The Cross-Section of Currency Volatility Premia*

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Abstract

We identify a global risk factor in the cross-section of implied volatility returns in currency markets. A zero-cost strategy that buys forward volatility agreements with downward sloping implied volatility curves and sells those with upward slopes – volatility carry strategy – generates significant excess returns. The covariation with volatility carry returns fully explains the cross-sectional variation of our slope-sorted portfolios. The lower the slope, the more the forward volatility agreement is exposed to volatility carry risk. We provide evidence that exposure to volatility carry risk is related to squared differences in growth between the US and the local economy.

Keywords: Currency Volatility Risk Premia, Forward Volatility Agreement, Foreign Exchange Volatility, Term Structure.

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1 Introduction

A recent literature documents the existence of pronounced volatility risk premia, especially at the short horizon, and shows that investors care about uncertainty shocks.[1] The properties of these premia in the foreign exchange market, the world's largest financial market, remain underexplored. This paper documents that a carry trade in volatility, a long-short strategy that buys implied volatility at discount and sells implied volatility at premium in the currency option market, generates a significantly large Sharpe Ratio. This finding is very much like the well-known carry trade strategy whereby an investor is long currencies at discount and short currencies in the foreign exchange market (e.g., Lustig, Roussanov, and Verdelhan 2011; Menkhoff, Sarno, Schmeling, and Schrimpf 2012). The volatility carry returns, however, are virtually uncorrelated with the traditional carry trade as well as other popular currency strategies. Also, we present evidence that the expected returns to volatility carry compensate investors for exposure to global macroeconomic risk.

There are several features of the foreign exchange volatility market that make it of particular interest to financial economists. The over-the-counter currency option market is large and liquid with a daily average turnover equal to $254 billion as of April 2016 and a notional amounts outstanding of $11.7 trillion as of June 2016 (BIS 2016a, b). A wide range of strikes and maturities is traded, so volatility risk premia across different currency pairs and across maturities can be computed with precision. The risks being priced and traded in the FX market are macroeconomic in nature (e.g., Gabaix and Maggiori 2015; Zviadadze 2017; Colacito, Croce, Gavazzoni, and Ready 2018), so the market provides an excellent testbed for investigating the link between volatility risk premia in financial markets and real macroeconomic variables.

We conduct our analysis by examining the profitability of trading strategies using Forward Volatility Agreements (FVAs) – forward contracts that deliver the difference between the implied volatility of an exchange rate observed on the maturity date and the forward im-

[1] The literature on volatility risk premia in the equity, fixed income, and currency markets includes, among many others, Coval and Shumway (2001); Bakshi and Kapadia (2003); Bollerslev, Tauchen, and Zhou (2009); Broadie, Chernov, and Johannes (2009); Carr and Wu (2009); Christoffersen, Heston, and Jacobs (2009); Bakshi, Panayotov, and Skoulakis (2011); Ammann and Buesser (2013); Kozhan, Neuberger, and Schneider (2013); Della Corte, Ramadorai, and Sarno (2016); Londono and Zhou (2016).

plied volatility determined at the inception date. Following the pioneering work of Lustig and Verdelhan (2007), we identify a common risk factor in the data by building monthly portfolios of forward volatility agreements sorted by their slopes of volatility term structure for a broad range of maturity combinations. The first portfolio contain the highest (positive) slope currencies, while the last contains the lowest (negative). Similar to the work of Lustig, Roussanov, and Verdelhan (2011), we find that the first two principal components of the forward volatility returns account for most of the time-series variation. The first principal component is a level factor and it is virtually equal to the average excess return on all forward volatility returns (unconditional volatility premium). The second principal component is a slope factor and is highly correlated with the returns on the volatility carry - a zero-cost strategy that goes long in the last portfolio and short in the first portfolio. The covariation with the volatility carry risk factor fully explains the cross-sectional variation of our FVA portfolios. The R^2 ranges from 73.0% to 99.0%. The pricing errors of volatility excess returns are jointly insignificant for all maturity contracts ranging from 1 to 24 months. Our paper is the first to document the common factor in the currency volatility returns.

Focussing on the term structure of volatility risk premia allows us investigate whether the volatility shocks that investors are exposed to are transitory or permanent in nature. There is clear evidence from the equity index market that spot and forward volatility markets behave rather differently. Dew-Becker, Giglio, Le, and Rodriguez (2016) show that while unconditional spot variance risk premia in the S&P500 index market are large, forward premia are insignificant at maturities in excess of a month or two. We find that much the same is true in the FX market, at least insofar as unconditional risk premia are concerned. We document however that while the average rate of return on the volatility carry declines steeply with the maturity, the Sharpe ratio barely changes and remains statistically significant up to two years. This suggests that the expected returns to volatility carry is related to permanent volatility shocks.

Using a simple reduced model of the macro-economy we show that the magnitude of the volatility risk premium of a country is closely related to the distance between the local and the US state variables as measured by their squared difference. Moreover, the expected return to the volatility carry strategy compensates investors for bearing both US and global risks.

Empirically, we show that the slope of the volatility term structure for a currency pair is related to differences in economic growth between the two countries. We further decompose the implied volatility slopes into macro-related and residual components and build portfolios that capture the decomposition. We find that up to 76% of the excess return of the volatility carry strategy is explained by the squared difference in the growth rate. Finally, we show that the components of volatility slope related to inflation rates, trade balances and term spreads are both economically and statistically negligible.

Our empirical evidence is robust to a number of additional exercises. First, we show that traditional currency factors (i.e., dollar, carry, global imbalance, global FX volatility and liquidity), Fama-French global equity risk factors, and futures VIX returns cannot explain the cross-sectional variation of our implied volatility portfolios returns. Second, our volatility carry returns remain economically significant after accounting for the average bid-ask spreads of forward volatility agreements. Third, we find that different methodologies for the construction of forward implied volatility returns do not alter our key results. Finally, our results work equally well for a cross-section of 20 developed and emerging market countries as well as a subset of 10 developed countries.

Our paper builds on the recent line of research that seeks to explain currency risk premia in a cross-sectional asset pricing setting.[2] Lustig, Roussanov, and Verdelhan (2011) find that the carry factor is major source of risk in the cross-section of currency portfolios sorted by forward premia. Menkhoff, Sarno, Schmeling, and Schrimpf (2012) find that currency excess returns provide compensation for exposure to global FX volatility risk. More recently, Della Corte, Riddiough, and Sarno (2016) provide evidence that exposure to countries' external imbalances explains the cross-sectional variation of currency excess returns. Gabaix and Maggiori (2015) and Colacito, Croce, Gavazzoni, and Ready (2018) provide a theoretical basis for these empirical findings.

Our paper also contributes to the literature on the term structure of the volatility risk premium more generally. Dew-Becker, Giglio, Le, and Rodriguez (2016), Eraker and Wu

[2]The literature on carry trade is vast and includes, among many others, Brunnermeier, Nagel, and Pedersen (2009), Della Corte, Sarno, and Tsiakas (2009), Burnside, Eichenbaum, Kleshchelski, and Rebelo (2011), Jurek (2014), Lustig, Roussanov, and Verdelhan (2014), Farhi, Fraiberger, Gabaix, Ranciere, and Verdelhan (2015), Colacito, Croce, Gavazzoni, and Ready (2016), Bekaert and Panayotov (2016), Colacito, Croce, Gavazzoni, and Ready (2016), and Richmond (2016).

(2016), and Johnson (2016) show that volatility risk premia in the equity market are the largest for short maturities and decrease at longer horizons. We also contribute to this research by showing that although unconditional FX volatility risk premium exhibit a similar pattern, the volatility carry premium remains both statistically and economically large al all horizons and is related to permanent volatility shocks. Also, our exercise speaks to the related literature on the time-varying nature of exposure to volatility risk. The volatility risk premium varies with the level of volatility and market conditions (e.g., Bakshi and Kapadia 2003; Bakshi and Madan 2006; Todorov 2016; Aït-Sahalia, Karaman, and Mancini 2016; Barras and Malkhozov 2016). We show that exposure to the global risk factor that drives the local volatility risk premia co-varies with the slope of the implied volatility curve.

The rest of this paper is organized as follows. Section 2 sets the framework for our paper and describes the data set we use. Section 3 documents cross-sectional properties of the FX volatility risk premia and shows that a single factor, VCA, explains most of the cross-sectional variation in volatility excess returns. Section 4 documents the behavior of the spot volatility risk premium. Section 5 relates the volatility carry risk to macroeconomic fundamentals. Section 6 concludes. A separate Internet Appendix provides additional robustness tests and supporting analysis.

2 The Term Structure of Volatility Risk Premia

The natural way to trade the term structure of volatility risk premium in the FX market is through the use of forward volatility agreements (FVAs). They are over-the-counter derivatives that allow traders to take positions on the future level of implied volatility. We show how to synthesize these agreements using quoted currency options and present some empirical evidence on the behavior of volatility risk premia based on a large cross-section of currency pairs and different maturity combinations. This analysis will motivate our key contribution reported in the following sections.

2.1 Forward Volatility Agreement

An FVA is a forward contract on the future implied volatility of a given exchange rate. It delivers, for a one dollar investment, the difference between the implied volatility observed on the maturity date (i.e., spot implied volatility) and its forward price determined at the inception date (i.e., forward implied volatility). Both spot and forward implied volatility are defined on the same time interval but quoted at different points in time.[3]

Figure 1 about here

FVAs can be traded for different maturity combinations. To keep the notation simple, consider the time interval between times t and $t + \tau$ and let $\tau = \tau_1 + \tau_2$ such that $t < t + \tau_1 < t + \tau$. Consider then a FVA that exchanges the τ_2 period spot implied volatility observed in τ_1 period from now (*floating leg*) against the τ_2 period forward implied volatility determined today but defined over the same future time interval (*fixed leg*). We summarize the key elements of this forward contract in Figure 1. A buyer that enters into this contract at time t receives from the seller on the maturity date $t + \tau_1$ a payoff equals to

$$\left(SVOL^{\tau_2}_{t+\tau_1} - FVOL^{\tau_2}_{t,\tau_1}\right) \times M, \tag{1}$$

where $SVOL^{\tau_2}_{t+\tau_1}$ is the spot implied volatility observed at time $t+\tau_1$ and defined over the time interval between times $t+\tau_1$ and $t+\tau$, $FVOL^{\tau_2}_{t,\tau_1}$ is the forward implied volatility determined at time t and defined over the same future time interval, M denotes the notional dollar amount that converts the volatility difference into a dollar payoff, τ_1 is the maturity of the FVA and τ_2 is the maturity of the underlying financial instrument (spot implied volatility).

2.2 Synthesizing the FVA

Spot and Forward Implied Variance. We compute spot implied variance from over-the-counter currency options using the model-free approach of Britten-Jones and Neuberger (2000). The risk-neutral expectation of the integrated variance between two dates t and $t + \tau$

[3] A forward volatility agreement differs from a volatility swap as the latter is a forward contract on future *realized volatility*.

can be calculated by integrating over an infinite range of the strike prices from European call and put options expiring on these dates as

$$SVAR_t^\tau = \frac{2}{B_t^\tau}\left\{\int_0^{F_t^\tau} \frac{P_t^\tau(K)}{K^2}dK + \int_{F_t^\tau}^{\infty} \frac{C_t^\tau(K)}{K^2}dK\right\}, \tag{2}$$

where $P_t^\tau(K)$ and $C_t^\tau(K)$ are the put and call option prices at time t with strike price K and maturity date $t+\tau$, respectively, F_t^τ is the forward exchange rate at time t with maturity date $t+\tau$, and B_t^τ is the price of a domestic bond at time t with maturity date $t+\tau$.[4]

In the FX market, over-the-counter (OTC) options are generally quoted in terms of Garman and Kohlhagen (1983) implied volatilities at fixed deltas. Following Jiang and Tian (2005) and Kozhan, Neuberger, and Schneider (2013), we infer the strike prices corresponding to the deltas, use a cubic spline to interpolate between these strikes, and set implied volatility to be constant outside the range of strikes. This interpolation method is standard in the literature. Finally, we compute the option values using the Garman and Kohlhagen (1983) valuation formula and solve the integral in Equation (2) via trapezoidal integration.[5]

The forward implied variance can be constructed using spot implied variances. Since variance is additive in the time dimension, the forward variance rate can be computed as the weighted difference of spot variances (e.g., Carr and Wu 2009):

$$SVAR_t^\tau = \frac{\tau_1}{\tau}SVAR_t^{\tau_1} + \frac{\tau_2}{\tau}FVAR_{t,\tau_1}^{\tau_2}, \tag{3}$$

where $SVAR_t^\tau$ is the spot implied variance in annual terms defined between times t and $t+\tau$, and $FVAR_{t,\tau_1}^{\tau_2}$ is the forward implied variance in annual terms determined at time t for the period $t+\tau_1$ and $t+\tau$.

Spot and Forward Forward Implied Volatility. FX market participants prefer to

[4] Demeterfi, Derman, Kamal, and Zou (1999) show that the model-free method is equivalent to a portfolio that combines a dynamically rebalanced long position in the underlying asset and a static short position in a portfolio of options and a forward contract that together replicate the payoff of a log contract (Neuberger 1994). More recently, Jiang and Tian (2005) further demonstrate that the model-free implied method is valid even when the underlying price exhibits jumps, thus relaxing the diffusion assumptions of Britten-Jones and Neuberger (2000).

[5] This method introduces two types of approximation errors: (1) the truncation errors arising from using a finite number of strike prices, and (2) a discretization error resulting from numerical integration. Jiang and Tian (2005), however, show that both errors are small, if not negligible, in most empirical settings.

trade volatility derivatives as opposed to variance derivatives. This is in part because the payoff of a variance derivative is convex in volatility and large swings in volatility give rise to very large payoffs, and partly because people find it more natural to think about volatility than variance. In this paper we too focus on volatility rather than variance; following a standard approach in the literature (e.g., Jiang and Tian 2005; Della Corte, Ramadorai, and Sarno 2016), we calculate the model-free spot implied volatility by simply taking the square root of the model-free implied variance, i.e., $SVOL_t^\tau = \sqrt{SVAR_t^\tau}$.

The forward implied volatility is then calculated as $FVOL_{t,\tau_1}^{\tau_2} = \sqrt{FVAR_{t,\tau_1}^{\tau_2}}$, an approximation that is widely used in the academic literature (e.g., Della Corte, Sarno, and Tsiakas 2011; Glasserman and Wu 2011) and among investment banks (e.g., Knauf 2003; Donner and Vibhor 2015).[6]

Currency Option Data. We collect daily over-the-counter option implied volatilities on exchange rates vis-à-vis the US dollar from JP Morgan and Bloomberg. We use monthly data by sampling end-of-month implied volatilities from January 1996 to December 2015. Our core analysis uses a sample that includes up to 20 developed and emerging market countries: Australia, Brazil, Canada, Czech Republic, Denmark, Euro Area, Hungary, Japan, Mexico, New Zealand, Norway, Poland, Singapore, South Africa, South Korea, Sweden, Switzerland, Taiwan, Turkey, and United Kingdom. It starts with 9 currencies at the beginning of the sample in 1996 and ends with 20 currencies at the end of the sample in 2015.

