less than 8% across developed countries. The carry, conditional carry, and dollar factors rarely appear significant. The most significant loadings are on interest rate differences. Overall, bid-ask spreads exhibit some comovement, but their variations are two orders of magnitude smaller than the changes in midquotes, and thus cannot infirm the benchmark results in this paper.

7.6 Other Base Currencies and Cross-Rates

All regressions so far pertain to exchange rates defined with respect to the U.S. Dollar. Similar results, however, emerge with other base currencies. I consider exchange rates defined with respect to the Japanese Yen, U.K. pound, and Swiss Franc. augmented-UIP tests, for example for pound-based exchange rates, are thus:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma(i_t^\star - i_t)Carry_{t+1} + \delta Carry_{t+1} + \tau Pound_{t+1} + \varepsilon_{t+1},$$

where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.K. Pound and $Pound_{t+1}$ corresponds to the average change in exchange rates against the U.K. Pound. The *Carry* factor is not changed much as it is dollar-neutral. The shares of systematic risk range from 39% to 71% for pound-based currencies, from 65% to 82% for Yen-based currencies, and from 35% to 77% for franc-based currencies. In each case, a country-specific factor appears necessary to account for exchange rate variation.

The dollar factor is thus a basis factor, linked to the choice of the basis currency. The dollar factor, however, explains also part of some cross-rates changes (i.e. exchange rates not defined with respect to the U.S. dollar). The dollar factor is a significant factor of cross-rates for currencies that exhibit very different loadings on the dollar factor in their U.S. dollar based exchange rates in the first place. Going back to Table 2, the Yen/Dollar exchange rate, for example, has a loading of 0.98 on the dollar factor, whereas the Swiss Franc/Dollar has a loading of 1.36. As a result, the Swiss Franc/Yen exchange rate exhibits a large and positive loading on the dollar factor. The risk-based model of Lustig et al. (forthcoming) provides an intuition for this finding. Recall that the dollar factor captures U.S.-specific shocks to the U.S. pricing kernel as well as global shocks. In a no-arbitrage model, the Swiss Franc / Yen exchange rate depends on the Swiss and Japanese SDFs and there is thus no role for U.S.-specific shocks, but the Swiss Franc / Yen exchange rate also depends on global shocks that affect the dollar factor as well. Teasing out the global component of the dollar factor is no easy task because of its heteroscedasticity.

To sum up, robustness tests show that the large R^2s and significant loadings on the carry and dollar factors are pervasive and, unlike macroeconomic variables, point towards large comovement across currencies.

8 Conclusion

A large share of each currency pair movement is related to other bilateral exchange rate changes. More precisely, two common components — a dollar and a carry components — account for 20% to 90% of bilateral exchange rates at daily, monthly, and quarterly frequencies. These common components are key objects of interest for researchers in international finance. I end this paper with a set of broader questions and a tentative research agenda.

The results in this paper as very encouraging for future research in international finance. If a large share of the time-series variation in bilateral exchange rates were just noise, uncorrelated to anything, then the scope for future research would be very limited. One could at best hope to understand a small share of exchange rate dynamics. The results in this paper suggest otherwise. A large share of the exchange rate dynamics is accounted for by two common factors. This finding highlights a potential path for future research in two directions.

First, one could focus on these common components. Are there other key common components? What are their drivers? Do they correspond to risk or characteristics? Would they arise under rational expectations and non-rational expectations alike? If they are truly risk factors, then what kind of risk do they capture? Macroeconomic risk? Liquidity risk? Are these factors predictable at short and long horizons?

Second, one needs to understand the heterogeneity across exchange rates. Lustig et al. (forthcoming) show that in any risk-based model pricing kernels must differ in the way they load on common shocks across countries. High interest rate countries must load less than low interest rate countries on common shocks. These loadings must also be time-varying. What is the source of heterogeneity in these loadings? Macroeconomics? Behavioral? What does explain the time-variation in these loadings? Is this source of heterogeneity enough to account for the difference in R^2s in the augmented-UIP regressions?

The large share of systematic risk in exchange rates makes these questions very relevant to researchers and practitioners alike.

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Table 1: Uncovered Interest Rate Parity Tests With and Without the Carry Factor

