The Share of Systematic Variation in Bilateral Exchange Rates

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Abstract

Sorting countries by their dollar currency betas produces a novel cross-section of average currency excess returns. A slope factor (long in high beta currencies and short in low beta currencies) accounts for this cross-section of currency risk premia. This slope factor is orthogonal to the high-minus-low carry trade factor built from portfolios of countries sorted by their interest rates. The two high-minus-low risk factors account for 18% to 80% of the monthly exchange rate movements. The two risk factors suggest that stochastic discount factors in complete markets' models should feature at least two global shocks to describe exchange rates.

Keywords: Exchange rates, risk.

JEL: F31, G12, G15.

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The correlation structure of bilateral exchange rates can be summarized by a small number of principal components, but those principal components offer a purely statistical description of exchange rates and are difficult to interpret in any micro- or macro-finance model. In this paper, in contrast, I report that two currency risk factors account for a substantial share of individual exchange rate time series. These factors are priced in currency markets and the shares of systematic currency risk have implications for any no-arbitrage model in international finance.

Two risk factors, namely, carry and dollar, are constructed from portfolios of currencies. The carry factor corresponds to the change in exchange rates between baskets of high and low interest rate currencies, while the dollar factor corresponds to the average change in the exchange rate between the U.S. dollar and all other currencies. All exchange rates are defined here with respect to the U.S. dollar. I regress changes in exchange rates on the carry factor, the same carry factor multiplied by the country-specific interest rate difference (the latter is referred to as "conditional carry"), and the dollar factor. The change in bilateral exchange rate on the left-hand side of these regressions is measured between t and t+1; on the right-hand side, the carry and dollar factors also correspond to changes between t and t+1, while the domestic and foreign interest rates are known at date t. The carry and dollar factors do not include the bilateral exchange rate that is the dependent variable.

The factor regressions offer a novel picture of bilateral exchange rate movements. Both factors appear highly significant. With the carry factors, the adjusted R^2s range from 0% to 23% among developed countries at the monthly frequency over the 1983 to 2010 sample. While a lot of research focuses on the carry trade, the dollar factor appears to be a more important driver of exchange rates. When the two factors are combined, the adjusted R^2s range from around 20% to 90% in developed countries and from 10% to 75% among developing countries with floating currencies. The distribution of R^2s on the factor regressions is quite stable across frequencies; similar distributions appear at daily, monthly, quarterly, and annual frequencies. The substantial R^2s of the factor regressions do not imply that bilateral exchange rates are easy to forecast: the corresponding regressions use contemporaneous variables, not predictive ones.

Large R^2s can naturally be obtained by using three or more principal components. The dollar factor is actually close to the first principal component, while the carry factor is different from any of them — the information contained in short-term interest rates matters. Both factors deliver a more stable description of exchange rates than the principal components. More crucially, principal components do not imply that risks are priced. In contrast, both the carry and the dollar factors are priced in currency markets. They are *risk* factors in the asset pricing sense, consistent with the logic of an Euler equation.

The risk-based interpretation of the carry factor is well known. Previous research on currency portfolios shows that the carry factor accounts for the cross-section of currency excess returns sorted by interest rates: covariances of the carry factor with currency returns align with the cross-section of average excess returns. A consistent result appears here on individual currencies: the higher the interest rate, the larger the loading on the carry risk factor. This is the risk-based explanation of the classic currency carry trade.

This paper shows that the dollar factor also has a risk-based interpretation. The price of dollar risk cannot be estimated precisely from portfolios of countries sorted by interest rates because these portfolios all load in the same way on the dollar factor. Instead, I build portfolios of countries sorted by their time-varying exposures to the dollar factor (i.e., dollar betas). After transaction costs, the low dollar-beta portfolio offers an average log excess return of just 0.6% per year for investors who go long foreign currencies when the average forward discount (average foreign minus U.S. interest rate) is positive and short otherwise. The high dollar beta portfolio offers an average log excess return of 5.8% for similar investments, implying a large Sharpe ratio of almost 0.6. Conditioning on the average forward discount, covariances of the dollar factor with portfolio returns account for this new cross-section of average excess returns, while covariances with the carry factor do not. The estimated price of dollar risk is significant and close to the mean of the factor, as implied by the absence of arbitrage. The key pricing information is contained in a long-minus-short risk factor, built from the same set of portfolios used as test assets as the difference in exchange rates between high and low dollar beta portfolios. The loadings of dollar beta portfolios on this long-minus-short risk factor are significant and vary monotonically across portfolios. I refer to the difference in exchange rates between high and low dollar beta portfolios as the global component of the dollar factor. It is highly correlated (0.85) with the dollar factor itself but its correlation with the carry factor is statistically insignificant.

Overall, by building portfolios of currency returns, one can extract two risk factors defined as differences in exchange rate changes, and thus immune to U.S.-specific shocks: the carry factor and the global component of the dollar factor. These two variables describe bilateral exchange rates expressed in U.S. dollars or in different units. Regressions of changes in bilateral exchange rates on the two high-minus-low risk factors deliver R^2s between 18% and 83% for exchange rates defined in U.S. dollars. This is the key result of the paper, as only "dollar-neutral" explanatory variables are used in these regressions. The same variables describe exchange rates defined in other currencies, for example, Japanese yen and U.K. pounds. The R^2s are lower but still range from 18% to 46% for yen-based exchange rates and from 6% to 48% for pound-based exchange rates. The loadings on the global component of the dollar factor are significant in 20 out of 26 regressions. If the factors were capturing country-specific shocks, they would not describe currencies in other units. The empirical findings in this paper suggest that global shocks are key to describing exchange rates.

The economic source of those global shocks is an open question. At the annual frequency, the global component of the dollar tends to be low when developed countries are close to the troughs of their business cycles, as measured by the OECD turning points. The dollar risk could thus be interpreted as global macroeconomic level risk, while carry shocks appear more related to volatility and uncertainty.[1] Of course, this tentative interpretation does not exclude others based on shocks to, for example, liquidity, intermediaries' wealth, monetary policies, international trade, or international capital flows. The different potential sources and interpretations of those global shocks, as well as the underlying economic sources of the differences in country betas, are potentially fruitful research avenues. As an initial step in that research agenda, I show in a qualitative reduced-form model that two kinds of global shocks to the stochastic discount

[1]The carry factor can be proxied by measures of global volatility on equity (Lustig, Roussanov, and Verdelhan, 2011) or on currency markets (Menkhoff et al., 2012a), or by measures of downside equity risk (Lettau, Maggiori, and Weber, 2014).

factors (SDF) are necessary to describe exchange rates.

In the tradition of Frachot (1996), Backus, Foresi, and Telmer (2001), and Hodrick and Vassalou (2002), I start from the law of motion of lognormal SDFs. In the model, each log SDF is driven by country-specific and two world shocks. When markets are complete, log changes in exchange rates correspond to the differences between domestic and foreign log SDFs. The volatilities of the SDF shocks are time-varying to account for the forward premium puzzle. For the sake of clarity, the main text focuses on a special case of the model, while the general case is presented in a separate internet Appendix that is available on the Journal of Finance website. This simple model offers closed-form expressions for interest rates, exchange rates, and dollar and carry factors, as well as their associated betas.

The model makes clear that SDFs must exhibit at least two kinds of global shocks. Under some parameter restrictions, and assuming that the law of large numbers applies (such that country-specific shocks average out inside the currency portfolios), the model proposes a simple interpretation of the previous empirical findings: the carry factor depends only on world shocks priced globally, while the dollar factor depends on U.S.-specific shocks and on world shocks priced locally. Without two kinds of global shocks, even if all parameters are country-specific, the model cannot produce two independent cross-sections of currency risk premia. This result also holds in the general case of the model.

The model offers a simple interpretation of the contemporaneous regressions of bilateral exchange rates on the carry and dollar factors. For example, in the regression involving the Australian dollar expressed in units of U.S. dollars, Australian-specific SDF shocks, U.S.-specific SDF shocks, and global SDF shocks (provided that the Australian and U.S. SDFs load differently on those global shocks) are on the left-hand side. On the right-hand side, assuming that the foreign-specific shocks cancel out inside the currency portfolios, the carry and dollar risk factors are driven by global shocks and, for the dollar factor, U.S.-specific shocks. Under the same assumptions, the carry factor and the global component of the dollar risk factor reflect only global shocks. The model has several additional implications that I study in detail in the following sections, notably on the time-variation of carry betas and the factor structure of exchange rate volatilities.

Finally, looking beyond the model, I explore the link between the shares of systematic currency risk and the comovement of macroeconomic variables. Direct links between changes in exchange rates and trade or capital flows have proved elusive in the international economics and finance literature. Therefore, this paper does not attempt to link directly changes in exchange rates to macroeconomic variables; in this respect, it describes but does not explain exchange rates. But the currency factor structure provides a key new insight. Cross-country differences in systematic currency risk appear strongly related to cross-country differences in international capital flows comovements, much more so than to the comovement in trade flows. The comovement of total capital outflows (or inflows, both scaled by GDP) for a given country is measured as the R^2 of a regression of that country's total capital outflows (inflows) on the first three principal components of the other countries' capital outflows. I find that a high share of systematic variation in exchange rates corresponds to a high share of systematic variation in total capital outflows, inflows, and their averages. Among the capital flow components, portfolio and other investments are much more informative than foreign direct investments. Differences in total capital flow characteristics account for up to 53% of the differences in systematic risk across currencies. By comparison, differences in systematic variation in exports and imports account for only 17% of the cross-country differences in exchange rates. In general equilibrium models, trade flows, investment flows, and exchange rates are all jointly determined. The cross-country differences in systematic currency risk, however, suggest that particular attention should be devoted to explaining international capital flows.

I turn now to a brief review of the related literature. This paper is related to principal component analyses of exchange rates.[2] Previous literature, however, does not offer any interpretation of the principal components. In contrast, the current paper focuses on two risk factors, noting

[2]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 characteristics, Bollerslev (1990), who estimates a GARCH model with constant conditional correlation on a set of five weekly exchange rates, and more recently, Engel, Mark, and West (2012), who 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.

that the existence of a principal component does not imply the existence of a cross-section of expected excess returns on beta-sorted currencies. Unlike principal components, the carry and dollar risk factors have a natural interpretation in any no-arbitrage model.

Although this paper builds on Lustig, Roussanov, and Verdelhan (2011), it is distinct from it. Lustig et al. (2011) do not report R^2s on any time-series regressions of bilateral exchange rates. They focus 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. Importantly, their carry trade portfolios cannot pin down the characteristics of the dollar risk factor that appears so crucial for bilateral rates. More generally, the current paper is part of a growing literature that focuses on currency portfolios to study currency risk.[3] A competing view argues that risk does not account for carry trade excess returns; see Burnside et al. (2011). Both views now rely on currency portfolios to study excess returns: portfolios are built in order to average out idiosyncratic components and thereby focus only on systematic risk. Thus, by construction, they are silent on the share of systematic versus idiosyncratic variation in *each* currency pair, which is the focus of this paper.

Hundreds of papers have been written on the forward premium puzzle.[4] This paper shows that the carry factor, while clearly significant, accounts for only 2% to 17% of daily changes in exchange rates among developed countries, while the dollar factor accounts for 13% to 84% of these changes, with a key role for global shocks.

[3]Following Lustig and Verdelhan (2005, 2007), papers by DeSantis and Fornari (2008), Farhi et al. (2009), Galsband and Nitschka (2010), Verdelhan (2010), Burnside, Eichenbaum, and Rebelo (2011), Christiansen, Ranaldo, and Soderlind (2011), Gilmore and Hayashi (2011), Hassan and Mano (2012), Menkhoff et al. (2012a, 2012b), Mueller, Stathopoulos, and Vedolin (2012), Gavazzoni, Sambalaibat, and Telmer (2012), Jurek (2014), Lettau, Maggiori, and Weber (2014), Daniel, Hodrick, and Lu (2014), and Dobrynskaya (2014) study the properties of one-month interest rate-sorted portfolios of currency excess returns. Ang and Chen (2010), Hu, Pan, and Wang (2013), Kozak (2011) consider new sorts, focusing on properties of the foreign yield curves at longer horizons or on liquidity risk. Asness, Moskowitz, and Pedersen (2013) study value and momentum in currency markets. Lustig, Roussanov, and Verdelhan (2014) study the predictability of the dollar risk factor (thus focusing on one single currency portfolio), while Maggiori (2013) uses a conditional Capital Asset Pricing Model to price the dollar excess return. Ranaldo and Soderlind (2008) and Hoffmann and Suter (2010) study the risk characteristics of the Swiss franc and other safe-haven currencies.

[4]Froot and Thaler (1990) survey 75 published estimates of the UIP condition. Many more papers have run similar tests and offered potential explanations. A simple search in *Scopus* in 2012 returns 310 articles published since 1990 that mention "exchange rates" and either "uncovered interest rate parity," "forward premium," or "carry trade" in their title, abstract, or keywords. Engel (1996), Sarno (2005), and Chinn (2006) provide recent surveys.

Finally, the findings recall similar results obtained on equity and bond markets. Roll (1988) studies contemporaneous regressions of individual U.S. stock returns (traded on the New York and American Stock Exchanges) on systematic risk factors and on the returns of other stocks in the same industry and 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, with three factors accounting for more than 95% of the total return variance. Currency markets do not appear much different.

The paper is organized as follows. Section I provides a simple framework to define systematic risk and global factors in bilateral exchange rates. Section II shows that the dollar and carry factors explain a large share of bilateral exchange rates. Section III uncovers a new cross-section of currency excess returns that is explained by the dollar risk factor, thus showing that dollar risk is priced. Section IV reports the share of bilateral exchange rates described by global shocks and the role of factors in exchange rate volatility, as well as the link between the shares of systematic currency risk and the comovement of different macroeconomic variables. Section V concludes. The Appendix at the end of this document describes the data set. The changes in exchange rates, the interest rates, the carry and dollar factors, as well as the time-varying loadings on those factors and the dollar beta portfolios are available on my website and thus the results in this paper can be easily replicated. The Internet Appendix reports many robustness checks and extensions.

I. Framework

This section lays down a simple qualitative reduced-form model to think about global shocks in bilateral exchange rates.