Unlike exchange traded options, over-the-counter currency options are quoted in terms of Garman and Kohlhagen (1983) implied volatilities at fixed deltas (at-the-money, 10 delta call and put, and 25 delta call and put options) and fixed maturities. To convert deltas into strike prices and implied volatilities into option prices, we employ spot and forward exchange rates from Barclays and Reuters via Datastream, and interest rates from JP Morgan and Bloomberg.[7] This recovery exercise yields data on plain-vanilla European calls and puts for currency pairs vis-à-vis the US dollar for the following maturities: 1 month, 3 month, 6 month,

[6] This approach may be subject to the convexity bias since expected volatility is generally less than the square root of expected variance. The impact of the convexity bias, however, is negligible in our empirical analysis as the spot-forward implied volatility relation is qualitatively identical to the spot-forward implied variance.

[7] We use money market rates and interest rate swap data from which we bootstrap zero-yield rates.

12 month and 24 month. We then construct spot and forward implied volatilities using the methodology presented above.

Although our main focus is on forward volatility risk premia, we do compare with spot volatility risk premia. The spot premium is computed as the difference between the implied one month volatility at the beginning of the month and the realized volatility over the month. The realized volatility is computed from the daily returns on forward contracts.

2.3 Testing for volatility risk premia

Armed with synthetic FVA rates for different maturities and currencies, we can explore the term structure of volatility risk premia. We first set out the testing framework and then present the empirical evidence.

Testing Framework. We focus on the *excess* return on an FVA over one month defined as

$$rx^{\tau_2}_{t+1,\tau_1} = \frac{FVOL^{\tau_2}_{t+1,\tau_1-1} - FVOL^{\tau_2}_{t,\tau_1}}{FVOL^{\tau_2}_{t,\tau_1-1}}. \tag{4}$$

So for example, we might look at the return from entering into a 12/18 month FVA today (an FVA with the floating leg being the 6 month implied volatility in 12 month's time) and exiting in one month's time (when it will be a 11/17 month FVA). By examining average FVA returns for different maturities and currency pairs, we can readily establish whether there are significant volatility risk premia, and how such premia vary with maturity of the FVA.

If volatility risk premia exist and if they are not very persistent, it is plausible that they will be reflected in the term structure of volatility. There is empirical evidence that this is so in the short end of the FX market (Della Corte, Sarno, and Tsiakas 2011) and also in the equity index market (Johnson 2016). Motivated by this, we investigate whether the forward volatility premium has power to predict FVA returns at longer horizons.

To test for time-variation in variance risk premium, we employ different maturity combinations ranging from 1 to 24 months, and also use a broader data set comprising 20 currency pairs from January 1996 to December 2015. We regress the FVA return on the slope of the term structure of implied volatility at the time the trade is put on

$$rx^{\tau_2}_{t+1,\tau_1} = \alpha + \gamma FVP^{\tau 2}_{t,\tau_1} + \varepsilon_{t+1}, \tag{5}$$

where the forward volatility premium for each currency on date t is defined as

$$FVP^{\tau_2}_{t,\tau_1} = \frac{FVOL^{\tau_2}_{t,\tau_1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}}. \tag{6}$$

In the absence of risk premia, the current forward volatility is an unbiased predictor of its value next month, the expected FVA return is zero, so in the regression we would expect to see that $\alpha = 0$, $\gamma = 0$, and ε_{t+1} is serially uncorrelated (see the Internet Appendix A for more formal and detailed arguments).

Empirical Evidence. Table 1 documents the term structure of unconditional volatility risk premia across different maturities. The equally-weighted average volatility risk premia are small and insignificant for horizons over 3 months (see Panel A of Table 1). The equally-weighted average excess returns for the forward volatility agreements at 1/3 month maturities is -2.90% and statistically significant at the 1% level. The GDP-weighted average volatility risk premia are somewhat smaller than their equally-weighted counterparts (Panel B of Table 1). This evidence is in line with findings for the equity index market (see Dew-Becker, Giglio, Le, and Rodriguez 2016).

Table 1 about here

To see if there is significant conditional volatility risk premium, we empirically test the relationship between spot and forward implied volatilities using the predictive regression defined in Equation (5). We focus on a cross-section of 20 currency pairs and four different τ_1/τ maturity combinations, i.e., 1/3 month (mth), 3/6 mth, 6/12 mth, and 12/24 mth.

Table 2 about here

Panel A of Table 2 presents cross-currency pooled regressions of monthly volatility excess returns on the forward volatility premia. We report least-squares estimates of α and γ with the corresponding t-statistics (in brackets) based on Driscoll and Kraay (1998) standard errors that are heteroscedasticity consistent and robust to very general forms of cross-sectional and temporal dependence. While the coefficient α is always statistically insignificant, the coefficient γ turns out to be always negative and statistically different from zero. The estimate of γ ranges between -0.65 (with a t-stat of -4.71) for 1/3 mth and -1.82 (with a t-stat of -1.82) for 12/24 mth. We also check the extent to which our results are affected by the convexity bias. Panel B of Table 2 shows that when we run cross-currency pooled regressions of variance (as opposed to volatility) excess returns on the lagged forward volatility premium curve the results remain unchanged. Finally, we run cross-maturity pooled regressions for each currency separately. Table A1 in the Internet Appendix confirms that the results are consistent for most of the currencies. This evidence strongly rejects the hypothesis that forward implied volatility is an unbiased predictor of future spot implied volatility. This supports the statement that there exists a time-varying FX volatility risk premium at the horizons up to 24 months.

3 Cross-Section of Volatility Excess Returns

In this section we study cross-sectional variation in volatility excess returns. The previous section shows that the volatility term structure is informative about future volatility excess returns. Motivated by this finding, we investigate whether information in volatility term structure also predicts future FVA returns in the cross-section.

3.1 Implied volatility portfolios

Using forward volatility premia as a predictor is intuitively equivalent to extracting information from the slopes of the implied volatility term structures: selling (buying) an FVA with a positive (negative) forward volatility premium is tantamount to having a short (long) position on an FVA when the implied volatility curve is upward (downward) sloping. Guided by this intuition, we build portfolios of FVAs using the slopes of the implied volatility curves as the sorting variable.[8] Specifically, we measure the slope of the implied volatility curve for each currency on date t as

$$SLOPE_t = \frac{SVOL_t^{24} - SVOL_t^3}{SVOL_t^3}. \tag{7}$$

We construct portfolios of FVAs sorted by their volatility slopes in the following way. At the end of period t, we allocate the FVAs to five baskets using the volatility slope observed on date t. We rank these portfolios from high to low slope such that Portfolio 1 contains the 20% of all FVAs with the highest slope and Portfolio 5 comprises the 20% of all FVAs with the lowest slope. We re-balance them monthly from January 1996 to December 2015, and compute the excess return for each basket as an equally weighted average of the volatility excess returns within that basket. This exercise is repeated for each maturity combination τ_1/τ (i.e., 1/3 mth, 3/6 mth, 6/12 mth and 12/24 mth) using a sample that includes up to 20 countries.

Similar to Lustig, Roussanov, and Verdelhan (2011), we also construct two additional portfolios: the level strategy, denoted LEV, which corresponds to a zero-cost strategy that equally invests in all implied volatility portfolios and the volatility carry strategy, denoted VCA, which is equivalent to a long-short strategy that buys Portfolio 5 and sells Portfolio 1.

Table 3 presents summary statistics for the five portfolios of FVAs. In brackets, we report t-stats based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection.

Table 3 about here

The average excess return increases monotonically from the first portfolio to the last portfolio for all maturity combinations. The average monthly excess return on Portfolio 1 (Portfolio 5) is about −4.66% (0.49%) in Panel A (1/3 mth) and −0.40% (2.10%) in Panel D (12/24 mth). While there is no clear pattern for the standard deviation, we find that skewness is always positive and higher (lower) for Portfolio 5 than Portfolio 1 in Panels A and B (Panels

[8] Using slope of volatility term structure allows us to apply the same conditioning information across different maturities. Forward volatility premium in contract is maturity specific and hence captures information imbedded in curvature of the volatility curve. All our results go through also when we continue using forward volatility premium as the conditioning variable.

C and D). Moreover, there is also some evidence of positive return autocorrelation, especially for Portfolio 5.

We also report the summary statistics for the LEV and VCA portfolios. The average excess return of the LEV portfolio ranges from -2.39% (in Panel A) to 0.63% per month (in Panel D) but it is statistically significant only for 1/3 mth. In contrast, the average excess return for the VCA strategy – long a portfolio of FVAs with the lowest volatility slope and short a portfolio of FVAs with the highest volatility slope – is always positive and highly statistically significant. We uncover an average excess return that ranges between 5.15% (with a t-stat of 5.91) and 2.50% (with a t-stat of 5.67) per month for 1/3 mth and 12/24 mth, respectively. The corresponding annualized Sharpe ratios are also monotonically decreasing from 1.46 to 1.25.[9] The last row reports the frequency of portfolio switches ($freq$) computed as the ratio between the number of portfolio switches and the total number of returns at each date, which reveals a substantial amount of variation in the composition of the volatility portfolios.[10]

Overall, our descriptive statistics confirm that there exists a substantial cross-sectional variation in excess returns of FVAs. Furthermore, we show that implied volatility slope has the ability to predict both statistically and economically significant excess returns in the cross-section.

Figure 2 about here

Figure 2 presents the one-year rolling Sharpe ratio for the VCA strategies (based on the slope-sorted portfolios) and their equally-weighted average. The strategies exhibit a clear counter-cyclical pattern producing higher risk-adjusted excess returns during financial crisis and lower risk-adjusted excess returns otherwise. In particular, the Sharpe ratios are economically large during the financially troubled period of 1997-1999 which included the Asian financial crisis, the Russian sovereign default, and the collapse of the hedge fund LTCM. The

[9] We also present summary statistics for the portfolios sorted by forward volatility premium in Table A19 in Appendix and find qualitatively similar results.

[10] Table A24 in the Internet Appendix presents percentages that each currency pair falls into one of the five slope-sorted portfolios.

Sharpe ratios of the VCA strategies are also high during the terroristic attacks on September 11, 2001, the wars in Afghanistan and Iraq, the recent global financial crisis that started with the collapse of Lehman Brothers in September 2008, and more recently during the European Sovereign crisis. Financial crises are generally characterized by a sudden increase in risk aversion and substantial exchange rate uncertainty which drive up the price of risk. Both factors are likely to be captured by the currency option implied volatilities (e.g., Marion 2010).

3.2 Common variation in volatility excess returns

A natural question to ask is whether volatility excess returns can be understood as compensation for risk, and if so, whether they respond to the same set of risk factors that price currency excess returns (e.g., Lustig, Roussanov, and Verdelhan 2011; Menkhoff, Sarno, Schmeling, and Schrimpf 2012). In this section, we study the (slope-sorted) implied volatility portfolios in a cross-sectional asset pricing framework and show empirically that they can be thought of as reward for time-varying global risk.

We start with examining whether average excess returns stemming from the cross-sectional predictability of implied volatility slopes reflect risk premia associated with exposure to a small set of risk factors. Similar to Lustig, Roussanov, and Verdelhan (2011), we employ principal component analysis on our implied volatility portfolios and find that up to 90% of the common variation in the excess returns of these portfolio can be explained by two factors.

Table 4 about here

Table 4 presents, for different maturity combinations, the loadings of our volatility portfolios on the first two principal components as well as the fraction of the total variance (in bold) of portfolio returns associated with each principal component. Across the four maturities the first two principal components explain between 88% and 90% of the common variation in portfolio returns.[11]

[11] An alternative strategy would be to perform the principal component analysis on all the maturities simultaneously. The conclusions are very similar; the first two components correspond closely to the average of the maturity-specific component, and capture 82% of the common variation in portfolio returns. Details of the analysis are contained in Table A2 of the Internet Appendix.

The first principal component can be understood as a *level* factor as all portfolio load with similar coefficients on it, ranging between 0.52 on Portfolio 1 and 0.42 on Portfolio 5. The second principal component can be interpreted as a *slope* factor as loadings increase monotonically across portfolios, ranging from −0.82 on Portfolio 1 to 0.49 on Portfolio 5.

Two candidate risk factors emerge from our principal component analysis. The first one can be approximated as the average excess return across all implied volatility portfolios (LEV) and can be seen as the average portfolio return of a US investor who buys all FVAs in the currency option market and represents the premium she is willing to pay to hedge her US volatility risk exposure. The second one can be approximated by the return difference between Portfolio 5 and Portfolio 1 (VCA) and can be interpreted as a zero-cost strategy that buys FVAs with the lowest implied volatility slopes and sells FVAs with the highest implied volatility slopes. The correlation of the first principal component with LEV is essentially one for all maturity combinations. The correlation of the second principal component with VCA is about 0.95 on average.[12]

3.3 Asset pricing tests

In this section we now turn to a more formal investigation using standard asset pricing methods. In the absence of arbitrage opportunities, risk-adjusted excess returns have a price of zero and satisfy the following Euler equation $E_t[m_{t+1} rx^j_{t+1}] = 0$ with a stochastic discount factor (SDF) linear in the pricing factors f_{t+1} given by $m_{t+1} = 1 - b' (f_{t+1} - \mu)$, where b is the vector of factor loadings, and μ denotes the factor means. This specification implies a beta pricing model in which the expected excess return on portfolio j is equal to the factor risk price λ times the risk quantities β^j. The beta pricing model is then defined as $E[rx^j] = \lambda' \beta^j$, where the market price of risk $\lambda = \Sigma_f b$ can be obtained via the factor loadings b. $\Sigma_f = E\left[(f_t - \mu)(f_t - \mu)'\right]$ is the variance-covariance matrix of the risk factors, and β^j are the regression coefficients of each portfolio's excess return rx^j_{t+1} on the risk factors f_{t+1}.

The factor loadings b are estimated via the Generalized Method of Moments (GMM)

[12]We also compute the correlations with the risk factors of Lustig, Roussanov, and Verdelhan (2011). The correlation of the LEV factor with the dollar factor revolves around −0.45 whereas the correlation of the VCA factor with the carry factor is 0.01 on average and ranges from 0.13 for 1/3 mth and −0.05 for 12/24 mth.

of Hansen (1982). To implement GMM, we use the pricing errors as a set of moments and a prespecified weighting matrix. Since the objective is to test whether the model can explain the cross-section of expected currency excess returns, we only rely on unconditional moments and do not employ instruments other than a constant and a vector of ones. The first-stage estimation (GMM_1) employs an identity weighting matrix. The second-stage estimation (GMM_2) uses an optimal weighting matrix based on a heteroskedasticity and autocorrelation consistent estimate of the long-run covariance matrix of the moment conditions. The model's performance is then evaluated using the cross-sectional R^2 and the HJ distance measure of Hansen and Jagannathan (1997), which quantifies the mean-squared distance between the SDF of a proposed model and the set of admissible SDFs.[13]

Motivated by the principal component analysis presented above, we study the risk exposure of our implied volatility portfolios using a two-factor SDF defined as

$$m_{t+1} = 1 - b_{LEV}\left(LEV_{t+1} - \mu_{LEV}\right) - b_{VCA}\left(VCA_{t+1} - \mu_{VCA}\right), \tag{8}$$

and present asset pricing tests on the cross-sections of volatility portfolios as test assets in Table 5. We report estimates of the factor loadings b and market prices of risk λ with t-stat in brackets, the cross-sectional R^2, and the p-value of the HJ distance in parenthesis for all maturity combinations.

