Global volatility and depreciation factors and the cross-section of currency returns*

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Abstract

We use currency option-implied moments to calculate two global risk factors that are priced in the cross section of currency returns. The U.S. dollar volatility and depreciation factors are calculated as the difference in the return of currencies sorted on, respectively, at-the-money option-implied volatilities and 10-delta risk reversals. We document that both factors are useful at pricing not only the cross-section of currency returns sorted by the factors but also at pricing the cross section of currencies associated with two traditional currency puzzles, namely the return of carry and currency momentum portfolios. Moreover, these factors contain information that can be exploited to generate profitable currency investment strategies that beat the return of random walk strategies.

JEL Classification: G12, G15, F31

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1. Introduction

Understanding the determinants of the cross section of currency returns remains a vibrant topic in the academic literature. Perhaps the most studied puzzles related to the cross section of currency returns relate to currency investment strategies based on interest rate differentials across countries or differences in the recent performance of currencies, which are commonly known as the carry and currency momentum strategies, respectively. These strategies yield economically meaningful average returns (see, for instance, Lustig et al. (2011) and Menkhoff et al. (2012c)). Differences in returns across currencies, including for carry and momentum portfolios, can be understood as compensation for heterogeneous exposures to global risk factors (Verdelhan (2018)). We propose two global risk factors calculated exploiting the heterogeneity in option-implied characteristics across currencies. We document that these factors are priced in the cross section of currency returns and are useful at explaining the carry and momentum strategies. We call these factors the U.S. dollar volatility and the U.S. dollar depreciation factor, and they are calculated using, respectively, at-the-money option-implied volatilities and 10-delta risk reversals of options quoted with respect to the U.S. dollar. Intuitively, the volatility factor aggregates information about investors' desire to hedge against changes in the exchange rate of the U.S. dollar with respect to other currencies, while the depreciation factor aggregates information about their desire to hedge only against a large depreciation of currencies with the respect to the U.S. dollar. Thus, our evidence suggests that carry and momentum strategies can be partially understood as compensation for being exposed to global currency volatility and directional tail risk related to large U.S. dollar appreciations.

We follow the intuition in Verdelhan (2018) to calculate global risk factors as carry-like strategies using currency option-implied characteristics, instead of interest rate differentials, as the return of high-minus-low (HML) portfolios. We present a stylized model wherein each country's stochastic discount factor (SDF) is exposed to multiple and potentially correlated global risk factors. According to this model, HML currency portfolios isolate these global factors, as long as countries are heterogeneously exposed to them. We motivate our global volatility and depreciation factors calculated from option-implied characteristics from the model in Bakshi and Londono (2024), wherein the global risk factors are related to volatility and tail currency movement.

We document substantial variation in option-implied volatility and 10-delta risk reversal across currencies, which provides preliminary evidence for heterogeneous exposures to global risk factors related to volatility and large U.S. dollar appreciations against other currencies. We aggregate currencies into five portfolios based on each currency's (end-of-the-month) option-implied volatility and 10-delta risk reversal. Excess returns of the portfolios sorted on both implied volatility and risk reversals are monotonically increasing, which suggests that currencies that are less exposed to these factors provide a hedge against currency volatility and large U.S. dollar appreciations. The HML volatility and depreciation portfolios generate statistically significant and economically meaningful returns—their average returns are 0.33% and 0.34%, compared to 0.47% and 0.27% for the carry and momentum strategies, respectively. These results confirm those for currency portfolio sorted on the basis of currency implied volatility in Fullwood et al. (2021) and risk reversals in Della Corte et al. (2016), which calculate volatility- and risk-reversal-based global factors comparable to ours, but do not assess their price of risk in the cross section of currency returns. We also document that, although the two factors are highly correlated and the currencies assigned to the low and high portfolios often overlap between volatility and depreciation portfolios, both factors provide useful and additional information to explain the cross section of currency returns, including for carry and momentum portfolios.

We use the traditional two-stage Fama and MacBeth (1973) approach (FMB) to estimate the price of risk associated with the volatility and depreciation factors. We first use portfolios sorted on option-implied volatility to assess the price of risk of the global volatility factor and portfolios sorted on 10-delta-risk-reversal to assess the price of risk of the global depreciation factor. To assess whether the volatility and depreciation factors contain additional useful information to explain the cross section of currency returns, we consider a three-factor model with the carry (CAR) and dollar (DOL) factors in Lustig et al. (2011) (LRV) and either the global volatility or the global depreciation factor. The estimated price of risk associated with the volatility factor is statistically significant for the cross section of portfolios sorted on ATM implied volatility and, as expected, close to the mean average return of the HML volatility portfolio. Moreover, adding the volatility factor yields substantial gains in R^2s compared to a benchmark model with only the DOL and CAR factors (36.67% versus 19.16%). Similarly, the price of risk associated with the depreciation factor is statistically significant for the cross section of portfolios sorted on 10-delta risk reversals, its estimate is close to the mean average return of the HML depreciation portfolio, and this factor yields substantial gains in R^2 with respect to the benchmark LRV model (33.04% versus 19.10%).

We then explore whether the significance of the price of risk of the volatility and depreciation factors extends to the cross section of carry and momentum portfolios. We consider a four-factor model with the DOL and CAR factors as controls and both the volatility and depreciation factors. We find that the price of risk associated with these two global factors is statistically significant for the carry and the momentum portfolios. Our evidence suggests that global risk factors obtained from currency option characteristics are useful at explaining the carry and momentum currency puzzles. Thus, the return of carry and momentum portfolios can be partially understood as exposure to global volatility and depreciation factors. Our evidence contributes to the literature for the global risk explanation of both carry and momentum puzzles (see, for instance, Della-Corte et al. (2014) and Fan et al. (2022)).

Our results for the significant price of risk associated with the global volatility and depreciation factors for carry and momentum portfolios remain robust to a battery of tests, including considering alternative option-implied volatility measures to calculate the global volatility factor, controlling for other global risk factors proposed in the literature, removing crisis episodes, and considering only the subsample of currencies from advanced economies. However, our results weaken when we consider cross-currency averages instead of HML portfolios to calculate the global volatility and depreciation factors. This result highlights the novelty of our contribution with respect to Menkhoff et al. (2012a), who construct a currency volatility factor as the average of realized return volatility across currencies and document that innovations to this factor partially explain the cross section of carry portfolios.

We also find that our results for the depreciation factor are very sensitive to the measure considered to assess investors' desire to hedge against large U.S. dollar appreciations. In particular, the significance of the price of risk for the cross section of carry and momentum portfolios disappears when considering a global risk factor calculated as the return of HML portfolios based on 25-delta risk reversals, instead of 10-delta risk reversals. 25-delta risk reversals embed information about the desire to hedge against less extreme appreciations of the U.S. dollar than 10-delta risk reversals. Moreover, the estimated price of risk associated with a global risk factor calculated from HML option-implied Skewness is only borderline significant. This evidence suggests that using options that are closer to being at the money or subsuming information from various degrees of moneyness to calculate Skewness to assess the risk of U.S. dollar appreciations is less useful to explain the carry and momentum puzzles than using 10-delta risk reversals. A global depreciation factor calculated from 10-delta risk reversals is then intuitively associated with crash risk in currency markets (Brunnermeier et al. (2009); Burnside et al. (2011); and Jurek (2014)), especially the risk of a large appreciation of the U.S. dollar with respect to foreign currencies.

Our paper joins a recent branch of the literature assessing whether information from derivative markets is useful at explaining the cross section of currency returns. Fan et al. (2022) find that an equity tail factor calculated from out-of-the-money equity options explains the cross section of carry and momentum portfolios. Foreign exchange (FX) option markets are considerably larger and more liquid than equity option markets—according to the 2022 survey of turnover in foreign exchange markets compiled by the Bank for International Settlements, the average daily turnover in FX options is over 300 billion dollars. Not surprisingly, currency options have been used to understand the cross-section of currency forward and option returns, but less attention has been paid to their ability to explain the cross section of currency returns. Della Corte et al. (2021) and Fullwood et al. (2021) also follow the intuition in Verdelhan (2018) to calculate global risk factors as carry-like strategies using currency option-implied characteristics. Della Corte et al. (2021) propose a global risk factor calculated as the return of HML currency portfolios sorted on the slope of the option-implied volatility curve; Fullwood et al. (2021) propose a global risk factor calculated forming portfolios based on currency option-implied volatility; and Zhang et al. (2024) compares the usefulness of global risk factors calculated from several option-implied volatility measures to explain the cross section of FX option returns. We extend this literature by assessing the estimated price of risk of global risk factors calculated from currency option-implied moments for the cross section of currency returns, including the carry and currency momentum puzzles.

We then assess whether the information in the volatility and depreciation factors can be exploited in an out-of-sample (OOS) exercise. Our findings contribute to a growing strand of literature using OOS settings with currency factors as predictors (FX quantos in Kremens and Martin (2019); real exchange rates within a present value model in Dahlquist and Pénasse (2022); and currency volatility in Della Corte et al. (2016)). We propose a simple strategy that takes long (short) positions in a currency portfolio if the return predicted for this portfolio from a model with the volatility and depreciation factors as predictors is positive (negative). We consider portfolios formed by assigning equal weights to all currencies in our sample or by considering only the currencies of advanced and emerging economies. We also consider the carry and momentum HML portfolios as well as their high (H) and low (L) components. While some effort has been devoted to the OOS predictability of carry trade returns as a popular currency performance criteria (Bakshi and Panayotov, 2013; Cenedese et al., 2014; Egbers and Swinkels, 2015), most papers focus on the OOS predictability of bilateral exchange rates (see Jackson and Magkonis, 2024 for a recent survey).

We find that the average returns of strategies with the volatility and depreciation factors as predictors are positive and often significant. Moreover, strategies including the depreciation factor as a predictor often beat the returns obtained from a random-walk (RW) strategy, wherein the best forecast of the return of a portfolio is its most current realization. A model with the depreciation factor beats the RW strategy in terms of average return, Sharpe ratio, and Sortino ratio for the portfolio of all currencies and those of emerging and advanced economies as well as for the carry portfolio, but not for the momentum portfolio.

This paper proceeds as follows: Section 2 introduces a stylized model for the intuition on how to extract global risk factors from currency-level return characteristics; Section 3 introduces the data and calculates the global volatility and depreciation factors; Section 4 provides empirical evidence for the price of risk of these factors and their ability to explain the cross section of currency returns; Section 5 documents the usefulness of the global factors in an OOS exercise; Section 6 concludes.

2. A currency model with multiple global factors

We propose a stylized model for currency returns wherein both the home country's (the U.S.) and the foreign country's stochastic discount factors (SDFs) are exposed to multiple global risk factors. The model is a multi-factor extension of the models in Verdelhan (2018) and Fan et al. (2022). The purpose of the model is to (i) illustrate how to extract global currency factors by forming portfolios on factors observed at the currency level and (ii) show the potential of these global factors to explain the cross section of currency returns.