A. Stochastic Discount Factors

Following Frachot (1996), Backus, Foresi, and Telmer (2001), Hodrick and Vassalou (2002), Brennan and Xia (2006), and Lustig, Roussanov, and Verdelhan (2011, 2014), I start from the law of motion of the log SDF $m_{i,t+1}$ in each country i. Each log nominal SDF follows a two-factor process in the tradition of Cox, Ingersoll, and Ross (1985):[5]

$$-m_{i,t+1} = \alpha_i + \chi_i \sigma_{i,t}^2 + \tau_i \sigma_{w,t}^2 + \gamma_i \sigma_{i,t} u_{i,t+1} + \delta_i \sigma_{w,t} u_{w,t+1} + \kappa_i \sigma_{i,t} u_{g,t+1}. \tag{1}$$

In this model, there are two kinds of shocks: some shocks are country-specific (denoted $u_{i,t+1}$, uncorrelated across countries), while others are global (denoted $u_{w,t+1}$ and $u_{g,t+1}$). All these shocks are *i.i.d* Gaussian, with zero mean and unit variance. Note that I use "common," "global," or "world" shocks to refer to SDF shocks, not endowment shocks. Trade in goods or assets would easily transform country-specific endowment shocks into common SDF shocks, but this model starts from the law of motion of SDFs, not endowments.

The variance of each log SDF in the model is time-varying; if it were not, the uncovered interest rate parity (UIP) condition would be satisfied.[6] The impact of each Gaussian shock on the log SDF is therefore multiplied by a time-varying volatility. The volatilities follow autoregressive Gamma processes,

$$\sigma_{i,t+1}^2 = \phi_i \sigma_{i,t}^2 + v_{i,t+1}, \tag{2}$$

$$\sigma_{w,t+1}^2 = \phi_w \sigma_{w,t}^2 + v_{w,t+1}, \tag{3}$$

where the shocks $v_{i,t+1}$ and $v_{w,t+1}$ are drawn from Gamma distributions. These distributions ensure that the volatilities remain positive.[7]

[5]Graveline (2006), Graveline and Joslin (2011), and Sarno, Schneider, and Wagner (2012) estimate similar affine term structure models in a multi-country setting.

[6]As Bekaert (1996), Bansal (1997), and Backus, Foresi, and Telmer (2001) have shown, when markets are complete and SDFs are log-normal, expected currency excess returns in logs and in levels are

$$E_t\left(r_{i,t}^f - r_t^f - \Delta s_{i,t+1}\right) = \frac{1}{2}Var_t\left(m_{t+1}\right) - \frac{1}{2}Var_t\left(m_{i,t+1}\right),$$

$$E_t\left(r_{i,t}^f - r_t^f - \Delta s_{i,t+1}\right) + \frac{1}{2}Var_t\left(\Delta s_{t+1}\right) = -cov_t\left(m_{t+1}, \Delta s_{i,t+1}\right).$$

If SDFs were homoskedastic, expected log excess returns would be constant and a regression of exchange rate changes on interest rate differences would deliver a slope coefficient of one, a clearly counterfactual implication. As a large literature on the forward premium puzzle shows, this slope coefficient is statistically different from one, and often even negative.

[7]A Gamma distribution is characterized by its shape, $k > 0$, and its scale, $\zeta > 0$. The mean of a Gamma-

For the sake of clarity, I consider the following parameter restrictions, which imply that the carry and dollar factors are uncorrelated:

$$\chi_i = \frac{1}{2}(\gamma_i^2 + \kappa_i^2) \text{ in all countries except the U.S., where } \chi < \frac{1}{2}(\gamma^2 + \kappa^2), \quad (4)$$

$$\overline{\delta_i} = \delta. \quad (5)$$

The subscript $i = U.S.$ is dropped for any variable or parameter that corresponds to the home country.

The first restriction implies that foreign risk-free rates do not depend on the foreign country-specific volatilities, in other words, the intertemporal and substitution effects of country-specific shocks cancel out. Foreign risk-free rates are driven solely by their exposure to global volatilities. All foreign interest rates are thus perfectly correlated in the model. The same restriction does not apply to the U.S., such that the average interest rate difference between foreign and U.S. interest rates appears strongly countercyclical with respect to U.S. economic conditions, as in the data (Lustig et al., 2014). In the U.S., the precautionary savings motive dominates: risk-free rates decrease when U.S.-specific volatility increases.

The second restriction assumes that the U.S. SDF loads on the world shocks as the average country in the sample. There is no claim that these knife-edge cases hold perfectly in the data. Empirically, the average cross-country correlation of short-term nominal rates is only 0.6 among developed countries (Australia, Canada, Denmark, Germany, extended using the euro series, Japan, New Zealand, Norway, Sweden, Switzerland, and the U.K.) over the 11/1983 to 12/2010 sample considered in this paper. But as we shall see, these two restrictions greatly simplify the analysis of the model by implying that the currency factors are orthogonal.

This model is a special case of a more general framework presented in the Internet Ap-

distributed random variable is $k\zeta$ and its variance is $k\zeta^2$. To simplify notation, the parameters of those distributions are chosen such that the unconditional mean of the country-specific and world state volatilities are $E(\sigma_i^2) = \theta_i^2$ and $E(\sigma_w^2) = \theta_w^2$ and the volatilities of the Gamma shocks are $var(v_i) = \sigma_i^2$ and $var(v_w) = \sigma_w^2$. The parameters k_i and ζ_i that govern the country-specific shocks $v_{i,t+1}$ are thus equal to $k_i = \left[\theta_i^2(1-\phi_i)\right]^2 / \sigma_i^2$ and $\zeta_i = \sigma_i^2 / \left[\theta_i^2(1-\phi_i)\right]$. A similar choice defines the distribution of the $v_{w,t+1}$ global shocks: $k_w = \left[\theta_w^2(1-\phi_w)\right]^2 / \sigma_w^2$ and $\zeta_w = \sigma_w^2 / \left[\theta_w^2(1-\phi_w)\right]$.

pendix. In the general case, the volatilities of all global shocks depend on both country-specific and state variables and there is no parameter restriction. While the general case is useful to study the robustness of the insights derived here, I focus on the special case for clarity. With this simple model in hand, I first derive closed-form expressions for interest rates, exchange rates, and currency factors. I then turn to currency betas.

B. *Interest Rates*

Since the shocks to the log SDF are Gaussian, the log risk-free rate is simply equal to $r_t = -E_t(m_{t+1}) - 0.5Var_t(m_{t+1})$. Taking into account the parameter restrictions, the foreign and U.S. risk-free rates are

$$r_{i,t} = \alpha_i + \left(\tau_i - \frac{1}{2}\delta_i^2\right)\sigma_{w,t}^2 \text{ for } i \neq U.S. \quad (6)$$

$$= \alpha + \underbrace{\left(\chi - \frac{1}{2}(\gamma^2 + \kappa^2)\right)}_{<0}\sigma_t^2 + \left(\tau - \frac{1}{2}\delta^2\right)\sigma_{w,t}^2 \text{ for the U.S.} \quad (7)$$

The average difference between the foreign and U.S. interest rates, or average forward discount, is then

$$AFD_t = \frac{1}{N}\sum_i (r_{i,t} - r_t) = \overline{r_{i,t}} - r_t = \overline{\alpha_i} - \alpha - \left(\chi - \frac{1}{2}(\gamma^2 + \lambda^2 + \kappa^2)\right)\sigma_t^2 + \left(\overline{\tau_i} - \tau - \frac{1}{2}\left(\overline{\delta_i^2} - \delta^2\right)\right)\sigma_{w,t}^2, \quad (8)$$

where a bar superscript ($\overline{x}$) denotes the average of any variable or parameter x across all countries and where N denotes the number of currencies in the sample.

C. Exchange Rates

When markets are complete, the log change in the nominal exchange rate, Δs_i, between the home country and foreign country i is equal to

$$\Delta s_{i,t+1} = m_{t+1} - m_{i,t+1},$$

where m and m_i denote the log nominal SDF of the domestic and country i investors and the exchange rate is defined in units of foreign currency per U.S. dollar.[8] An increase in s_i means an appreciation in the home currency. In the model, the log change in bilateral exchange rates is thus

$$\begin{aligned} \Delta s_{i,t+1} &= \alpha_i - \alpha + \chi_i \sigma_{i,t}^2 - \chi \sigma_t^2 + (\tau_i - \tau)\, \sigma_{w,t}^2 \overbrace{+ \gamma_i \sigma_{i,t} u_{t+1}^i}^{Country\ i-spec.} - \overbrace{\gamma \sigma_t u_{t+1}}^{U.S.-spec.} \\ &+ \underbrace{(\delta_i - \delta)\, \sigma_{w,t} u_{w,t+1} + (\kappa_i \sigma_{i,t} - \kappa \sigma_t)\, u_{g,t+1}}_{Global\ shocks}. \end{aligned} \quad (9)$$

The dollar risk factor is by definition the average of all exchange rates expressed in terms of U.S. dollars, and thus corresponds to

$$Dollar_{t+1} = \frac{1}{N} \sum_i \Delta s_{i,t+1}. \quad (10)$$

The carry risk factor is by definition the average exchange rate of high- versus low-interest rate currencies,

$$Carry_{t+1} = \frac{1}{N_H} \sum_{i \in H} \Delta s_{i,t+1} - \frac{1}{N_L} \sum_{i \in L} \Delta s_{i,t+1}, \quad (11)$$

[8] This result derives from the Euler equations of the domestic and foreign investors buying any asset R_i that pays off in foreign currency: $E_t[M_{t+1} R_{i,t+1} S_{i,t} / S_{i,t+1}] = 1$ and $E_t[M_{i,t+1} R_{i,t+1}] = 1$. When markets are complete, the pricing kernel is unique and thus exchange rates are defined as $S_{i,t+1}/S_{i,t} = M_{t+1}/M_{i,t+1}$, or in logs $\Delta s_{i,t+1} = m_{t+1} - m_{i,t+1}$.

where N_H (N_L) denotes the number of high (low) interest rate currencies in the sample. In the model, the dollar and carry factors are equal to

$$
\begin{aligned}
Dollar_{t+1} &= \overline{\alpha_i} - \alpha + \overline{\chi_i \sigma_{i,t}^2} - \chi \sigma_t^2 + \overline{\gamma_i \sigma_{i,t} u_{i,t+1}} - \gamma \sigma_t u_{t+1} + (\overline{\kappa_i \sigma_{i,t}} - \kappa \sigma_t)\, u_{g,t+1} \qquad (12) \\
Carry_{t+1} &= \overline{\alpha_i}^H - \overline{\alpha_i}^L + \overline{\chi_i \sigma_{i,t}^2}^H - \overline{\chi_i \sigma_{i,t}^2}^L + \left(\overline{\tau_i}^H - \overline{\tau_i}^L\right) \sigma_{w,t}^2 + \overline{\gamma_i \sigma_{i,t} u_{i,t+1}}^H - \overline{\gamma_i \sigma_{i,t} u_{i,t+1}}^L \\
&+ \left(\overline{\delta_i}^H - \overline{\delta_i}^L\right) \sigma_{w,t} u_{w,t+1} + \left(\overline{\kappa_i \sigma_{i,t}}^H - \overline{\kappa_i \sigma_{i,t}}^L\right) u_{g,t+1}. \qquad (13)
\end{aligned}
$$

In theory, a base factor, similar to the dollar factor, can be defined for exchange rates expressed in other currencies. For a U.K. investor, for example, the pound factor is driven by U.K.-specific shocks as well as common shocks, under the condition that the U.K. SDF exposure to common shocks is different from the average exposure of the other countries' SDFs. The carry factor is a difference in exchange rates and thus dollar-neutral in the sense that it does not depend on the U.S. log SDF. As long as the pound and the dollar do not enter the high and low interest rate portfolios, the carry factor would be the same when built from the perspective of a U.K. investor. The common shocks are the key components of these factors because they capture risks that cannot be diversified away and thus imply risk premia.

To gain intuition on the currency risk premia, it is useful to assume that the law of large numbers holds and thus consider the case in which the number of currencies N tends to infinity. In practice, however, the number of currencies in the data set is small, limited to at most 39 currencies in this paper. To stress the importance of this large N assumption, all subsequent results are specified as limit cases when $N \to \infty$. Under this assumption, the orthogonality of the carry and dollar risk factors appears clearly.

Let us first focus on the carry factor. As equation (6) shows, sorting foreign countries by the level of their short-term interest rate is similar to sorting countries by their exposures to global shocks (δ_i) or by two other preference parameters (α_i and τ_i). However, none of these parameters is informative about the level of the country-specific volatility $\sigma_{i,t}$. As a result, when $N \to \infty$, baskets of high and low interest rate countries exhibit the same average country-specific volatilities: $\lim_{N\to\infty} \overline{\sigma_{i,t}}^H = \lim_{N\to\infty} \overline{\sigma_{i,t}}^L$ and $\lim_{N\to\infty} \overline{\sigma_{i,t}^2}^H = \lim_{N\to\infty} \overline{\sigma_{i,t}^2}^L$. This is a direct consequence of the assumption that foreign interest rates do not depend on country-specific volatilities. In the limit, therefore, when $N \to \infty$, the carry factor does not depend on country-specific shocks $u_{i,t+1}$ or on the global shock $u_{g,t+1}$.

I turn now to the dollar factor. The dollar factor does not depend on the world shocks $u_{w,t+1}$ because of the restriction expressed in equation (5): $\overline{\delta_i} = \delta$. In addition, the dollar factor does not depend on the foreign country-specific shocks, since when $N \to \infty$ the law of large numbers applies: $\lim_{N\to\infty} \overline{u_{i,t+1}} = 0$. The dollar and carry factors are therefore equal to

$$\lim_{N\to\infty} Dollar_{t+1} = \overline{\alpha_i} - \alpha + \overline{\chi_i \sigma_{i,t}^2} - \chi\sigma_t^2 - \gamma\sigma_t u_{t+1} + \left(\overline{\kappa_i \sigma_{i,t}} - \kappa\sigma_t\right) u_{g,t+1} \quad (14)$$

$$\lim_{N\to\infty} Carry_{t+1} = \overline{\alpha_i}^H - \overline{\alpha_i}^L + \left(\overline{\tau_i}^H - \overline{\tau_i}^L\right)\sigma_{w,t}^2 + \left(\overline{\delta_i}^H - \overline{\delta_i}^L\right)\sigma_{w,t} u_{w,t+1}. \quad (15)$$

The exchange rate volatilities are then simply

$$Var_t\left(\Delta s_{t+1}^i\right) = \gamma_i^2\sigma_{i,t}^2 + \gamma^2\sigma_t^2 + (\delta_i - \delta)^2\sigma_{w,t}^2 + (\kappa_i\sigma_{i,t} - \kappa\sigma_t)^2. \quad (16)$$

$$Var_t\left(\lim_{N\to\infty} Carry_{t+1}\right) = \left(\overline{\delta_i}^H - \overline{\delta_i}^L\right)^2 \sigma_{w,t}^2 \quad (17)$$

$$Var_t\left(\lim_{N\to\infty} Dollar_{t+1}\right) = \gamma^2\sigma_t^2 + \left(\overline{\kappa_i\sigma_{i,t}} - \kappa\sigma_t\right)^2. \quad (18)$$

The volatilities of the dollar and carry factors depend on two different state variables, $\sigma_{w,t}^2$ for the former and σ_t^2 for the latter. The volatilities of the two factors have no common component. As a result, the changes in volatilities of the dollar and carry factors are orthogonal if the Gamma shocks are independent: the former depends on the shocks $v_{w,t+1}$ while the latter depends on the shocks v_{t+1}.