Table 5 about here

We find overall a positive and statistical significant price of VCA risk. In Panel A (the short term end the implied volatility curve), the estimate of λ_{VCA} is about 4.75% (with a t-stat of 4.86) per month for the first-stage GMM. This implies that an asset with a beta of one earns a risk premium of 475 basis points per month. This estimate remains very similar in terms of magnitude and statistical significance when moving to the second-stage GMM or

[13] To test whether the HJ distance is statistically significant, we simulate p-values using a weighted sum of χ^2_1-distributed random variables (see Jagannathan and Wang 1996). We also calculate the χ^2 test statistic for the null hypothesis that all cross-sectional pricing errors (i.e., the difference between actual and predicted excess returns) are jointly equal to zero. The χ^2 test results are perfectly in line with the HJ distance results and therefore are not reported to conserve space.

the FMB method. Since VCA is a tradable risk factor, its factor price of risk must equal its average excess return as the Euler equation applied to the risk factor itself would produce a coefficient β equal to one. This no-arbitrage conditions is indeed satisfied in our exercise as the average monthly excess return on the VCA factor is 5.15%, slightly higher than the estimate of λ_{VCA}. A positive estimate of the VCA risk price indicates higher (lower) risk premia for implied volatility portfolios sorted on downward (upward) sloping implied volatility curves. We also uncover strong cross-sectional fit in terms of R^2 and are unable to reject the null hypotheses that pricing errors are zero as measured by the HJ distance. Results for the other maturity combinations (see Panels B to D of Table 5) remain qualitatively very similar.

Table 5 also reports the price of LEV risk. Panel A, for instance, displays a λ_{LEV} of -2.37% per month which compares well with the average return of -2.39% per month of the LEV portfolio. This factor, then, is also statistically significant (with a t-stat of -2.20). We uncover a positive and statistically significant b_{VCA} (0.03 with a t-stat of 2.67) and a statistically insignificant b_{LEV} (-0.01 with a t-stat of -1.31), and conclude that the LEV factor does not help explain variation in volatility excess returns given the presence of the VCA factor. Our finding remains qualitatively identical in Panels B to D of Table 5, thus confirming that we can price the cross-section of the implied volatility portfolios just as well without the LEV factor as with it. While the level factor does not help explain the cross-sectional variation in expected returns, it is important for the level of average returns as it works as a constant that allows for a common mispricing in the cross-sectional regression. In sum, we find that the volatility carry factor is the only source of priced risk in the cross-section of our implied volatility portfolios.

3.4 Exposure to VCA and other global risk factors

If VCA is the only source of risk that matters in the cross-section, the volatility excess return should increase with its exposure to the VCA factor as measured by the factor betas. We estimate the exposure of each portfolio to the LEV and VCA factors by running the following time-series regressions for each maturity combination (we omit subscripts corresponding to maturities for simplicity)

$$rx^j_{t+1} = \alpha^j + \beta^j_{LEV} LEV_{t+1} + \beta^j_{VCA} VCA_{t+1} + \varepsilon^j_{t+1} \tag{9}$$

We present the least squares estimates of these regressions in Table 6. In Panel A, we find that the first and the last portfolios have an estimate of α of 0.81% per month, statistically significant at 5% level. The estimates of α for the other portfolios are smaller and negative, and the null hypothesis that the alphas are jointly zero cannot be rejected at the 5% or 10% significance level since the p-value of the χ^2_α statistic is 0.21. The next column reports the beta estimates of the LEV factor which are all statistically significant and indistinguishable from one. This is expected as LEV is essentially the first principal component and does not explain any of the variation in average excess returns across portfolios.

Table 6 about here

The third column presents the beta estimates for the VCA factor which increase monotonically from −0.58 (with a t-stat of −13.37) for Portfolio 1 to 0.42 (with a t-stat of −9.76) for Portfolio 5. Moreover, the goodness of fit is very high since the R^2 is in the range between 86.0% and 93.7%. These results remain largely comparable for the other maturity combinations presented in Panels B to D of Table 6.

Alternative Risk Factors. We also check if the volatility carry factor explains the cross-section of our implied volatility portfolios beyond what is explained by a set of other alternative risk factors, like traditional currency factors, global equity factors or the US equity volatility factors. We use the following traditional currency factors: dollar (DOL), carry (CAR), global imbalance (IMB), FX global volatility (VOL) and liquidity (LIQ) risk factors (e.g., Lustig, Roussanov, and Verdelhan 2011; Menkhoff, Sarno, Schmeling, and Schrimpf 2012; Della Corte, Riddiough, and Sarno 2016). We briefly outline how these tradable factors are constructed in the Internet Appendix B. To test for the exposure to the global equity risks, we use the global equity factor such as global equity (MKT), size (SMB), value (HML), profitability (RMW)

and investment (CMA).[14] Finally, we use the VIX futures returns ranging from 1-month (R_1) to 6-month (R_6) to proxy the US equity volatility factors. The data on VIX futures returns are from Travis Johnson's website. For this exercise we use a reduced sample due to VIX futures data availability: from April 2004 to December 2015.

Table 7 about here

Armed with these factors, we regress the volatility excess return for each of the 20 implied volatility portfolios on a constant, the level factor and the set of factors outlined above. We present the least-squares estimates of the alphas for each portfolio in Table 7. The alphas are statistically significant in most of the cases and the null hypothesis that the intercepts are jointly equal to zero is rejected at the 1% significance level. On the basis of this exercise, we conclude that the existing risk factors are unable to fully explain the variation in the excess returns of our implied volatility volatility portfolios.[15]

3.5 Impact of transaction costs

We also examine the effect of transaction costs on the profitability of our volatility carry strategies by computing excess returns net of bid-ask spreads. In the Internet Appendix C, we provide a detailed description of how we compute and account for transaction costs. Bid and ask quotes for over-the-counter volatility derivatives are notoriously difficult to obtain, especially for a fairly long period of time and a large cross-section of countries. For our calculations, we rely on average quoted bid-ask spreads, different across countries and maturities, obtained from a large market participant in the currency option market. In particular, the average bid-ask spread is about 100 *bps* for the shortest maturity and 80 *bps* for the longest maturity in our sample. While the profitability of the volatility carry strategies drops on average by 24%, it remains both economically and statistically significant (see Tables A4-A5 in the Internet Appendix).

[14] We use ex-US equity factors as our test assets are dollar-neutral. We also use cum-US equity factors but results remain qualitatively identical.

[15] While the LEV factor is always highly statistically significant, the explanatory power of other factors is small and statistically insignificant with very few exceptions. This is further corroborated by the fact that the R^2 (based on all factors) and R^2_{LEV} (based on the level factor only) are by and large identical. See Tables A13-A15 in the internet Appendix.

3.6 Additional exercises

We analyze a variety of other issues. We briefly discuss some of these exercises here and refer to the Internet Appendix for additional details. Some countries in our sample may be subject to capital controls and their currency options might not be tradable in large amounts. To address this concern, we consider a subsample of 10 developed countries but our results remain substantially unaltered (see the Internet Appendix D). We show that the VCA factor does a reasonably good job at pricing the cross-section of country-level volatility excess returns (see the Internet Appendix E). Finally, we also find that alternative methods to synthesize spot and forward implied volatility lead to qualitatively identical results (see the Internet Appendix F).

4 Spot volatility risk premia

We have explored the behaviour of forward volatility risk premia through the lens of FVAs. It is natural to ask how this analysis relates to the more traditional approach to measuring volatility risk premia, which uses variance or volatility swaps. The relationship is in fact a close one. Going long a 3/6 mth FVA is very similar to going long a 6 mth volatility swap and going short a 3 month volatility swap (there is a small convexity correction since we are working with volatilities rather than variances, and there is a difference in the timing of cash flows). In effect, the strategy of going long a 1 month volatility swap can be seen as the limit case of a 0/1 mth FVA strategy.

In Panel A of Figure 3, the average excess returns from the VCA and LEV strategies are plotted for the five maturities; Panel B shows the corresponding Sharpe ratios.[16]

Figure 3 about here

The behaviour of LEV is strikingly similar to the behaviour of the equity market risk premium shown in Dew-Becker, Giglio, Le, and Rodriguez (2016); there is a large, highly significant negative spot volatility risk premium that declines rapidly in magnitude with horizon

[16]The underlying data for the forward strategies is tabulated in Table 3; the tabulated results for the spot volatility strategies are in Table A9 in the Internet Appendix.

and is insignificantly different from zero at longer maturities. As they argue, this suggests that the spot volatility risk premium is related to transient volatility shocks. The behaviour of VCA is quite different. While its magnitude declines with maturity, its risk declines too so its Sharpe ratio is virtually independent of horizon. This suggests that the VCA risk premium is related to permanent volatility shocks.

The fact that transient volatility shocks are priced whereas permanent ones are not suggests that it is not asset price volatility per se that is bad but rather a sudden change to the level of instantaneous volatility; the explanation may lie more with the fragile funding of intermediaries than with the preferences of long term investors. Whatever the correct explanation, it is worth noting that the marked difference between spot and forward risk premia is not unique to the volatility markets. Much of the work on bond risk premia has looked at the excess return of long-term rates on the short rate, defined as the 1 or 3 months rate; this is analogous to the forward risk premium. The analog to the spot risk premium is the difference between the short rate and the overnight rate. As shown for example by Longstaff (2000), Della Corte, Sarno, and Thornton (2008) the spot risk premium behaves very differently from the forward premium – whereas the forward premium is large and positive, the spot premium (the difference between the one month and overnight rates) is close to zero.[17]

5 FX Volatility Risk and Macroeconomic Variables

The main purpose of this paper is to demonstrate the existence of the forward volatility risk premium in the FX market and to document its properties. But these findings in turn raise a host of other questions: what explains the volatility risk premium? What type of information does the slope of volatility term structure capture? Can one link the global volatility risk factors we have identified to macro-economic variables?

In this section we do not presume to resolve these questions comprehensively. Our aim is to build a reduced form model that captures, at least in qualitative terms, the properties of the long term volatility risk premium we have documented and sheds light on the relation

[17]Table A10 in the Internet Appendix provides the results of the asset pricing tests using portfolios of volatility swap returns. We find contrasting results with those in the forward volatility. Specifically, the LEV factor now is significant, while the VCA factor is significant only in some of the specifications.

between the volatility risk premium in the FX market and macroeconomic variables.

5.1 Modelling the Volatility Risk Premium

Our model is loosely based on Bakshi, Carr, and Wu (2008) and Lustig, Roussanov, and Verdelhan (2011) in modelling the stochastic discount factors (SDFs) in each country directly, and having them subject to both local and global risk. We do not specify the functional form of the dependence of the SDFs on the risk factors so as to keep the model flexible. We have a world of J identical countries, with local and global risk. The price of local risk depends on the local state variable, while the price of global risk depends on both the local and the global state variable:

$$E[dm_t^j] - dm_t^j = k(z_t^j)du_t^j + n(z_t^j, z_t^w)du_t^w. \tag{10}$$

z_t^w is a global variable which enters the SDF of all countries, z_t^j is a local variable which enters the SDF of country j, u_t^w and u_t^i are uncorrelated standard Brownian processes that capture global and local shocks, and k and n are arbitrary functions.

The state variables follow identical (but uncorrelated) Brownian processes[18]

$$\begin{aligned} dz_t^j &= -\beta z_t^j dt + du_t^j \\ dz_t^w &= -\beta z_t^w dt + du_t^w. \end{aligned} \tag{11}$$

The instantaneous variance of the exchange rate between countries f and h is just the variance of the difference between the two stochastic discount factors

$$V^f = (k^f)^2 + (k^h)^2 + \left(n^f - n^h\right)^2, \tag{12}$$

where k^j and n^j are abbreviations for $k(z_t^j)$ and $n(z_t^j, z_t^w)$ respectively. Exchange rate volatility depends not only on the level of state variables in the two countries, but also on the distance between them.

[18]It is more conventional to assume the state variables follow a square root process, but it is simpler for our purpose to build in all the functional dependency between the state variables and the SDFs into Equation (10).

The unexpected change in the variance is

$$dV^f - E\left[dV^f\right] = 2\left[\left(k^f\frac{\partial k^f}{\partial z^f} + \left(n^f - n^h\right)\frac{\partial n^f}{\partial z^f}\right)du^f + \left(k^h\frac{\partial k^h}{\partial z^h} + \left(n^h - n^f\right)\frac{\partial n^h}{\partial z^h}\right)du^h + \left(n^f - n^h\right)\left(\frac{\partial n^f}{\partial z^w} - \frac{\partial n^h}{\partial z^w}\right)du^w\right]. \qquad (13)$$

The variance of a currency pair changes in response both to domestic and global shocks. Before using the model to make predictions about volatility risk premia, we first examine whether domestic and global shocks to the SDFs can explain changes in FX volatility. We cannot observe SDFs directly so we use equity market returns as proxies for SDF returns, with the signs reversed. We estimate the following regression of changes in volatility at various maturities τ on local and global shocks using the monthly data:

$$\Delta SVOL_{i,t}^{\tau} = \gamma_0 + \gamma_f ret_{i,t} + \gamma_h ret_{us,t} + \gamma_w ret_{w,t} + \varepsilon_{i,t}, \qquad (14)$$

where we proxy foreign, home and global state variables state variables by the equity market return of country i in month t ($ret_{i,t}$), the US equity market return ($ret_{us,t}$) and the the global equity market return ($ret_{w,t}$) respectively.[19]

Table 8 about here

The estimation results are given in Table 8. The relation between changes in volatility and global market return is negative and statistically significant. This result is an international analogue of the well known leverage effect observed in the equity index market. The exposure of the FX volatility to the local state variable is also negative but about four to five times smaller in magnitude than the exposure to the global market return. Finally, the exposure to the US market return is also relatively small and mainly insignificant. This suggests that exchange rate volatility is more sensitive to global shocks than domestic shocks.

[19]Both local and the US market returns are orthogonilized with respect the global market return prior to estimating Equation (14).

The variance risk premium is the covariance of the change in the variance with the stochastic discount factor in the home country h, times -1:

$$E_t\left[-\frac{dV^f dm}{dt}\right] = 2\left((k^h)^2\frac{\partial k^h}{\partial z^h} + (n^h - n^f)k^h\frac{\partial n^h}{\partial z^h} + n^h(n^h - n^f)\left(\frac{\partial n^f}{\partial z^w} - \frac{\partial n^h}{\partial z^w}\right)\right). \tag{15}$$

Foreign domestic shocks are not priced while home domestic shocks and global shocks are priced. Equation (15) implies that the variance risk premium can be then seen as the sum of three elements: a priced exposure to domestic (the US in our data, which are based on dollar denominated FVAs) risk which is common to all currencies, a second term that is also related to domestic risk, and which is locally linear in the difference between the state of the home and foreign countries, and a third term that relates to global risk, and is quadratic in the difference between the states of the two economies.

When constructing our high-minus-low portfolio (volatility carry), the first term is eliminated as it is common for all of the currencies. Hence, the volatility carry returns are effectively driven by the linear (compensation for the US risk) and the quadratic (compensation for global risk) terms. The results in Table 8 suggest that it is the quadratic term that should be dominant in explaining the volatility carry returns.