	Panel I: UIP			Panel II: UIP with Carry					
Country	α	β	R^2	α	β	γ	δ	R^2	N
Australia	0.17	−0.93	**0.13**	0.08	−1.03	0.74	0.28	**15.56**	311
	[0.28]	[0.84]	(0.95)	[0.27]	[0.70]	[0.32]	[0.11]	(5.97)	
Canada	−0.07	−0.44	**-0.23**	−0.14	−0.26	0.04	0.23	**7.25**	311
	[0.13]	[0.61]	(0.40)	[0.13]	[0.63]	[0.26]	[0.07]	(3.75)	
Denmark	−0.19	−0.42	**-0.19**	−0.12	−1.44	1.25	−0.11	**7.38**	311
	[0.18]	[0.65]	(0.50)	[0.17]	[0.54]	[0.23]	[0.10]	(2.82)	
Euro Area	−0.15	−0.44	**-0.68**	−0.17	−1.01	0.95	0.08	**-0.42**	142
	[0.29]	[1.93]	(0.90)	[0.28]	[1.77]	[0.91]	[0.17]	(4.91)	
France	−0.21	−0.10	**-0.56**	−0.06	−1.16	1.16	−0.13	**5.88**	180
	[0.25]	[0.96]	(0.88)	[0.24]	[0.75]	[0.33]	[0.12]	(3.94)	
Germany	−0.29	−0.16	**-0.55**	−0.37	−1.67	2.19	0.07	**24.01**	180
	[0.28]	[1.04]	(0.92)	[0.21]	[0.71]	[0.23]	[0.08]	(6.01)	
Italy	−0.06	0.16	**-0.56**	0.35	−1.01	0.77	−0.20	**1.92**	176
	[0.35]	[1.08]	(1.82)	[0.40]	[0.99]	[0.60]	[0.20]	(6.11)	
Japan	−0.94	−2.53	**1.87**	−0.85	−2.67	0.48	−0.33	**14.83**	324
	[0.27]	[0.88]	(1.61)	[0.27]	[0.89]	[0.44]	[0.11]	(4.76)	
New Zealand	0.09	−0.67	**0.24**	0.09	−0.97	0.46	0.18	**9.56**	311
	[0.27]	[0.58]	(1.27)	[0.25]	[0.48]	[0.29]	[0.14]	(4.49)	
Norway	−0.16	0.07	**-0.32**	−0.12	−0.43	0.54	0.05	**2.43**	311
	[0.20]	[0.66]	(0.40)	[0.19]	[0.56]	[0.26]	[0.11]	(3.20)	
Sweden	−0.13	0.22	**-0.29**	−0.11	−0.30	0.98	−0.01	**6.09**	311
	[0.20]	[1.01]	(0.71)	[0.19]	[0.66]	[0.39]	[0.10]	(4.52)	
Switzerland	−0.49	−1.35	**0.47**	−0.59	−2.45	1.81	0.05	**11.71**	324
	[0.27]	[0.96]	(1.09)	[0.21]	[0.76]	[0.39]	[0.12]	(3.44)	
United Kingdom	0.22	−1.39	**0.43**	0.19	−1.71	2.05	−0.14	**9.83**	324
	[0.21]	[1.27]	(1.35)	[0.20]	[0.92]	[0.64]	[0.11]	(4.86)	

Notes: The left panel of this table reports country-level results from the following regression:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \varepsilon_{t+1},$$

where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, and $i_t^\star - i_t$ is the interest rate difference between the foreign country and the U.S. The right panel of this table reports country-level results from the following regression:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma(i_t^\star - i_t)Carry_{t+1} + \delta Carry_{t+1} + \varepsilon_{t+1},$$

where $Carry_{t+1}$ denotes the dollar-neutral average change in exchange rates obtained by going long a basket of high interest rate currencies and short a basket of low interest rate currencies. The table reports the constant α, the slope coefficients β, γ, and δ, as well as the R^2 of this regression (in percentage points), and the number of observations. Standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). The standard errors for the R^2s are reported in parentheses; they are obtained by bootstrapping. Data are monthly, from Barclays and Reuters (Datastream). All variables are in percentage points. The sample period is 11/1983–12/2010.

Table 2: UIP Tests with the Carry and Dollar Factors

Country	α	β	γ	δ	τ	R^2	N
Australia	−0.08	0.11	1.04	0.13	0.93	**42.52**	311
	[0.24]	[0.66]	[0.30]	[0.11]	[0.11]	(6.27)	
Canada	−0.13	0.39	−0.07	0.20	0.41	**21.98**	311
	[0.11]	[0.68]	[0.28]	[0.05]	[0.08]	(6.13)	
Denmark	0.03	−0.48	0.45	−0.23	1.48	**89.27**	311
	[0.07]	[0.32]	[0.14]	[0.03]	[0.03]	(1.56)	
Euro Area	0.07	−0.62	0.21	−0.28	1.56	**83.10**	142
	[0.10]	[0.82]	[0.21]	[0.04]	[0.07]	(3.22)	
France	−0.11	−0.16	0.60	−0.09	1.32	**91.96**	180
	[0.07]	[0.32]	[0.18]	[0.03]	[0.03]	(1.53)	
Germany	−0.20	−0.24	0.87	−0.03	1.37	**92.11**	180
	[0.09]	[0.34]	[0.15]	[0.04]	[0.04]	(1.20)	
Italy	0.13	−0.21	0.76	−0.17	1.23	**67.30**	176
	[0.17]	[0.47]	[0.34]	[0.13]	[0.09]	(5.40)	
Japan	−0.30	−0.72	−0.27	−0.60	0.98	**47.67**	324
	[0.20]	[0.73]	[0.33]	[0.10]	[0.09]	(4.49)	
New Zealand	0.05	−0.42	0.88	−0.07	1.13	**46.89**	311
	[0.18]	[0.34]	[0.23]	[0.10]	[0.10]	(4.80)	
Norway	−0.02	0.08	0.44	−0.02	1.36	**73.18**	311
	[0.11]	[0.34]	[0.15]	[0.06]	[0.07]	(3.76)	
Sweden	−0.06	0.75	0.78	−0.07	1.40	**74.01**	311
	[0.10]	[0.47]	[0.21]	[0.04]	[0.06]	(2.75)	
Switzerland	−0.16	−0.70	0.52	−0.26	1.36	**80.66**	324
	[0.11]	[0.43]	[0.22]	[0.07]	[0.05]	(1.89)	
United Kingdom	−0.00	0.06	1.15	−0.10	1.06	**57.64**	324
	[0.14]	[0.64]	[0.43]	[0.08]	[0.08]	(4.78)	

Notes: This table reports country-level results from the following regression:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma(i_t^\star - i_t)Carry_{t+1} + \delta Carry_{t+1} + \tau Dollar_{t+1} + \varepsilon_{t+1},$$

where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, and $i_t^\star - i_t$ is the interest rate difference between the foreign country and the U.S., $Carry_{t+1}$ denotes the dollar-neutral average change in exchange rates obtained by going long a basket of high interest rate currencies and short a basket of low interest rate currencies, and $Dollar_{t+1}$ corresponds to the average change in exchange rates against the U.S. dollar. The table reports the constant α, the slope coefficients β, γ, δ, and τ, as well as the R^2 of this regression (in percentage points) and the number of observations. Standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). The standard errors for the R^2s are reported in parentheses; they are obtained by bootstrapping. Data are monthly, from Barclays and Reuters (Datastream). All variables are in percentage points. The sample period is 11/1983–12/2010.