To sum up, by construction, the dollar factor captures the U.S.-specific shocks u_{t+1} and the global shocks $u_{g,t+1}$, while the carry factor captures the global shocks $u_{w,t+1}$. The dollar and carry factors are thus useful to summarize the systematic variation in the bilateral exchange rates. To measure the share of systematic risk, the next section considers contemporaneous regressions of each bilateral exchange rate on the dollar and carry factors. In the model, the corresponding conditional dollar and carry betas are

$$\beta^i_{\lim_{N\to\infty} Dollar,t} = \frac{cov_t(\Delta s^i_{t+1}, \lim_{N\to\infty} Dollar_{t+1})}{var_t(\lim_{N\to\infty} Dollar_{t+1})} = \frac{\gamma^2\sigma_t^2 + (\kappa_i\sigma_{i,t} - \kappa\sigma_t)\left(\overline{\kappa_i\sigma_{i,t}} - \kappa\sigma_t\right)}{\gamma^2\sigma_t^2 + \left(\overline{\kappa_i\sigma_{i,t}} - \kappa\sigma_t\right)^2} \tag{19}$$

$$\beta^i_{\lim_{N\to\infty} Carry,t} = \frac{cov_t(\Delta s^i_{t+1}, \lim_{N\to\infty} Carry_{t+1})}{var_t(\lim_{N\to\infty} Carry_{t+1})} = \frac{\delta_i - \delta}{\overline{\delta_i}^H - \overline{\delta_i}^L}. \tag{20}$$

The dollar betas vary across countries because of different country-specific volatilities ($\kappa_i\sigma_{i,t}$). The carry betas differ across countries because of different loadings (δ_i) on the global shocks.

D. Interpretation of Two Currency Risk Premia

Since the carry and dollar betas vary across countries, this simple model offers an interpretation to two empirical cross-sections of currency risk premia.

In the data, an investor who is long in high and short in low interest rate countries (or long in high and short in low carry beta countries) pockets large average excess returns (Lustig et al., 2011). In the model, sorting countries by their interest rates can be interpreted as sorting countries by their exposure (δ^i) to global shocks priced globally ($u_{w,t+1}$); high interest rate countries are low δ_i countries. During bad global shocks, $u_{w,t+1} < 0$, these currencies depreciate, as can be verified in equation (9). Carry trades are risky because high (low) interest rate currencies depreciate (appreciate) in bad times. This is the risk-based explanation of the average carry trade excess return proposed in Lustig et al. (2011). The model here also features a characteristics-based explanation of the same average returns, built on cross-country differences in the preference parameters α_i and τ_i: high interest rate currencies may offer higher returns than low interest rate currencies even if high (low) interest rate currencies do not depreciate (appreciate) in bad times. The difference in returns may in this case simply be linked to some intrinsic difference in interest rates. As Lustig et al. (2011) show, however, high (low) interest rate currencies tend to depreciate (appreciate) in times of high uncertainty, as measured by the global volatility on equity markets.

In the data, an investor who is long in high and short in low dollar beta countries when the U.S. interest rate is lower than the world average (and follows the opposite strategy otherwise) also pockets large average excess returns as we shall see in Section III In the model, sorting countries by their dollar betas is the same as sorting countries by the level of their country-specific volatilities ($\kappa_i \sigma_{i,t}$), which is relevant for global shocks priced locally ($u_{g,t+1}$). As shown in equation (19), when the U.S.-specific volatility is relatively high ($\overline{\kappa_i \sigma_{i,t}} < \kappa \sigma_t$), countries with high dollar betas are countries with low country-specific volatilities ($\kappa_i \sigma_{i,t}$). In the case of bad global shocks ($u_{g,t+1} < 0$), these currencies depreciate, as can be verified in equation (9). As equation (8) shows, the average forward discount is a signal, albeit imperfect, of U.S.-specific volatility, and thus a key conditioning variable here: when U.S.-specific volatility is relatively high, the U.S. risk-free rate tends to be low and the investor tends to be long in high dollar beta currencies.[9] When the U.S. risk-free rate tends to be high, the position is reversed: the investor is then long the U.S. dollar and short foreign currencies. The foreign high dollar beta countries are then countries with high local volatilities, whose currencies appreciate in the case of a bad global shock ($u_{g,t+1} < 0$). The investor is at that point short those currencies and thus exposed to the same risk. In all cases, the investor takes on global risk and is thus compensated by large average returns. This is a risk-based explanation of the dollar beta portfolio returns.

The interest rate-sorted portfolios are well known; the dollar beta portfolios are new. These new portfolios exhibit a novel risk-return tradeoff. They are also useful to extract a measure of the global component of the dollar factor by going long in a set of high dollar beta currencies and short in a set of low dollar beta currencies:

$$Dollar\ Global_{t+1} = \frac{1}{N_{H\beta}} \sum_{i \in H\beta} \Delta s^i_{t+1} - \frac{1}{N_{L\beta}} \sum_{i \in L\beta} \Delta s^i_{t+1}, \tag{21}$$

where $N_{H\beta}$ and $N_{L\beta}$ denote the number of currencies in the high ($H\beta$) and low ($L\beta$) dollar beta portfolios. As equation (19) shows, high and low dollar beta portfolios can differ in their

[9]The average forward discount is an imperfect signal because it is not perfectly correlated with the relative price of risk (in the model, $\overline{\kappa_i \sigma_{i,t}} - \kappa \sigma_t$). This condition could be an additional parameter restriction, but there is no empirical proof that the average forward discount is a perfect signal.

average values for κ_i and $\sigma_{i,t}$. When regressing exchange rate changes on the dollar factor, the U.S.-specific shocks are on both sides. But in this long-short excess return, the U.S.-specific shocks cancel out. When $N \to \infty$, the global component of the dollar factor is thus

$$\lim_{N \to \infty} Dollar\ Global_{t+1} = \overline{\chi_i \sigma_{i,t}^2}^{H\beta} - \overline{\chi_i \sigma_{i,t}^2}^{L\beta} + \left(\overline{\kappa_i \sigma_{i,t}}^{H\beta} - \overline{\kappa_i \sigma_{i,t}}^{L\beta} \right) u_{g,t+1}. \tag{22}$$

Empirically, I use this long-short excess return, along with the carry factor, to measure the share of systematic exchange rate risk due to global shocks.

E. Key Insight

Along with this interpretation of two cross-sections of currency risk premia, the model offers a key insight: SDFs must exhibit at least two global shocks.

This paper argues that two kinds of global shocks are priced in currency markets. In the simple framework presented in this section, in the absence of the second global shocks $u_{g,t+1}$, the dollar factor is driven only by U.S.-specific shocks. As a result, the dollar betas are the same across countries, and the global component of the dollar factor does not exist. These implications are strongly rejected by the data. The need for two global shocks is also present in the general model described in the Internet Appendix, even when each global shock depends on both country-specific and global volatilities and all parameters are country-specific and their values unrestricted. The result remains valid when the law of large numbers does not apply inside the dollar factor. The proof is intuitive: with only one global shock (no $u_{g,t+1}$ shocks, for example), one cannot build two independent cross-sections of currency risk premia, where two long-short excess returns (thus dollar-neutral) are two orthogonal risk factors. In the data, as we shall see, there are statistically different dollar betas, and the cross-section of dollar beta portfolio average returns is as large as the usual cross-section of interest rate (or carry beta-sorted) portfolio average returns, but the correlation between the carry factor and the global component of the dollar factor is insignificant. The model thus needs two sets of global shocks in the law of motions of log SDFs and heterogeneous loadings on those shocks.[10]

To sum up, the existence of two currency factors and their associated global shocks, exchange rate betas, and risk premia have implications for a large class of no-arbitrage models. Lustig et al. (2011) show that equilibrium SDFs need to differ in their exposure to one global shock such that high interest rate countries correspond to low exposures to that shock. If that condition is satisfied, then an investor going long in high interest rate currencies bears the risk of foreign currency depreciation in bad times. This paper shows that equilibrium SDFs need to differ in their exposure to another global shock. In times when the price (i.e., log SDF volatility) of that additional risk is relatively high at home (compared to its average foreign counterpart), high dollar beta currencies correspond to low exposures to that second global shock. As a result, these currencies tend to depreciate in bad times. An investor going long in high dollar beta currencies when the price of that risk is relatively high at home will thus bear that depreciation risk: the higher the dollar beta, the larger the risk and the larger the risk premium. SDFs must thus differ in their exposure to that second global shock, and the average interest rate difference (between the domestic and foreign interest rates) must capture the relative price of that shock.

There are two key limits to generalizing the results presented in this section: (i) the shocks to the log SDFs are Gaussian — this assumption implies that one can focus on the first two moments of the log SDFs and exchange rates and hence the proofs rely on those moments, and (ii) the theoretical results pertain to conditional moments, while the empirical results pertain to unconditional moments or imperfect conditioning information. A potential caveat is thus that the results may not hold in a more complicated model, in particular one with time-varying higher moments. I turn now to the data to study the share of systematic risk in bilateral exchange rates.

[10] The source of this heterogeneity, along with its impact on exchange rates, is the subject of ongoing research in international finance and international economics. For example, Hassan (2013) considers the impact of different country sizes on asset returns, Gourinchas, Rey, and Govillot (2011) entertain different risk-aversion coefficients, Maggiori (2017) studies the consequence of different levels of financial development, and Ready, Roussanov, and Ward (2013) study different exposures to international commodity trade.

II. Measuring Systematic Currency Variations

This section shows that the dollar and carry factors account for a large part of each currency-pair's variation, uncovering cross-country differences in the shares of systematic currency risk.

A. Data

The data consist of end-of-month series built from daily spot and forward exchange rates in U.S. dollars and the sample period runs from November 1983 to December 2010. These data are collected by Barclays and Reuters and are available on Datastream. Spot and forward exchange rates correspond to midpoint quotes. The Appendix lists all the countries in the sample. Interest rate differences are derived from one-month log forward rates, denoted by f and expressed in units of foreign currency per U.S. dollar. In most of the sample, forward rates exactly satisfy the covered interest rate parity condition: the forward discount is equal to the interest rate differential, $f_{i,t} - s_{i,t} \approx r_{i,t} - r_t$, where again $r_{i,t}$ and r_t denote the foreign and domestic nominal risk-free rates over the maturity of the contract.[11]

UIP Redux 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 is equivalent to an Euler equation for risk-neutral investors. It implies that a regression of exchange rate changes on interest rate differentials should produce a slope coefficient of one and a zero constant. Instead, empirical work following Tryon (1979), Hansen and Hodrick (1980), Bilson (1981), and Fama (1984) consistently reveals a slope coefficient that is smaller than one and very often negative.

In my data set, as in the rest of the literature, these slope coefficients are always below one, most of them are negative, and all but one are statistically insignificant. The adjusted R^2s

[11] 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. This relation, however, was violated during the extreme episodes of the financial crisis in the fall of 2008 (see Baba and Packer, 2009) and even post-crisis (see Du, Tepper, and Verdelhan, 2016). Including or excluding those observations, or using Treasury bill rates instead of implied interest rates, does not have a major effect on the results presented in this paper.

on these regressions are tiny, and often negative, with a maximum of 1.7% and an average of -0.2%. Evans (2012) reports similar results. Interest rates explain little of the changes in exchange rates. A more interesting view of exchange rates emerges when relying on contemporaneous risk factors.

B. Carry and Dollar Factors

To extract risk factors from currency markets, I build six *portfolios* of currencies, following Lustig and Verdelhan (2005, 2007). All developed and emerging countries are sorted each month according to their interest rates. By averaging out idiosyncratic risk and conditioning on interest rates, these portfolios deliver a cross-section of exchange rates and currency risk premia. The carry factor, denoted $Carry_{t+1}$, is the average change in exchange rate between countries in the last portfolio (high interest rate countries) and countries in the first portfolio (low interest rate countries). The dollar factor is the average change in exchange rate across all six portfolios at each point in time.

The framework proposed in the previous section suggests describing exchange rate changes with the carry and dollar factors, which would capture the relevant global shocks, as well as the interest rate difference between the foreign country and the U.S., in order to proxy for the expected component of the exchange rate changes. Equations (19) and (20) imply that the loadings on the carry factor are constant while the loadings on the dollar factor are not. As already noted, in a more general version of the model, the loadings on the carry factor are also time-varying.

Theoretically, the time-variation in the dollar loadings depends on the U.S. and foreign (as well as its cross-country average) country-specific volatilities (denoted $\kappa_i \sigma_{i,t}$) of the global shock of the log SDF (denoted $u_{g,t+1}$). Empirically, as there is no obvious measure of such volatilities. I use the information contained in the country-specific interest rate difference (or the cross-country average interest rate difference) to build a conditional version of the dollar factor ($(r_{i,t} - r_t) Dollar_{t+1}$ or $(\overline{r_{i,t}} - r_t) Dollar_{t+1}$) in an attempt to capture the potential time-variation in dollar loadings in a simple linear regression setting. The regression results are reported in the Internet

Appendix. The interest rate difference does not appear to be a powerful signal of the time-variation in dollar loadings. I thus ignore this time-variation for now and revisit the issue in the next section using simple rolling-window estimates.

The general case of the model suggests that the carry betas vary with the same state variables that govern interest rate differences. The model, however, does not imply that the interest rate difference is the optimal conditioning variable. When describing bilateral exchange rates, I use the carry factor and the same carry factor multiplied by the difference between the foreign and domestic interest rates because the state variables are unknown.