5.2 Empirical Evidence

Motivated by the results in the previous section, we test if the variation in the slope of the volatility curve can be explained by the squared differences in macro-economic variables. As candidate economic variables, we use year-on-year inflation rates, year-on-year industrial production growth rates, trade balances (scaled by monthly-interpolated quarterly GDP data) and term spreads (i.e., the difference between long and short-term interest rates).[20] We source all our data from the OECD and IMF.

For each period t, we run the following cross-sectional regression

$$y_{i,t} = \sum_s \beta^s (x^s_{i,t} - x^s_{us,t})^2 + \varepsilon_{i,t},$$

[20] Bansal and Shaliastovich (2013) show theoretically that inflation and consumption (proxied by real economic growth) of the foreign and home countries are the drivers of FX risk premia.

where $y_{i,t}$ is the implied volatility slope of country i in deviation from the cross-sectional median value, $x^s_{i,t}$ is the shock to the macro variable s for country i, and $x^s_{us,t}$ is the shock to the corresponding macro variable for the US (both shocks are computed as first difference). We will use these estimates to construct zero-cost investment strategies with an equal number of long and short positions.

Table 9 about here

The average estimates of the coefficient β^s is given at the bottom of Table 9. The economic growth variables is statistically significant at the 1% level. The relation between the slope and the economic growth is positive suggesting that when the foreign country is very different from the US in terms of the output growth, the slope of impled volatility tends to be positive. The trade balance variable is also significant at the 1% level but only when all other macroeconomic variables are included in the specification. However, when the trade balance is used as the only explanatory variable in the regression (see Table A18 in the Internet Appendix) the relation between the slope and the trade balance becomes insignificant. The results overall demonstrate the existence of a significant relation between the volatility slope and macroeconomic variables.

The next step is to understand how much of the volatility carry returns is due to the variation in macroeconomic factors. To do so, we decompose volatility slopes into macro-related signals and residual components (e.g., Della Corte, Sarno, Schmeling, and Wagner 2018). First, we construct a long-short dynamic slope-sorted portfolio (DSP). Similar to the VCA portfolio, the DSP is long (short) the low (high) slope currencies but the portfolio weights are different within the long and the short basket. Whereas the VCA portfolio is long the highest quintile currencies in equal amounts, short the lowest quintile and has no position in the middle quintiles, the DSP has portfolio weights that are linear in the slope. As we show later in our analysis, the performance of the DSP and VCA strategies are broadly similar. Second, we construct a portfolio of currencies for each variable which has weights proportional to that macro variable times the corresponding $\hat{\beta}^s$ coefficient, and a residual portfolio. The m macro-based portfolios and the residual portfolio together sum up to the DSP. The portfolio weights in the residual portfolio are uncorrelated in the cross-section with any of the macro factors.

The final step is to measure the performance of the $m+1$ portfolios. By construction, the excess returns must sum to the excess return on the DSP. By seeing which of the component portfolios is responsible for the excess return, one can draw conclusions about the extent to which the performance of the slope sorted portfolios can be explained by any or all of the chosen macro-variables. We outline the procedure more formally in the Internet Appendix G.

In Table 9, we report the average excess return in percentage per month (with robust t-statistics in brackets) and annualized Sharpe ratio for the overall strategy based on the total volatility slope and its decomposition into macro-related and residual components. Our empirical evidence suggests that the implied volatility slopes are both statistically and economically related to squared difference in economic growth between foreign country and the US. For the 1/3 mth, for instance, the overall excess return is 4.57% per month with a t-stat of 5.18. This is quite similar to the 5.15% return on the VCA reported in Table 3. The decomposition into macro-related and residual components, then, reveals that up to 76% of this excess return is explained by the lagged changes in economic growth (average monthly excess return of 3.46%) and 26% by the residual component (average monthly excess return of 1.20%). The link between implied volatility slopes and changes in economic growth weakens but remain both statistically and economically important for longer maturity combinations. For 12/24 mth, the overall excess return is 2.21% per month with a t-stat of 5.05. The changes in economic growth can explain up to 45% of this excess return (average monthly excess return of 1.01%) and 68% by the residual component (average monthly excess return of 1.52%). The other macro-related components continue to appear both economically and statistically insignificant. The link between implied volatility slopes and changes in economic growth weakens but remain both statistically and economically important for longer maturity combinations. In sum, we find evidence that real economic growth is able to significantly explain FX volatility risk premia.

We also estimate similar regressions and run portfolio decomposition using the linear terms (differences between the foreign and the US macro-economic variables). The results are presented in Table A16 in the Internet Appendix. As expected, the linear terms have also a significant relation with the slope variable and explain some part of volatility carry returns, but the effect is substantially smaller than the corresponding quadratic terms.

6 Conclusions

By sorting currencies by their term structure of implied volatilities we identify a common risk factor in the currency volatility returns. A zero-cost portfolio strategy that buys forward volatility agreements with the lowest implied volatility slopes (or forward volatility premia) and sells forward volatility agreements with the highest implied volatility slopes (or forward volatility premia) produces a significant excess returns. A risk factor – volatility carry strategy – fully explains the cross-sectional variation of slope-sorted volatility excess returns. The lower is the slope of the implied volatility curve, the more the forward volatility agreement return is exposed to this volatility carry premium. More importantly, the risk factor suggested by the recent literature – carry, global imbalance, global volatility and liquidity – cannot explain the cross-sectional variation of the forward volatility agreement returns. We show that empirically the state variables determining the exposure to the common risk factor are related to squared deviations of changes in economic growth.

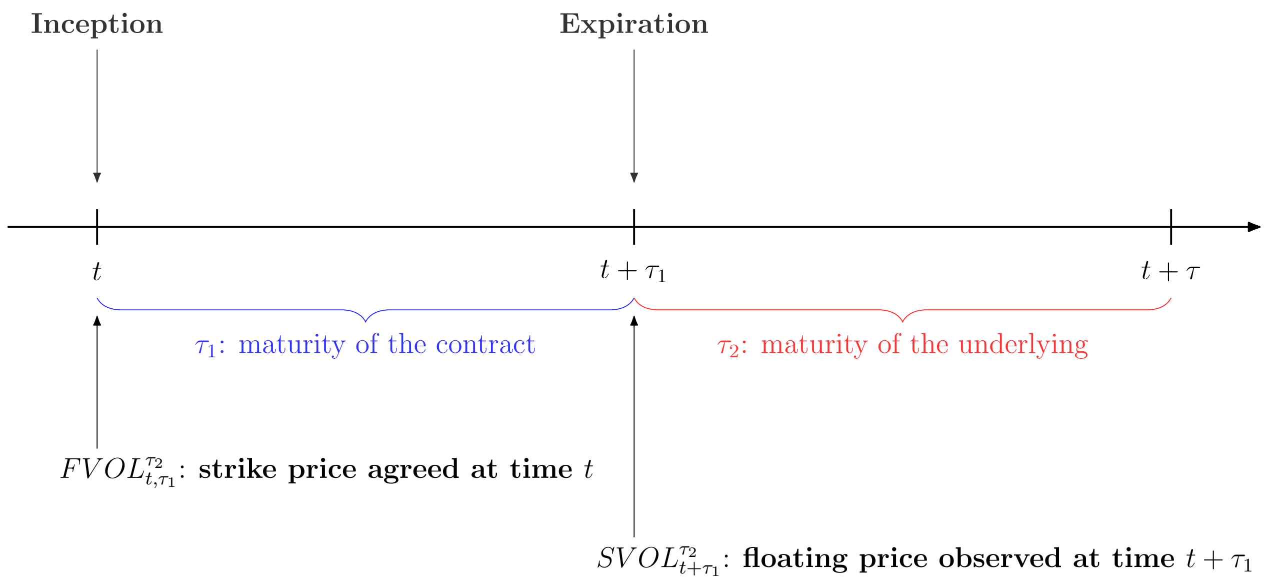

Figure 1. Forward Volatility Agreement

This figures describes a forward volatility agreement, i.e., a forward contract that exchanges the τ_2 period spot implied volatility ($SVOL^{\tau_2}_{t+\tau_1}$) observed at time $t+\tau_1$ against the forward implied volatility ($FVOL^{\tau_2}_{t,\tau_1}$) determined today but defined over the same future time interval. The buyer enters this contract at time t and receives on the maturity date $t+\tau_1$ a payoff equals to ($SVOL^{\tau_2}_{t+\tau_1} - FVOL^{\tau_2}_{t,\tau_1}$) for each dollar of notional amount.

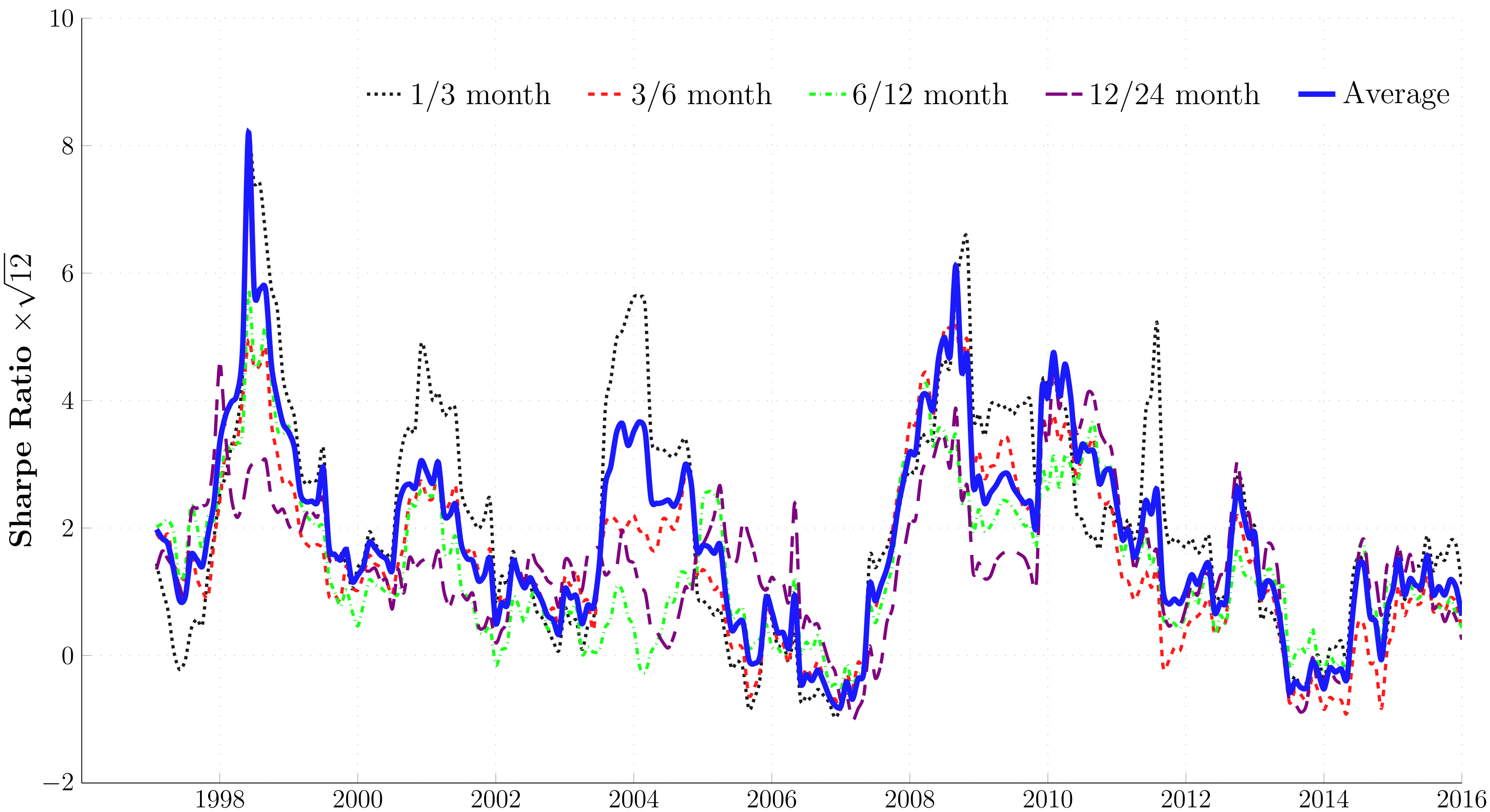

Figure 2. The Sharpe Ratios of Volatility Carry Strategies

This figures displays the annualized 1-year rolling Sharpe ratios of the volatility carry (VCA) strategies described in Table 3. Each strategy is constructed as a long-short strategy that buys a basket of forward volatility agreements with the lowest implied volatility slopes and sells a basket of forward volatility agreements with the highest implied volatility slopes using a cross-section of 20 developed and emerging market countries. The implied volatilities are model-free as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). Each slope is based on the 24-month and 3-month implied volatility. *Average* denotes the rolling Sharpe ratio of an equally-weighted basket of volatility carry strategies. The strategies are rebalanced monthly from January 1996 to December 2015. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Figure A3 in the Internet Appendix displays results for a cross-section of 10 developed countries.