Table 3: RMSE Errors: Risk Factors vs Random Walk

Country	$\sigma_{\Delta s}$	$RMSE$	$RMSE_{RW}$	$RMSE_{RW}/RMSE$
Panel A: Developed Countries				
Australia	12.01	9.01	11.48	0.78
Canada	7.04	6.61	7.39	0.89
Denmark	11.06	3.94	10.76	0.37
Euro Area	10.73	4.32	11.14	0.39
France	11.20	3.71	10.67	0.35
Germany	11.72	3.74	10.90	0.34
Italy	11.30	8.05	11.16	0.72
Japan	11.50	8.78	11.30	0.78
New Zealand	12.18	8.81	11.26	0.78
Norway	10.99	5.93	10.88	0.55
Sweden	11.47	6.46	11.83	0.55
Switzerland	11.91	5.74	11.31	0.51
United Kingdom	10.52	6.94	9.90	0.70
Panel B: Developing Countries				
Hong Kong	0.54	0.47	0.47	1.01
Czech Republic	13.13	7.19	13.10	0.55
Hungary	13.73	8.22	14.85	0.55
India	5.91	4.96	6.06	0.82
Kuwait	2.69	2.12	2.85	0.74
Malaysia	10.57	12.27	11.39	1.08
Mexico	9.36	7.40	9.11	0.81
Poland	13.82	7.72	16.48	0.47
South Korea	17.56	10.10	14.14	0.71
Taiwan	5.88	3.95	4.80	0.82
Thailand	12.85	8.40	7.01	1.20
United Arab Emirates	0.18	0.19	0.19	1.01

Notes: This table reports the standard deviation of log changes in spot exchange rates (denoted $\sigma_{\Delta s}$), as well as the square root of mean squared errors (RMSE) obtained with the carry and dollar factors. These RMSE use the augmented-UIP slope coefficients obtained in the previous period. These RMSE do *not* correspond to out-of-sample predictions though as the carry and dollar factors are assumed to be known one period in advance. The last column reports the ratio of RMSE obtained by assuming that exchange rates are random walks to those obtained with the carry and dollar factors. Data are monthly, from Barclays and Reuters (Datastream). Standard deviations and RMSEs are annualized (i.e multiplied by $\sqrt{12}$) and reported in percentages. The sample period is 11/1983–12/2010.

Table 4: Lustig et alii's (2010) Model: UIP Tests With and Without the Carry and Dollar Risk Factors on Simulated Data

Country	α	β	γ	δ	τ	R^2
			Panel A			
Low Delta	0.57	−1.60				0.26
	[0.50]	[1.48]				
Med. Delta	−0.06	−2.12				1.31
	[0.11]	[1.21]				
High Delta	−0.18	−0.59				−0.23
	[0.54]	[1.39]				
			Panel B			
Low Delta	0.06	−0.12	2.38	−0.53		69.62
	[0.32]	[0.83]	[0.28]	[0.11]		
Med. Delta	−0.04	−0.36	3.17	0.10		65.27
	[0.07]	[0.62]	[0.16]	[0.02]		
High Delta	0.06	0.23	1.58	0.14		81.43
	[0.27]	[0.52]	[0.20]	[0.12]		
			Panel C			
Low Delta	−0.28	0.65	1.32	0.16	1.03	85.32
	[0.21]	[0.53]	[0.16]	[0.07]	[0.06]	
Med. Delta	−0.05	−0.40	2.00	0.22	0.81	81.46
	[0.05]	[0.41]	[0.14]	[0.02]	[0.05]	
High Delta	−0.05	0.03	1.14	0.04	0.78	89.04
	[0.19]	[0.41]	[0.16]	[0.08]	[0.08]	

Notes: This table reports results from the following set of regressions:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma(i_t^\star - i_t)Carry_{t+1} + \delta Carry_{t+1} + \tau Dollar_{t+1} + \varepsilon_{t+1},$$

where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, and $i_t^\star - i_t$ is the interest rate difference, $Carry_{t+1}$ denotes the dollar-neutral average change in exchange rates obtained by going long a basket of high interest rate currencies and short a basket of low interest rate currencies, and $Dollar_{t+1}$ corresponds to the average change in exchange rates against the U.S. dollar. The table reports the constant α, the slope coefficients β, γ, δ and τ, and the adjusted R^2 of this regression. Standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). The standard errors for the R^2s are reported in parentheses; they are obtained by bootstrapping. Data are simulated at monthly frequency. The sample corresponds to the last 300 months of the simulated series. Panel A focuses on the standard UIP tests; panel B introduces the carry trade risk factor; panel C introduces both the carry and dollar risk factors. In each case, we report results obtained on a low, medium, and high δ-country: δ measures the loading of the SDF on world shocks; it is the only source of heterogeneity in the model.