The benchmark country-level regressions thus take the following form:

$$\Delta s_{i,t+1} = \alpha_i + \beta_i(r_{i,t} - r_t) + \gamma_i(r_{i,t} - r_t)Carry_{t+1} + \delta_i Carry_{t+1} + \tau_i Dollar_{t+1} + \varepsilon_{i,t+1}.$$

There is no direct relation between the symbols in the model and the symbols used to describe the slope coefficients in these regressions. Each variable is expressed in percentage points, and as a result the slope coefficient on the conditional carry factor is 100 times smaller than if all series were not in percentage points. As already noted, for each currency on the left-hand side of a regression, that currency is excluded from any portfolio that appears on the right-hand side (all the other currencies, from developed and developing countries, are used to build the currency factors). Table I reports results for developed countries, while Table II focuses on emerging countries. Regressions that include the conditional dollar factor are reported in the Internet Appendix; results are similar to those reported in the paper.

Developed Countries The loadings on the dollar factor are positive and statistically significant in all 13 developed countries, with values ranging from 0.3 to 1.6. 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, but in different proportions. This common component explains a large share of the variation in bilateral exchange rates. The adjusted R^2s are between 19% and 91%. The average R^2 among the 13 developed countries is 61%. Without the carry factors, the average R^2 is 57%; not surprisingly, the difference is particularly large for Australia and Japan (26% versus 20% and 30% versus 24%), two textbook examples of carry traders' favorites. Without the dollar factor, adjusted R^2s range from 0% to 23%, with an average of 7%. The large explanatory power overall of the dollar factor may not be surprising, but the significant differences in the loadings are.

The conditional carry loadings (γ) in Table I are positive in 11 out of 13 countries (the only exceptions are Canada and Japan, where the coefficients are negative but insignificant). They are positive and statistically significant in nine out of 13 countries. These findings are consistent with those of Lustig et al. (2011): as already noted, in their portfolios of currencies sorted by interest rates, the higher the interest rate (i.e., going from the first to the last portfolio), the larger the loading on the carry factor. The findings in the current paper are different, however, from those of Lustig et al. (2011), who focus to cross-sectional differences in interest rates (i.e., whether one currency has a higher interest rate than another). Here, the conditional carry loading indicates that, for a given country, times of larger interest rate differences are also times of higher comovement with the carry factor. By focusing on one bilateral exchange rate at a time, each test explores time-series, not cross-sectional, variations (see Hassan and Mano (2012) for more on this difference).

The total sensitivity of each bilateral exchange rate to the carry factor depends on the conditional and unconditional carry components. Table I shows that the corresponding slope coefficients are jointly statistically significant at the 1% (10%) confidence level in 11 (12) out of 13 countries (the only exception is the U.K.).[12] A total sensitivity that is positive means that the foreign currency depreciates when the carry factor does too (i.e., when high interest rate currencies depreciate against low interest rate currencies). The Japanese yen, for example, tends to appreciate when the carry factor tanks, while the Australian dollar tends to depreciate. Such currency

[12]The interest rate difference, the conditional carry, and the unconditional carry factors are correlated, and thus standard errors offer only a partial view of the significance of each coefficient. Table I thus reports the result of a Wald test where the null hypothesis is that the regression coefficients gamma (γ) and delta (δ) on the conditional and unconditional carry factors are jointly zero. The null hypothesis is rejected at the 10% confidence interval for all developed countries except the U.K. At the daily frequency, as shown in Table III, the null hypothesis is rejected at the 1% level for all countries.

movements correspond to the funding and investment roles of these currencies that are commonly reported in articles on carry trades and is at the heart of any risk-based explanation of carry trade returns. For other countries, the total sensitivity to the carry factor switches sign along the sample. For example, when the carry factor depreciates, the Swiss franc depreciates (appreciates) in the 1980s (2000s), a time of relatively high (low) Swiss interest rates.

Emerging Markets Table II reports similar tests on a set of 18 developing countries (using the same factors as for developed countries). A simple finding emerges: for floating currencies, the results tend to be similar to those of developed countries, whereas pegs, reassuringly, appear different. On the one hand, loadings on the dollar factor are positive and significant for 15 out of 18 countries, loadings on the carry factors are jointly significant for nine countries, and the R^2s in Table II range from 10% to 75% for floating currencies. On the other hand, Hong Kong, Saudi Arabia, and the United Arab Emirates, which have pegged their currencies to the U.S. dollar at some point in the sample, do not exhibit significant loadings on the dollar factor. This broad dichotomy hides more subtle nuances. For example, Thailand and Malaysia, although they also experienced currency pegs, do not appear much different from the other developing countries. The carry and dollar factors thus highlight the uncertainty behind exchange rate regime classifications, and rolling-window estimates could be used to refine such classifications.

Overall, these simple regressions highlight two key results. First, the dollar factor accounts for a large share of exchange rate dynamics on average, with large differences across countries. Second, the carry factor accounts for a smaller share on average, but carry betas are highly significant and time-varying for most countries.

C. *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.[13]

[13] I consider additional robustness checks (other factors, like momentum; rolling window estimations; bid-ask spreads on spot exchange rates; and different base currencies). The results, presented in the Internet Appendix, all reinforce the findings presented in the main text.

Table I
Carry and Dollar Factors: Monthly Tests in Developed Countries

This table reports country-level results from the regression

$$\Delta s_{i,t+1} = \alpha_i + \beta_i(r_{i,t} - r_t) + \gamma_i(r_{i,t} - r_t)Carry_{t+1} + \delta_i Carry_{t+1} + \tau_i Dollar_{t+1} + \varepsilon_{i,t+1},$$

where $\Delta s_{i,t+1}$ denotes the bilateral exchange rate in foreign currency per U.S. dollar, $r_{i,t} - r_t$ 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 adjusted R^2 of this regression (in percentage points) and the number of observations N. Standard errors in parentheses 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 brackets; they are obtained by bootstrapping. $R^2_{\$}$ denotes the adjusted R^2 of a similar regression with only the *Dollar* factor (i.e., without the conditional and unconditional *Carry* factors). $R^2_{no\ \$}$ denotes the adjusted R^2 of a similar regression without the *Dollar* factor. W denotes the result of a Wald test: the null hypothesis is that the loadings γ and δ on the conditional and unconditional carry factors are jointly zero. *** corresponds to a rejection of the null hypothesis at the 1% confidence level; ** and * correspond to the 5% and 10% confidence levels. Data are monthly, from Barclays and Reuters (Datastream). All variables are in percentage points. The sample period is 11/1983 to 12/2010.

Country	α	β	γ	δ	τ	R^2	$R^2_{\$}$	$R^2_{no\ \$}$	W	N
Australia	0.07	-0.44	0.77	0.16	0.74	25.59	20.05	7.71	***	312
	(0.23)	(0.60)	(0.49)	(0.13)	(0.13)	[5.77]	[5.72]	[4.31]		
Canada	-0.11	-0.02	-0.61	0.21	0.34	19.38	13.11	8.14	***	312
	(0.11)	(0.63)	(0.42)	(0.06)	(0.07)	[6.94]	[4.34]	[4.97]		
Denmark	-0.01	-0.20	0.53	-0.16	1.51	86.08	83.63	3.97	***	312
	(0.07)	(0.38)	(0.13)	(0.03)	(0.04)	[1.67]	[2.03]	[3.99]		
Euro Area	0.07	-0.52	0.10	-0.28	1.62	80.60	76.22	-0.05	***	143
	(0.11)	(0.86)	(0.23)	(0.05)	(0.08)	[3.58]	[3.99]	[4.81]		
France	-0.15	-0.10	0.80	-0.13	1.38	90.97	87.58	12.30	***	181
	(0.07)	(0.34)	(0.14)	(0.03)	(0.04)	[1.48]	[1.93]	[5.90]		
Germany	-0.21	-0.03	0.79	-0.03	1.42	91.00	88.35	22.83	***	181
	(0.09)	(0.34)	(0.17)	(0.04)	(0.04)	[1.36]	[1.75]	[6.20]		
Italy	-0.03	0.26	0.68	-0.07	1.24	68.97	64.59	2.16	***	177
	(0.22)	(0.69)	(0.20)	(0.11)	(0.10)	[5.25]	[6.92]	[6.13]		
Japan	-0.44	-1.13	-0.10	-0.39	0.83	29.52	23.58	5.34	***	325
	(0.24)	(0.86)	(0.45)	(0.11)	(0.12)	[5.51]	[5.45]	[3.47]		
New Zealand	0.10	-0.58	0.76	-0.11	0.95	29.80	26.96	3.43	*	312
	(0.20)	(0.39)	(0.38)	(0.11)	(0.11)	[5.31]	[5.78]	[2.85]		
Norway	-0.07	0.29	0.48	-0.06	1.35	71.23	69.87	3.13	***	312
	(0.12)	(0.37)	(0.11)	(0.05)	(0.08)	[3.99]	[3.98]	[3.36]		
Sweden	0.06	-0.28	0.99	-0.06	1.39	72.42	67.65	5.94	***	312
	(0.10)	(0.35)	(0.16)	(0.04)	(0.06)	[2.90]	[3.41]	[3.46]		
Switzerland	-0.14	-0.19	0.94	-0.11	1.46	74.61	69.03	12.09	***	325
	(0.11)	(0.41)	(0.19)	(0.06)	(0.06)	[2.45]	[2.98]	[3.70]		
United Kingdom	0.06	-0.15	0.63	-0.03	1.06	50.76	49.90	2.13		325
	(0.15)	(0.71)	(0.47)	(0.09)	(0.09)	[5.09]	[5.29]	[3.01]		

Table II
Carry and Dollar Factors: Monthly Tests in Emerging and Developing Countries

This table reports country-level results from the regression

$$\Delta s_{i,t+1} = \alpha_i + \beta_i(r_{i,t} - r_t) + \gamma_i(r_{i,t} - r_t)Carry_{t+1} + \delta_i Carry_{t+1} + \tau_i Dollar_{t+1} + \varepsilon_{i,t+1},$$

where $\Delta s_{i,t+1}$ denotes the bilateral exchange rate in foreign currency per U.S. dollar, $r_{i,t} - r_t$ 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 adjusted R^2 of this regression and the number of observations N. $R^2_{\$}$ ($R^2_{no\ \$}$) denotes the adjusted R^2 of a similar regression with only (without) the *Dollar* factor. W denotes the result of a Wald test on the joint significance of γ and δ. See Table I for additional information.

Country	α	β	γ	δ	τ	R^2	$R^2_{\$}$	$R^2_{no\ \$}$	W	N
Hong Kong	-0.00	-0.15	0.06	0.00	0.02	5.40	4.85	1.29		325
	(0.01)	(0.09)	(0.05)	(0.00)	(0.01)	[3.32]	[3.10]	[2.29]		
Czech Republic	-0.14	-0.11	-0.04	-0.21	1.76	64.09	62.28	-0.62	**	167
	(0.17)	(0.35)	(0.16)	(0.09)	(0.09)	[4.71]	[4.64]	[2.34]		
Hungary	0.39	-0.35	-0.40	0.18	1.86	67.69	67.14	1.17	**	158
	(0.38)	(0.57)	(0.18)	(0.15)	(0.14)	[5.09]	[4.89]	[4.54]		
India	0.31	-0.57	0.22	0.03	0.49	31.38	30.72	7.61		158
	(0.24)	(0.66)	(0.29)	(0.11)	(0.07)	[7.05]	[6.59]	[5.80]		
Indonesia	1.93	-1.21	0.21	0.22	1.75	9.75	10.80	1.72		90
	(1.31)	(1.41)	(0.44)	(0.44)	(0.50)	[7.14]	[5.88]	[6.22]		
Kuwait	-0.16	2.17	0.53	-0.09	0.22	52.24	44.45	25.66	***	167
	(0.03)	(0.19)	(0.10)	(0.02)	(0.04)	[11.14]	[10.00]	[14.37]		
Malaysia	0.09	0.10	0.10	0.19	0.42	23.04	18.17	6.40		230
	(0.13)	(0.53)	(0.23)	(0.10)	(0.07)	[5.19]	[4.57]	[5.22]		
Mexico	0.40	-0.36	-0.29	0.68	0.22	26.09	9.11	24.48	***	167
	(0.28)	(0.36)	(0.15)	(0.16)	(0.15)	[8.44]	[6.94]	[8.19]		
Philippines	0.13	-0.02	0.63	-0.01	0.47	32.59	19.48	23.92	***	167
	(0.37)	(0.88)	(0.21)	(0.10)	(0.10)	[7.79]	[6.35]	[8.63]		
Poland	-0.08	1.09	1.13	0.10	1.89	74.77	70.73	18.44	***	106
	(0.20)	(0.71)	(0.30)	(0.08)	(0.11)	[5.43]	[6.09]	[8.37]		
Saudi Arabia	0.00	-0.39	0.18	-0.00	0.00	8.57	2.83	8.84		167
	(0.01)	(0.35)	(0.10)	(0.00)	(0.00)	[11.24]	[8.18]	[10.84]		
Singapore	-0.17	-0.29	0.12	0.08	0.50	48.19	47.19	6.29	*	312
	(0.11)	(0.60)	(0.15)	(0.03)	(0.04)	[4.19]	[4.38]	[4.05]		
South Africa	0.87	-0.58	0.04	0.18	1.07	24.87	24.14	2.36		324
	(0.51)	(0.79)	(0.37)	(0.28)	(0.14)	[5.50]	[5.66]	[2.44]		
South Korea	0.27	0.60	0.62	0.14	1.38	51.83	51.30	13.63		106
	(0.27)	(1.71)	(0.49)	(0.11)	(0.27)	[6.21]	[5.99]	[9.19]		
Taiwan	0.05	0.45	0.29	0.08	0.50	35.77	34.39	6.94	**	167
	(0.12)	(0.31)	(0.13)	(0.06)	(0.06)	[5.41]	[6.11]	[5.19]		
Thailand	-0.07	-0.36	0.88	-0.01	0.79	27.98	19.20	13.50		167
	(0.18)	(1.16)	(0.43)	(0.12)	(0.17)	[5.82]	[5.63]	[7.29]		
Turkey	-0.71	0.69	-0.19	1.12	0.65	39.03	27.34	32.80	***	154
	(0.39)	(0.11)	(0.04)	(0.25)	(0.17)	[8.08]	[8.00]	[7.26]		
United Arab Emirates	-0.00	-0.22	0.10	-0.00	0.00	15.10	3.32	15.39		162
	(0.00)	(0.14)	(0.07)	(0.00)	(0.00)	[19.30]	[12.36]	[19.27]		

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 III is the counterpart to Table I: 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 325 months to a maximum of 7,048 days.