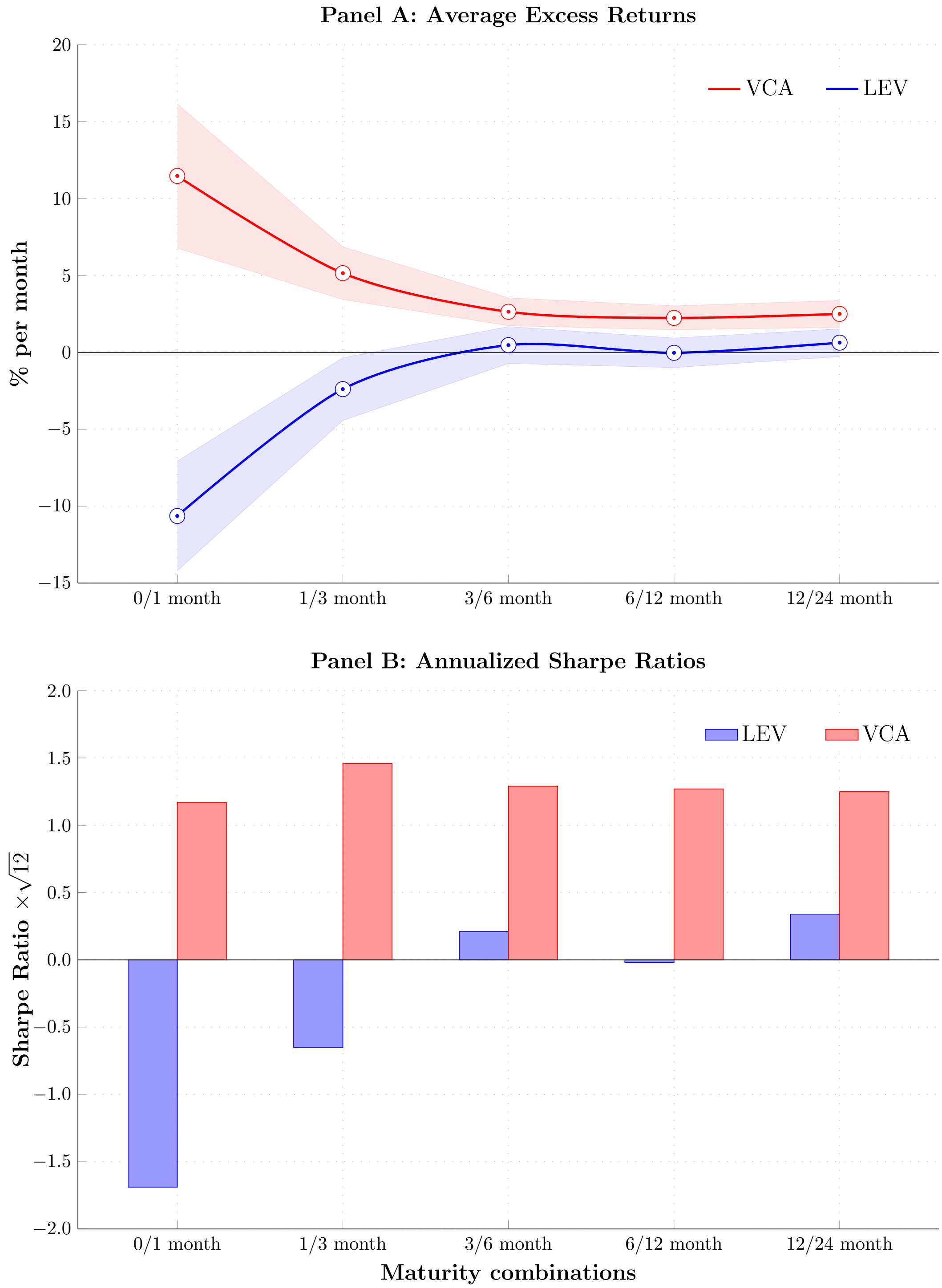

Figure 3. Performance of Volatility Carry Strategies

This figure reports average excess returns in Panel A, and annualized Sharpe Ratios in Panel B. VCA and LEV denote strategies based on portfolios of (i) forward volatility agreements from 1/3 month to 12/24 month (see Table 3), and (ii) volatility swaps for 0/1 month (see Table A9 in the Internet Appendix). Figure A4 in the Internet Appendix displays results for a cross-section of 10 developed countries.

Table 1. Descriptive Statistics: Volatility Excess Returns

This table presents descriptive statistics of equally-weighted (in Panel A) and GDP-weighted (in Panel B) volatility excess returns based on forward volatility agreements. Excess returns are computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). The table also reports the Sharpe ratio (SR) and the first order autocorrelation coefficient ac_1. t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. Excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging market countries. Table A21 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	1/3 month	3/6 month	6/12 month	12/24 month
		Panel A: Equally-weighted		
mean	-2.90	0.30	-0.17	0.54
	[-3.07]	[0.56]	[-0.40]	[1.39]
sdev	11.80	7.14	5.74	5.59
skew	1.67	1.26	1.08	1.35
$SR \times \sqrt{12}$	-0.85	0.15	-0.10	0.34
ac_1	0.23	0.16	0.16	0.09
		Panel B: GDP-weighted		
mean	-2.82	0.23	-0.15	0.43
	[-3.15]	[0.45]	[-0.40]	[1.21]
sdev	11.41	7.10	5.77	5.46
skew	1.33	0.89	0.77	1.01
$SR \times \sqrt{12}$	-0.86	0.11	-0.09	0.27
ac_1	0.18	0.11	0.06	0.03

Table 2. Predictive Regressions: Volatility Excess Returns

This table presents country-fixed effects panel regression estimates. The dependent variable is the volatility excess return whereas the explanatory variable is the lagged forward implied volatility premium, both computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). The coefficient estimates α and γ shoduld equal zero under the null that the unbiasedness hypothesis holds. t-statistics (reported in brackets) are base on Driscoll and Kraay (1998) standard errors that are heteroscedasticity consistent and robust to very general forms of cross-sectional and temporal dependence. Excess returns are expressed in percentage per month and the sample runs from January 1996 to December 2015. Data on over-the-counter currency options are from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging market countries. Table A22 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	α		γ		$R^2(\%)$
Panel A: Spot and Forward Implied Volatilities					
1/3 month	0.21	[0.19]	-0.65	[-4.71]	7.7
3/6 month	0.54	[0.92]	-0.79	[-3.00]	2.6
6/12 month	0.52	[0.98]	-1.52	[-3.21]	1.9
12/24 month	0.03	[0.05]	-1.82	[-3.74]	2.0
Panel B: Spot and Forward Implied Variances					
1/3 month	2.32	[0.87]	-0.65	[-3.85]	5.8
3/6 month	1.77	[1.44]	-0.79	[-2.78]	2.2
6/12 month	1.53	[1.34]	-1.55	[-3.18]	1.8
12/24 month	0.51	[0.41]	-1.91	[-3.71]	1.9

Table 3. Descriptive Statistics: Slope-sorted Portfolios

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their implied volatility slopes. Volatility excess returns are computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). Slopes are computed using 3 month and 24 month model-free implied volatility. The first (last) portfolio P_1 (P_5) contains forward volatility agreements with the highest (lowest) implied volatility slopes. LEV denotes a strategy that equally invests in all five portfolios whereas VCA is a long-short strategy that buys P_5 and sells P_1. The table also reports the Sharpe ratio (SR), the first order autocorrelation coefficient ac_1, and the frequency of portfolio switches ($freq$). t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table A23 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	P_1	P_2	P_3	P_4	P_5	LEV	VCA
			Panel A: 1/3 month				
$mean$	-4.66	-3.02	-2.35	-2.42	0.49	-2.39	5.15
	[-3.91]	[-2.82]	[-2.17]	[-2.61]	[0.38]	[-2.31]	[5.91]
$sdev$	16.33	14.08	13.41	12.13	14.16	12.72	12.25
$skew$	2.20	2.76	2.18	1.66	2.51	2.48	-1.34
$SR \times \sqrt{12}$	-0.99	-0.74	-0.61	-0.69	0.12	-0.65	1.46
ac_1	0.19	0.18	0.23	0.14	0.30	0.25	0.08
			Panel B: 3/6 month				
$mean$	-0.83	0.37	0.58	0.44	1.81	0.47	2.64
	[-1.31]	[0.50]	[0.93]	[0.86]	[2.58]	[0.78]	[5.75]
$sdev$	9.42	10.18	7.85	7.82	8.86	8.00	7.09
$skew$	1.64	5.22	1.63	1.30	2.34	2.73	-0.16
$SR \times \sqrt{12}$	-0.30	0.13	0.26	0.19	0.71	0.21	1.29
ac_1	0.08	0.17	0.21	0.02	0.18	0.18	0.00
			Panel C: 6/12 month				
$mean$	-1.13	-0.04	-0.08	-0.01	1.11	-0.03	2.24
	[-2.34]	[-0.06]	[-0.17]	[-0.03]	[1.92]	[-0.06]	[5.67]
$sdev$	7.28	8.47	6.51	6.47	7.49	6.49	6.12
$skew$	1.27	5.56	1.36	1.18	2.72	2.65	0.43
$SR \times \sqrt{12}$	-0.54	-0.02	-0.04	-0.01	0.52	-0.02	1.27
ac_1	0.08	0.19	0.18	0.00	0.20	0.18	0.01
			Panel D: 12/24 month				
$mean$	-0.40	0.38	0.37	0.68	2.10	0.63	2.50
	[-0.86]	[0.67]	[0.83]	[1.67]	[3.63]	[1.37]	[5.67]
$sdev$	7.01	8.05	6.39	6.42	8.14	6.31	6.95
$skew$	1.82	4.89	1.57	1.04	2.85	2.98	1.45
$SR \times \sqrt{12}$	-0.20	0.16	0.20	0.37	0.89	0.34	1.25
ac_1	0.08	0.12	0.12	-0.05	0.14	0.14	-0.04
$freq$	0.26	0.47	0.56	0.56	0.32		

Table 4. Principal Components: Slope-sorted Portfolios

This table presents the loadings for the first (PC_1) and second (PC_2) principal component of slope-sorted portfolios of forward volatility agreements presented in Table 3. In each panel, the last column reports the cumulative share of total variance (CV) explained by the common factors. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table A25 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	P_1	P_2	P_3	P_4	P_5	CV
			Panel A: 1/3 month			
PC_1	0.52	0.46	0.43	0.40	0.42	0.82
PC_2	-0.82	0.10	0.20	0.20	0.49	0.90
			Panel B: 3/6 month			
PC_1	0.46	0.53	0.40	0.40	0.44	0.81
PC_2	-0.79	0.01	0.08	0.18	0.58	0.89
			Panel C: 6/12 month			
PC_1	0.43	0.54	0.41	0.40	0.45	0.80
PC_2	-0.76	-0.04	0.02	0.13	0.63	0.88
			Panel D: 12/24 month			
PC_1	0.42	0.52	0.40	0.40	0.48	0.76
PC_2	-0.36	-0.26	-0.22	-0.10	0.86	0.88

Table 5. Asset Pricing Tests: Risk Prices

This table presents cross-sectional asset pricing tests. Both test assets (slope-sorted portfolios of forward volatility agreements) and pricing factors (level and volatility carry strategies) are presented in Table 3. The table reports GMM (first and second-stage) estimates of the factor loadings b, the market price of risk λ, and the cross-sectional R^2. t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. HJ refers to the Hansen and Jagannathan (1997) distance (with simulated p-values in parentheses) for the null hypothesis that the pricing errors per unit of norm is equal to zero. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table A27 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	b_{LEV}	b_{VCA}	λ_{LEV}	λ_{VCA}	$R^2(\%)$	HJ
			Panel A: 1/3 month			
GMM_1	-0.01	0.03	-2.37	4.75	84.1	0.23
	[-1.31]	[2.67]	[-2.20]	[4.86]		(0.43)
GMM_2	-0.02	0.04	-2.30	4.86	73.0	
	[-1.92]	[4.33]	[-2.45]	[5.63]		
			-2.39	**5.15**		
			Panel B: 3/6 month			
GMM_1	0.01	0.05	0.47	2.59	96.8	0.11
	[1.31]	[5.19]	[0.76]	[5.45]		(0.66)
GMM_2	0.01	0.06	0.38	2.61	89.3	
	[1.07]	[6.16]	[0.75]	[5.78]		
			0.47	**2.64**		
			Panel C: 6/12 month			
GMM_1	0.00	0.06	-0.03	2.23	99.0	0.05
	[-0.41]	[5.61]	[-0.05]	[5.52]		(0.93)
GMM_2	0.00	0.07	-0.16	2.19	97.8	
	[-0.33]	[6.48]	[-0.39]	[5.88]		
			-0.03	**2.24**		
			Panel D: 12/24 month			
GMM_1	0.01	0.05	0.62	2.51	98.6	0.07
	[1.24]	[5.11]	[1.33]	[5.98]		(0.87)
GMM_2	0.01	0.05	0.55	2.40	97.8	
	[1.31]	[5.73]	[1.40]	[6.13]		
			0.63	**2.50**		

Table 6. Asset Pricing Tests: Factor Betas

The table reports least-squares estimates of time series regressions. Both test assets (slope-sorted portfolios of forward volatility agreements) and pricing factors (level and volatility carry strategies) are presented in Table 3. t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table A28 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	α		β_{LEV}		β_{VCA}		$R^2(\%)$	χ^2_α
				Panel A: 1/3 month				
P_1	0.81	[2.11]	1.04	[29.68]	-0.58	[-13.37]	93.7	(0.21)
P_2	-0.65	[-1.79]	1.04	[30.98]	0.02	[0.64]	87.2	
P_3	-0.24	[-0.52]	0.98	[20.63]	0.05	[1.05]	86.0	
P_4	-0.72	[-2.07]	0.90	[25.49]	0.09	[2.15]	87.6	
P_5	0.81	[2.11]	1.04	[29.68]	0.42	[9.76]	91.6	
				Panel B: 3/6 month				
P_1	0.11	[0.63]	1.01	[48.02]	-0.54	[-14.00]	93.1	(0.76)
P_2	-0.17	[-0.80]	1.18	[9.41]	-0.01	[-0.14]	85.5	
P_3	0.15	[0.71]	0.91	[20.42]	0.00	[-0.03]	85.2	
P_4	-0.20	[-1.24]	0.91	[13.19]	0.08	[2.14]	85.4	
P_5	0.11	[0.63]	1.01	[48.02]	0.46	[12.16]	92.2	
				Panel C: 6/12 month				
P_1	0.07	[0.50]	0.99	[45.07]	-0.52	[-13.89]	92.4	(0.99)
P_2	0.02	[0.09]	1.20	[8.25]	-0.01	[-0.17]	84.2	
P_3	-0.06	[-0.36]	0.92	[15.17]	0.00	[0.01]	84.3	
P_4	-0.10	[-0.66]	0.90	[10.87]	0.05	[1.34]	82.0	
P_5	0.07	[0.50]	0.99	[45.07]	0.48	[12.71]	92.8	
				Panel D: 12/24 month				
P_1	-0.03	[-0.16]	0.99	[39.98]	-0.40	[-9.56]	89.5	(0.94)
P_2	-0.12	[-0.68]	1.18	[10.88]	-0.10	[-2.68]	85.6	
P_3	-0.01	[-0.04]	0.92	[18.20]	-0.08	[-1.96]	82.5	
P_4	0.18	[0.95]	0.91	[11.35]	-0.03	[-0.66]	78.5	
P_5	-0.03	[-0.16]	0.99	[39.98]	0.60	[14.44]	92.2	

Table 7. Asset Pricing Tests: Alternative Risk Factors

This table presents the estimates of the alpha parameters from time-series asset pricing tests. The test assets (slope-sorted portfolios) are presented in Table 3. Besides the level factor, the set of traded pricing factors includes dollar, carry, global imbalance, foreign exchange volatility, and currency liquidity factors (Panel A); the Fama-French global equity factors, i.e., market excess return, size, value, profitability, and investment factors (Panel B); the VIX futures returns ranging from 1-month to 6-month (Panel C). The superscripts ***, **, and * denote statistical significance at the 1%, 5%, and 10%, respectively, based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. Excess returns are expressed in percentage per month and range from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Tables A13-A15 in the Internet Appendix presents the estimation results for the rest of the parameters. Tables A29-A31 in the Internet Appendix displays similar results for a cross-section of 10 developed countries.