Table 5: Daily Uncovered Interest Rate Parity Tests with the Carry and Dollar Factors

Country	α	β	γ	δ	τ	R^2	N
Australia	−0.01	0.01	0.60	0.24	0.92	36.52	6775
	[0.01]	[0.03]	[0.11]	[0.03]	[0.03]	(1.69)	
Canada	−0.01	0.04	−0.42	0.20	0.47	21.45	6775
	[0.01]	[0.03]	[0.11]	[0.02]	[0.02]	(1.49)	
Denmark	−0.00	−0.02	0.52	−0.22	1.51	83.54	6775
	[0.00]	[0.01]	[0.05]	[0.01]	[0.02]	(0.56)	
Euro Area	0.00	−0.05	0.17	−0.25	1.53	68.53	3109
	[0.01]	[0.04]	[0.11]	[0.02]	[0.03]	(1.31)	
France	−0.01	−0.01	0.69	−0.05	1.33	85.60	3936
	[0.00]	[0.02]	[0.08]	[0.02]	[0.01]	(0.88)	
Germany	−0.01	−0.01	0.75	−0.03	1.43	88.58	3936
	[0.00]	[0.02]	[0.05]	[0.01]	[0.01]	(0.52)	
Italy	0.00	0.00	0.62	−0.18	1.25	68.92	3864
	[0.01]	[0.03]	[0.12]	[0.04]	[0.02]	(1.82)	
Japan	−0.01	−0.04	−0.13	−0.59	0.99	43.45	7047
	[0.01]	[0.03]	[0.11]	[0.04]	[0.03]	(1.35)	
New Zealand	0.01	−0.04	0.44	0.28	0.97	38.72	6775
	[0.01]	[0.04]	[0.12]	[0.05]	[0.03]	(1.54)	
Norway	−0.00	0.01	0.46	−0.02	1.49	70.38	6775
	[0.01]	[0.01]	[0.06]	[0.02]	[0.02]	(1.36)	
Sweden	0.00	−0.01	0.28	0.00	1.37	59.99	6775
	[0.01]	[0.02]	[0.08]	[0.02]	[0.02]	(1.24)	
Switzerland	−0.01	−0.01	0.53	−0.25	1.45	76.38	7047
	[0.01]	[0.02]	[0.07]	[0.02]	[0.02]	(0.72)	
United Kingdom	−0.00	0.02	0.45	−0.01	1.17	57.05	7047
	[0.01]	[0.03]	[0.11]	[0.03]	[0.02]	(1.20)	

Notes: This table reports country-level results from the following regression:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma(i_t^\star - i_t)Carry_{t+1} + \delta Carry_{t+1} + \tau Dollar_{t+1} + \varepsilon_{t+1},$$

where where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, and $i_t^\star - i_t$ is the interest rate difference between the foreign country and the U.S., $Carry_{t+1}$ denotes the dollar-neutral average change in exchange rates obtained by going long a basket of high interest rate currencies and short a basket of low interest rate currencies, and $Dollar_{t+1}$ corresponds to the average change in exchange rates against the U.S. dollar. The table reports the constant α, the slope coefficients β, γ, δ, and τ, as well as the R^2 of this regression and the number of observations. Standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). The standard errors for the R^2s are reported in parentheses; they are obtained by bootstrapping. Data are daily, from Barclays and Reuters (Datastream). All variables are in percentage points. The sample period is 30/11/1983–31/12/2010.

Table 6: Monthly Uncovered Interest Rate Parity Tests with Macroeconomic Variables

Country	α	β	γ	δ	R^2	N
Australia	0.15	−1.78	−8.21	52.90	0.11	311
	[0.26]	[1.49]	[10.78]	[73.86]	(1.83)	
Canada	−0.32	−2.83	−15.04	−67.56	1.44	311
	[0.23]	[1.68]	[9.02]	[58.60]	(2.04)	
Denmark	−0.19	−0.49	−6.08	−89.03	1.77	311
	[0.16]	[0.51]	[6.09]	[47.73]	(2.01)	
Euro Area	−0.04	1.59	−4.56	−197.41	8.59	142
	[0.30]	[1.81]	[8.44]	[91.95]	(5.98)	
France	−0.08	−0.84	0.84	47.89	−1.81	107
	[0.27]	[0.73]	[10.65]	[87.57]	(2.52)	
Germany	−0.18	0.01	−9.67	−15.74	−1.06	180
	[0.34]	[0.88]	[9.22]	[58.70]	(1.66)	
Italy	0.09	−0.53	−5.73	42.18	−0.82	176
	[0.22]	[0.62]	[8.99]	[77.41]	(1.91)	
Japan	−0.99	−1.12	−13.19	−130.94	2.27	324
	[0.51]	[1.04]	[7.82]	[65.23]	(2.03)	
New Zealand	−0.09	0.39	−13.03	−31.21	−0.33	311
	[0.22]	[0.58]	[9.56]	[47.62]	(1.20)	
Norway	−0.01	−0.46	−8.91	−38.27	0.33	311
	[0.14]	[0.50]	[7.90]	[36.78]	(1.56)	
Sweden	0.02	−0.18	−11.95	−87.57	2.47	311
	[0.16]	[0.73]	[7.12]	[34.20]	(2.29)	
Switzerland	−0.55	−0.76	−5.77	−67.93	0.57	324
	[0.29]	[0.66]	[6.49]	[53.43]	(1.62)	
United Kingdom	−0.19	−1.38	−11.15	−6.47	0.35	324
	[0.21]	[1.28]	[8.05]	[32.25]	(1.60)	

Notes: This table reports country-level results from the following regression:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma \Delta ip_{t+1} + \delta(\Delta cpi_{t+1}^\star - \Delta cpi_{t+1}) + \varepsilon_{t+1},$$

where where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, and $i_t^\star - i_t$ is the interest rate difference between the foreign country and the U.S., Δip_{t+1} denotes the log difference in the industrial production index and $\Delta cpi_{t+1}^\star - \Delta cpi_{t+1}$ denotes the foreign minus domestic log difference in the consumer price indices. Changes in exchange rates and interest rate differences are expressed in percentage points. The table reports the constant α, the slope coefficients β, γ, δ, and τ, as well as the R^2 of this regression (in percentage points) and the number of observations. Standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). The standard errors for the R^2s are reported in parentheses; they are obtained by bootstrapping. Data are quarterly, from Barclays and Reuters (Datastream). All variables are in percentage points. The sample period is 1983.11–2010.12.