For simplicity, we introduce the case of a model with two orthogonal global factors for which we do not assume a specific nature. As will become clear later, the extension to more than two factors is trivial. Later in this section, we discuss the extension to correlated global factors. Finally, we also discuss the existing literature on how the nature of these factors could be related to SDFs' exposure to global volatility and jump components, therefore, introducing a potential role for global factors related to currency volatility and asymmetric tail dynamics, which connects to our empirical evidence in Sections 3 and 4.

The SDF of any foreign country, with subscript k, is given by:

$$-m_{k,t+1} = i_{k,t} + a_{k,t} + \gamma_k u_{k,t+1} + \delta_k u_{g,t+1} + \lambda_k V_{k,t+1} + \eta_k D_{k,t+1}, \tag{1}$$

where i_k represents the risk-free interest rate of country k; a_k is a constant such that $E_t[e^{m_{k,t+1}}] = e^{i_{k,t}}$; $u_{k,t+1}$ and $u_{g,t+1}$ capture, respectively, country-specific and global shocks, which are iid normal, and the V and D factors have an idiosyncratic and a global component, as follows:

$$V_{k,t+1} = v_k V_{t+1}^g + V_{t+1}^k, \tag{2}$$

$$D_{k,t+1} = d_k D_{t+1}^g + D_{t+1}^k. \tag{3}$$

V_t^g and D_t^g are the global risk factors and V_t^k and D_t^k are the purely idiosyncratic components of factors V and D, respectively. The SDF for the U.S., which we will refer to as the home country or the country with the reference currency, follows a similar process as that in Equation (1), but, for simplicity, we remove the subscripts.

Assuming complete markets, the log change in the nominal exchange rate between the home country and any foreign country k, Δs_k, is equal to the difference of the log pricing kernels of the two countries (see, for instance, Backus et al. (2001)). That is,

$$\Delta s_{k,t+1} = m_{t+1} - m_{k,t+1}. \tag{4}$$

Thus, the excess return of investing in a foreign currency by an investor in the home country is given by:

$$\begin{aligned} rx_{k,t+1} &= -\Delta s_{k,t+1} + i_{k,t} - i_t \qquad (5) \\ &= a_t - a_{k,t} + \gamma u_{t+1} - \gamma_k u_{k,t+1} + (\delta - \delta_k) u_{g,t+1} + \lambda V_{t+1}^{US} - \lambda_k V_{t+1}^k + \eta D_{t+1}^{US} - \eta_k D_{t+1}^k \\ &+ \underbrace{(\lambda v - \lambda_k v_k) V_{t+1}^g}_{\text{Differential exposure to Factor V}} + \underbrace{(\eta d - \eta_k d_k) D_{t+1}^g}_{\text{Differential exposure to Factor D}} . \end{aligned}$$

Sorting currencies into portfolios based on an observable currency-level return characteristic associated with factor V_t^g, that is, based on $\lambda_k v_k$, yields the following return for the high-minus-low (HML) V portfolio:

$$\begin{aligned} HML_{t+1}^V &= \frac{1}{N_{HV}} \sum_{i \in HV} rx_{k,t+1} - \frac{1}{N_{LV}} \sum_{i \in LV} rx_{k,t+1} \qquad (6) \\ &= \overline{a_t}^{HV} - \overline{a_t}^{LV} + \overline{a_{k,t}}^{LV} - \overline{a_{k,t}}^{HV} + \overline{\gamma_k u_{k,t+1}}^{LV} - \overline{\gamma_k u_{k,t+1}}^{HV} + \overline{\lambda_k V_{t+1}^k}^{LV} \\ &- \overline{\lambda_k V_{t+1}^k}^{HV} + -\overline{\eta_k D_{t+1}^k}^{LV} - \overline{\eta_k D_{t+1}^k}^{HV} - (\overline{\delta_k}^{LV} - \overline{\delta_k}^{HV}) u_{g,t+1} \\ & (\overline{\lambda_k v_k}^{LV} - \overline{\lambda_k v_k}^{HV}) V_{t+1}^g + (\overline{\eta_k d_k}^{LV} - \overline{\eta_k d_k}^{HV}) D_{t+1}^g, \end{aligned}$$

where, for any parameter X, $\overline{X}^j = \frac{1}{N_j}\sum_{i\in j} X^i$ for $j = LV, HV$, where HV are all currencies with high exposure to V_t^g and LV are all currencies with low exposure to V_t^g. In the limit, that is, for a sufficiently large cross section of currencies, for portfolios sorted on $\lambda_k v_k$, $Lim_{N\to\infty}(\overline{\lambda_k v_k}^{HV} - \overline{\lambda_k v_k}^{LV}) \neq 0$. However, assuming that V^g and D^g are orthogonal global factors, this portfolio is not exposed to the D^g factor; i.e., $Lim_{N\to\infty}(\overline{\eta_k d_k}^{HV} - \overline{\eta_k d_k}^{LV}) = 0$. Thus, the HML^V portfolio isolates the global component of the V factor:

$$Lim_{N\to\infty} HML_{t+1}^V = (\overline{\lambda_k v_k}^{LV} - \overline{\lambda_k v_k}^{HV})V_{t+1}^g. \tag{7}$$

Similarly, sorting currencies into portfolios based on their exposure to the D_t^g factor, that is, based on $\eta_k d_k$ (see Equation (5)), yields the return of the HML^D currency portfolio, which isolates the global component of the D factor:

$$Lim_{N\to\infty} HML_{t+1}^D = (\overline{\eta_k d_k}^{HD} - \overline{\eta_k d_k}^{LD})D_{t+1}^g, \tag{8}$$

where HD are all currencies with high exposure to D_t^g and LD are all currencies with low exposure to H_t^g.

In a more general version of the model, V^g and D^g could be correlated, in which case,

$$Lim_{N\to\infty} HML_{t+1}^V = (\overline{\lambda_k v_k}^{HV} - \overline{\lambda_k v_k}^{LV})V_{t+1}^g + (\overline{\eta_k d_k}^{HV} - \overline{\eta_k d_k}^{LV})D_{t+1}^g, \tag{9}$$

and

$$Lim_{N\to\infty} HML_{t+1}^D = (\overline{\eta_k d_k}^{HD} - \overline{\eta_k d_k}^{LD})D_{t+1}^g + (\overline{\lambda_k v_k}^{HD} - \overline{\lambda_k v_k}^{LD})V_{t+1}^g. \tag{10}$$

For this general model, the returns of the HML portfolios are correlated; while the HML^V portfolio is dominated by the V_t^g component, the HML^D portfolio is dominated by the D_t^g component.

The intuition on how to extract global currency factors applies irrespective of the nature of the factors, as long as the exposure to these global factors differs across countries or currencies (See Equation (5)). The model in Bakshi and Londono (2024) assumes that SDFs have differential exposures to (i) global diffusive volatility and (ii) the probability of a tail currency movement and jump uncertainty. The nature of the factors in Bakshi and Londono (2024) connects to our main empirical evidence in Section 4, wherein we document that two factors obtained from currency options, namely the at-the-money (ATM) option-implied volatility and 10-delta risk reversal, are priced in the cross section of currencies and are useful at explaining the carry and currency momentum puzzles. The volatility implied by ATM currency options reflects the price paid by currency investors to hedge against changes in the exchange rate in either direction, while 10-delta risk reversals, which are measured as the implied volatility differential between 10-delta OTM calls and 10-delta OTM puts, reveal the desire to hedge against large depreciations of the foreign currency with respect to the U.S. dollar.

3. The global currency volatility and depreciation factors

In this section, we apply the intuition in Section 2 on how to extract global currency factors from differential exposures of currencies to these factors. We calculate two global factors using currency options, and we refer to them as the volatility factor and the depreciation factor. We first introduce the data and then calculate the global factors using currency portfolios sorted on either currency option-implied volatility or risk reversals. To dig deeper into the underlying mechanism behind the pricing power of these global risk factors, we investigate the association between our factors and several currency risk factors from the earlier literature as well as several characteristics of the global financial and business cycles.

3.1. Data

Our data consist of monthly quotes for 30-day maturity currency option prices as well as observations on spot exchange rates and one-month currency forward contracts. By convention, currency option prices are quoted in the form of 10-delta, 25-delta, and ATM put or call volatilities and 10-delta and 25-delta risk reversals. These quotes are obtained from a major bank. For all foreign currencies, we follow a quote convention such that the *reference* currency is the U.S. dollar. Therefore, exchange rates, S_t, are quoted from the point of view of a U.S. investor as the number of foreign currency units per one U.S. dollar. Intuitively, then, long positions in call options hedge investors against the appreciation of the U.S. dollar with respect to foreign currencies, while long positions in a put hedge investors against the depreciation of the U.S. dollar. Risk reversals, which are calculated as the difference in implied volatility between similar calls and puts, reflect the difference between the cost of insurance against the depreciation of the foreign currency with respect to the U.S. dollar and the cost of insurance against their appreciation.

Our sample runs from January 2000 to December 2020. Based on the availability of currency option data, our analysis considers the following 15 currencies: Australian dollar (AUD), British pound (GBP), Canadian dollar (CAD), Czech koruna (CZK), Danish krone (DKK), Euro (EUR), Hungarian forint (HUF), Japanese yen (JPY), New Zealand dollar (NZD), Norwegian krone (NOK), Polish zloty (PLN), South African rand (ZAR), South Korean won (KRW), Swedish krona (SEK), and Swiss franc (SEK).

Table 1 presents a set of summary statistics for currency returns, which are calculated as log changes in exchange rates, Δs_t, interest rate differentials with the U.S., which are calculated as forward discounts minus spot rates, $f_t - s_t$, and option-implied characteristics for the currencies in our sample. These option-implied characteristics are the volatility of ATM options and 10-delta risk reversals. We also show summary statistics for a global currency portfolio, which assigns equal weights to all currencies in our sample. On average, spot rate changes for all 15 currencies are negative, suggesting that the U.S. dollar depreciated on average against most major currencies during our sample period. The volatility of currency returns ranges from 0.52 for GBP to 1.12 for ZAR.

[Table 1 here.]

Table 1 documents a considerable heterogeneity across currencies in terms of interest rate differentials, option-implied volatilities, and risk reversals. Interest rate differentials are negative for the euro-area and for several European countries in our sample, while they are large and positive for the emerging market economies in our sample. Interest rate differentials range from 0.14% for Japan, the most traditional funding currency in carry trade strategies, to 0.53% for South Africa. The average ATM implied volatility is 11.52%, ranging from 9.05% (for the Canadian Dollar) to 17.96% (for the South African rand). The average 10-delta risk reversal is 1.49%, with reversals aligned with interest rate differentials ranging from -1.97% to 4.89% corresponding to the Japanese Yen and the South African rand, respectively. In line with the intuition from the model in Section 2, this large variation in option-implied characteristics across currencies suggests differential exposures to global factors.