	1/3 month	3/6 month	6/12 month	12/24 month	χ^2_α
		Panel A: Currency Risk Factors			
P_1	−3.76***	-0.48	−0.92***	−0.19	(<.01)
P_2	−2.38***	0.63**	0.17	0.66***	
P_3	−1.63***	0.92***	0.13	0.62***	
P_4	−1.96***	0.73***	0.24	0.90***	
P_5	0.73	1.94***	1.31***	2.33***	
		Panel B: Global Equity Risk Factors			
P_1	−4.06***	-0.40	−0.85***	−0.05	(<.01)
P_2	−2.46***	0.79***	0.26	0.62***	
P_3	−2.05***	0.76***	0.09	0.50**	
P_4	−2.06***	0.59***	0.19	0.79***	
P_5	1.26*	2.30***	1.46***	2.32***	
		Panel C: VIX Futures Returns			
P_1	−2.65**	0.23	−0.16*	0.25	(<.01)
P_2	−3.07***	-2.65**	0.17	−2.65**	
P_3	−2.06***	1.01***	0.30	−2.65**	
P_4	−2.33***	0.68***	0.16	0.72***	
P_5	0.01	1.90***	1.35***	1.99***	

Table 8. Exposures of FX Volatility to Equity Returns

This table presents panel regression estimates of the following regression model: we estimate the following regression of changes in volatility on local and global state variables using monthly data:

$$\Delta IVOL_{i,t} = \gamma_0 + \gamma_f ret_{i,t} + \gamma_h ret_{us,t} + \gamma_w ret_{w,t} + \varepsilon_{i,t},$$

where the dependent variable is the monthly change in implied volatility of exchange rate i computed using spot model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005), $ret_{i,t}$ is the equity market return of country i in month t, $ret_{us,t}$ is the US equity market return and $ret_{w,t}$ is the the global equity market return. Both local and the US market returns are orthogonilized with respect the global market return prior to estimating the model. Different rows of the table corresponds to different maturities of the inplied volatility. t-statistics (reported in brackets) are based on standard errors clustered by currency and time. Excess returns are expressed in percentage per month and the sample runs from January 2001 to December 2015. Data on over-the-counter currency options are from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging market countries.

	γ_f		γ_h		γ_w		$R^2(\%)$
1 month	-0.015	[-1.83]	0.018	[0.81]	-0.064	[-3.47]	17.1
3 months	-0.025	[-2.21]	0.011	[0.48]	-0.099	[-3.66]	21.7
6 months	-0.031	[-2.30]	-0.003	[-0.13]	-0.126	[-3.92]	23.2
12 months	-0.036	[-2.31]	-0.020	[-0.69]	-0.162	[-4.17]	23.8
24 months	-0.035	[-2.23]	-0.038	[-0.82]	-0.217	[-3.79]	25.3

Table 9. Understanding Global Risk: Squared Component

This table presents descriptive statistics of implied volatility strategies decomposed into macro and residual components. In each month t, we run the following cross-sectional regression with multiple regressors

$$y_{i,t} = \sum_s \beta^s (x^s_{i,t} - x^s_{us,t})^2 + \varepsilon_{i,t},$$

where $y_{i,t}$ is the implied volatility slope at time t for country i in deviation from the cross-sectional median value, $x^s_{i,t}$ is the shock to the macro variable s for country i, $x^s_{us,t}$ is the corresponding component for the US, and $\varepsilon_{i,t}$ captures the error term unrelated to economic fundamentals. The least-squares estimates of β^s are used to construct the linear portfolio weights at time t whereas the portfolio returns are realized at time $t+1$. Shocks to macro variables are computed as first linear difference. The portfolio return based on the implied volatility slopes is, by construction, equal to the sum of all macro-based components plus the residual component. The table reports the average return in percentage per annum, the annualized Sharpe ratio, and the average least-squares estimates of β^s. t-statistic based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The sample runs monthly from January 1996 to December 2015, and includes a cross-section of 20 developed and emerging market countries. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Macro data are from the OECD and IMF. Table A18 in the Internet Appendix reports the decomposition performed for each component separately.

	Implied Slope	Economic Growth	Inflation Rate	Trade Balance	Term Spread	Residual
			Panel A: 1/3 month			
mean	4.57	3.46	0.81	-1.37	0.46	1.20
	[5.18]	[3.50]	[1.03]	[-1.93]	[0.49]	[1.29]
$SR \times \sqrt{12}$	1.16	0.86	0.22	-0.39	0.09	0.35
			Panel B: 3/6 month			
mean	2.42	1.62	-0.07	-0.45	-0.17	1.48
	[4.96]	[3.12]	[-0.16]	[-1.13]	[-0.29]	[2.76]
$SR \times \sqrt{12}$	1.08	0.71	-0.03	-0.25	-0.06	0.69
			Panel C: 6/12 month			
mean	1.97	1.43	-0.08	-0.33	-0.14	1.10
	[5.00]	[3.39]	[-0.25]	[-0.97]	[-0.28]	[2.22]
$SR \times \sqrt{12}$	1.10	0.78	-0.05	-0.22	-0.06	0.61
			Panel D: 12/24 month			
mean	2.21	1.01	-0.07	0.00	-0.26	1.52
	[5.05]	[2.42]	[-0.21]	[0.00]	[-0.42]	[3.56]
$SR \times \sqrt{12}$	1.09	0.56	-0.04	0.00	-0.10	0.86
β^s		2.93	4.18	-5.20	2.61	
		[4.38]	[0.68]	[-2.76]	[0.69]	

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Internet appendix to

"The Cross-section of Currency Volatility Premia"

(not for publication)

This appendix presents supplementary results not included in the main body of the paper.

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A Predictive Regressions for Implied Volatilities

This section reviews the analogue of the Fama (1984) predictive regressions for implied volatility returns used in Della Corte, Sarno, and Tsiakas (2011), and extends them to non-overlapping implied volatility returns.

Regressions with Overlapping Returns. An FVA has zero net market value at entry, so no arbitrage arguments dictate that the forward implied volatility equals the risk-neutral expected value of the future spot implied volatility as (e.g., Carr and Wu 2009; Glasserman and Wu 2011)

$$E_t\left[SVOL_{t+\tau_1}^{\tau_2}\right] = FVOL_{t,\tau_1}^{\tau_2}, \tag{A1}$$

where $E_t[\cdot]$ denotes the time-t conditional expectation operator under some risk-neutral measure. Similar to the spot-forward exchange rate relationship (e.g., Bilson 1981; Fama 1984), this condition suggests that the forward implied volatility conditional on time t information set is an unbiased predictor of the future spot implied volatility and the expected payoff from buying an FVA at the inception date and holding it until the maturity date equals zero.

The pricing condition presented in Equation (A1) can be equivalently represented in a return space as

$$E_t\left[\frac{SVOL_{t+\tau_1}^{\tau_2} - SVOL_t^{\tau_2}}{SVOL_t^{\tau_2}}\right] = \frac{FVOL_{t,\tau_1}^{\tau_2} - SVOL_t^{\tau_2}}{SVOL_t^{\tau_2}} \tag{A2}$$

by first subtracting and then dividing by the lagged value of the spot implied volatility observed at time t. In Equation (A2), the left-hand-side can be thought as of the expected implied volatility change and the right-hand-side as the forward volatility premium. Alike the spot-forward exchange rate relationship studied by Fama (1984), Della Corte, Sarno, and Tsiakas (2011) define the equivalent predictive regressions for the spot-forward implied volatility relationship.

Starting from Equation (A2) and using ex-post returns, the predictive regressions are easily derived as

$$\frac{SVOL^{\tau_2}_{t+\tau_1} - SVOL^{\tau_2}_{t}}{SVOL^{\tau_2}_{t}} = \alpha + \beta\left(\frac{FVOL^{\tau_2}_{t,\tau_1} - SVOL^{\tau_2}_{t}}{SVOL^{\tau_2}_{t}}\right) + \varepsilon_{t+\tau_1} \tag{A3}$$

$$\frac{SVOL^{\tau_2}_{t+\tau_1} - FVOL^{\tau_1,\tau_2}_{t}}{SVOL^{\tau_2}_{t}} = \alpha + \gamma\left(\frac{FVOL^{\tau_2}_{t,\tau_1} - SVOL^{\tau_2}_{t}}{SVOL^{\tau_2}_{t}}\right) + \varepsilon_{t+\tau_1}. \tag{A4}$$

While the first predictive regression follows naturally from Equation (A1), the second predictive regression is obtained by simply subtracting the forward volatility premium on both sides. As a result, $\gamma = \beta - 1$ by construction and the predictive regressions are equivalent to each other. Under the null that the unbiasedness hypothesis holds, the first regression suggests that the implied volatility change can be predicted by the forward volatility premium, i.e., $\alpha = 0$, $\beta = 1$ and $\varepsilon_{t+\tau_1}$ is serially uncorrelated. The second regression, moreover, implies that the volatility excess return is unpredictable and equal to zero since $\gamma = \beta - 1 = 0$.

Predictive Regressions with Non-overlapping Returns. The predictive regressions defined in Equations (A3)-(A4) will be characterized by overlapping returns when $\tau_1 > 1$. We deal with this problem as follows. Using the law of iterated expectations, we first rewrite the risk-neutral expectation of the future spot implied volatility as

$$E_t[SVOL^{\tau_2}_{t+\tau_1}] = E_t[E_{t+1}(SVOL^{\tau_2}_{t+\tau_1})] = E_t[FVOL^{\tau_2}_{t+1,\tau_1-1}] \tag{A5}$$

and then redefine the pricing condition in Equation (A1) as

$$E_t[FVOL^{\tau_2}_{t+1,\tau_1-1}] = FVOL^{\tau_2}_{t,\tau_1}. \tag{A6}$$

Similar to before, subtract and divide by the lagged value of the forward implied volatility observed at time t, and rewrite Equation (A6) in return space as

$$E_t\left[\frac{FVOL^{\tau_2}_{t+1,\tau_1-1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}}\right] = \frac{FVOL^{\tau_2}_{t,\tau_1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}} \tag{A7}$$

where the left-hand-side can be interpreted as the monthly expected implied volatility change and the right-hand-side as the monthly forward volatility premium. Using then ex-post returns, the analogue of the Fama (1984) predictive regressions are then easily obtained as

$$\frac{FVOL^{\tau_2}_{t+1,\tau_1-1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}} = \alpha + \beta \left(\frac{FVOL^{\tau_2}_{t,\tau_1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}} \right) + \varepsilon_{t+1} \quad \text{(A8)}$$

$$\frac{FVOL^{\tau_2}_{t+1,\tau_1-1} - FVOL^{\tau_2}_{t,\tau_1}}{FVOL^{\tau_2}_{t,\tau_1-1}} = \alpha + \gamma \left(\frac{FVOL^{\tau_2}_{t,\tau_1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}} \right) + \varepsilon_{t+1} \quad \text{(A9)}$$

where $\gamma = \beta - 1$ by construction. In our empirical analysis, we only focus on the second regression.[21]

The predictive regressions presented in Equations (A8)-(A9) are equivalent to the predictive regressions in Equations (A3)-(A4) when $\tau_1 = \tau_2 = 1$. To show this, rewrite the regressions in Equations (A8)-(A9) by setting $\tau_1 = 1$ (while removing the superscript $\tau_2 = 1$ for easy notation) as

$$\frac{FVOL_{t+1,0} - FVOL_{t,0}}{FVOL_{t,0}} = \alpha + \beta \left(\frac{FVOL_{t,1} - FVOL_{t,0}}{FVOL_{t,0}} \right) + \varepsilon_{t+1}$$

$$\frac{FVOL_{t+1,0} - FVOL_{t,1}}{FVOL_{t,0}} = \alpha + \gamma \left(\frac{FVOL_{t,1} - FVOL_{t,0}}{FVOL_{t,0}} \right) + \varepsilon_{t+1}$$

where $FVOL_{t,1}$ is the 1 month forward price at time t with time to maturity equal to one, and $FVOL_{t,0}$ is the 1 month forward price at time t with time to maturity equal to zero. Since the latter forward price is equivalent to $SVOL_t$, we can rewrite the predictive regressions as

$$\frac{SVOL_{t+1} - SVOL_{t}}{SVOL_{t}} = \alpha + \beta \left(\frac{FVOL_{t,1} - SVOL_{t}}{SVOL_{t}} \right) + \varepsilon_{t+1}$$

$$\frac{SVOL_{t+1} - FVOL_{t,1}}{SVOL_{t}} = \alpha + \gamma \left(\frac{FVOL_{t,1} - SVOL_{t}}{SVOL_{t}} \right) + \varepsilon_{t+1}$$

which are equivalent to the predictive regressions defined in Equations (A3)-(A4).

[21] When the implied volatility for a given maturity is not directly available (e.g., the 5 month implied volatility), we obtain it by linearly interpolating implied variances (e.g., using the 3 month and 6 month implied variances) as in Carr and Wu (2009).

B Tradable Currency Factors

In this section we briefly outline the construction of the currency factors used in the main analysis.

Dollar and Carry Factor. At the end of each period t, we allocate currencies to five portfolios on the basis of their forward premia (or interest rate differential relative to the US): 20% of all currencies with the highest forward premia are assigned to Portfolio 1, whereas 20% of all currencies with the lowest forward premia are assigned to Portfolio 5. We then compute the excess return for each portfolio as an equally weighted average of individual currency excess returns within that portfolio. Following Lustig, Roussanov, and Verdelhan (2011), the DOL factor is computed as an equally weighted average of these portfolios and the CAR factor as a long-short portfolio formed by going long Portfolio 5 (high-yielding currencies) and short Portfolio 1 (low-yielding currencies).

Global Imbalance Factor. At the end of each period t, we first group currencies into two baskets using the net foreign asset position relative to GDP and then rank the currencies within each basket using the percentage share of external liabilities denominated in domestic currency (LDC). Hence, we allocate them to five portfolios as in Della Corte, Riddiough, and Sarno (2016). Portfolio 1 corresponds to creditor countries whose external liabilities are primarily denominated in domestic currency (safest currencies), whereas Portfolio 5 comprises debtor countries whose external liabilities are primarily denominated in foreign currency (riskiest currencies). We then compute the excess return for each portfolio as an equally weighted average of individual currency excess returns within that portfolio. We construct the global imbalance factor IMB as return difference between Portfolio 5 and Portfolio 1. The construction of these is theoretically motivated by the work of Gabaix and Maggiori (2015) and Colacito, Croce, Gavazzoni, and Ready (2016).

FX Global Volatility Factor. Following Menkhoff, Sarno, Schmeling, and Schrimpf (2012), we start off by calculating the absolute daily log exchange rate return for each currency in our sample. We proceed by first averaging them over all currencies and then averaging daily up to the monthly frequency. Specifically, we construct this quantity in month t is given by $v_t = T_\tau^{-1} \sum_{\tau \in T_\tau} (\sum_{k \in K_\tau} |\Delta s_\tau^k| / K_\tau)$, where Δs_τ^k is the daily log exchange rate return for currency k, K_t denotes the number of available currencies on day τ, and T_t denotes the total number of trading days in month t. The sample of spot exchange rates runs from January 1994 to December 2015. We convert the innovations to this measure into a tradable strategy as follows. At the end of each period t, we regress individual currency excess returns on a constant and the foreign exchange volatility innovations using a 36 month rolling window. We then rank currencies according to their volatility betas and allocate them to five portfolios at time t. Portfolio 1 contains currencies with high volatility beta (low volatility risk) whereas Portfolio 5 contains currencies with low volatility beta (high volatility risk). The spread between Portfolio 5 and Portfolio 1 denotes our tradable factor denoted as VOL.

FX Global Liquidity Factor. We compute the daily percentage bid-ask spread for each currency in our sample and then employ the same aggregating scheme as for the FX global volatility to obtain a global bid-ask spread measure. Since higher bid-ask spreads indicate lower liquidity, this measure can be interpreted as a global measure of FX market illiquidity. We convert the innovations to this liquidity measure into a tradable strategy as follows. At the end of each period t, we regress individual currency excess returns on a constant and the foreign exchange liquidity innovations using a 36 month rolling window. We then rank currencies according to their liquidity betas and allocate them to five portfolios at time t. Portfolio 1 contains currencies with high liquidity beta (low liquidity risk) whereas Portfolio 5 contains currencies with low liquidity beta (high liquidity risk). The spread between Portfolio 5 and Portfolio 1 denotes our tradable foreign exchange liquidity factor LIQ.