The similarity to the monthly estimates is obvious. The adjusted R^2 still ranges from 17% to almost 90% even when looking at daily changes in exchange rates. The average adjusted R^2 is 54% among developed countries. The carry loadings are negative for 10 out of 13 countries (they are positive for Australia, Canada, and New Zealand). 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, and are now significantly different from zero for all 13 countries. The dollar loadings are quite similar to the monthly estimates too, ranging from 0.4 (Canada, as in the monthly data) to almost 1.5 (mostly Scandinavian countries, again as in the monthly data). The R^2s and loading estimates thus appear very similar across these two frequencies.

Quarterly and Annual Data Similar conclusions emerge using overlapping series built at quarterly and annual frequencies. The average share of systematic currency risk increases from high to low frequencies. Among both developed and developing countries, the average R^2 is 51% at a daily frequency, 56% at a monthly frequency, 60% at a quarterly frequency, and 68% at an annual frequency. The relative ranking of each country is generally preserved across frequencies. The correlation is 0.95 between the monthly and daily R^2s, 0.99 between the monthly and quarterly R^2s, and 0.94 between the monthly and annual R^2s.

D. *Principal Components*

Obtaining large R^2s per se does not require the use of currency portfolios. Large R^2s can be obtained by using a sufficient number of principal components, without forming portfolio.

Table III
Carry and Dollar Factors: Daily Tests in Developed Countries

This table reports country-level results from the regression

$$\Delta s_{i,t+1} = \alpha_i + \beta_i(r_{i,t} - r_t) + \gamma_i(r_{i,t} - r_t)Carry_{t+1} + \delta_i Carry_{t+1} + \tau_i Dollar_{t+1} + \varepsilon_{i,t+1},$$

where $\Delta s_{i,t+1}$ denotes the bilateral exchange rate in foreign currency per U.S. dollar, and $r_{i,t} - r_t$ 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 adjusted R^2 of this regression and the number of observations N. $R^2_{\$}$ denotes the R^2 of a similar regression with only the *Dollar* factor. $R^2_{no\ \$}$ denotes the adjusted R^2 of a similar regression without the *Dollar* factor. W denotes the result of a Wald test on the joint significance of γ and δ. Standard errors in parentheses 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 brackets; 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 to 31/12/2010.

Country	α	β	γ	δ	τ	R^2	$R^2_{\$}$	$R^2_{no\ \$}$	W	N
Australia	-0.00	0.01	0.38	0.22	0.80	24.28	20.24	7.91	***	6776
	(0.01)	(0.03)	(0.12)	(0.03)	(0.03)	(1.62)	[1.36]	[1.42]		
Canada	-0.01	0.05	-0.45	0.20	0.38	17.23	12.80	6.75	***	6776
	(0.01)	(0.03)	(0.10)	(0.02)	(0.02)	(1.43)	[1.08]	[1.06]		
Denmark	-0.00	-0.01	0.50	-0.17	1.52	79.76	77.40	8.13	***	6776
	(0.00)	(0.01)	(0.04)	(0.01)	(0.02)	(0.64)	[0.73]	[0.85]		
Euro Area	0.00	-0.04	0.25	-0.25	1.56	63.78	59.85	1.53	***	3110
	(0.01)	(0.04)	(0.11)	(0.02)	(0.03)	(1.43)	[1.59]	[0.60]		
France	-0.01	0.01	0.65	-0.07	1.41	82.05	79.96	11.11	***	3937
	(0.00)	(0.02)	(0.08)	(0.02)	(0.02)	(1.07)	[1.21]	[1.88]		
Germany	-0.01	0.00	0.66	-0.01	1.48	86.10	84.08	17.39	***	3937
	(0.00)	(0.02)	(0.06)	(0.02)	(0.02)	(0.70)	[0.72]	[1.66]		
Italy	0.00	-0.00	0.48	-0.10	1.26	67.11	65.26	6.47	***	3865
	(0.01)	(0.04)	(0.15)	(0.04)	(0.02)	(2.23)	[2.21]	[1.78]		
Japan	-0.02	-0.05	-0.23	-0.37	0.82	22.88	18.30	2.73	***	7048
	(0.01)	(0.04)	(0.12)	(0.04)	(0.04)	(1.41)	[1.54]	[0.56]		
New Zealand	-0.01	-0.00	0.25	0.15	0.85	22.17	19.68	5.12	***	6776
	(0.01)	(0.03)	(0.08)	(0.04)	(0.03)	(1.43)	[1.24]	[0.89]		
Norway	-0.00	0.02	0.39	-0.03	1.47	66.30	65.51	5.41	***	6776
	(0.01)	(0.02)	(0.05)	(0.02)	(0.02)	(1.57)	[1.58]	[0.89]		
Sweden	-0.00	0.01	0.41	0.02	1.32	56.30	55.10	5.55	***	6776
	(0.01)	(0.02)	(0.05)	(0.02)	(0.02)	(1.37)	[1.30]	[0.87]		
Switzerland	-0.01	-0.01	0.57	-0.15	1.56	67.91	64.53	10.27	***	7048
	(0.01)	(0.02)	(0.08)	(0.03)	(0.02)	(0.91)	[1.01]	[0.95]		
United Kingdom	-0.00	0.03	0.45	-0.04	1.15	51.90	51.43	3.48	***	7048
	(0.01)	(0.03)	(0.09)	(0.03)	(0.02)	(1.30)	[1.29]	[0.77]		

Not surprisingly, the first principal component of a large set of bilateral exchange rate changes is highly correlated with the dollar factor with a correlation of 0.95. But 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. The carry factor is close to the second principal component of portfolios of currencies sorted by interest rates, but not to the second principal component of a simple set of exchange rates. Conditioning on interest rate levels (as portfolios do) matters.

Moreover, loadings on the carry and dollar factors appear more stable than loadings on principal components. To quantify this point, I conduct a pseudo-predictability exercise in the spirit of the seminal Meese and Rogoff (1983) experiment.[14] Loadings on the carry and dollar factors are estimated over rolling windows of 60 months. The one-month-ahead expected changes in exchange rates are then derived using the loadings estimated on past observations and the actual value of the currency factors. The pseudo-predicted change in exchange rate is thus given by

$$\widehat{\Delta s_{i,t+1}} = \alpha_{i,t} + \beta_{i,t}(r_{i,t} - r_t) + \gamma_{i,t}(r_{i,t} - r_t)Carry_{t+1} + \delta_{i,t}Carry_{t+1} + \tau_{i,t}Dollar_{t+1},$$

where $\alpha_{i,t}$, $\beta_{i,t}$, $\gamma_{i,t}$, $\delta_{i,t}$, and $\tau_{i,t}$ are estimated on samples that end at date t. This exercise is similar to 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). These are *not* true forecasts since they assume that the factors are known one period in advance — a strong assumption given that the two factors are actually hard to predict, hence the *pseudo* characteristic of the predictability test. A similar test is run by estimating the loadings on the first three principal components, or a simple random walk with drift.

The square root of mean squared errors (RMSE) compares favorably for the carry and dollar factors, attesting to the persistence of the factor loadings. To save space, results are reported in the Internet Appendix. The first three principal components only beat the carry and dollar fac-

[14] Meese and Rogoff (1983) estimate multivariate regressions that link changes in exchange rates to macro variables. They assume that such macroeconomic variables are known one period in advance and compare the pseudo-predicted value of the exchange rate with that implied by a random walk. The random walk leads to lower mean squared error than any macroeconomic variable, even if that variable were known one period in advance.

tors for currency pegs; in all of the other cases, the RMSEs are lower with the carry and dollar factors than with the principal components. The carry and dollar factors also beat the random walk benchmark easily in the pseudo-predictability exercise of Meese and Rogoff (1983). Building on this paper, Malone, Gramacy, and ter Horst (2016) reproduce the above pseudo-predictability results and find actual predictability for bilateral rates by forecasting the carry and dollar factors.

Focusing on the benchmark carry and dollar factors (instead of the principal components) has therefore three advantages. First, the carry and dollar factors account for a large share of currency dynamics in a parsimonious way. Second, they are easily interpretable: they arise naturally in any complete market model of exchange rates. No meaningful closed-form expression for the principal components could be obtained in the simple model of Section I, for example. Third, the loadings on the carry and dollar factors appear more stable than those of the principal components. But I turn now to the most important characteristic of the carry and dollar factors, a key feature that distinguishes them from other statistical descriptions of bilateral exchange rates: the corresponding risks are priced in currency markets.

III. Dollar Risk

The literature review at the beginning of this paper presents evidence in favor of a risk-based interpretation of the carry factor. This section presents new evidence on the dollar risk factor.

A. *Portfolios of Countries Sorted by Dollar Exposures*

I combine the dollar predictability shown in Lustig, Roussanov, and Verdelhan (2011) with the heterogeneity in the loadings on the dollar shown in the previous section to build a new, large cross-section of portfolio excess returns.[15] The new portfolios are based on each currency's

[15]Lustig, Roussanov, and Verdelhan (2014) show that the average forward discount rate of developed countries (i.e., the average interest rate difference between foreign and U.S. short-term interest rates) predicts the returns on the aggregate currency portfolio and its exchange rate component (i.e., the dollar factor). They find that expected currency excess returns on the dollar basket are strongly countercyclical with respect to a large set of U.S. economic

time-varying exposure to the dollar factor. At each date t, each country i's change in exchange rate is regressed on a constant and the dollar and carry factors, as in the previous section, using a 60-month rolling window that ends in period $t-1$. Currency i's exposure to the dollar factor is denoted by $\tau_{i,t}$; it only uses information available at date t. Currencies are then sorted into six groups at time t based on the slope coefficients $\tau_{i,t}$. Portfolio 1 contains currencies with the lowest exposures (i.e., low τ_i), while portfolio 6 contains currencies with the highest exposures. I refer to these portfolios as dollar beta-sorted. At each date t and for each portfolio, the investor goes long if the average forward discount rate among all developed countries is positive and goes short otherwise.

Panel A of Table IV reports summary statistics on the portfolios of countries sorted by dollar exposures. Average log excess returns range from 1.3% to 7.1% on an annual basis for portfolios 1 to 6. Mean excess returns on portfolios 2 to 6 are statistically different from zero (the standard errors are obtained by bootstrapping and thus take the sample size into account). Taking bid-ask spreads of forward and sport exchange rates into account reduces the average excess returns (from 0.6% to 5.8%) but does not change the cross-sectional pattern.

Without conditioning on the average forward discount rate, the dollar beta-sorted portfolios deliver a cross-section of gross average excess returns ranging from 0.3% to 2.4%. Because the average forward discount rate predicts future dollar returns, the conditional average excess returns are much larger, particularly for large loadings on the dollar factor: the higher the loading on the dollar factor, the more predictable the future currency excess returns and thus the higher the average conditional excess returns. After conditioning on the average forward discount, the average return on a long-short dollar beta strategy is significant and equal to 5.2% per year. Similar results obtain when sorting countries on dollar betas estimated over shorter (48 months) or longer (72 months) rolling windows.

The cross-section of dollar beta-sorted currencies is key to estimating the price of dollar risk. This estimation does not appear in previous work on currency carry trades, because all portfolios of currencies sorted by interest rates load in the same way on the dollar factor; they

variables.

Table IV
Portfolios of Countries Sorted By Dollar Exposures

Panel A reports summary statistics for portfolios of currencies sorted on their exposure to the dollar factor. See Section III for details on the construction of these portfolios. Panel B reports results from GMM and Fama-MacBeth asset pricing procedures. The market price of risk λ, the adjusted $\bar{R}^2$, the square root of mean squared errors (RMSE) and the p-values of χ^2 tests on pricing errors are reported in percentage points. b denotes the vector of factor loadings ($m_{t+1} = 1 - bCond.Dollar_{t+1}$). The last row reports the mean of the risk factor. Excess returns used as test assets and risk factors do not take into account bid-ask spreads. All excess returns are multiplied by 12 (annualized). The second step of the FMB procedure does not include a constant. The last two panels report OLS estimates of the factor betas obtained either with the conditional dollar excess return (Panel C) or with the global component of the dollar factor (built as the difference in exchange rate changes between the last and first dollar beta portfolios). R^2s and p-values are reported in percentage points. The standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). The alphas are annualized and in percentage points. Data are monthly, from Barclays and Reuters (Datastream). The sample period is 12/1988 to 12/2010.

			Panel A: Summary Statistics			
Portfolio	1	2	3	4	5	6
			Spot change: Δs			
Mean	−0.97	−2.12	−2.88	−3.66	−2.99	−5.07
Std	3.29	5.31	6.70	7.72	10.19	10.68
			Forward Discount: $r_i^f - r^f$			
Mean	0.34	0.74	0.99	1.47	2.00	2.07
Std	0.54	1.11	1.24	1.44	0.70	0.55
			Excess Return: rx			
Mean	1.31	2.86	3.87	5.13	4.99	7.14
	[0.70]	[1.17]	[1.41]	[1.61]	[2.16]	[2.18]
			Excess Return: rx (with bid-ask spreads)			
Mean	0.58	1.43	2.11	3.73	3.73	5.84
	[0.72]	[1.11]	[1.40]	[1.61]	[2.05]	[2.37]
Sharpe Ratio	0.18	0.27	0.32	0.49	0.36	0.55
			Panel B: Risk Prices			
	$\lambda_{Cond.Dollar}$	$b_{Cond.Dollar}$	R^2	$RMSE$	χ^2	
GMM_1	4.73	0.94	83.06	0.80		
	[1.54]	[0.31]			66.57	
GMM_2	4.51	0.90	81.74	0.83		
	[1.50]	[0.30]			66.91	
FMB	4.73	0.94	85.22	0.80		
	[1.41]	[0.28]			50.40	
Mean	4.61					
			Panel C: Conditional Dollar Betas			
Portfolio	1	2	3	4	5	6
α	0.81	0.87	0.64	0.76	−1.17	0.44
	[0.90]	[1.00]	[1.06]	[0.91]	[0.99]	[0.90]
β	0.11	0.44	0.71	0.99	1.40	1.52
	[0.03]	[0.06]	[0.06]	[0.06]	[0.06]	[0.05]
R^2	4.40	28.98	48.00	71.64	78.97	86.39
			Panel D: Global Dollar Betas			
Portfolio	1	2	3	4	5	6
β	−0.04	−0.08	−0.12	−0.26	−0.36	−0.41
	[0.02]	[0.04]	[0.06]	[0.06]	[0.10]	[0.11]
R^2	1.84	2.82	3.76	14.51	14.84	17.63

do not offer the different dollar exposures needed to estimate the price of dollar risk. As a result, the dollar factor plays the role of a constant in the second stage of a Fama-McBeth regression on currency carry trades and its price appears insignificant. The novel cross-section of dollar beta-sorted currencies, in contrast, leads to a precise estimation of the market price of dollar risk.