3.2. Construction of the global volatility and depreciation factors

To calculate the return of the HML^V portfolio (see Equation (7)), which isolates information about the global currency volatility factor, we proceed as follows. At the end of each month t, we sort the currencies in our sample into quintiles according to their end-of-the-month ATM implied volatility. HML^V is calculated as the excess return difference between the portfolio of currencies with high volatility, those currencies for which agents are willing to pay more to hedge the risk of changes in the exchange rate, and that of currencies with low volatility. Similarly, the depreciation factor (see Equation (8)) is constructed by sorting currencies into quintiles at the end of each month according to their 10-delta risk reversal, similar to the procedure in Della Corte et al. (2016). The global depreciation factor, HML^D, is, by definition, the excess return difference between a portfolio of high risk-reversal currencies—those for which investors are willing to pay more to hedge against a large depreciation of the foreign currency with respect to the U.S. dollar—and a portfolio of low risk-reversal currencies.

In Table 2, we assess whether sorting currencies by volatility and risk reversal leads to significant variation in currency returns across currency portfolios and how this variation compares to the largely documented carry and currency momentum puzzles. Panel A shows the results for currencies sorted into quintiles according to their option-implied volatilities, while Panel B shows the average excess currency returns of the portfolios constructed by sorting currencies on the basis of their 10-delta risk reversals. Excess returns of the portfolios sorted on both implied volatility and risk reversals are monotonically increasing. That is, high-volatility and high-risk-reversal currencies yield higher excess returns than, respectively, low-volatility and low-risk-reversal currencies. This evidence suggests that currencies that are less exposed to these factors provide a hedge against currency volatility and large U.S. dollar appreciations, making these currencies more attractive to investors looking to hedge these risks. These investors are, therefore, willing to accept a lower expected return for holding currencies in these high portfolios. Consequently, the returns of both high-minus-low volatility and high-minus-low risk reversal portfolios are positive—0.33% and 0.34%, respectively—and statistically significant at any standard confidence level. The results for the risk reversal HML portfolio qualitatively replicate those in Della Corte et al. (2021).

[Table 2 here.]

Panel C and D of Table 2 report, respectively, the returns of the carry and currency momentum strategies, which are obtained by sorting portfolios based on, respectively, the forward discount (interest rate differential with the U.S.) and the lagged change in their exchange rate with respect to the U.S. dollar. As it has been widely documented in the literature (see, for instance Lustig et al. (2011) and Menkhoff et al. (2012c)), the carry and momentum strategies are quite profitable. The carry portfolio yields the highest excess return and Sharpe ratios—0.47% and 0.74, respectively. Although smaller than the carry strategy, the volatility and risk-reversal strategies yield higher returns and Sharpe ratios than the currency momentum strategy, which speaks of the economic magnitude of the return of HML^V and HML^D—Sharpe ratios for the volatility and risk-reversal strategies are, respectively, 0.58 and 0.51, compared to 0.48 for the momentum strategy.

3.3. The dynamics of the volatility and depreciation factors

We explore the relation of our global risk factors to the business cycle and their different informational content with respect to currency risk factors in the extant literature and . Table 3 investigates the contemporaneous association between our global volatility factor (left panel) and global depreciation factor (right panel) and several currency risk factors and business cycle variables. We run univariate contemporaneous time-series regressions of our global volatility and depreciation factors on several variables that can be classified into the following three groups: option-implied risk factors (panel A), global risk factors in the extant FX literature (panel B), and U.S. macroeconomic variables (panel C).

As can be seen in panel A, the global volatility and depreciation factors are highly correlated (0.75). We also assess the correlation between our factors obtained by sorting currencies into portfolios and factors calculated as simple equally-weighted cross-currency averages or the first principal component of time series for all currencies.[1] Both the global volatility and depreciation factors are positively and significantly correlated with the average implied volatility and the first principal component of implied volatilities, with correlations ranging from 0.15 (between global volatility and average volatility) and 0.20 (between global depreciation and the first principal component of volatilities). Although the correlations remain positive for the average implied risk reversal and the first principal component of risk reversals, these correlations are quite small and not statistically significant.

In panel B, we consider the following currency risk factors previously considered in the literature: the dollar (DOL) and carry (CAR) factors in Lustig et al. (2011), the global dollar factor (DOLglobal) in Verdelhan (2018), the global factor in risky asset prices (RAP) in Miranda-Agrippino et al. (2015), the business cycle factor (BCF), which is based on sorting countries on their output gaps, in Colacito et al. (2020), and the VIX in Lustig et al. (2011).[2] Our global risk factors are weakly correlated with global risk factors that have been shown useful for pricing currency returns. This evidence suggests that the volatility and depreciation factors contain different information with respect to factors previously suggested in the literature. R^2s are small in all regressions and estimated βs are, in general, not statistically significant. The only statistically significant relation is that between the global volatility factor and the global dollar, which have a correlation of -0.13.

[1]In Section 4.4.4, we compare the ability of portfolio-based global factors to price the cross-section of currency returns with that of cross-currency averages.

[2]Data for the dollar and carry risk factors are obtained from Hanno Lustig's website, where DOL is measured as the average of currency returns across 35 different currencies, and CAR is the return differential between the portfolio with the largest forward discount and the one with the smallest forward discount using using six portfolios for the 35 different currencies. The dollar global data are obtained from Adrian Verdelhan's website (available until April 2020). We obtain the BCF data directly from the authors (available only until January 2016).

In panel C, we asses the cyclicality of our global factors by considering a series of macroeconomic and financial U.S. variables. Both global factors are procyclical, as evidenced by the positive correlation with industrial production and the term spread, which is measured as the yield of the 10-Year Treasury bond minus that of the 2-Year Treasury bond, although the coefficient associated with IP is only statistically significant for the global volatility factor. Both factors are also positively and significantly associated with the Merrill Lynch bond market Option Volatility Estimate Index (MOVE) index, which suggests that global volatility and depreciation factors increase with uncertainty about U.S. interest rates.

[Table 3 here.]

Table 4 reports the percentage of months each currency in our sample is assigned to each quintile portfolio constructed by sorting currencies on the basis of their volatilities (left panel) and 10-delta risk reversals (right panel). We find that the low-volatility portfolio usually includes the Canadian Dollar and the Euro, while the low risk-reversal portfolio usually includes the Japanese Yen and the Swiss franc, two currencies traditionally associated with safe-haven flows and commonly used as funding currencies in carry-trade investment strategies. Conversely, both high-volatility and high risk-reversal portfolios usually include the Hungarian forint and the Polish zloty. There is often overlap between the currencies in the volatility-sorted portfolios and those in the risk reversal sorted portfolios, as suggested by the correlation between the volatility and the depreciation factors documented in Table 3.

[Table 4 here.]

3.4. Addressing the correlation between the volatility and depreciation factors

Because our global factors are highly correlated and currencies in the volatility- and depreciation-sorted portfolios often overlap, we now explore the extent to which these two factors incorporate different information. To do so, we create portfolios sorted on both characteristics simultaneously. We repeat the procedure explained in Section 3.2 to create four portfolios.

For each month, we first split the sample into low volatility and high volatility currencies; that is, those with below mean ATM volatility and those with above mean ATM volatility, respectively. We split the samples of low volatility and high volatility currencies into subsamples of low depreciation and high depreciation currencies. For instance, using only the low volatility currencies, we create two portfolios, one with currencies that have low (below mean) 10-delta risk reversals and one with currencies with high (above mean) 10-delta risk reversal currencies. We repeat this procedure of splitting into high and low risk reversals for the high volatility currencies.

The excess returns of the double-sorted portfolios are shown in Table 5. All HML portfolios yield statistically significant returns, ranging from 0.08% for the low depreciation HML volatility portfolio to 0.18% for the high volatility HML depreciation portfolio. This implies that even within low volatility currencies, high risk reversal currencies yield a significantly higher return than low risk reversal currencies The same logic applies to all other possible portfolio combinations. Our results then suggest that, event when highly correlated, both factors contain differential information.

[Table 5 here.]

4. The price of global volatility and depreciation risks in the cross section of currency returns

In this section, we estimate the price of risk associated with the global volatility and depreciation factors. We first assess whether these global factors are priced in the cross section of currencies sorted on the factors themselves. We then assess whether the factors are priced in the cross section of carry and currency momentum portfolios. We run a comprehensive set of additional tests to assess the robustness of our results.

4.1. Cross-sectional regression analysis

To test whether the global volatility and depreciation factors are useful at explaining the cross section of currency returns, we use the traditional two-pass regression methodology of Fama and MacBeth (1973) (denoted as FMB). In the first pass, we run a time series regression of currency excess returns on risk factors:

$$r_{i,t+1} = \alpha_i + \beta_{i,V/D} HML_{t+1}^{V/D} + \beta_{i,DOL} DOL_{t+1} + \beta_{i,CAR} CAR_{t+1} + \xi_{i,t+1}. \tag{11}$$

Our main explanatory variables of interest, HML^V and HML^D, are the returns of the high-minus-low portfolios that extract the global components in option-implied volatilities and 10-delta risk reversals, respectively (see Table 2). To account for systematic risk in the currency market, we control for the dollar (DOL) and carry (CAR) factors in Lustig et al. (2011).

In the second pass, we run a cross sectional regression of average excess returns on the estimated betas from the first stage to estimate the prices of risk:

$$\bar{r}_{i,t} = \hat{\beta}_{1i} \lambda_{V/D} + \hat{\beta}_{2i} \lambda_{DOL} + \hat{\beta}_{3i} \lambda_{CAR} + \xi_t. \tag{12}$$

Following Lustig et al. (2011) and Menkhoff et al. (2012b), we do not include a constant in the second pass. Equation (12) relies on the notion that currency returns are exposed to systematic risk that is related to information in global volatility and or depreciation risks, and that HML^V and HML^D contain information that is additional to the information in the DOL and CAR control factors.

We first explore a three-factor model that includes either the volatility or the depreciation factor for currency portfolios sorted on ATM implied volatility or 10-delta risk reversal, respectively.[3] We compare these results with the benchmark model in Lustig et al. (2011), wherein we only include the DOL and CAR factors. Table 6 shows the results for the second pass of the FMB procedure. In the table, we report the estimated risk prices, the estimated λs in Equation (12), the Chi-squared for the null hypothesis that pricing errors are zero, the R-squared statistics, and the root mean squared pricing errors (RMSE).

[Table 6 here.]

[3] Della Corte et al. (2021) show that the global depreciation factor is priced in the cross section of all currencies.

Estimates of λ^V are positive and statistically significant for currency portfolios sorted on ATM implied volatility and estimates of λ^D are also positive and significant for portfolios sorted on 10-delta risk reversals. Thus, both global factors bear a positive price of risk, which is, in each case, comparable to the unconditional mean of the return of HML factor-sorted portfolios (see Table 2).