C Impact of Transaction Costs

Bid-ask spreads are likely to vary over time but we only have access to average spreads. Moreover, bid-ask spreads on volatility derivatives are typically proportional to those of similar instruments such as the delta-neutral straddles – they are both based on portfolios of plain-vanilla options and traded to take a view on market volatility. Hence, we can proxy for time-varying bid-ask spreads on the FVAs by appropriately scaling the bid-ask spreads on the delta-neutral straddles. Specifically, we compute the time-varying bid-ask spread for each country and maturity as $s_t = s_t^\star \times (s/s^\star)$, where $s_t^\star$ is the quoted bid-ask spread on the delta-neutral straddle obtained from Bloomberg, $s^\star$ is the sample mean of $s_t^\star$, and s is the average spread on the FVA (while omitting the subscript denoting the country and the maturity for simplicity).[22]

Using these computed bid-ask spreads, we calculate monthly excess returns adjusted for transaction costs. Similar to Menkhoff, Sarno, Schmeling, and Schrimpf (2012), the net excess return accounts for the full round-trip transaction cost when the FVA is purchased at time t and sold at time $t+1$. Similarly, when an investor sells the FVA at time t and offsets her position at time $t+1$. If the investor, instead, buys (sells) the FVA at time t but decides to maintain the long (short) position at time $t+1$, the net excess return is computed by only deducting half the bid-ask spread unless the contract has expired and the investor has to engage into a new contract. We equivalently charge half the bid-ask spread when the investor closes at time $t+1$ a position already existing at time t. Table A4 reports the slope-sorted portfolios with excess returns adjusted for transaction costs. We also perform the analysis when s_t is calculated using the largest bid-ask spread s across countries for each maturity and the profitability continues to be both economically and statistically significant (see Table A5).

D Evidence from Developed Countries

We also examine the robustness of our main findings using a cross-section of 10 developed countries – Australia, Canada, Denmark, Euro Area, Japan, New Zealand, Norway, Sweden, Switzerland, and the United Kingdom – and find no qualitative changes. We report these additional results in the Internet Appendix. Table A21 presents equally-weighted (in Panel A) and GDP-weighted (in Panel B) average volatility excess returns based on forward volatility agreements and show that they exhibit similar term structure patterns as the corresponding returns based on the 20 countries. Table A22 presents the country-fixed effects predictive regressions of monthly volatility excess returns on the lagged monthly forward volatility premia pooled across countries and confirms the rejection of the unbiasedness hypothesis using both discrete and log returns. Table A23 displays summary statistics of the returns on implied

[22]We thank Philippos Kassimatis from Maven Global for helpful discussions on how to proxy for time-varying bid-ask spreads on FVA contracts.

volatility portfolios sorted on the volatility slope: the average excess returns increase monotonically from Portfolio 1 to Portfolio 5 for all maturities and the profitability of the VCA strategy remain both statistically and economically significant. For example, the average excess return amounts to 4.00% and 2.18% per month for 1/3 mth and 12/24 mth, respectively. Finally, Tables A25 through A30 confirm that VCA exposure is the only source of risk in the cross-section of our implied volatility portfolios, and global currency and equity risk factors are of little importance.

E Country-level Asset Pricing Tests

Sorting asset returns into portfolios is popular in the literature as it improves the estimates of the time-series slope coefficients. Lewellen, Nagel, and Shanken (2010), however, point out that grouping assets into portfolios creates a strong factor structure whereas Ang, Liu, and Schwarz (2010) advocate the use of individual returns as forming portfolios can potentially destroy information by shrinking the dispersion of betas. Table A11 presents cross-sectional asset pricing tests based on Fama-MacBeth regressions with country-level volatility excess return as test assets, and LEV and VCA as risk factors. Similar to Lustig, Roussanov, and Verdelhan (2011), we construct these excess returns between times t and $t+1$ by going long (short) FVAs with implied volatility slopes lower (higher) than their median value at time t such that the strategy is dollar-neutral. We find a positive and statistically significant factor price of volatility carry risk.[23]

F Alternative Methods for Implied Volatilities

The implied volatilities are based on the model-free approach of Britten-Jones and Neuberger (2000) using the cubic spline interpolation method across five plain-vanilla implied volatility points (e.g., Jiang and Tian 2005). We also present results using different procedures. Firstly, we construct the spot and forward implied volatilities using the modified model-free approach

[23]As a robustness, we also compute bootstrapped standard errors based on 10,000 replications but conclusions remain unchanged. We use the stationary bootstrap of Politis and Romano (1994) which resamples with replacement blocks of random length of excess returns and pricing factors realizations from the original sample without imposing the model's restrictions. This procedure preserves both contemporaneous cross-correlations and serial correlations for excess returns and pricing factors.

of Martin (2013) which is robust to price jumps (see Table A7 for portfolio results). Secondly, we replace the cubic spline interpolation method with the vanna-volga method presented in Castagna and Mercurio (2007). This procedure uses only three plain-vanilla option quotes – typically the delta-neutral straddle and the 25-delta call and put options – to construct the volatility smile, and is popular among FX brokers and market makers when there less trading activity on deep out-of-the-money options (see Table A6 for the results). Finally, there is evidence that FVAs can also be written on at-the-money implied volatilities, in which case the smile is irrelevant (e.g., Knauf 2003). In Table A8, we present summary statistic of sloped-sorted implied volatility portfolios based on at-the-money implied volatilities. All exercises reveal that our results are robust to alternative methods of computing implied volatilities.[24]

G Decomposition of Dynamic Slope-sorted Portfolios

We start by running in each month t the following cross-sectional regression:

$$y_{i,t} = \sum_{s=1}^{m} \beta^s z_{i,t}^s + \varepsilon_{i,t} \tag{G10}$$

for $i = 1, \dots N$, where $y_{i,t}$ is the implied volatility slope at time t for country i in deviation from the cross-sectional median value, $z_{i,t}^s$ denotes a conditioning state variables for country i, $\varepsilon_{i,t}$ captures the error term unrelated to economic fundamentals, and N is the number of countries at time t. For the portfolio corresponding to macro-variable s we construct linear portfolio weights as

$$w_{i,t}^s = K_{i,t}^s / c_t,$$

where c_t is a scaling factor such that the positive and negative weights sum to one and minus one, respectively, and $K_{i,t}^s$ is the signal extracted from the cross-sectional regression at time t corresponding to the state variable $z_{i,t}^s$. Our DSP portfolio is defined by setting up $K_{i,t} = y_{i,t}$. For the macro-related conditioning variables, we set $K_{i,t}^s = \hat{\beta}^s z_{i,t}^s$, and for the residual

[24] Carr and Lee (2009) show that the risk-neutral expectation of the integrated volatility is well approximated by the at-the-money implied volatility under certain conditions such as a risk-neutral measure exists (i.e., no frictions and no arbitrage), the underlying asset price is positive and continuous over time (i.e., no bankruptcy and no price jumps), and increments in instantaneous variance are independent of instantaneous volatility are independent of returns (i.e., no leverage effect).

component portfolio we set $K^{\varepsilon}_{i,t} = \hat{\varepsilon}^i_t$. We compute the scaling factor by setting $c_t = \sum_i^N (y^i_t)^+$ for positive values of y^i_t and $c_t = -\sum_i^N (y^i_t)^-$ for negative values of y^i_t, respectively. The superscript + (−) indicates that the sum is only computed across positive (negative) values. This allows the construction of a dollar-neutral strategy that displays both long and short positions that offset each other (i.e., the sum of weights across all countries at time t is equal to zero). Moreover, we use the same scaling factor for all different components such that the decomposition holds exactly.

Finally, we calculate next month excess return by means of these portfolio weights as

$$RX_{t+1} = \sum_{i=1}^{N} -w^i_t rx^i_{t+1}, \tag{G11}$$

where rx^i_{t+1} is the implied volatility excess return for country i as defined by Equation (4), and w^i_t is multiplied by minus one as our strategy implies buying (selling) forward volatility agreements with low (high) implied volatility slopes.

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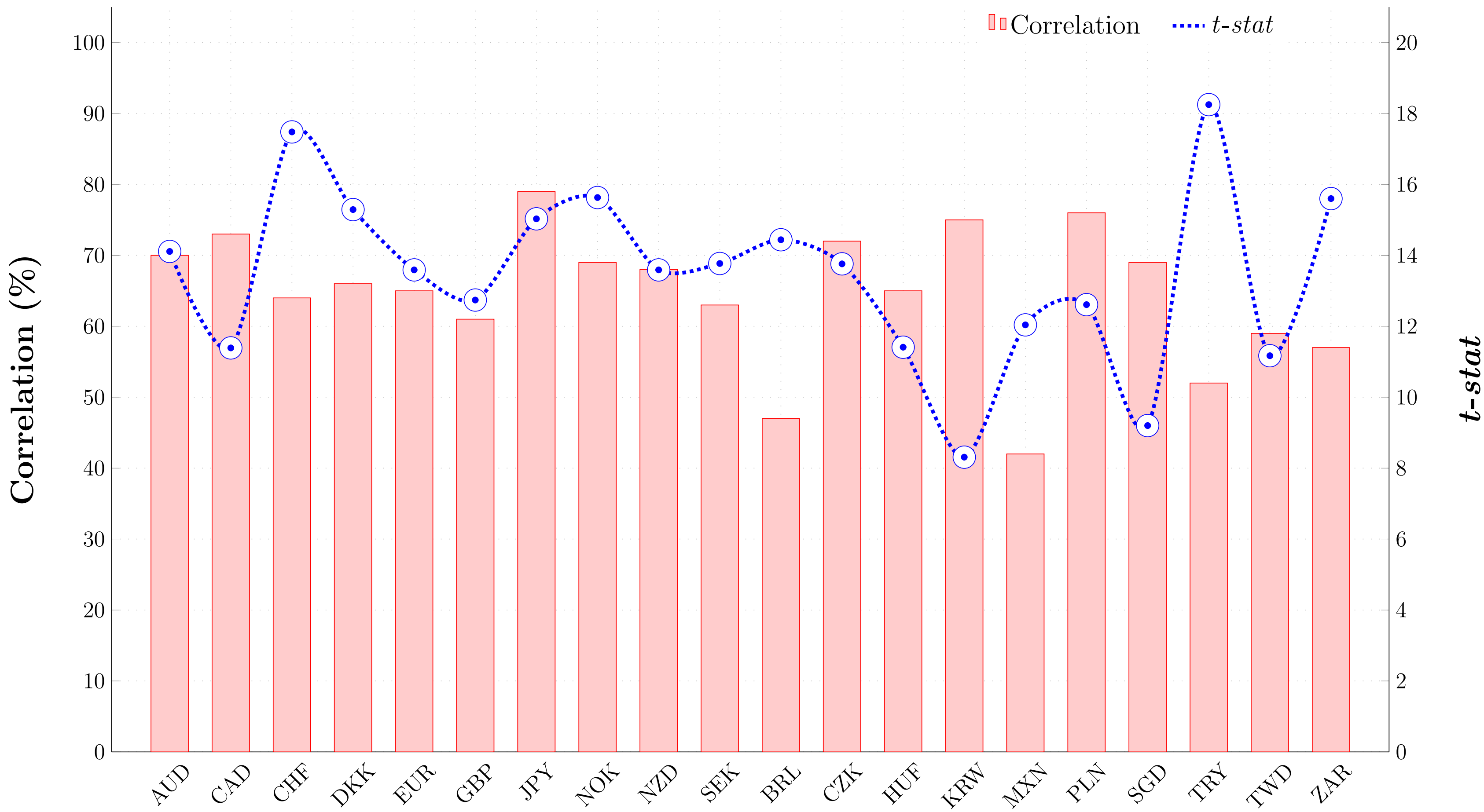


Figure A1. Forward Volatility Premia and Implied Volatiliy Slopes

This figure plots the country-level correlations between forward volatility premia and implied volatility slope (with the corresponding t-statistics). Forward volatility premia are computed using model-free implied volatilities (e.g., Britten-Jones and Neuberger 2000; Jiang and Tian 2005) for various maturity combinations, i.e., 1/3 month, 3/6 month, 6/12 month and 12/24 month. Implied volatility slopes are measured using 24 month and 3 month model-free implied volatility. For each country, the correlation is computed by regressing forward volatility premia on the implied volatility slope while controlling for both lagged dependent and explanatory variables. t-statistics are based on standard errors that are heteroscedasticity consistent and robust to cross-sectional and temporal dependence (Driscoll and Kraay 1998). The sample runs from January 1996 to December 2015 and uses over-the-counter currency options are from JP Morgan and Bloomberg.

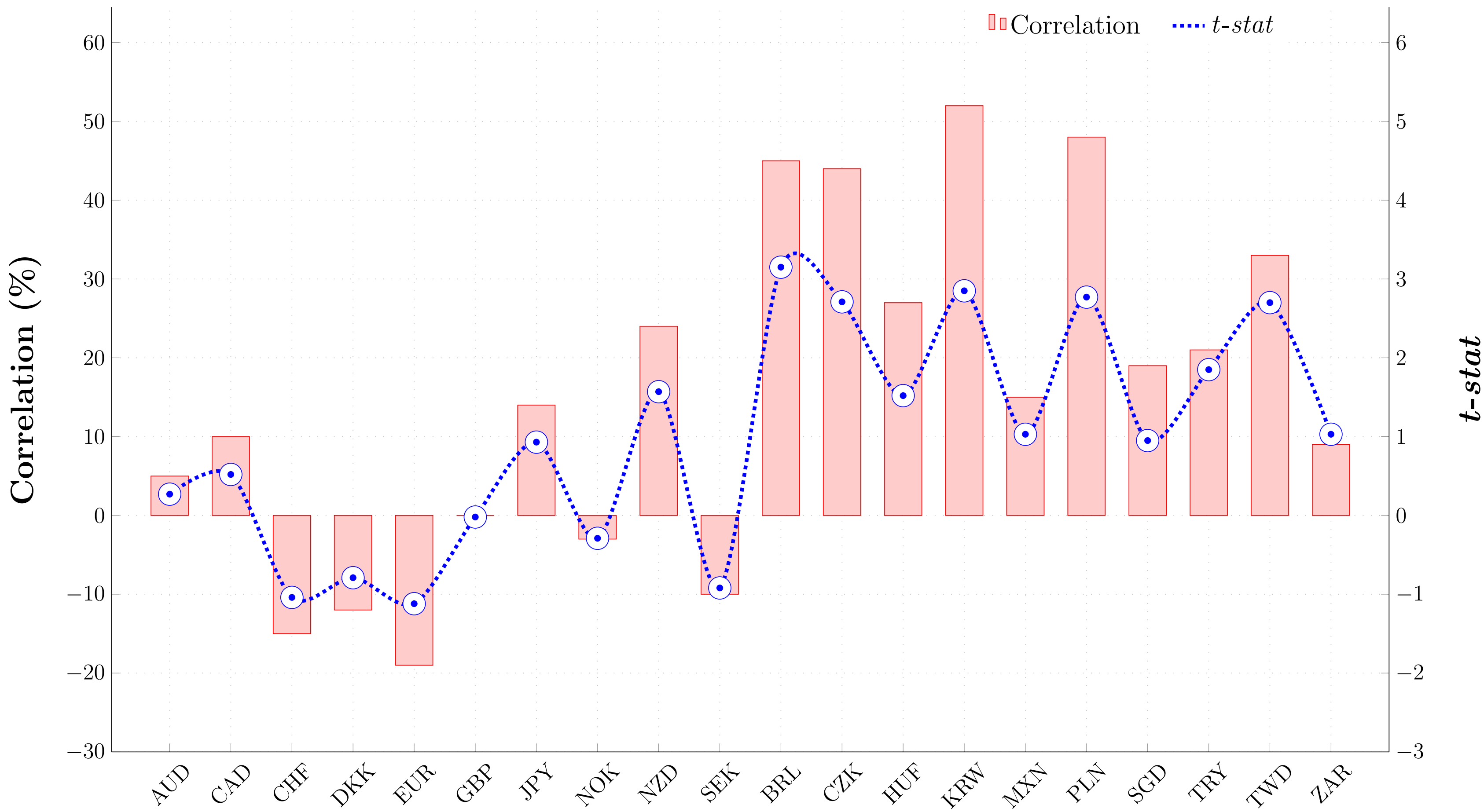


Figure A2. Spot Volatility Premia and Implied Volatiliy Slopes

This figure plots the country-level correlations between spot volatility premia and implied volatility slope (with the corresponding t-statistics). Spot volatility premia is computed as difference between the 1-month model-free spot implied volatilities (e.g., Britten-Jones and Neuberger 2000; Jiang and Tian 2005) and the 1-month lagged realized volatility based on daily forward exchange rate changes. Implied volatility slopes are measured using 24 month and 3 month model-free implied volatility. For each country, the correlation is computed by regressing the spot volatility premium on the implied volatility slope while controlling for both lagged dependent and explanatory variables. t-statistics are based on standard errors that are heteroscedasticity consistent and robust to cross-sectional and temporal dependence (Driscoll and Kraay 1998). The sample runs from January 1996 to December 2015 and uses over-the-counter currency options are from JP Morgan and Bloomberg.