B. The Price of Dollar Risk

Panel B of Table IV reports Generalized Method of Moments (GMM) and Fama-McBeth (FMB) asset pricing results. The market price of dollar risk λ is positive, significant, and close to the mean of the risk factor, as implied by a no-arbitrage condition.[16] Average excess returns of the dollar beta-sorted portfolios correspond to the covariances between excess returns and a single risk factor, the aggregate conditional dollar excess return. The pricing errors are not statistically significant. Panel C of Table IV reports Ordinary Least Squares (OLS) estimates of the factor betas. Betas are precisely estimated and increase monotonically from 0.11 to 1.52. They are driven by the dynamics of exchange rates, not by changes in interest rates — similar regressions on changes in exchange rates instead of excess returns deliver similar results. The alphas (which measure the returns after correction for their risk exposure) are not statistically different from zero. The portfolios differ in their betas because the dollar factor contains a key global component: a long-short factor (built, as defined in Section I, as the difference in exchange rate changes between the last and first dollar beta portfolios) also delivers a monotonic cross-section of betas, increasing from -0.04 to -0.41.

The dollar risk differs from both the carry risk and the equity risk. The carry trade risk factor (which is dollar neutral) and the aggregate U.S. stock market excess returns *cannot* account for the excess returns of portfolios sorted on dollar exposures: for the CAPM, loadings tend to increase from portfolios 1 to 6, but they are too small, implying a large market price of risk that

[16]The Euler equation implies a beta pricing model: $E[R^e] = \beta\lambda$, where β measures the quantity of risk and λ the price of risk. Since the risk factor is an excess return, the Euler equation applies to the risk factor itself, which has a beta of one, and thus implies that $E[R^e_{Dollar}] = \lambda$. Note that the Greek letters used in this section are not related to those used to describe the model or the country-level regressions of the previous section.

is not in line with the mean U.S. stock market excess return. Likewise, the loadings on the carry trade risk factor are small and imply large and statistically significant pricing errors. Sorts on dollar exposures thus reveal a novel cross-section of currency risk premia.

Figure 1 reports the realized and predicted average excess returns. Each portfolio j's actual excess return is regressed on a constant and the conditional dollar excess return to obtain the slope coefficient β^j. Each predicted excess return then corresponds to the OLS estimate β^j multiplied by the mean of the conditional dollar excess return. Figure 1 clearly shows that predicted excess returns are aligned with their realized counterparts. An investor who takes on more dollar risk is rewarded by higher excess returns on average. The dollar risk is intuitive. When the U.S. economy approaches a recession, U.S. short-term interest rates tend to be low relative to other developed economies, and the average forward discount is thus positive. If U.S. investors then buy a basket of currency forward contracts, they are long foreign currencies and short the U.S. dollar. They therefore run the risk of dollar appreciation during difficult times in the U.S. Such appreciation of the dollar is not unlikely: if markets are complete, the U.S. dollar should appreciate when pricing kernels are higher in the U.S. than abroad, that is, when the U.S. experiences relatively bad times. The appreciation of the dollar and the resulting depreciation of foreign currencies is consistent with the expected foreign currency appreciation in the future and thus the countercyclical dollar risk premium reported in Lustig et al. (2014). Shorting the dollar is thus a risky strategy and risk-averse investors expect to be compensated for bearing that risk. When shorting the U.S. dollar to invest in the last portfolio, the investor takes more of that risk than when shorting the dollar to invest in the first portfolio.

As a robustness check, I run country-level Fama and MacBeth (1973) tests, using country-level excess returns as test assets. The country-level results confirm the previous findings: the dollar risk is priced in currency markets, and the price of risk is not statistically different from the mean of the risk factor's excess return, as implied by the absence of arbitrage. Not surprisingly, the pricing errors are larger than those obtained on currency portfolios, but the null hypothesis that all pricing errors are jointly zero cannot be rejected. Portfolios of countries sorted by dollar exposures and conditional excess returns at the country level thus offer clear

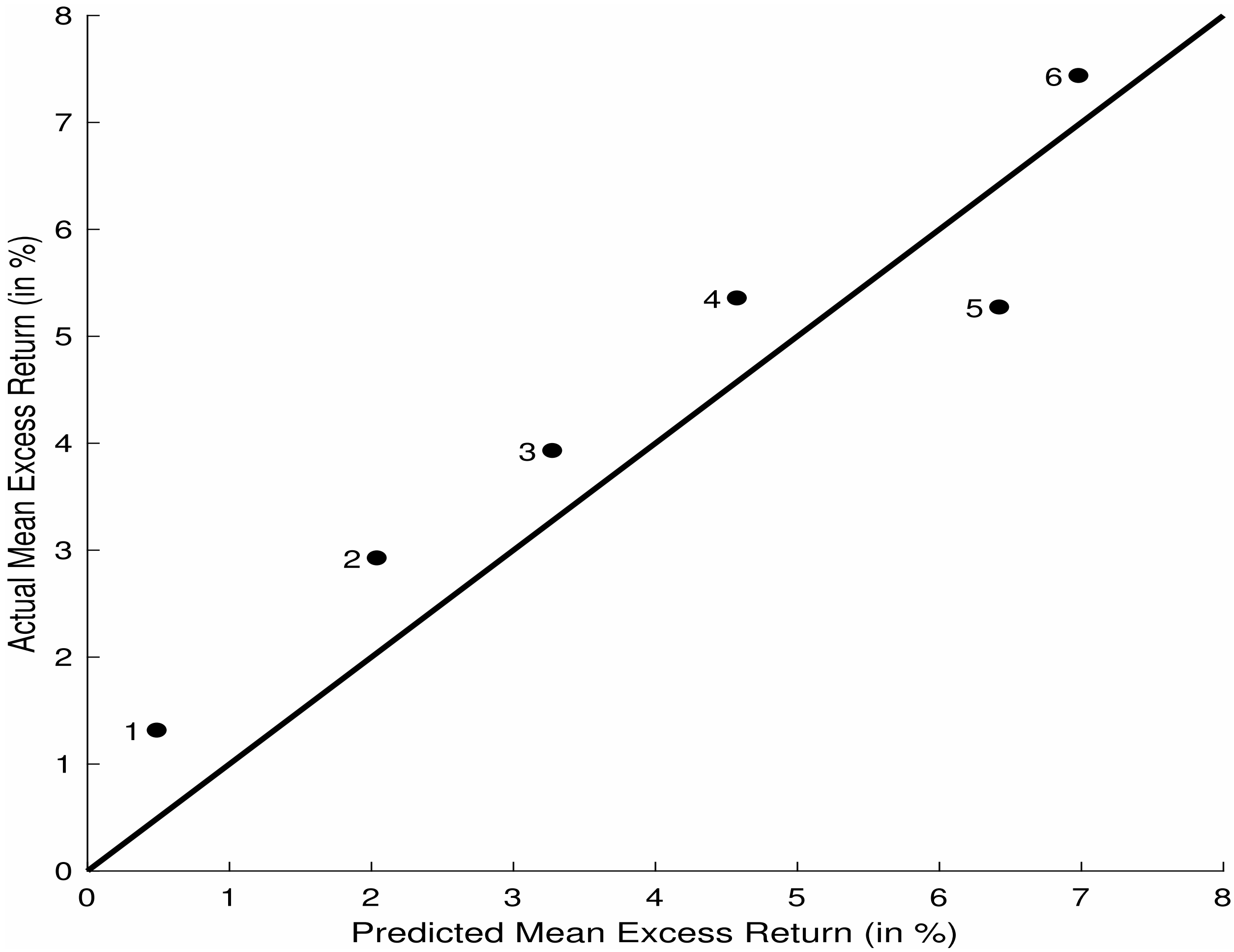

Figure 1. Realized versus predicted excess returns: Portfolios of countries sorted on dollar exposures. The figure plots realized average excess returns on the vertical axis against predicted average excess returns on the horizontal axis. The portfolios are based on each currency's exposure to the dollar factor. At each date t, each currency i change in exchange rate is regressed on a constant and the dollar and carry factors using a 60-month rolling window that ends in period $t-1$. Currency i's exposure to the $Dollar$ factor is denoted τ_t^i. Currencies are then sorted into six groups at time t based on the slope coefficients τ_t^i. Portfolio 1 contains currencies with the lowest τ. Portfolio 6 contains currencies with the highest τ. At each date t and for each portfolio, the investor goes long if the average forward discount is positive and short otherwise. Each portfolio j's actual excess return is regressed on a constant and the conditional dollar excess return to obtain the slope coefficient β^j. Each predicted excess return then corresponds to the OLS estimate β^j multiplied by the mean of the conditional dollar excess return. All returns are annualized. Data are monthly. The sample period is 12/1988 to 12/2010.

evidence in favor of a risk-based explanation of exchange rates.

IV. Key Implications and Additional Tests

This section builds on the previous empirical results and establishes three novel facts: (i) global shocks account for a large share of the variation in bilateral exchange rates, (ii) the carry factors describe exchange rate volatility changes, (iii) the carry trade risk premium is a conditional risk premium, and (iv) the comovement of exchange rates appears to be related to the comovement of macroeconomic variables, particularly capital flows. The first three facts are tightly linked to the framework in Section I, while the fourth suggests that this framework be extended to study its portfolio implications.

A. Global Risk

The factor structure reveals that global shocks are important drivers of bilateral exchange rates. This is the key implication of the previous sections. I first estimate the share of dollar-based exchange rates driven by global shocks. I then show that the same shocks are significant drivers of nondollar-based exchange rates.

Global Systematic Shocks in Bilateral Exchange Rates The model introduced in Section I suggests that the difference in exchange rates between high and low interest rate portfolios captures the global shocks responsible for the carry trade risk premium. Likewise, the difference in exchange rates between high and low dollar beta portfolios cancels out the U.S.-specific component of the U.S. pricing kernel and focuses on its global component, thus extracting the global component of the dollar factor.

I therefore regress the changes in bilateral exchange rates on the conditional and unconditional carry factors and the global component of the dollar factor, using only high-minus-low risk factors. Table V reports the slope coefficients and the R^2s of this regression. Table V also reports, for the same sample, the R^2s obtained with the carry factors and the dollar factor (denoted $R^2_\$$). Loadings on the global component of the dollar factor are significant for all developed currencies. Not surprisingly, the global component of the dollar factor accounts for a lower share of the variation in exchange rates than the dollar factor itself, which incorporates U.S.-specific shocks. But global shocks account for a large share of the exchange rate changes, with R^2s between 17% and 82%, close to those obtained with the carry and dollar factors. Global shocks thus appear to be key to understanding exchange rates.

U.S.-Specific Shocks Table V illustrates the relative importance of U.S. versus foreign-specific SDF shocks, under the null of the model.

For a given currency, the difference in R^2s between a regression with the global component of the dollar factor and a regression with the dollar factor itself measures (up to a scaling factor equal to the volatility of the bilateral exchange rate) the U.S.-specific shocks in the U.S. SDF. Take the Japanese yen/dollar for example: the R^2 is 24% in a regression without U.S.-specific shocks, but $R^2_{\$} = 40\%$ in a regression that includes U.S.-specific shocks. The variance of the U.S.-specific shocks is thus $R^2_{\$} - R^2 = 16\%$ of the variance of the yen/dollar exchange rate. Under the null of the model, the carry and dollar factors describe all global shocks as well as the U.S.-specific shocks. The only shocks not captured by those two factors are the foreign country-specific SDF shocks. In the example above, the Japan-specific components of the Japanese SDF are the missing variables in the regression, and the reason why, under the null of the model, the $R^2_{\$}$ is not 100%. Therefore, the variance of the Japan-specific shocks is $1 - R^2_{\$} = 1 - 40\% = 60\%$ of the variance of the yen/dollar exchange rate. Japan-specific shocks are much bigger than U.S.-specific shocks.

The same conclusion appears for all developed countries: Japan and New Zealand exhibit the largest difference between the two R^2s (for the other countries, the difference is less than 8% and $1 - R^2_{\$}$ is always above 8%). In all cases, the foreign-specific shocks are larger than the U.S.-specific shocks. In the case of the U.S., most shocks that affect the SDF are global; this is less the case for other developed countries.

Other Base Currencies To check that the regressors capture global shocks, I turn now to other base currencies, i.e., other numeraires. Table VI reports regression results similar to those in

Table V
Monthly Shares of Global Shocks in Bilateral Exchange Rates

This table reports country-level results from the regression

$$\Delta s_{i,t+1} = \alpha_i + \beta_i(r_{i,t} - r_t) + \gamma_i(r_{i,t} - r_t)Carry_{t+1} + \delta_i Carry_{t+1} + \tau_i Dollar^{global}_{t+1} + \varepsilon_{i,t+1},$$

with the same notation as in the previous tables, and where $Dollar^{global}_{t+1}$ corresponds to the change in exchange rates in a high dollar beta portfolio minus the change in exchange rates in a low dollar beta portfolio. See Section III for details on the construction of these portfolios. Note that, unlike in the previous tables, the currency on the left-hand side of these regressions is not excluded from the portfolios on the right-hand side: the dollar beta portfolios are built using all currencies in the sample; for consistency, the carry factors are also constructed using all currencies. The table reports the constant α, the slope coefficients γ, δ, and τ, as well as the adjusted R^2 of this regression (in percentage points) and the number of observations N. Results are obtained on a smaller number of observations than in the previous monthly tables because building the dollar beta portfolios uses 60 observations. Standard errors in parentheses 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 brackets; they are obtained by bootstrapping. $R^2_{Global\$}$ denotes the adjusted R^2 of a similar regression with only the $Dollar^{global}$ factor (i.e., without the conditional and unconditional *Carry* factors). $R^2_{\$}$ denotes the adjusted R^2 of a similar regression using the same *Carry* factors, along with the *Dollar* factor. W denotes the result of a Wald test: the null hypothesis is that the loadings γ and δ on the conditional and unconditional carry factors are jointly zero. Data are monthly, from Barclays and Reuters (Datastream). All variables are in percentage points. The sample period is 11/1983 to 12/2010.