The gains in R^2s for the three-factor model with respect to the model with only DOL and CAR are substantial, from 19.16% to 36.67% for the volatility portfolios and from 19.10% to 33.04% for the depreciation portfolios. RMSEs also decrease in both cases, from 0.55 to 0.47 for the volatility portfolios and from 0.55 to 0.49 for the depreciation portfolios. In both panels, the χ^2 imply that we cannot reject the null that the pricing errors are zero for both test portfolios.

4.2. Other currency puzzles

After documenting that excess returns on currencies can be explained by the factor used to sort the portfolios, we examine the extent to which these factors are priced in the cross section of carry and momentum portfolios. To do so, in Table 7, we consider a four-factor model that includes both the global volatility and depreciation factors and controls for DOL and CAR. Our test assets comprise the excess returns for the carry portfolios (panel A) and the momentum portfolios (panel B).[4]

Estimates for both λ^V and λ^D are positive and statistically significant at any standard confidence level. There are only small differences (starting from the third decimal) in the estimated price of risk associated with the volatility and depreciation factors between the carry and momentum portfolios. The estimated price of risk associated with the volatility factor is 0.39% and that associated with the momentum portfolios is 0.21% for both the carry and momentum portfolios. While the estimated price of risk associated with the volatility factor is close to the average return of the HML^V portfolio, for the depreciation factor, the estimated price of risk is roughly half the average return of the HML^D, a divergence mostly

[4] We follow Lewellen and Nagel (2010) and include the factors as additional test assets.

explained by the correlation between the volatility and depreciation factors.

In terms of explanatory power, R^2s (RMSE) are 43.10% (0.47) for the carry portfolios and 44.35% (0.45) for the momentum portfolios. Moreover, R^2s increase and RMSE decrease considerably for the four-factor model with respect to the benchmark model that only includes the DOL and CAR factors—R^2s (RMSE) increase (decrease) from 17.98% (0.56) for the carry portfolios and 19.20 (0.54) for the momentum portfolios.

[Table 7 here.]

Our results suggest that both the volatility and depreciation factors are priced in the cross section of currencies for both the carry and momentum strategies. Moreover, these factors are priced in addition to the dollar and carry factors, which have been shown in the literature to successfully play at role at explaining the cross section of currency returns. Overall, our findings provide additional support to the idea that global volatility and depreciation factors associated with the U.S. dollar are useful to understand the carry and momentum puzzles. Hence, the carry and momentum puzzles can be partially understood from the exposure of currencies to the volatility and depreciation factors. Low interest rate currencies and currencies with low returns in the past month have lower exposures to the volatility and depreciation factors. These currencies will tend to appreciate when these factors increase, essentially providing a hedge against fluctuations in these global factors.

4.3. Global factors from other currency option-implied moments

We explore whether global factors could be constructed from other currency-option-implied characteristics related to the desire to hedge against currency fluctuations and the appreciation of the U.S. dollar. We assess the price of global risk factors extracted from: (i) VIX-like option-implied volatility, which is calculated as a weighted average of the implied volatility of OTM options, instead of the ATM implied volatility (Table 8), (ii) 25-delta risk reversals, instead of 10-delta risk reversals (Table 9), and (iii) option-implied skewness, instead of 10-delta risk reversals (Table 10). For each characteristic, we repeat the procedure to extract global factors explained in Section 3.2. We then repeat the two-step FMB procedure explained in Section 4.1 to estimate the price of risk associated with these factors.

As can be seen in Table 8, considering the VIX-like currency-option-implied volatility instead of the ATM volatility yields essentially the same results for the price of risk of a volatility factor. That is, HML^{VIX} has a positive and statistically significant price of risk. Moreover, cross-sectional R^2s and χ^2s are quite similar to those reported using the HML^V factor, which suggests that gains in explanatory power when a volatility factor is added to other traditional global factors is substantial and that we cannot reject the null hypothesis that residuals are zero. The interpretation of both factors is intuitively related to fluctuations in exchange rates without specifying a direction (appreciation or depreciation). If anything, the ATM implied volatility has the advantage of being directly observable from option prices and simpler to calculate than the VIX-like implied volatility.

[Table 8 here.]

Our benchmark depreciation factor is calculated from 10-delta risk reversals; that is, from information about the desire of investors to hedge large depreciations of a particular currency with respect to the U.S. dollar. Therefore, as mentioned in the discussion of the stylized model, this factor could be related to jump or crash risk. We now explore two alternative ways to measure depreciation and jump risk. One way is to use 25-delta risk reversals, which are calculated using options that also hedge against depreciations of the foreign currency with respect to the U.S. dollar, but using options that are less far OTM than 10-delta risk reversals and, therefore, might include information closer to that of the volatility and less related to jump risk. Indeed, the results in Table 9 suggest that a global factor calculated from 25-delta risk reversals is not priced in the cross section of currencies in addition to the global volatility factor.

[Table 9 here.]

Another way to obtain information about jumps is to look at skewness, which provides information about asymmetry in the risk-neutral distribution and, therefore, on whether

U.S. dollar appreciations demand a higher risk compensation than U.S. dollar depreciations. As can be see in Table 10, the price of risk of a global skewness factor is positive, although only borderline significant. Thus, although skewness intuitively contains information about the desire to hedge against the appreciation of the U.S. dollar, as for 25-delta risk reversals, skewness subsumes information from options at different degrees of moneyness, instead of exclusively far OTM options as is the case of 10-delta risk reversals.

[Table 10 here.]

4.4. Additional robustness tests

We explore several robustness checks for the evidence regarding the pricing power of volatility and depreciation risk factors in the cross section of currency excess return. We center the attention on evidence for the carry and momentum portfolios. First, we subject our baseline model to a more stringent test by controlling for global risk factors (Table 11). Second, we show that our evidence holds if we restrict the sample of currencies to those of developed market economies (Table 12). Third, we exclude the turbulent periods in the aftermath of the subprime crisis and the COVID-19 pandemic (Table 13). Lastly, we consider simple statistical average measures (such as cross-country average and first principal component) of volatilities and risk reversals as global risk measures (Table 14).

4.4.1. Controlling for other global risk factors

Table 11 shows the estimated price of risk for an augmented version of our four-factor model in Equation (12) which includes the Delta VIX in Lustig et al. (2011), the global dollar factor in Verdelhan (2018), or the business cycle factor in Colacito et al. (2020). Estimates of both λ^V and λ^D continue to be consistently significant across all various model specifications, which suggests that exposure to these control risk factors cannot explain our findings for the significant price of risk of the global volatility and depreciation factors in the cross-section of carry and momentum portfolios. In fact, only the VIX factor appears significant in the cross section of currency returns for all test assets considered once we control for DOL, CAR,

HML^V, and HML^D.

[Table 11 here.]

4.4.2. Currencies of developed economies

We test whether our results are driven by our choice of the sample currencies. So far, all our asset pricing tests consider the entire sample of currencies, but country-specific financial conditions may play a role for the pricing of our risk factors. Table 12 reports the results for the asset-pricing tests when we restrict our sample to the 10 major developed economy currencies. These currencies are: Australian dollar, Canadian dollar, Danish krone, Euro, Japanese yen, New Zealand dollar, Norwegian krone, Swedish krona, Swiss franc, and British pound. Our findings for the usefulness of global volatility and depreciation factors in explaining the cross section of currencies hold for this sample. Interestingly, however, the carry risk factor becomes insignificant, most likely because carry strategies involve taking positions in high interest rate currencies, which are usually attributed to emerging market economies.

[Table 12 here.]

4.4.3. Non-crisis subsample period

We assess the robustness of our results to removing episodes of heightened uncertainty. In these episodes, currency volatility tends to be higher than in tranquil periods and the U.S. dollar tends to suffer large appreciations. We consider a subsample from January 2009 to December 2019. This subsample removes the financial turmoil associated with the global financial crisis in 2007-2008 and the COVID-19 pandemic period since the Spring of 2020.

The results for this subsample are shown in Table 13. Compared to the results for the full sample, we find that the pricing power of our risk factors remains significant for both carry and momentum portfolios, providing further evidence that the role of currency option volatilities and risk reversals in capturing the currencies' dynamic exposures to common sources of risk does not depend on episodes of market turbulence.

[Table 13 here.]

4.4.4. Cross-currency averages as global factors

Our method to calculate global risk factors relies on extracting their global component by exploiting the heterogeneous exposure of currencies to these global factors. We consider two alternative methods to calculate the global volatility and depreciation factors. The first method calculates global factors as the equally-weighted average of ATM option-implied volatilities and 10-delta risk reversals across all currencies. The second method considers the first principal component of either the ATM volatility or the 10-delta risk reversal for all currencies. Because exchange rates are relative quantities, portfolio-based measures isolate global factors better than cross-currency averages (Fan et al. (2022)).

The results for these alternative global factors are shown in Table 14. We find consistent evidence that cross-currency averages or principal components are less useful at explaining the cross section of currencies than HML^V and HML^D. In many cases, these alternative factors become statistically insignificant. Furthermore, the gains in R^2s are small relative to the benchmark LRV model in Table 7. For the carry portfolios, R^2 for the model with average volatility is 25.32% and for the model with the first principal component of volatilities in 23.48%, compared to 17.98% for the benchmark LRV model. Similarly, for the momentum portfolios, R^2 for the model with average volatility is 26.31% and for the model with the first principal component of volatilities in 24.44%, compared to 19.20% for the two-factor benchmark LRV model.

[Table 14 here.]

5. Conditional trading strategies

To investigate further the value of information from currency option-implied volatility and risk reversal for currency trading strategies, in this section, we perform out-of-sample (OOS) tests for the ability of the volatility and risk reversal factors to predict exchange rates. We then explore whether the predictability of these factors can be exploited to implement a profitable trading strategy.

5.1. Out-of-sample forecasting

We examine the ability of global volatility and depreciation factors to predict exchange rate returns in an OOS context. To do so, we consider the following regression:

$$r_{i,t+1} = \alpha + B(HML_t^{V/D}) + \xi_{i,t+1}, \tag{13}$$

where $r_{i,t+1}$ is the return of a currency portfolio and $HML^{V/D}$ is either the global volatility factor, HML^V, the global depreciation factor, HML^D, or a multivariate specification wherein both factors are considered (combined). To generate the predicted return of a currency portfolio, which we denote as $\hat{r}_{i,t+1}$, we use the first 120 monthly observations as the in-sample period. We then roll through the rest of the OOS period, which is employed to evaluate the statistical accuracy of each model specification and for each currency portfolio.