Table 7: Augmented UIP Tests in Emerging and Developing Countries

Country	α	β	γ	δ	τ	R^2	N
Hong Kong	−0.00	−0.08	0.04	−0.00	0.02	5.10	324
	[0.01]	[0.07]	[0.02]	[0.00]	[0.01]	(2.99)	
Czech Republic	−0.13	−0.03	−0.09	−0.18	1.79	68.74	166
	[0.15]	[0.43]	[0.16]	[0.08]	[0.09]	(4.43)	
Hungary	0.16	0.02	−0.51	0.37	1.84	70.56	157
	[0.35]	[0.52]	[0.17]	[0.15]	[0.13]	(4.82)	
India	0.11	−0.07	0.20	0.04	0.50	34.61	157
	[0.20]	[0.57]	[0.32]	[0.11]	[0.07]	(7.74)	
Kuwait	−0.14	1.84	0.71	−0.10	0.24	50.40	166
	[0.03]	[0.31]	[0.15]	[0.02]	[0.04]	(10.97)	
Malaysia	0.30	3.10	−0.57	0.19	0.36	13.84	165
	[0.20]	[2.47]	[0.52]	[0.11]	[0.12]	(8.49)	
Mexico	0.35	−0.36	−0.18	0.68	0.31	36.58	166
	[0.27]	[0.34]	[0.16]	[0.14]	[0.13]	(8.73)	
Poland	−0.15	1.32	1.02	0.04	1.79	77.54	105
	[0.21]	[0.72]	[0.27]	[0.10]	[0.12]	(4.48)	
South Korea	0.49	−2.90	1.34	−0.13	1.43	59.71	105
	[0.26]	[1.64]	[0.62]	[0.15]	[0.21]	(5.79)	
Taiwan	−0.02	−0.26	0.52	0.07	0.51	40.57	166
	[0.12]	[0.32]	[0.13]	[0.05]	[0.06]	(6.22)	
Thailand	−0.10	−0.77	1.45	−0.10	0.69	50.67	166
	[0.18]	[1.02]	[0.44]	[0.10]	[0.11]	(8.99)	
United Arab Emirates	0.00	−0.06	0.04	−0.00	−0.00	−1.43	114
	[0.00]	[0.12]	[0.05]	[0.00]	[0.00]	(4.20)	

Notes: This table reports country-level results from the following regression:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma(i_t^\star - i_t)Carry_{t+1} + \delta Carry_{t+1} + \tau Dollar_{t+1} + \varepsilon_{t+1},$$

where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, and $i_t^\star - i_t$ is the interest rate difference between the foreign country and the U.S., $Carry_{t+1}$ denotes the dollar-neutral average change in exchange rates obtained by going long a basket of high interest rate currencies and short a basket of low interest rate currencies, and $Dollar_{t+1}$ corresponds to the average change in exchange rates against the U.S. dollar. The table reports the constant α, the slope coefficients β, γ, δ, and τ, as well as the R^2 of this regression and the number of observations. Standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). The standard errors for the R^2s are reported in parentheses; they are obtained by bootstrapping. Data are monthly, from Barclays and Reuters (Datastream). All variables are in percentage points. The sample period is 11/1983–12/2010.

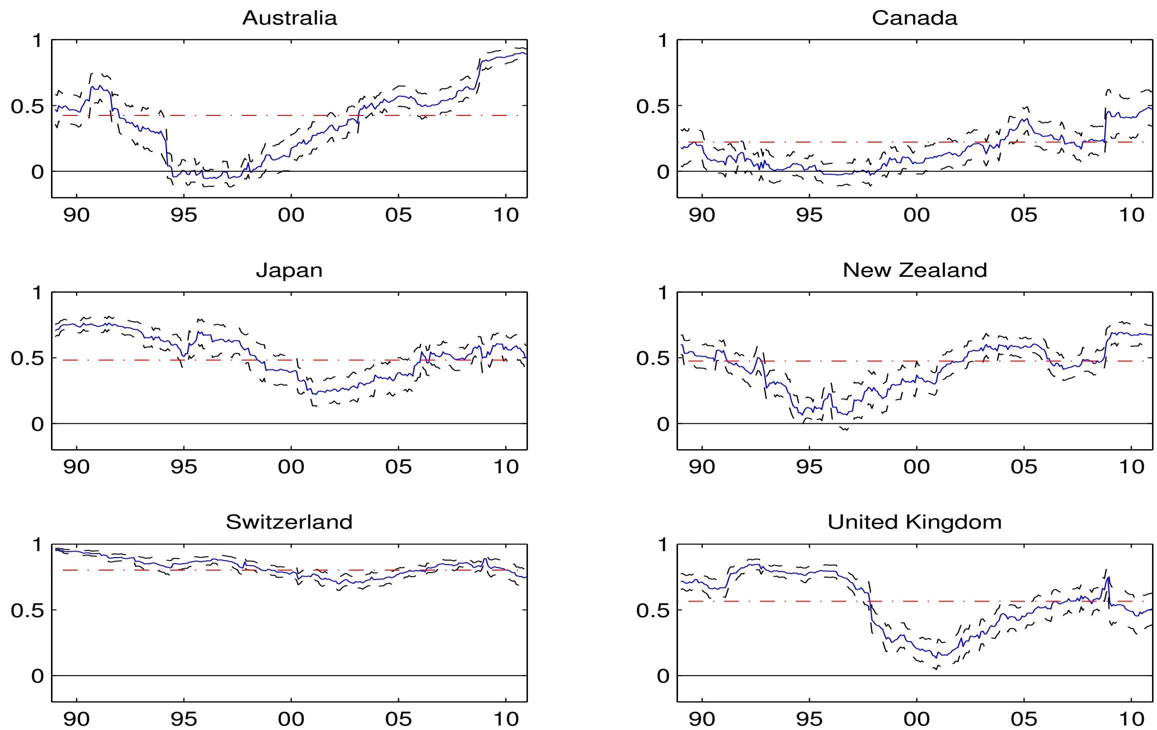

Figure 1: Adjusted R^2s Estimated on Rolling Windows

The figure plots the adjusted R^2 in the following regression:

$$\Delta s_{t+1} = \alpha_t + \beta_t(i_t^\star - i_t) + \gamma_t(i_t^\star - i_t)Carry_{t+1} + \delta_t Carry_{t+1} + \tau_t Dollar_{t+1} + \varepsilon_{t+1},$$

where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, and $i_t^\star - i_t$ is the interest rate difference, $Carry_{t+1}$ denotes the dollar-neutral average change in exchange rates obtained by going long a basket of high interest rate currencies and short a basket of low interest rate currencies, and $Dollar_{t+1}$ corresponds to the average change in exchange rates against the U.S. dollar. Data are monthly and estimates are obtained on rolling windows of 60 months. . The solid line presents the time-varying R^2s (R_t^2 corresponds to an estimate over the sample from $t-60$ to t). The dotted line corresponds to the estimated value plus or minus one standard deviation of the estimate. This standard deviation is obtained by bootstrapping the regression above assuming that changes in exchange rates are *i.i.d.* The dash-dotted line reports the R^2 obtained on the full sample. The full sample period is 1/1983–12/2010.

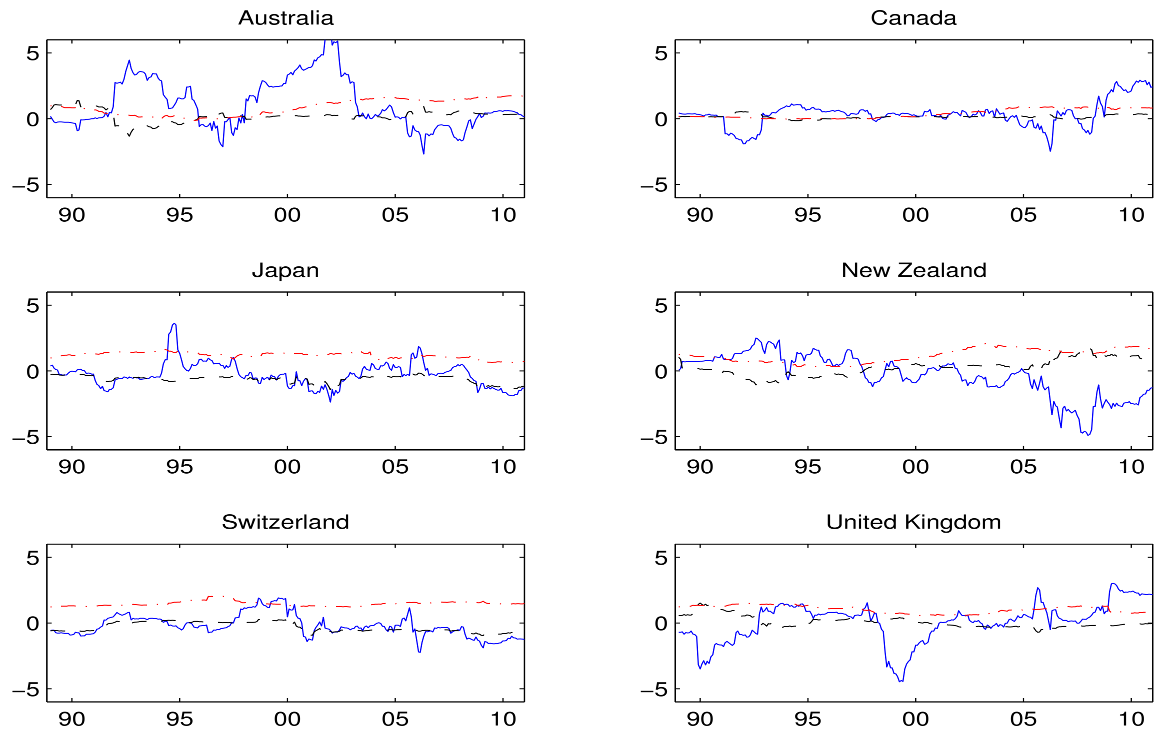

Figure 2: Carry and Dollar Factor Loadings Estimated on Rolling Windows

The figure plots the carry (δ_t, dashed black line), conditional carry (γ_t, solid blue line), and dollar (τ_t, dash-dot red line) slope coefficients in the following regression:

$$\Delta s_{t+1} = \alpha_t + \beta_t(i_t^\star - i_t) + \gamma_t(i_t^\star - i_t)Carry_{t+1} + \delta_t Carry_{t+1} + \tau_t Dollar_{t+1} + \varepsilon_{t+1},$$

where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, and $i_t^\star - i_t$ is the interest rate difference, $Carry_{t+1}$ denotes the dollar-neutral average change in exchange rates obtained by going long a basket of high interest rate currencies and short a basket of low interest rate currencies, and $Dollar_{t+1}$ corresponds to the average change in exchange rates against the U.S. dollar. Data are monthly and estimates are obtained on rolling windows of 60 months. The sample period is 1/1983–12/2010.