Country	α	γ	δ	τ	R^2	$R^2_{\$}$	$R^2_{Global\$}$	W	N
Australia	-0.10	0.83	0.31	0.33	24.81	39.55	13.42	***	266
	(0.18)	(0.57)	(0.12)	(0.10)	[7.14]	[6.93]	[6.06]		
Canada	-0.10	-0.86	0.24	0.21	17.67	25.59	8.58	***	266
	(0.11)	(0.48)	(0.06)	(0.06)	[8.17]	[7.62]	[5.05]		
Denmark	0.10	0.04	0.04	0.87	80.61	85.26	80.65		266
	(0.08)	(0.12)	(0.04)	(0.03)	[3.26]	[1.93]	[3.08]		
Euro Area	0.15	-0.21	-0.15	0.89	82.68	83.44	81.72	**	143
	(0.10)	(0.20)	(0.06)	(0.04)	[3.45]	[3.24]	[3.84]		
France	0.04	-0.02	0.16	0.88	82.03	89.58	80.31	***	122
	(0.10)	(0.16)	(0.04)	(0.06)	[4.69]	[2.26]	[4.75]		
Germany	0.07	-0.13	0.14	0.92	82.22	89.04	80.85	***	122
	(0.11)	(0.17)	(0.04)	(0.06)	[4.98]	[2.14]	[4.87]		
Italy	0.22	0.82	0.15	0.66	68.98	71.16	51.34	***	122
	(0.17)	(0.24)	(0.07)	(0.06)	[4.95]	[5.61]	[8.87]		
Japan	0.05	-0.27	-0.51	0.43	24.40	40.06	13.17	***	266
	(0.17)	(0.50)	(0.12)	(0.09)	[5.72]	[5.79]	[5.13]		
New Zealand	-0.04	0.23	0.18	0.49	27.28	44.12	24.45	***	266
	(0.17)	(0.61)	(0.18)	(0.08)	[6.55]	[5.39]	[5.94]		
Norway	0.06	0.24	0.15	0.77	68.04	72.53	65.82	***	266
	(0.10)	(0.12)	(0.04)	(0.06)	[5.91]	[4.15]	[5.68]		
Sweden	0.14	0.54	0.17	0.81	68.58	75.30	64.63	***	266
	(0.10)	(0.26)	(0.05)	(0.04)	[4.45]	[2.83]	[5.48]		
Switzerland	0.05	0.27	-0.11	0.84	69.03	77.14	67.61	*	266
	(0.10)	(0.29)	(0.07)	(0.05)	[3.84]	[2.49]	[4.16]		
United Kingdom	0.11	0.93	0.09	0.55	47.73	50.12	41.84	***	266
	(0.11)	(0.55)	(0.10)	(0.06)	[5.91]	[6.57]	[5.91]		

Table V (i.e., with the same explanatory variables), but for exchange rates expressed in Japanese yen and U.K. pounds. Different base currencies offer a simple robustness check: if the long-short strategies are not driven by global shocks, their associated returns should not matter for nondollar-based exchange rates.

In contrast to the above prediction, the global component of the dollar factor appears significant for nine out of 13 exchange rates defined in yen, and 10 out of 13 exchange rates defined in pounds. The conditional and unconditional carry factors are jointly significant in 11 (nine) out of 13 exchange rates defined in yen (pounds). The carry factors, along with the global component of the dollar factor, account for 6% to 45% of those exchange rates. These regressions do not measure the total share of systematic currency risk from the perspective of the Japanese or U.K. investor since they do not include the Japan-specific or U.K.-specific shocks that cannot be diversified away by those investors. But they do show that the long-short exchange rates built from interest rate and dollar beta portfolios capture global shocks.

B. Systematic Variation in Exchange Rate Changes and Volatilities

The model introduced in Section I implies a clear factor structure, not only for exchange rate changes, but also for exchange rate volatilities. I now rapidly review the model's implications and the role of global shocks in the exchange rate volatilities in the data. Empirically, the monthly volatility of each bilateral exchange rate is obtained as the standard deviation of its daily changes. Since volatilities are persistent, all tests are conducted on changes in volatilities, controlling for the past value of the exchange rate volatility. To save space, the detailed results are reported in the Internet Appendix.

Equations (16), (17), and (18) in Section I imply that (i) the volatilities of the dollar and carry factors are orthogonal, and (ii) each exchange rate volatility is driven by the same variables that affect the volatilities of the dollar and carry factors. The first implication is clearly rejected by the data: the changes in volatilities of the dollar and carry factors exhibit a significant correlation of around 0.5. In the general case of the model, however, the volatilities of the carry and dollar

Table VI
Other Base Currencies and Cross Exchange Rates

This table reports country-level results from the regression

$$\Delta s_{i,t+1} = \alpha_i + \beta_i(r_{i,t} - r_t) + \gamma_i(r_{i,t} - r_t)Carry_{t+1} + \delta_i Carry_{t+1} + \tau_i Dollar^{global}_{t+1} + \varepsilon_{i,t+1},$$

where $\Delta s_{i,t+1}$ denotes the bilateral exchange rate in foreign currency per Japanese yen (left panel) or per U.K. pound (right panel), $r_{i,t} - r_t$ is the interest rate difference between the foreign country and Japan (left panel) or the U.K. (right panel), $Carry_{t+1}$ 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 $Dollar^{global}_{t+1}$ corresponds to the change in exchange rates in a high dollar beta portfolio minus the change in exchange rates in a low dollar beta portfolio. See the caption of Table V for variable definitions and the list of parameters reported. Note that, as in Table V but unlike in the previous tables, the currency on the left-hand side of these regressions is not excluded from the portfolios on the right-hand side. In the left panel (where exchange rates are defined in units of foreign currency per yen), regression results for Japan are replaced by those for the U.S. (U.S. dollars per yen). Likewise, in the right panel (where exchange rates are defined in units of foreign currency per U.K. pound), regression results for the U.K. are replaced by those for the U.S. (U.S. dollars per U.K. pound). Data are monthly, from Barclays and Reuters (Datastream). All variables are in percentage points. The sample period is 11/1983 to 12/2010.

Country	α	γ	δ	τ	R^2	α	γ	δ	τ	R^2	N
	Yen-Based Exchange Rates					Pound-Based Exchange Rates					
Australia	-0.11	2.57	-0.28	0.02	30.96	-0.18	2.23	0.19	-0.24	13.38	266
	(0.23)	(0.72)	(0.30)	(0.13)	[6.91]	(0.19)	(0.60)	(0.10)	(0.10)	[6.25]	
Canada	-0.15	-0.11	0.69	-0.23	19.60	-0.21	1.18	0.16	-0.39	16.34	266
	(0.21)	(0.65)	(0.19)	(0.12)	[5.27]	(0.16)	(0.59)	(0.12)	(0.08)	[5.29]	
Denmark	0.06	-0.25	0.55	0.47	31.67	0.03	-0.82	-0.27	0.35	20.89	266
	(0.17)	(0.36)	(0.16)	(0.07)	[7.44]	(0.12)	(0.42)	(0.10)	(0.06)	[5.21]	
Euro Area	0.23	-1.31	0.82	0.58	45.54	0.02	-1.48	-0.37	0.41	25.60	143
	(0.20)	(0.67)	(0.16)	(0.08)	[9.47]	(0.16)	(1.23)	(0.21)	(0.10)	[7.96]	
France	-0.13	1.37	-0.11	0.22	21.08	0.03	-0.62	-0.29	0.27	15.39	122
	(0.26)	(0.49)	(0.24)	(0.08)	[8.17]	(0.19)	(0.37)	(0.12)	(0.06)	[5.83]	
Germany	-0.07	0.34	0.29	0.31	18.14	0.04	-0.45	-0.32	0.26	14.72	122
	(0.27)	(0.32)	(0.15)	(0.08)	[8.64]	(0.20)	(0.54)	(0.17)	(0.07)	[6.17]	
Italy	0.15	1.04	0.03	0.19	24.57	0.21	0.97	-0.04	0.06	15.25	122
	(0.32)	(0.39)	(0.32)	(0.12)	[9.49]	(0.19)	(0.17)	(0.07)	(0.06)	[8.67]	
United States	-0.05	-0.27	0.51	-0.43	24.40	-0.05	-1.37	-1.26	-0.10	25.35	266
/Japan	(0.17)	(0.50)	(0.12)	(0.09)	[5.87]	(0.19)	(0.54)	(0.25)	(0.08)	[6.58]	
New Zealand	-0.07	1.40	-0.09	0.15	20.70	-0.13	1.65	-0.16	-0.07	5.77	266
	(0.22)	(0.64)	(0.34)	(0.12)	[6.86]	(0.17)	(0.57)	(0.12)	(0.11)	[4.61]	
Norway	-0.00	0.47	0.41	0.37	29.23	-0.02	-0.21	-0.05	0.24	7.91	266
	(0.19)	(0.39)	(0.18)	(0.08)	[7.42]	(0.13)	(0.33)	(0.07)	(0.05)	[3.64]	
Sweden	0.08	0.79	0.34	0.43	33.35	0.05	-0.08	-0.01	0.29	10.01	266
	(0.19)	(0.39)	(0.17)	(0.08)	[6.74]	(0.14)	(0.45)	(0.08)	(0.06)	[4.24]	
Switzerland	0.00	0.39	0.23	0.45	23.67	-0.03	-1.07	-0.70	0.36	23.15	266
	(0.17)	(0.65)	(0.12)	(0.07)	[6.03]	(0.14)	(0.53)	(0.20)	(0.08)	[4.44]	
United Kingdom	0.05	-1.37	1.26	0.10	25.35	-0.11	0.93	-0.09	-0.55	47.73	266
/ United States	(0.19)	(0.54)	(0.25)	(0.08)	[6.53]	(0.11)	(0.55)	(0.10)	(0.06)	[6.07]	

factors are correlated as soon as the price of a global shock depends on both global and local state variables. The second implication is in line with the data. The changes in volatilities of the dollar and carry factors are jointly significant for all 13 exchange rate volatility changes. This result is consistent with the findings of Section II: if the factors are orthogonal and exchange rate changes are *i.i.d*, then the significant factor decomposition on exchange rate changes at the daily frequency implies a similar decomposition in terms of exchange rate volatilities.

Without any additional assumption on the correlation between the SDF shocks and the Gamma volatility shocks, the model is silent on the link between exchange rate volatilities and the carry and dollar factors. The data, however, suggest a strong link between volatility shocks and the carry factor. On the one hand, in regressions of volatility changes on the carry and dollar factors (similar to those run on exchange rate changes in Section II, the carry and conditional carry factors appear jointly significant for 12 out of 13 developed countries at the 10% significance level. On the other hand, the dollar factor appears significant in only two cases, and the global component of the dollar factor is never significant. The findings suggest that a continuous-time version of the model, in which the volatilities could be driven by Gaussian shocks and still remain positive, could feature the same global shocks for the volatility and SDF processes, a key element of the most common term structure models.

C. *Conditional versus Unconditional Carry Trade Risk Premium*

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This paper suggests that the currency carry trade risk premium is a conditional risk premium. In other words, rebalancing portfolios should deliver higher average excess returns than single sorts done once and for all, as Lustig et al. (2011) find. The difference between conditional and unconditional risk premia, however, is difficult to assess using average excess returns because averages are imprecisely measured in short samples. But this difference shows up in contemporaneous regressions of bilateral exchange rates on the carry factor: if the carry risk premium is unconditional, the carry betas should be constant, as they are in the special case of the model presented here. In the data, however, carry betas are not constant. The special case of the model here is clearly counterfactual.[17] Empirically, the carry and conditional carry factors appear significant in exchange rate regressions. Thus, the time-varying carry betas, along with the evidence on the volatilities of the factors, do not support the assumption of an unconditional carry trade risk premium.

D. *Systematic Currency Risk and World Comovement*

This paper ends with an example of the potential use of the factor structure to study exchange rates. I show that the differences in currency systematic risk are related to measures of comovement in macroeconomic quantities, such as real consumption and GDP growth rates, and even more strongly related to measures of comovement in capital flows.

Comovement of GDP and Consumption In the language of the model in Section I, the share of world shocks versus country-specific shocks in each SDF is governed by the relative prices of the global (u^w and u^g) and local (u) shocks. In the international real business cycle literature, those shocks are related to fundamental macroeconomic variables, for example, consumption growth or GDP growth. In such models, the importance of global shocks would therefore be linked to the comovement of output and consumption growth rates across countries.[18] While direct links between bilateral changes in exchange rates and macroeconomic variables are dif-

[17] I show in the Internet Appendix that constant carry betas also have counterfactual implications in terms of the factors' volatilities. In the special case presented in this section, the constant carry betas happen while the correlation between the volatilities of the carry and dollar factors is zero. The same is true for the volatilities of the carry and the global component of the dollar factor. The general model presented in the Internet Appendix shows that constant carry betas happened when the volatility of the global component of the dollar factor is either perfectly correlated or uncorrelated with the volatility of the carry factor. Neither is supported by the data, where this correlation is statistically different from one and zero and close to 0.4. These counterfactual implications of constant betas could be addressed in a richer model with more state variables. It remains, however, that the carry betas are time-varying in simple regressions of exchange rates on the carry factor.

[18] The link between comovement in consumption growth and comovement in exchange rates can be interpreted in the reduced-form model of Section I. Assuming that the reduced-form model starts from the SDF of a representative agent with constant relative risk aversion, the log SDF is simply equal to the risk-aversion coefficient multiplied by consumption growth; SDF shocks are then related to consumption growth shocks (GDP growth shocks in an endowment economy). A consumption growth process in country i that is driven mostly by global consumption growth may correspond to a large loading (κ_i in the model) on global shocks. A high share of comovement in consumption growth would then relate to a high share of currency systematic risk.

ficult to establish empirically, the shares of systematic currency risk appear related to the comovement of consumption and output growth rates.