In Table 15, we evaluate the OOS predictive power of the volatility and depreciation factors for nine portfolios: a portfolio with all individual currencies (panel A), one with only the currencies of developed economies (panel B), one with only the currencies of emerging economies (panel C), the carry portfolio (panel D) and its low and high components (C1 and C5 in Table 2 in panels E and F, respectively), the momentum portfolio (panel G) and its low and high components (M1 and M5 in Table 2 in panels H and I, respectively). To assess the statistical accuracy of $\hat{r}_{i,t+1}$, we use four statistical measures: (1) the Mean Square Forecast Error (MSFE); (2) the relative MSFE statistic of equal predictive accuracy, given by Rel-$MSFE = \frac{1}{T}\sum_{t=M+1}^{T}(r_{t+1} - \hat{r}_{i,t+1|t})^2$, where $(r_{t+1} - \hat{r}_{i,t+1|t})^2$ is the rolling one-step ahead forecast error; (3) the OOS R^2, which is estimated as follows: $R^2_{OOS}(\%) = (1 - \frac{MSFE}{MSFE^{RW}})$*100; and (4) The Clark and West (2007b)'s (CW) test of equal predictive ability. If the relative MSFE statistic is any number less than one, or, equivalently, the OOS $R^2_{OOS}(\%)$ is positive or the CW statistic is significant, then our models are expected to generate better forecasts than the benchmark random walk (RW) model, wherein the forecast of next month's return for each portfolio is its currency month's return.

We find evidence for the ability of the depreciation factor, HML^D, whether used as a a single predictor or combined with the HML^V factor, to predict currency returns for the portfolio of all currencies or of the currencies of advanced economies. HML^D is also a useful predictor for the C1 component of the carry portfolio and the M5 component of the momentum portfolio. However, the volatility factor does not seem to be a useful OOS predictor for any of the portfolios. Moreover, the volatility and depreciation factors are less useful predictors for currency carry and momentum portfolios.

[Table 15 here.]

5.2. Trading strategy

We expand our forecasting analysis further and investigate whether the OOS predicted currency returns, $\hat{r}_{i,t+1}$, can be exploited to implement profitable trading strategies. In this simple strategy, investors long (short) the currencies in a portfolio if the predicted return is positive, $\hat{r}_{i,t+1} > 0$ (negative, $\hat{r}_{i,t+1} < 0$). The return on this strategy equals the actual return $r_{i,t+1}$ multiplied by the trading signal, which takes the value of 1 (-1) if $\hat{r}_{i,t+1} > 0$ ($\hat{r}_{i,t+1} < 0$). Intuitively, investors generate a profit only when they correctly predict the direction of the OOS predicted returns obtained using the global volatility and depreciation factors. This trading strategy is similar to that in Cenedese et al. (2016).[5]

In Table 16, we evaluate the economic performance of these trading strategies using the following six performance measures: (1) mean (μ), (2) volatility (σ), (3) skewness (γ), (4) kurtosis (κ), (5) Sharpe ratio (SR), and (6) Sortino ratio (SO), which is a modification of the Sharpe ratio that considers only negative returns to calculate the standard deviation in the denominator. We consider the same nine currency portfolios as those in Table 15, and we consider the volatility or depreciation factors individually or combined as predictors. For comparison, we report the results of a RW strategy.

[Table 16 here.]

[5] In unreported results, we also design a less aggressive trading strategy where investors do not benefit from negative returns by taking long (no position) in currency i if $\hat{r}_{i,t+1} > 0$ ($\hat{r}_{i,t+1} < 0$). The results of this long-only strategy are similar to those of the long-short strategy. These resuls are available, upon request, from the authors.

When we consider all currencies (panel A), we find positive and statistically significant returns for all model specifications (univariate and combined). Although the variance of all strategies is similar, the strategy including the depreciation factor is less negatively skewed and displays a lower kurtosis than all other strategies. Moreover, the returns obtained with the combined model comfortably beat those of the RW model in terms of average return, Sharpe ratio, and Sortino ratio—1.71%, 0.26, and 0.37, respectively, compared to 1.37%, 0.21, and 0.28 for the RW model. Although the investment strategy including the depreciation factor (individually or combined) beats the RW for both advanced (panel B) and emerging market (panel C) currencies, for the currencies of emerging markets the gains in average return, Sharpe ratio, and Sortino ratio with respect to the RW model are much higher than those for advanced economies. These results highlight differences in the economic sucess of global factors in designing a profitable currency trading strategy between the currencies of emerging and advanced economy currencies, which is consistent with the evidence documenting that currency trading strategies using emerging market currencies perform better than analogue strategies using developed market currencies (see Bansal and Dahlquist (2000), Frankel and Poonawala (2010), De Zwart et al. (2009), and Jamali and Yamani (2019)).

For the carry portfolio (panel D), the model with the depreciation factor as predictor beats the RW model—4.86% and statistically significant average return, 0.60 Sharpe ratio, and 0.76 Sortino ratio for the HML^D model compared to 4.76, 0.58, and 0.75 for the RW model. Results for the carry portfolios extend the evidence in Bakshi and Panayotov (2013); Cenedese et al. (2014); and Egbers and Swinkels (2015). The results also suggest that a profitable investment strategy can also be implemented for the currencies in the C1 component of the carry portfolio (panel E) but not for the currencies in its C5 component, for which the Sharpe and Sortino ratios are too close to those for the RW model.

Although the long-short strategy yields significant average returns for momentum portfolios, in this case, models with global volatility and depreciation factors do not beat the RW model.

These results provide consistent evidence on the economic success of our global risk factors in designing economically profitable currency trading strategies, especially for the carry portfolio or for a portfolio including the currencies of emerging market economies.

6. Conclusion

In this paper, we propose two global risk factors containing information about investors' desire to hedge against fluctuations in exchange rates with respect to the U.S. dollar and against large depreciations of foreign currencies with respect to the U.S. dollar. Thus, our factors align with the existing evidence of volatility and crash risk in currency markets. These factors are calculated from FX options, which we show contain useful information about heterogeneous exposures to global factors across currencies.

Our empirical evidence shows that the volatility and depreciation factors are priced in the cross section of currency returns, which broadens our understanding for the nature of risk compensations demanded by currency investors. Moreover, these factors are useful at explaining the cross section of carry and momentum returns, the two most studied currency puzzles in the academic literature. Thus, our evidence suggests that these puzzles can be partially explained by the exposure of carry and momentum portfolios to global volatility and large depreciation factors.

In an out-of-sample setting, we also document that the global volatility and depreciation factors can be used as predictors to implement profitable currency investment strategies. These strategies comfortably beat those obtained from a random walk for portfolios including all currencies, especially those of emerging market economies, and for the carry portfolio. These strategies are relatively easy to implement given the availability and liquidity of at-the-money and far out-of-the-money FX options.

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Table 1: Currency-level descriptive statistics

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Country	Currency symbol	$\Delta s_{k,t}$ Mean	SD	$f_t - s_t$ Mean	SD	ATM IV Mean	10-delta risk reversal Mean
Australia	AUD	-0.1	0.75	0.19	0.14	11.50	1.99
Canada	CAD	-0.01	0.59	0.01	0.07	9.05	0.73
Czech Rep.	CZK	-0.11	0.77	-0.04	0.12	11.52	1.63
Denmark	DKK	-0.09	0.62	-0.05	0.12	9.89	0.86
Euro	EUR	-0.09	0.62	-0.05	0.11	9.77	0.56
Hungary	HUF	-0.17	0.89	0.26	0.30	13.59	3.37
Japan	JPY	-0.04	0.66	-0.14	0.13	10.02	-1.97
New Zealand	NZD	-0.13	0.77	0.21	0.14	12.47	2.07
Norway	NOK	-0.13	0.73	0.06	0.15	11.55	1.28
Poland	PLN	-0.16	0.79	0.13	0.36	13.96	2.24
South Africa	ZAR	-0.04	1.12	0.53	0.19	17.96	4.89
South Korea	KRW	-0.06	0.57	0.06	0.15	10.23	2.52
Sweden	SEK	-0.08	0.76	-0.02	0.15	11.49	1.15
Switzerland	CHF	-0.14	0.67	-0.13	0.10	10.13	-0.04
U.K.	GBP	-0.14	0.52	0.03	0.11	9.60	1.05
Global Portfolio		-0.10	0.53	0.07	0.12	11.52	1.49

This table presents descriptive statistics (mean and standard deviation) for currency-level characteristics based on the following 15 currencies: Australian dollar, Canadian dollar, Czech koruna, Danish krone, Euro, Hungarian forint, Japanese yen, New Zealand dollar, Norwegian krone, Polish zloty, South African rand, South Korean won, Swedish krona, Swiss franc, and British pound. Currency symbols are shown in column (2). We show the mean and standard deviation ("SD") of raw currency returns calculated as log changes in spot rates (columns (3) and (4)). We also report the mean and standard deviation of interest rate differential with the U.S. or forward discount, $(f_t - s_t)$, which is measured as the logarithm of the one-month forward exchange rate, f_t, minus the log spot rate, s_t (columns (5) and (6)). Monthly averages of ATM option-implied volatility and 10-delta risk reversal are whown in columns (8) and (9), respectively. For all time series, we consider end-of-the month values. Our full sample period spans from January 2002 to December 2020. The last row in the table, "Global portfolio", reports aggregate summary statistics for a portfolio of all currencies, where we assign the same weight to every currency.

Table 2: Currency portfolios (U.S. investor)

Panel A: Currency volatility-sorted portfolios

Portfolio	V1	V2	V3	V4	V5	HML^V
Mean	0.07*	0.08**	0.15***	0.15***	0.40***	0.33***
Std	0.47	0.52	0.62	0.67	0.77	0.57
Skewness	-0.69	-0.55	0.00	-0.11	0.14	0.33
Kurtosis	4.32	2.75	2.23	2.64	2.55	1.84
Sharpe	0.14	0.15	0.24	0.23	0.52	0.58

Panel B: Currency risk-reversal-sorted portfolios

Portfolio	D1	D2	D3	D4	D5	HML^D
Mean	0.03	0.09*	0.13***	0.23***	0.37***	0.34***
Std	0.51	0.59	0.61	0.61	0.75	0.66
Skewness	-0.33	-0.67	-0.06	-0.32	0.09	0.48
Kurtosis	2.53	3.70	2.62	2.06	2.86	4.15
Sharpe	0.06	0.15	0.21	0.37	0.49	0.51

Panel C: Currency carry portfolios

Portfolio	C1	C2	C3	C4	C5	C5-C1
Mean	-0.01	0.03	0.13***	0.22***	0.47***	0.47***
Std	0.55	0.57	0.59	0.60	0.77	0.64
Skewness	-0.28	-0.19	-0.72	-0.55	0.02	-0.48
Kurtosis	1.27	2.98	4.26	4.22	2.83	3.16
Sharpe	-0.01	0.06	0.22	0.37	0.61	0.74

Panel D: Currency momentum portfolios

Portfolio	M1	M2	M3	M4	M5	M5-M1
Mean	0.04	0.12**	0.18***	0.19***	0.31***	0.27***
Std	0.64	0.63	0.61	0.57	0.62	0.57
Skewness	-0.31	-0.36	0.18	0.20	-0.39	0.10
Kurtosis	3.15	2.47	3.06	1.48	1.30	0.55
Sharpe	0.06	0.19	0.29	0.34	0.51	0.48

The table reports the average monthly currency excess returns, standard deviation, skewness, kurtosis, and Sharpe ratios of four currency investment strategies calculated as the returns of currency portfolios sorted on four different variables. We sort currencies based in their currency ATM implied volatility (Panel A), 10-delta risk reversal (Panel B), lagged forward discounts (Carry in Panel C), and lagged currency excess returns (Momentym in Panel D). In each panel, all currencies are sorted into five portfolios based on their sorting variable. For instance, one-fifth of currencies with the lowest values of the sorting variable are allocated to the first portfolio and one-fifth of currencies with the highest values of the sorting variable are allocated to the fifth portfolio. We also report statistics for the high-minus-low (H/L) portfolios which are constructed as the difference in returns between the fifth and the first portfolios. HML^V is the long-short portfolio of buying high volatility currencies and shorting low volatility currencies. Analogously, HML^D is the long-short portfolio of buying high reversal currencies and shorting low reversal currencies. *, ** and *** denote, respectively, statistical significance at the 10%, 5% and 1% levels.