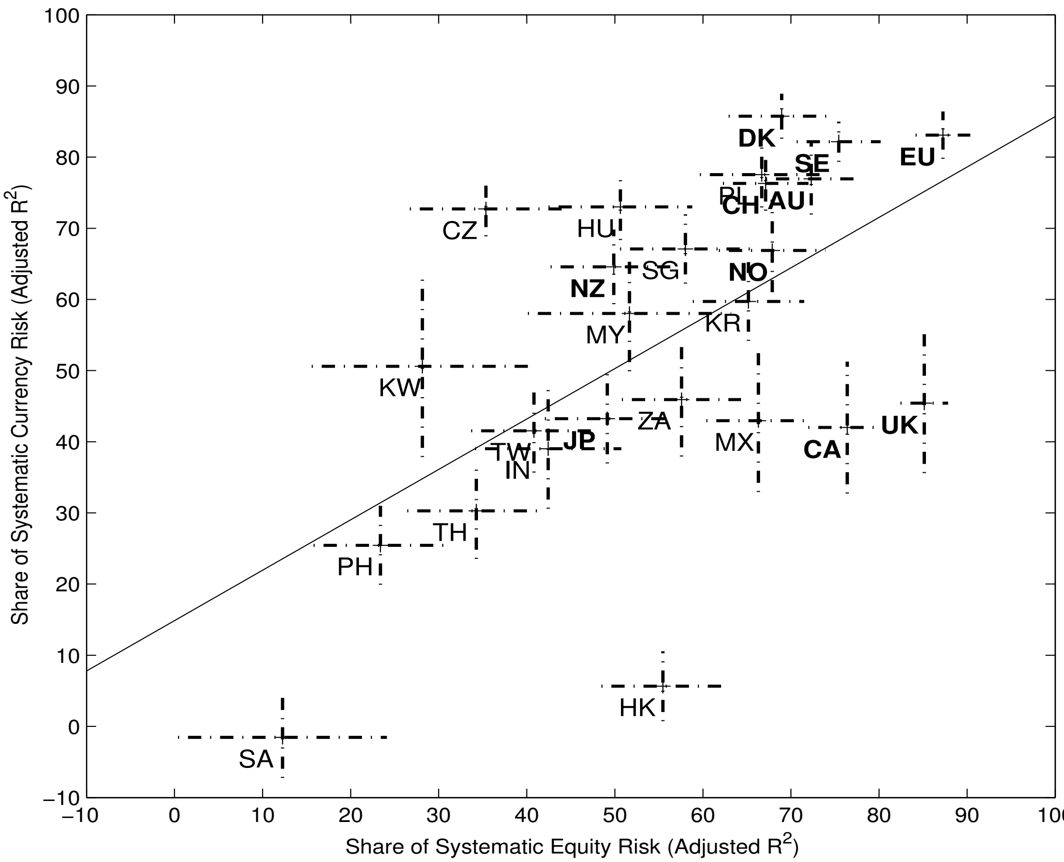

Figure 3: World Equity Market Integration and Systematic Currency Risk

The figure plots adjusted R^2s on currency markets as a function of adjusted R^2s on equity markets. Dots correspond to point estimates, while dotted lines represent confidence intervals (defined as one-standard error above and below the point estimates). Standard errors are obtained by bootstrapping. Adjusted R^2s on currency markets are obtained from the following regressions:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma(i_t^\star - i_t)Carry_{t+1} + \delta Carry_{t+1} + \tau Dollar_{t+1} + \varepsilon_{t+1},$$

where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, $i_t^\star - i_t$ denotes the interest rate difference, $Carry_{t+1}$ denotes the dollar-neutral average change in exchange rates obtained by going long a basket of high interest rate currencies and short a basket of low interest rate currencies, and $Dollar_{t+1}$ corresponds to the average change in exchange rates against the U.S. dollar. Adjusted R^2s on equity markets are derived from:

$$r_{t+1}^{m,\star} = \alpha + \beta r_{t+1}^{m,world} + \gamma r_{t+1}^{hml,world} + \varepsilon_{t+1},$$

where $r_{t+1}^{m,\star}$ denotes the returns on a given foreign country MSCI stock market index, $r_{t+1}^{m,world}$ corresponds to returns on the MSCI world equity index, and $r_{t+1}^{hml,world}$ is the difference between returns on the world MSCI value equity index and the world MSCI growth equity index (i.e., high minus low book-to-market equity returns). Data are monthly. The sample is 1999.1–2010.12. The country codes correspond to the international standard: Australia (AU), Canada (CA), Hong Kong (HK), Czech Republic (CZ), Denmark (DK), Finland (FI), Hungary (HU), India (IN), Indonesia (ID), Japan (JP), Kuwait (KW), Malaysia (MY), Mexico (MX), New Zealand (NZ), Norway (NO), Philippines (PH), Poland (PL), Saudi Arabia (SA), Singapore (SG), South Africa (ZA), South Korea (KR), Sweden (SE), Switzerland (CH), Taiwan (TW), Thailand (TH), Turkey (TR), United Kingdom (UK), as well as the Euro area (EU).