As for exchange rates, the measure of comovement across countries is obtained as a simple adjusted R^2 on consumption and output growth rates or trade flows, derived from the regression

$$\Delta y_{i,t+1} = \alpha_i + \beta_i \Delta y_{t+1}^{world} + \varepsilon_{i,t+1},$$

where $\Delta y_{i,t+1}$ denotes the annual growth rate of real foreign consumption (or output) and Δy_{t+1}^{world} corresponds to the annual growth rate of the world consumption or output (e.g., measured as the sum of all consumption or output in OECD countries). The GDP and consumption series, measured at purchasing power parity, as well as the exports and imports scaled by GDP, come from the World Bank and are available at an annual frequency. Adjusted R^2s on trade flows are derived similarly. The ratio of exports and imports (divided by GDP), a common measure of trade openness, is regressed on its world counterpart (obtained as the average across countries).

The different shares of systematic currency risk across countries appear significantly related to measures of macroeconomic comovement. A simple cross-country regression confirms the findings:

$$R_i^{2,FX} = \alpha + \beta R_i^{2,X} + \varepsilon_i,$$

where $R_i^{2,FX}$ denotes the share of systematic variation in the exchange rate of country i, obtained as in the previous sections using the carry and dollar factors, and $R_i^{2,X}$ denotes the share of systematic variation measured with macroeconomic variables. Panel A of Table VII reports the slope coefficients (β) on these cross-country regressions. The slope coefficients are all positive and significant. A large share of systematic variation in output or consumption growth is associated with a large share of systematic currency risk. Slope coefficients range between 0.45 and 0.6 across macroeconomic measures of comovement. The R^2s on the cross-country regressions, however, remain low. Thus, differences in GDP, consumption, and trade comovement explain only a limited part of the differences in the shares of systematic currency risk.

Table VII
Shares of Currency Systematic Variation and World Comovement

The table reports results from the second-stage cross-country regression

$$R_i^{2,FX} = \alpha + \beta R_i^{2,X} + \varepsilon_i.$$

In the first stage, $R_i^{2,FX}$ is obtained as the share of systematic variation in the exchange rate of country i measured by the carry and dollar factors as in Tables I and II. Likewise, $R_i^{2,X}$ are obtained in tests of world comovement, using either GDP growth, consumption growth, trade openness (Panel A), or measures of capital flows (Panel B): each country's R^2 corresponds to a regression of that country's macroeconomic variable on a world aggregate (the OECD total in Panel A and the first three principal components in Panel B). Consumption and GDP series are expressed in purchasing power parity (PPP) dollars. Trade openness is measured as the average of imports and exports divided by GDP. Capital flows are expressed as percentages of GDP. The table reports the slope coefficients β, the standard errors, the cross-sectional R^2s (in percentage points), as well as the number of observations N (i.e., countries) of the second-stage regression described above. R^2s on currencies are obtained using monthly series, while R^2s on capital flows are obtained on quarterly series. R^2s on macroeconomic variables (consumption and output) are obtained using annual series. The sample period is 11/1983 to 12/2010. The standard errors (s.e., reported in brackets) are obtained by bootstrapping the entire estimation (i.e., the two stages) on either annual (Panel A) or quarterly (Panel B) data.

	Panel A: GDP , Consumption, and Trade		
	GDP	Consumption	Trade
β	0.61	0.44	0.45
s.e	[0.16]	[0.20]	[0.10]
R^2	23.68	11.26	17.32
s.e	[10.27]	[7.60]	[6.54]
N	36	35	38
	Panel B: Capital Flows		
	Outflows	Inflows	Average
	Foreign Direct Investment		
β	0.73	0.40	0.59
s.e	[0.11]	[0.10]	[0.10]
R^2	9.95	3.34	9.33
s.e	[7.85]	[5.93]	[6.40]
	Portfolio Investment		
β	0.90	0.27	0.73
s.e	[0.11]	[0.13]	[0.12]
R^2	32.91	1.56	24.55
s.e	[7.63]	[7.65]	[8.07]
	Other Investment		
β	0.81	1.04	0.98
s.e	[0.09]	[0.09]	[0.09]
R^2	33.72	43.94	46.78
s.e	[7.39]	[7.82]	[7.67]
		Total	
β	1.02	0.95	1.03
s.e	[0.10]	[0.11]	[0.10]
R^2	52.95	38.62	48.29
s.e	[9.13]	[9.06]	[9.14]
N	35	35	35

Comovement of Capital Flows In contrast, comovement among capital flows appears strongly related to the shares of systematic currency risk.

Capital flows are reported in the balance of payments of each country, in particular in their financial accounts. Such accounts decompose capital flows into foreign direct investments, portfolio investments, other investments, and reserve assets. Other investments correspond to trade credits, loans, currencies and deposits, and other assets not classified elsewhere. Reserve assets correspond to gold, IMF drawing rights and reserve positions, as well as currencies held by monetary authorities. For each category, the balance of payments reports gross inflows and gross outflows: the former are net sales of domestic financial instruments to foreign residents, while the latter are net purchases of foreign financial instruments by domestic residents.

A recent literature in international economics shows that gross outflows and inflows are more informative than net flows (see Lane and Milesi-Ferretti, 2007, Obstfeld, 2012, Forbes and Warnock, 2012, and Broner et al., 2013). Notably, Rey (2013) shows that gross outflows and inflows are highly correlated across countries, while net flows are not. I follow this literature and study the comovement among gross capital inflows and outflows, scaled by GDP.

The share of systematic variation of total capital outflows for a given country is measured as the R^2 of a regression of that country's total capital outflows on the first three principal components of all the other countries' capital outflows (excluding the U.S.). Shares of systematic variation are obtained for inflows, and for each category of capital inflows and outflows. Using the mean of all capital flows instead of the first three principal components leads to similar results. Averaging the capital inflows and outflows leads to a measure of financial openness, which is the counterpart to trade openness. The data come from the IMF database and are compiled by Bluedorn et al. (2013).[19] The series are quarterly, over the same 1983 to 2010 sample as the exchange rates.

The shares of systematic capital flow variation appear strongly related to the shares of sys-

[19]The data set is constructed from balance of payment statistics (version 5), supplemented with other IMF and country sources. The data set does not include the euro area, but includes its members. It does not report outflows and inflows related to the changes in reserves, but rather the net flows. For this reason, they are not included in the subsequent analysis.

tematic currency variation. Panel B of Table VII reports the results from cross-country regressions of one on the other. The standard errors are obtained by bootstrapping the two stages of the estimation, using quarterly nonoverlapping data. All of the slope coefficients are positive and significant. A high share of systematic variation in exchange rates corresponds to a high share of systematic variation in total capital outflows, inflows, and their averages. Differences in capital flows account for up to 53% of the differences in systematic risk across currencies. As Figure 2 shows, this strong link is pervasive across countries; it is not driven by a few outliers. The U.K. actually appears as a sole outlier, with U.K. capital flows much more correlated with world flows than the pound is correlated with world currency factors. The singularity of the U.K. seems naturally linked to its role as a world financial hub.

The strong link between capital flows and exchange rates can be traced back to each component of capital flows. While the comovement of foreign direct investments does not explain much of the cross-country differences in systematic currency risk, the comovement of portfolio flows and, in particular, other investment flows does.[20] These findings may appear intuitive, as moments of prices should be related to moments of quantities. Yet such simple relationships between prices and quantities have been difficult to establish empirically for exchange rates. The shares of systematic currency risk therefore appear as a novel and useful characteristic of exchange rates.

V. Conclusion

This paper shows that two global risk factors are necessary to describe bilateral exchange rates. Those priced risk factors account for a large share of exchange rate dynamics. Currencies load differently on the risk factors, and the cross-currency differences in the shares of systematic variation appear related to the comovement of capital flows.

[20]The empirical link between the comovement of exchange rates and the comovement of capital flows suggests a prominent role for the portfolio balance channel of exchange rates, as recently suggested by Gabaix and Maggiori (2015). In the logic of that model, global shocks emerge from the wealth dynamics of financial intermediaries. DellaCorte, Sarno, and Riddiough (2014) present related evidence on the levels of net foreign asset positions and interest rates.

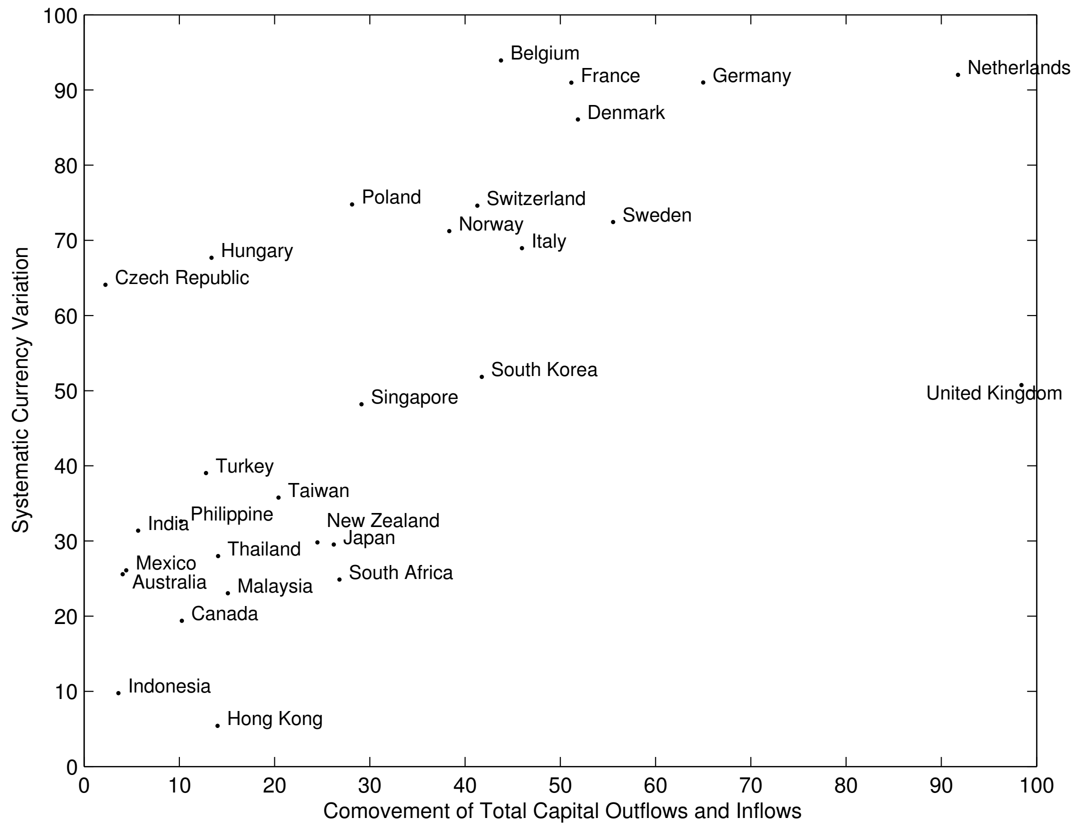

Figure 2. Systematic currency variation and international capital flows comovement The figure plots the share of systematic variation in the exchange rate of each country (on the vertical axis) as a function of the comovement of that country's capital flows with aggregate capital flows (on the horizontal axis). The shares of systematic variation in the exchange rates correspond to the R^2s of regressions of bilateral exchange rates on the carry and dollar factors, as reported in Tables I and II. Comovement in capital flows for country i is measured as the R^2 of a regression of country i's capital flows on the first three components of all capital flow series (excluding the U.S.). Measures of capital flows correspond to the average of total inflows and total outflows scaled by GDP. Exchange rate data are monthly, while capital flows are quarterly. The sample period is 11/1983 to 12/2010.

The paper's findings are important for both academics and practitioners. For practitioners, the findings imply the need for global currency risk management. But the decomposition of exchange rate changes into two risk factors simplifies optimal global portfolio allocation and hedging. As an example, a mean-variance investor allocating resources among N currencies would need to estimate the inverse of a small (instead of a $N \times N$) covariance matrix.

For researchers, the role of the carry and dollar factors should motivate studies of the systematic components in exchange rates, since those components account for a large share of bilateral exchange rate movements. From this perspective, and in light of the large literature on the carry trade, the dollar factor appears relatively understudied. Unlike many covariances between exchange rates and macroeconomic variables, the loadings on the risk factors and R^2s are precisely estimated. They thus offer a new source of cross-country differences and new potential targets for future models in macroeconomics that seek to link the underlying characteristics of each economy to the behavior of its exchange rate.

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Appendix

The main data set contains at most 39 different currencies of the following countries: Australia, Austria, Belgium, Canada, China (Hong Kong), the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Kuwait, Malaysia, Mexico, the Netherlands, New Zealand, Norway, the Philippines, Poland, Portugal, Saudi Arabia, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Turkey, the United Arab Emirates, the U.K., as well as the euro area. The euro series start in January 1999. Euro area countries are excluded after this date; only the euro series remains. All the countries are included in the carry and dollar factors. Tables I, V, and VI report regression results for 13 developed countries, while Table II reports regression results for 18 developing countries. To save space in the tables, country-level results for eight countries are not reported: Austria, Finland, Greece, Ireland, Portugal, and Spain are omitted because there are few forward rate observations for these countries (less than 30 months of data for these countries), and Belgium and the Netherlands are omitted because the tables already contain many European countries (results for these countries are similar to those for France and Germany).

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; and the United Arab Emirates from the end of June 2006 to the end of November 2006.

Two important points need to be highlighted. First, note that for each currency placed 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 from arising, above and beyond the link implied by the identical numeraire. Excluding or not excluding a single currency pair, however, has little impact on the properties of the factors because a large sample of countries is used to build them. Excluding one currency does not mean that all relevant information is dropped. Assume that 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 there would be no point in trying to exclude all the countries whose exchange rates might be correlated.

Second, portfolios always use the largest available sample of countries. Even when studying bilateral changes in the exchange rates of developed countries, portfolios and thus risk factors are derived from the large sample of developed and emerging countries. The average forward discount is obtained using all developed countries in the sample: Australia, Austria, Belgium, Canada, Denmark, euro area, Finland, France, Germany, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, and the U.K.

The factors, as all of the bilateral exchange rates, are posted online on my website. The carry factor has an annualized standard deviation of 9.1% and a first-order autocorrelation of 0.14, while the dollar factor has a standard deviation of 7.0% and a first-order autocorrelation of 0.08. The correlation between the dollar and carry factors is equal to 0.09.