Table 3: Differential information content of volatility and depreciation risk factors

Dep. Var. (right)	Global Volatility (HML^V)			Global Depreciation (HML^D)		
Indep. Var. (down)	$\widehat{\beta}$	$R^2(\%)$	ρ	$\widehat{\beta}$	$R^2(\%)$	ρ
A. Option-implied risk factors						
(1) HML^V			1	0.87***	56.35	0.75
(2) HML^D	0.65***	56.35	0.75			1
(3) VOL_{AVE}	1.97**	2.37	0.15	2.88***	3.78	0.19
(4) VOL_{PCA}	0.50**	2.41	0.16	0.73***	3.88	0.20
(5) REV_{AVE}	0.00	0.00	0.00	0.02	0.11	0.03
(6) REV_{PCA}	0.00	0.00	0.001	0.01	0.35	0.06
B.Risk factors in the literature						
(1) DOL	1.32	0.17	0.04	1.37	0.14	0.04
(2) CAR	1.98	0.61	0.08	1.18	0.16	0.04
(3) DOLglobal	-2.39*	1.58	-0.13	-2.42	1.19	-0.11
(4) RAP	-0.02	0.47	-0.07	-0.03	0.71	-0.08
(5) BCF	-2.36	0.83	-0.09	-1.29	0.18	-0.04
(6) VIX	0.00	0.01	0.01	0.01	0.48	0.07
C. Macroeconomic variables						
(1) log(IP)	1.55	0.34	0.06	2.02	0.44	0.07
(2) TERM	0.07*	1.32	0.11	0.05	0.39	0.06
(3) MOVE	0.00*	1.55	0.12	0.00**	2.18	0.15

The table reports the results of univariate contemporaneous time-series regressions of the global volatility factor, HML^V, in the left panel, and the global depreciation factor, HML^D, in the right panel, on several explanatory variables. We report the estimated coefficient ($\widehat{\beta}$) associated with each independent variable. All regressions have constants, but, for brevity, we do not report their estimated values. The table also shows the correlation coefficients, ρ. Independent or explanatory variables are classified into the following three groups: Panel A shows the results for option-implied risk factors; panel B shows the results for currency risk factors proposed in the extant literature; and panel C shows the results for U.S. macroeconomic variables. VOL_{AVE} (REV_{AVE}) and VOL_{PCA} (REV_{PCA}) are, respectively, the equally weighted average of ATM implied volatilities (10-delta risk reversal) across all 15 currencies and the first principal component of the ATM implied volatility (risk reversal) time series. We also consider the dollar (DOL) and carry (CAR) factors in Lustig et al. (2011), the global dollar factor (DOLglobal) in Verdelhan (2018), the global factor in risky asset prices (RAP) in Miranda-Agrippino et al. (2015), the business cycle factor (BCF), which is based on sorting countries on their output gaps, in Colacito et al. (2020), and the VIX, the option-implied volatility of the S&P 500. For U.S. macroeconomic variables, we consider the log of industrial production (IP), the term spread, calculated as the yield of the 10-Year Treasury bond minus that of the 2-Year Treasury bond, and the Merrill Lynch Option Volatility Estimate (MOVE) Index. *, ** and *** denote, respectively, statistical significance at the 10%, 5% and 1% levels.

Table 4: Currency portfolio assignment

Country	Volatility-sorted portfolios 1	2	3	4	5	Risk-reversal-sorted portfolios 1	2	3	4	5
Australia	4.8	16.2	39.9	31.6	7.5	0.4	6.1	22.4	58.3	12.7
Canada	65.8	26.8	3.9	3.5	0	28.9	36.8	29.8	3.9	0.4
Czech Rep.	3.1	14.5	42.1	36.8	3.5	4.4	20.2	35.5	35.1	4.8
Denmark	26.3	49.1	18.9	4.4	1.3	13.2	53.1	21.5	9.6	2.6
Euro	39.5	46.9	12.7	0.9	0	29.4	53.5	15.4	1.8	0
Hungary	3.9	11.8	9.2	18	57	5.3	2.6	4.8	18.9	68.4
Japan	28.5	31.6	20.2	13.6	6.1	92.5	3.9	2.2	0.9	0.4
New Zealand	3.9	21.5	42.5	32	0	8.8	23.7	55.3	12.3	0
Norway	3.1	6.1	33.3	48.2	9.2	3.9	29.8	43.4	16.2	6.6
Poland	0.9	5.7	8.3	23.2	61.8	15.8	2.2	6.6	25.9	49.6
South Africa	0.9	0.4	6.1	92.5	0	1.3	6.6	92.1	0	0
South Korea	43	25	12.3	11	8.8	9.6	11	16.2	31.6	31.6
Sweden	0.4	9.6	39	46.5	4.4	3.5	32	46.5	15.8	2.2
Switzerland	23.7	31.1	32.5	9.2	3.5	66.2	13.6	7.9	4.8	7.5
U.K.	57	20.6	5.7	4.4	12.3	22.4	26.3	30.3	16.2	4.8

This table reports the percentage of months each currency is assigned to each quintile portfolio sorted by ATM implied volatility (left panel) and 10-delta risk reversal (right panel) over our entire sample period spanning from January 2002 to December 2020. The construction method of the quintile portfolios is described in Section 3.

Table 5: Descriptive statistics for double-sorted portfolios

	V_L	V_H	V_{H-L}
D_L	0.04	0.12**	0.08**
t-value	(1.12)	(2.03)	(2.28)
Std	0.49	0.74	0.44
Skewness	-0.94	-0.66	-0.91
Kurtosis	6.01	2.74	4.27
Sharpe	0.09	0.17	0.17
D_H	0.15***	0.30***	0.15***
t-value	(4.23)	(5.92)	(4.25)
Std	0.48	0.68	0.54
Skewness	-0.16	0.01	-0.81
Kurtosis	0.98	2.92	7.55
Sharpe	0.31	0.44	0.28
D_{H-L}	0.10***	0.18***	
t-value	(3.82)	(4.52)	
Std	0.39	0.53	
Skewness	0.66	0.25	
Kurtosis	4.65	1.84	
Sharpe	0.26	0.34	

The table reports the descriptive statistics (average monthly currency excess returns, standard deviation, skewness, kurtosis, and Sharpe ratios) along with the t-statistics (for testing the null hypothesis that the mean return is equal to zero) for cross-sectional double-sorted currency portfolios based on their ATM implied volatilities and 10-delta risk reversals. Currencies with volatilities/reversals that are lower (higher) than the median are allocated to the low (high) portfolio. We also report statistics for the high-minus-low (H/L) portfolios which are constructed as the difference in returns between the "high" and "low" portfolio for each sorting variable. The V_{H-L} is the long-short portfolio of buying (selling) currencies with a volatility that is higher (lower) than the median, for a given level (high or low) of risk reversal. The D_{H-L} is constructed in a similar fashion. D_{H-L} denotes the returns on long-short portfolio in which the volatility is held constant and the difference in returns are computed based on 10-delta risk reversals.

Table 6: Cross-sectional asset pricing results

	DOL	CAR	HML^V	HML^D	χ^2	RMSE	R^2(%)
Panel A: Volatility portfolios							
$\widehat{\lambda}$	10.73***	3.65**			5.42	0.55	19.16
t-value	10.79	2.24			(0.22)		
s.e.	0.99	1.63					
$\widehat{\lambda}$	8.56***	2.76**	0.41***		8.48	0.47	36.67
t-value	7.37	2.54	5.83		(0.24)		
s.e.	1.16	1.08	0.07				
Panel B: Depreciation portfolios							
$\widehat{\lambda}$	10.77***	3.60**			5.60	0.55	19.10
t-value	10.84	2.18			(0.20)		
s.e.	0.99	1.66					
$\widehat{\lambda}$	11.16***	1.38		0.37***	8.83	0.49	33.04
t-value	11.65	0.74		5.43	(0.28)		
s.e.	0.96	1.86		0.07			

The table presents the price of risk estimates from the second-stage of the FMB asset-pricing tests for the linear three-factor model based on the dollar factor (DOL), the carry factor (CAR), and either the global volatility factor (HML^V), in panel A, or the global depreciation factor (HML^D), in panel B. The regression setting is that in Equation (12). Data for both DOL and CAR risk factors are obtained from Adrian Verdelhan's website. The HML^V factor is constructed as the excess return differential between the high and the low currency volatility portfolios (see Panel A of Table 2), and the HML^D factor is calculated as the excess return differential between the high and the low currency depreciation portfolios (see Panel B of Table 2). The test assets are the five volatility-sorted portfolios constructed by sorting currencies based on their ATM option-implied volatility (panel A) and the depreciation-sorted reversal portfolios constructed by sorting currencies based on their 10-delta risk reversal (panel B). We report estimates of λ, in annualized percentage points (along with t-statistics and Newey–West standard errors). We also report the following cross-sectional statistics: the Chi-squared (χ^2) (with p-values in parentheses), root mean squared pricing errors (RMSE), and R-squared in percentage. *,**,*** denote statistical significance at 10%, 5% and 1% levels, respectively.