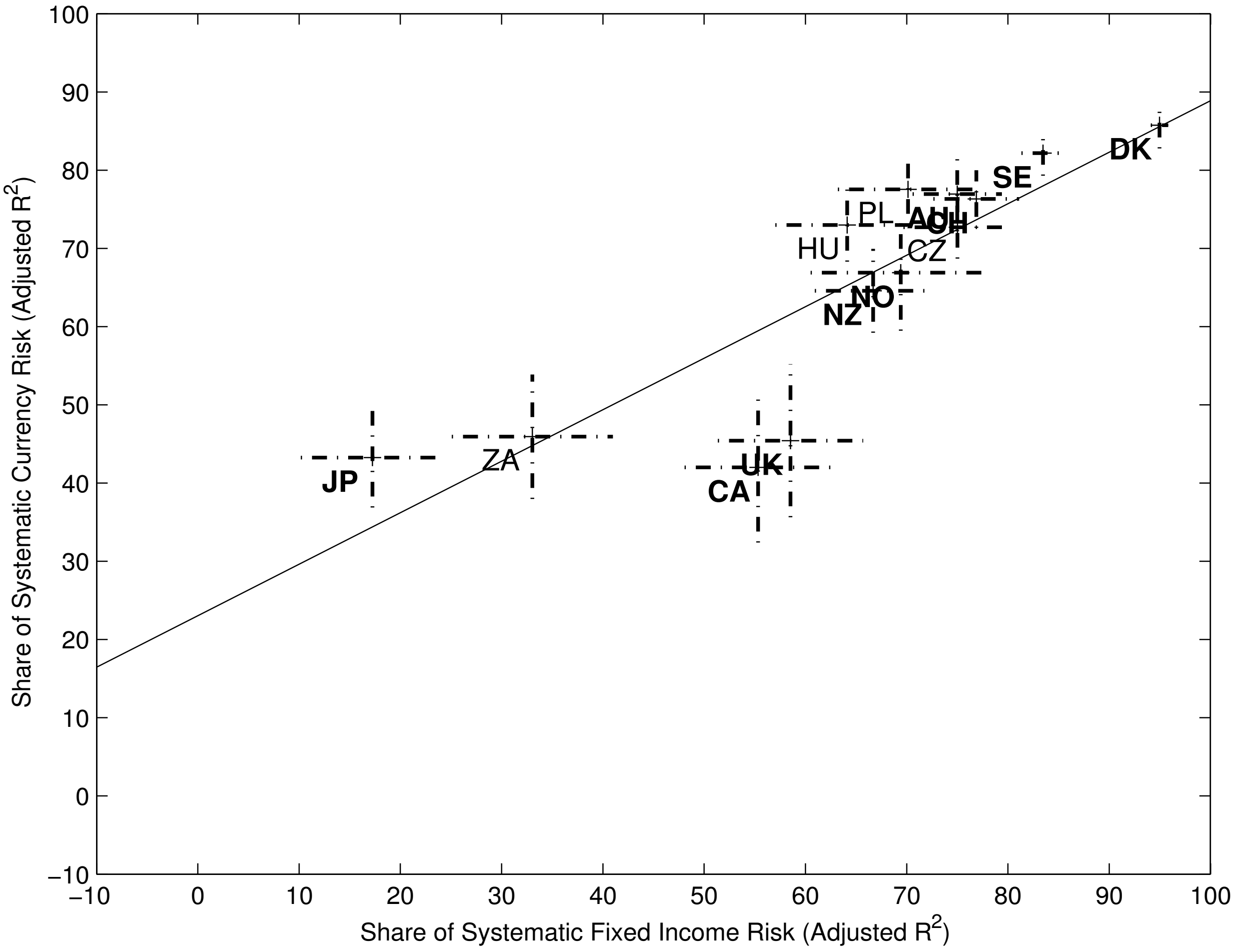

Figure 4: Shares of Systematic Fixed Income and Currency Risk

The figure plots adjusted R^2s on currency markets as a function of adjusted R^2s on bond markets. Dots correspond to point estimates, while dotted lines represent confidence intervals (defined as one-standard error above and below the point estimates). Standard errors are obtained by bootstrapping. Adjusted R^2s on currency markets are obtained from the following regressions:

$$\Delta s_{t+1} = \alpha + \beta(i_t^\star - i_t) + \gamma(i_t^\star - i_t)Carry_{t+1} + \delta Carry_{t+1} + \tau Dollar_{t+1} + \varepsilon_{t+1},$$

where Δs_{t+1} denotes the bilateral exchange rate in foreign currency per U.S. dollar, $i_t^\star - i_t$ denotes the interest rate difference, $Carry_{t+1}$ denotes the dollar-neutral average change in exchange rates obtained by going long a basket of high interest rate currencies and short a basket of low interest rate currencies, and $Dollar_{t+1}$ corresponds to the average change in exchange rates against the U.S. dollar. Adjusted R^2s on bond markets are derived from:

$$r_{t+1}^{b,\star} = \alpha + \beta r_{t+1}^{m,world} + \gamma r_{t+1}^{b,world} + \varepsilon_{t+1},$$

where $r_{t+1}^{b,\star}$ denotes the returns on a given foreign country 10-year bond return index, $r_{t+1}^{m,world}$ corresponds to returns on the MSCI world equity index, and $r_{t+1}^{b,world}$ is the world bond return, obtained as the average of all the 10-year bond returns. Data are monthly. The sample is 1999.1–2010.12. The country codes correspond to the international standard: Australia (AU), Austria (AT), Belgium (BE), Canada (CA), Hong Kong (HK), Czech Republic (CZ), Denmark (DK), Finland (FI), France (FR), Germany (DE), Greece (GR), Hungary (HU), India (IN), Indonesia (ID), Ireland (IE), Italy (IT), Japan (JP), Kuwait (KW), Malaysia (MY), Mexico (MX), Netherlands (NL), New Zealand (NZ), Norway (NO), Philippines (PH), Poland (PL), Portugal (PT), Saudi Arabia (SA), Singapore (SG), South Africa (ZA), South Korea (KR), Spain (ES), Sweden (SE), Switzerland (CH), Taiwan (TW), Thailand (TH), Turkey (TR), United Arab Emirates (AE), United Kingdom, as well as the Euro area (EU).