Table 7: Cross-sectional asset pricing results, carry and momentum portfolios

	DOL	CAR	HML^V	HML^D	χ^2	RMSE	R^2(%)
Panel A: Carry portfolios							
λ	10.73***	3.65**			6.10	0.56	17.98
t	10.79	2.24			(0.21)		
s.e.	0.10	1.63					
$\widehat{\lambda}$	6.51***	2.28***	0.39***	0.21***	15.34	0.47	43.10
t-value	6.46	3.06	4.80	3.33	(0.16)		
s.e.	1.01	0.75	0.08	0.06			
Panel B: Momentum portfolios							
λ	10.73***	3.65**			6.79	0.54	19.20
t	10.78	2.24			(0.16)		
s.e.	0.10	1.63					
$\widehat{\lambda}$	6.51***	2.27***	0.39***	0.21***	15.13	0.45	44.35
t-value	6.46	3.05	4.79	3.32	(0.17)		
s.e.	1.01	0.75	0.08	0.06			

The table presents the price of risk estimates from the second-stage of the FMB asset-pricing tests for the linear four-factor model based on the dollar factor (DOL), the carry factor (CAR), the global volatility factor (HML^V), and the global depreciation factor (HML^D) in Equation (12). Data for both DOL and CAR risk factors are obtained from Adrian Verdelhan's website. The HML^V factor is constructed as the excess return differential between the high and the low currency volatility portfolios (see Panel A of Table 2), and the HML^D factor is calculated as the excess return differential between the high and the low currency depreciation portfolios (see Panel B of Table 2). The test assets are the five carry portfolios constructed by sorting currencies based on their lagged forward discount (panel A) and the five momentum portfolios constructed by sorting currencies based on their lagged currency excess return (panel B). We add the volatility and depreciation factors as test assets in all cases. We report estimates of λ, in annualized percentage points (along with t-statistics and Newey–West standard errors). We also report the following cross-sectional statistics: the Chi-squared (χ^2) (with p-values in parentheses), root mean squared pricing errors (RMSE), and R-squared in percentage. *,**,*** denote statistical significance at 10%, 5% and 1% levels, respectively.

Table 8: Cross-sectional asset pricing results, VIX-like currency implied volatility

Panel A: Carry portfolios

	DOL	CAR	HML^{VIX}	HML^{D}	χ^2	RMSE	R^2(%)
λ	6.36***	2.38***	0.38***	0.20***	15.88	0.47	43.58
t-value	7.57	3.10	5.38	3.65	(0.15)		
s.e.	0.84	0.77	0.07	0.06			

Panel B: Momentum portfolios

	DOL	CAR	HML^{VIX}	HML^{D}	χ^2	RMSE	R^2(%)
λ	6.36***	2.38***	0.38***	0.20***	15.15	0.45	44.85
t-value	7.58	3.09	5.38	3.64	(0.17)		
s.e.	0.84	0.77	0.07	0.06			

The table presents the asset pricing results for an alternative specification of our linear four-factor model (with the dollar factor, the carry factor, the global volatility factor, and the global depreciation factor, see Table 7), wherein we replace HML^{V} with HML^{VIX}. HML^{VIX} is calculated as the excess return difference between the high and the low VIX-like volatility portfolios. That is, we use a weighted average of the volatility implied by options at different degrees of moneyness using the method in Bakshi and Madan (2000), instead of the ATM implied volatility. The test assets are the five carry portfolios constructed by sorting currencies based on their lagged forward discount (panel A) and the five momentum portfolios constructed by sorting currencies based on their lagged currency excess return (panel B). We add the volatility and depreciation factors as test assets in all cases. We report estimates of λ, in annualized percentage points (along with t-statistics and Newey–West standard errors). We also report the following cross-sectional statistics: the Chi-squared (χ^2) (with p-values in parentheses), root mean squared pricing errors (RMSE), and R-squared in percentage. *,**,*** denote statistical significance at 10%, 5% and 1% levels, respectively.

Table 9: Cross-sectional asset pricing results, 25-delta risk reversals

Panel A: Carry portfolios

	DOL	CAR	HML^V	$HML^{D_{25}}$	χ^2	RMSE	R^2(%)
λ	6.64***	2.33***	0.46***	0.12	15.37	0.47	43.16
t-value	6.26	3.41	5.54	1.69	(0.18)		
s.e.	1.06	0.69	0.08	0.07			

Panel B: Momentum portfolios

	DOL	CAR	HML^V	$HML^{D_{25}}$	χ^2	RMSE	R^2(%)
λ	6.64***	2.33***	0.46***	0.12	14.92	0.45	44.33
t-value	6.25	3.41	5.64	1.69	(0.18)		
s.e.	1.06	0.68	0.08	0.07			

The table presents the asset pricing results for an alternative specification of our linear four-factor model (with the dollar factor, the carry factor, the global volatility factor, and the global depreciation factor, see Table 7), wherein we replace HML^D with $HML^{D_{25}}$. $HML^{D_{25}}$ is calculated as the excess return difference between the high and the low 25-delta risk reversal portfolios. That is, we use more near the money options to assess investors desire to hedge against U.S. dollar appreciations that are less severe than those hedged by 10-delta risk reversals. The test assets are the five carry portfolios constructed by sorting currencies based on their lagged forward discount (panel A) and the five momentum portfolios constructed by sorting currencies based on their lagged currency excess return (panel B) We add the volatility and depreciation factors as test assets in all cases. We report estimates of λ, in annualized percentage points (along with t-statistics and Newey–West standard errors). We also report the following cross-sectional statistics: the Chi-squared (χ^2) (with p-values in parentheses), root mean squared pricing errors (RMSE), and R-squared in percentage. *,**,*** denote statistical significance at 10%, 5% and 1% levels, respectively.

Table 10: Cross-sectional asset pricing results, Skewness risk

Panel A: Carry portfolios

	DOL	CAR	HML^V	HML^{Skew}	χ^2	RMSE	R^2(%)
λ	7.09***	2.33***	0.50***	0.11*	15.32	0.47	41.36
t-value	5.83	3.59	8.01	1.87	(0.16)		
s.e.	1.22	0.65	0.06	0.06			

Panel B: Momentum portfolios

	DOL	CAR	HML^V	HML^{Skew}	χ^2	RMSE	R^2(%)
λ	7.09***	2.32***	0.50***	0.11*	14.96	0.46	42.69
t-value	5.82	3.58	7.10	1.86	(0.17)		
s.e.	1.218	0.65	0.06	0.06			

The table presents the asset pricing results for an alternative specification of our linear four-factor model (with the dollar factor, the carry factor, the global volatility factor, and the global depreciation factor, see Table 7), wherein we replace HML^D with HML^{Skew}. HML^{Skew} is calculated as the excess return difference between the high and the low Skewness portfolios. Option-implied skewness is calculated using the method in Bakshi and Madan (2000). The test assets are the five carry portfolios constructed by sorting currencies based on their lagged forward discount (panel A) and the five momentum portfolios constructed by sorting currencies based on their lagged currency excess return (panel B). We add the volatility and depreciation factors as test assets in all cases. We report estimates of λ, in annualized percentage points (along with t-statistics and Newey–West standard errors). We also report the following cross-sectional statistics: the Chi-squared (χ^2) (with p-values in parentheses), root mean squared pricing errors (RMSE), and R-squared in percentage. *,**,*** denote statistical significance at 10%, 5% and 1% levels, respectively.

Table 11: Cross-sectional asset pricing results, additional control factors

Panel A: Carry portfolios

Model	DOL	CAR	HML^V	HML^D	VIXchg	DOLglobal	BCF	Gain in R^2
(1)	5.65***	1.49*	0.40***	0.20***	-0.02**			0.72
(2)	6.94***	1.26	0.34***	0.27***		1.24		1.56
(3)	6.30***	2.34***	0.42***	0.21**			4.89	1.19

Panel B: Momentum portfolios

Model	DOL	CAR	HML^V	HML^D	VIXchg	DOLglobal	BCF	Gain in R^2
(1)	5.65***	1.48*	0.39***	0.20***	-0.02**			0.78
(2)	6.94***	1.26	0.34***	0.27***		1.24		1.57
(3)	6.30***	2.33***	0.42***	0.21**			4.89	1.28

The table reports the asset pricing results for an augmented version of our linear four-factor model (with the dollar factor, the carry factor, the global volatility factor, and the global depreciation factor, see Table 7), wherein we include the following additional global risk factors (1) the change in VIX in Lustig et al. (2011), (2) the global dollar factor (DOLglobal) in Verdelhan (2018), and (3) the business cycle factor (BCF) in Colacito et al. (2020). The test assets are the five carry portfolios constructed by sorting currencies based on their lagged forward discount (panel A) and the five momentum portfolios constructed by sorting currencies based on their lagged currency excess return (panel B). We add the volatility and depreciation factors as test assets in all cases. We report estimates of λ, in annualized percentage points (along with t-statistics and Newey–West standard errors). We also report the following cross-sectional statistics: the Chi-squared (χ^2) (with p-values in parentheses), root mean squared pricing errors (RMSE), and the gains in R-squared when adding the new control favor with respec to the benchmark four-factor specification (see Table 7). *,**,*** denote statistical significance at 10%, 5% and 1% levels, respectively.

Table 12: Cross-sectional asset pricing results, developed countries

Panel A: Carry portfolios

	DOL	CAR	HML^V	HML^D	χ^2	RMSE	R^2(%)
λ	4.16***	1.83	0.48***	0.18**	15.57	0.48	37.94
t-value	4.35	1.41	8.18	3.17	(0.15)		
s.e.	0.96	1.30	0.06	0.06			

Panel B: Momentum portfolios

	DOL	CAR	HML^V	HML^D	χ^2	RMSE	R^2(%)
λ	4.16***	1.83	0.48***	0.18**	15.79	0.46	39.40
t-value	4.35	1.41	8.18	3.17	(0.17)		
s.e.	0.96	1.30	0.06	0.06			

The table presents the price of risk estimates from the second-stage of the FMB asset-pricing tests for the linear four-factor model based on the dollar factor (DOL), the carry factor (CAR), the global volatility factor (HML^V), and the global depreciation factor (HML^D) in Equation (12). We restrict our sample to the 10 major developed market currencies: Australian dollar, Canadian dollar, Danish krone, Euro, Japanese yen, New Zealand dollar, Norwegian krone, Swedish krona, Swiss franc, and British pound. The test assets are the five carry portfolios constructed by sorting currencies based on their lagged forward discount (panel A) and the five momentum portfolios constructed by sorting currencies based on their lagged currency excess return (panel B) We add the volatility and depreciation factors as test assets in all cases. We report estimates of λ, in annualized percentage points (along with t-statistics and Newey–West standard errors). We also report the following cross-sectional statistics: the Chi-squared (χ^2) (with p-values in parentheses), root mean squared pricing errors (RMSE), and R-squared in percentage. *,**,*** denote statistical significance at 10%, 5% and 1% levels, respectively.

Table 13: Cross-sectional asset pricing results, non-crisis subsample period

Panel A: Carry portfolios

	DOL	CAR	HML^V	HML^D	χ^2	RMSE	R^2(%)
λ	8.25***	1.78	0.33***	0.28***	14.34	0.44	45.50
t-value	5.82	1.58	5.99	4.38	(0.19)		
s.e.	1.42	1.13	0.06	0.06			

Panel B: Momentum portfolios

	DOL	CAR	HML^V	HML^D	χ^2	RMSE	R^2(%)
λ	8.25***	1.78	0.33***	0.28***	14.62	0.42	46.92
t-value	5.82	1.58	5.99	4.38	(0.20)		
s.e.	1.42	1.13	0.06	0.06			

The table presents the price of risk estimates from the second-stage of the FMB asset-pricing tests for the linear four-factor model based on the dollar factor (DOL), the carry factor (CAR), the global volatility factor (HML^V), and the global depreciation factor (HML^D) in Equation (12). The sample period spans from January 2009 (as the onset of the recovery period after the 2007-2008 global financial crisis) to December 2019 (before the COVID-19 pandemic). The test assets are the five carry portfolios constructed by sorting currencies based on their lagged forward discount (panel A) and the five momentum portfolios constructed by sorting currencies based on their lagged currency excess return (panel B) We add the volatility and depreciation factors as test assets in all cases. We report estimates of λ, in annualized percentage points (along with t-statistics and Newey–West standard errors). We also report the following cross-sectional statistics: the Chi-squared (χ^2) (with p-values in parentheses), root mean squared pricing errors (RMSE), and R-squared in percentage. *,**,*** denote statistical significance at 10%, 5% and 1% levels, respectively.

Table 14: Cross-sectional asset pricing results, cross-currency average measures

Panel A: Carry portfolios

	DOL	CAR	VOL_{AVE}	REV_{AVE}	VOL_{PCA}	REV_{PCA}	χ^2	RMSE	R^2(%)
λ	7.11***	2.03	2.64**	-0.06			15.09	0.54	25.32
t-value	5.97	1.44	2.87	-1.26			(0.16)		
s.e.	1.19	1.41	0.92	0.05					
λ	7.14***	0.80			0.61	-0.03**	16.36	0.55	23.48
t-value	2.95	0.56			0.92	-2.56	(0.13)		
s.e.	2.41	1.44			0.67	0.01			

Panel B: Momentum portfolios

	DOL	CAR	VOL_{AVE}	REV_{AVE}	VOL_{PCA}	REV_{PCA}	χ^2	RMSE	R^2(%)
λ	7.11***	2.03	2.64**	-0.06			15.13	0.53	26.31
t-value	5.97	1.44	2.87	-1.26			(0.17)		
s.e.	1.19	1.41	0.92	0.05					
λ	7.13***	0.79			0.61	-0.03**	16.72	0.54	24.44
t-value	2.95	0.55			0.92	-2.56	(0.13)		
s.e.	2.42	1.44			0.67	0.01			

The table presents the price of risk estimates from the second-stage of the FMB asset-pricing tests for the linear four-factor model based on the dollar factor (DOL), the carry factor (CAR), and alternative global volatility and depreciation factors calculated from either cross-currency averages (VOL_{AVE} and REV_{AVE}) or the first principal component of the time series for both ATM implied volatilities and risk reversals (VOL_{PCA} and REV_{PCA}). The sample period spans from January 2009 (as the onset of the recovery period after the 2007-2008 global financial crisis) to December 2019 (before the COVID-19 pandemic). The test assets are the five carry portfolios constructed by sorting currencies based on their lagged forward discount (panel A), the five momentum portfolios constructed by sorting currencies based on their lagged currency excess return (panel B), the 10 portfolios which are the joint cross section of carry and momentum portfolios (panel C), and the 15 individual currencies in our sample. We add the volatility and depreciation factors as test assets in all cases. We report estimates of λ, in annualized percentage points (along with t-statistics and Newey–West standard errors). We also report the following cross-sectional statistics: the Chi-squared (χ^2) (with p-values in parentheses), root mean squared pricing errors (RMSE), and R-squared in percentage. *,**,*** denote statistical significance at 10%, 5% and 1% levels, respectively.

Table 15: Out-of-sample predictive regressions using rolling windows

	A. All currencies			B. Developed economies			C. Emerging economies		
	HML^V	HML^D	Combined	HML^V	HML^D	Combined	HML^V	HML^D	Combined
MSFE	0.33	0.31	0.31	0.31	0.30	0.30	0.46	0.44	0.45
Rel-MSFE	1.04	0.98	0.99	1.02	0.99	0.99	1.06	1.01	1.02
R2OOS	-4.20	1.87	1.40	-2.39	1.52	1.17	-5.69	-1.00	-2.36
CW	1.33	2.27**	2.22**	1.46	2.13**	2.36**	0.64	2.13**	1.46

	D. Carry (HML)			E. C1 (Low carry)			F. C5 (High carry)		
	HML^V	HML^D	Combined	HML^V	HML^D	Combined	HML^V	HML^D	Combined
MSFE	0.48	0.56	0.60	0.332	0.33	0.33	0.68	0.69	0.69
Rel-MSFE	1.03	1.22	1.29	1.00	0.98	1.01	1.05	1.08	1.07
R2OOS	-3.27	-21.49	-29.43	-0.32	1.83	-0.50	-5.20	-7.71	-7.23
CW	-1.44	-0.80	-1.64	1.77*	3.20***	2.91***	-0.07	0.52	0.45

	G. Momentum (HML)			H. M1 (Low momentum)			I. M5 (High momentum)		
	HML^V	HML^D	Combined	HML^V	HML^D	Combined	HML^V	HML^D	Combined
MSFE	0.35	0.33	0.34	0.53	0.51	0.52	0.41	0.40	0.39
Rel-MSFE	1.05	0.99	1.04	1.08	1.04	1.06	1.00	0.99	0.96
R2OOS	-4.65	0.25	-3.53	-7.90	-4.31	-6.35	-0.16	0.901	4.11
CW	-0.27	1.64	0.059	0.47	1.52	1.01	1.85*	2.26**	2.63***

The table shows the results for the rolling-window one-month-ahead OOS forecasts generated from the following regression:

$$r_{i,t+1} = \alpha + B(HML_t^{V/D}) + \xi_{i,t+1},$$

where $r_{i,t+1}$ is the return of a currency portfolio, and $HML^{V/D}$ is either the global volatility factor, HML^V, the global depreciation factor, HML^D, or a multivariate specification wherein both factors are considered (combined). We consider separately nine portfolios: a portfolio with all individual currencies (panel A), one with only the currencies of developed economies (panel B), one with only the currencies of emerging economies (panel C), the carry portfolio (panel D) and its low and high components (C1 and C5 in Table 2 in panels E and F, respectively), the momentum portfolio (panel G) and its low and high components (M1 and M5 in Table 2 in panels H and I, respectively). The rolling OOS forecasts are obtained with rolling regressions that use the first 120 monthly observations as the in-sample period, and we then roll through the rest of the OOS period using a fixed window size of 120 observations. The table reports the following four forecast accuracy measures: MSFEs, MSFEs relative to the random walk benchmark, OOS R2(%), and Clark and West (2007a) statistics. *,**,*** denote statistical significance 10%, 5% and 1% levels, respectively.

Table 16: Economic evaluation of trading strategies

	A. All currencies				B. Developed economies				C. Emerging economies			
	RW	HML^V	HML^D	Combined	RW	HML^V	HML^D	Combined	RW	HML^V	HML^D	Combined
μ	1.37**	1.25**	1.22**	1.71***	0.25	0.77	0.87*	1.02**	2.71***	2.24***	2.82***	2.80***
σ	0.55	0.55	0.55	0.54	0.54	0.53	0.53	0.53	0.65	0.66	0.65	0.65
γ	-0.18	-0.23	-0.01	-0.00	-0.61	-0.50	-0.28	-0.20	0.07	-0.47	0.57	0.23
κ	3.74	3.72	3.53	3.77	3.47	3.71	3.64	3.67	3.84	4.17	3.18	3.67
SR	0.21	0.19	0.18	0.26	0.04	0.12	0.14	0.16	0.35	0.28	0.36	0.36
SO	0.28	0.25	0.26	0.37	0.05	0.16	0.19	0.22	0.49	0.35	0.59	0.53

	D. Carry (HML)				E. C1 (Low carry)				F. C5 (High carry)			
	RW	HML^V	HML^D	Combined	RW	HML^V	HML^D	Combined	RW	HML^V	HML^D	Combined
μ	4.76***	4.76***	4.86***	4.42***	-0.29	0.42	1.65***	1.38***	4.52***	4.05***	4.48***	4.36***
σ	0.68	0.68	0.67	0.70	0.57	0.57	0.55	0.55	0.80	0.81	0.80	0.80
γ	-0.41	-0.41	-0.43	-0.42	-0.18	0.05	0.13	0.03	0.14	-0.59	0.15	-0.57
κ	3.04	3.04	3.20	2.74	1.50	1.52	1.59	1.63	3.24	4.18	3.19	4.44
SR	0.58	0.58	0.60	0.53	-0.04	0.06	0.25	0.21	0.47	0.41	0.47	0.45
SO	0.75	0.75	0.76	0.68	-0.06	0.09	0.38	0.31	0.67	0.48	0.66	0.53

	G. Momentum (HML)				H. M1 (Low momentum)				I. M5 (High momentum)			
	RW	HML^V	HML^D	Combined	RW	HML^V	HML^D	Combined	RW	HML^V	HML^D	Combined
μ	2.78***	2.44***	2.73***	2.60***	-0.73	0.15	0.01	0.50	2.88***	2.44***	2.85***	3.16***
σ	0.58	0.59	0.58	0.58	0.68	0.69	0.69	0.68	0.62	0.64	0.62	0.61
γ	0.15	0.18	0.16	0.16	0.62	0.02	0.25	-0.12	-0.36	-0.36	0.13	0.08
κ	0.74	0.65	0.72	0.70	3.21	2.94	2.94	2.99	1.78	1.57	1.01	1.16
SR	0.40	0.35	0.39	0.37	-0.09	0.02	0.00	0.06	0.39	0.32	0.38	0.43
SO	0.70	0.61	0.69	0.65	-0.14	0.02	0.00	0.08	0.56	0.46	0.66	0.72

The table shows the results for a trading strategy where investors long (short) the currencies in a portfolio if the predicted return is positive, $\hat{r}_{i,t+1} > 0$ (negative, $\hat{r}_{i,t+1} < 0$). The return on this strategy equals the actual return $r_{i,t+1}$ multiplied by the trading signal, which takes the value of 1 (-1) if $\hat{r}_{i,t+1} > 0$ ($\hat{r}_{i,t+1} < 0$). Predicted returns are obtained from a model that considers either the global volatility factor, HML^V, the global depreciation factor, HML^D, or a multivariate specification wherein both factors are considered (combined) (see Table 15). We consider separately nine portfolios: a portfolio with all individual currencies (panel A), one with only the currencies of developed economies (panel B), one with only the currencies of emerging economies (panel C), the carry portfolio (panel D) and its low and high components (C1 and C5 in Table 2 in panels E and F, respectively), the momentum portfolio (panel G) and its low and high components (M1 and M5 in Table 2 in panels H and I, respectively). The table reports the following performance measures: mean (μ), volatility (σ), skewness (γ), kurtosis (κ), Sharpe ratio (SR), and Sortino ratio (SO) conditional on the one-month ahead OOS forecasts (obtained from rolling regressions). *,**,*** denote statistical significance 10%, 5% and 1% levels, respectively.