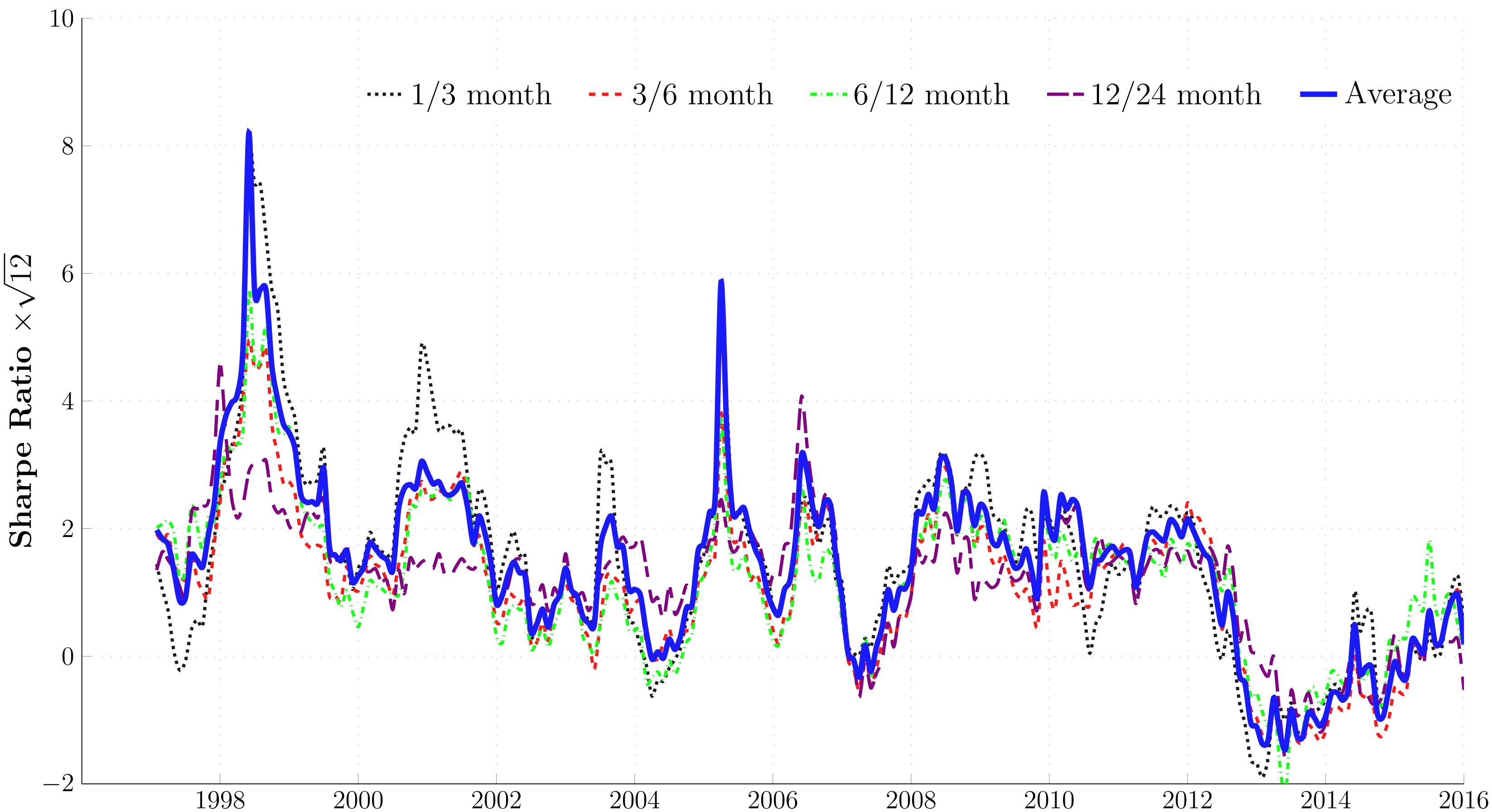
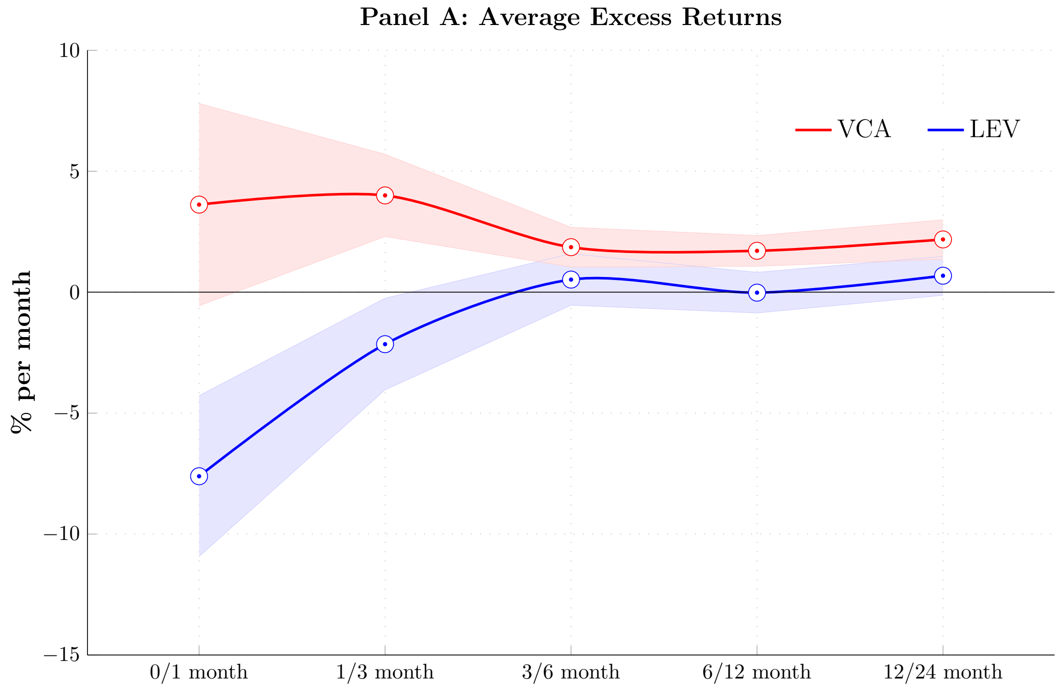


Figure A3. The Sharpe Ratios of Volatility Carry Strategies (Developed)

This figures displays the annualized 1-year rolling Sharpe ratios for the volatility carry (VCA) strategies described in Table A23. Each strategy is constructed as a long-short strategy that buys a basket of forward volatility agreements with the lowest implied volatility slopes and sells a basket of forward volatility agreements with the highest implied volatility slopes using a cross-section of 10 developed economies. The implied volatilities are model-free as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). Each slope is based on the 24-month and 3-month implied volatility. *Average* denotes the rolling Sharpe ratio of an equally-weighted basket of volatility carry strategies. The strategies are rebalanced monthly from January 1996 to December 2015. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Figure 2 displays results for a cross-section of 20 developed and emerging market countries



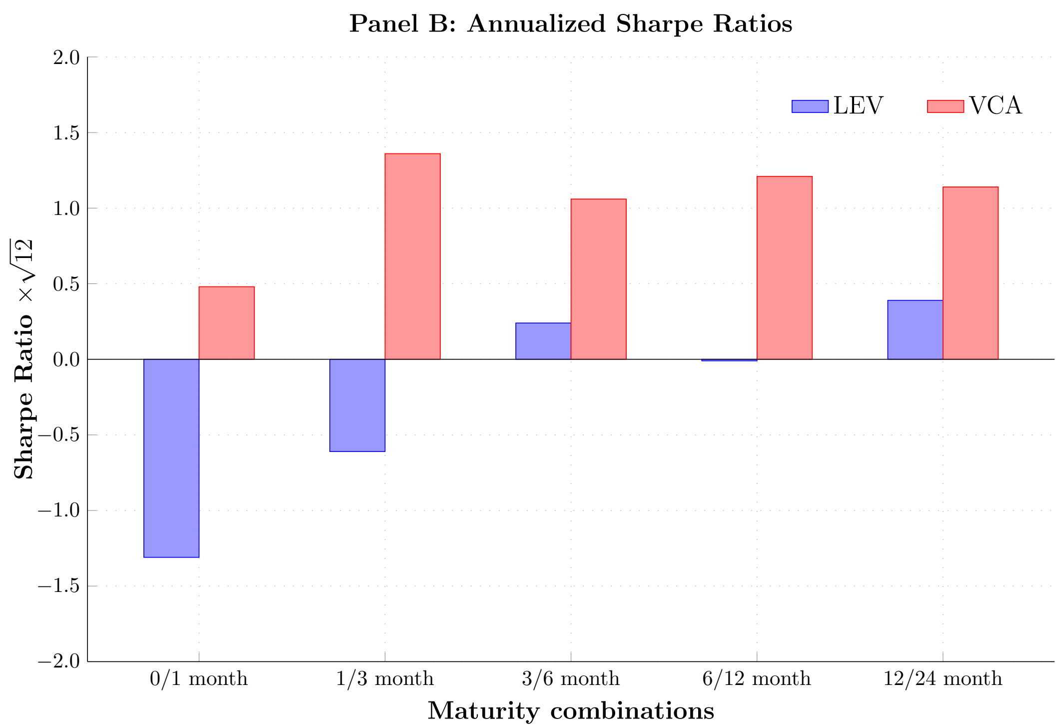


Figure A4. Performance of Volatility Carry Strategies (Developed)

This figure reports average excess returns in Panel A, and annualized Sharpe Ratios in Panel B. VCA and LEV denote strategies based on portfolios of (i) forward volatility agreements from 1/3 month to 12/24 month (see Table A23), and (ii) volatility swaps for 0/1 month (see Table A9). Figure 3 displays results for a cross-section of 20 developed and emerging market countries.

H.1 Robustness and Extensions

Table A1. Country-level Predictive Regressions: Volatility Excess Returns

This table presents estimates of country-level pooled regressions. The dependent variable is the volatility excess return whereas the explanatory variable is the lagged forward implied volatility premium, both computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). The coefficient estimates α and γ should equal zero under the null that the unbiasedness hypothesis holds. t-statistics (reported in brackets) are base on Driscoll and Kraay (1998) standard errors that are heteroscedasticity consistent and robust to very general forms of cross-sectional and temporal dependence. The table also presents country-fixed effect regression estimates for 10 developed countries (DEV ranging from AUD to SEK), 10 emerging market countries (EME ranging from BRL to ZAR), and all countries (ALL). Excess returns are expressed in percentage per month and the sample runs from January 1996 to December 2015. Data on over-the-counter currency options are from JP Morgan and Bloomberg.

	α		γ		$R^2(\%)$	α		γ		$R^2(\%)$
	Panel A: Spot/Forward Implied Volatilities					Panel B: Spot/Forward Implied Variances				
AUD	0.50	[0.81]	-0.88	[-5.84]	10.7	1.90	[1.36]	-0.84	[-4.54]	8.3
CAD	0.52	[0.88]	-0.85	[-5.53]	7.2	1.91	[1.47]	-0.83	[-4.91]	6.2
CHF	0.02	[0.05]	-0.59	[-3.79]	3.6	0.82	[0.73]	-0.57	[-3.40]	3.1
DKK	0.01	[0.01]	-0.67	[-6.19]	5.4	0.72	[0.63]	-0.65	[-5.54]	4.9
EUR	0.04	[0.07]	-0.66	[-5.06]	5.1	0.78	[0.61]	-0.63	[-4.44]	4.6
GBP	-0.14	[-0.24]	-0.68	[-3.64]	5.9	0.33	[0.26]	-0.60	[-2.56]	4.4
JPY	-0.01	[-0.01]	-0.66	[-4.53]	4.9	0.79	[0.73]	-0.67	[-4.18]	4.9
NOK	0.27	[0.53]	-0.73	[-5.34]	5.4	1.36	[1.18]	-0.71	[-4.36]	4.3
NZD	0.60	[1.11]	-0.85	[-7.05]	11.2	2.00	[1.69]	-0.83	[-6.17]	9.6
SEK	0.09	[0.20]	-0.63	[-5.78]	4.7	0.86	[0.86]	-0.61	[-4.98]	4.0
BRL	0.58	[0.43]	-0.70	[-3.22]	6.1	2.78	[0.89]	-0.65	[-2.74]	4.4
CZK	0.22	[0.26]	-0.79	[-4.00]	6.7	1.27	[0.72]	-0.79	[-3.82]	6.3
HUF	-0.08	[-0.12]	-0.74	[-6.59]	7.6	0.51	[0.36]	-0.72	[-6.19]	6.8
KRW	1.75	[0.83]	-1.11	[-3.23]	10.0	6.55	[1.22]	-1.12	[-2.70]	7.6
MXN	-0.49	[-0.44]	-0.72	[-4.51]	7.6	0.62	[0.22]	-0.67	[-3.25]	5.5
PLN	-0.07	[-0.09]	-0.84	[-5.19]	10.6	0.58	[0.33]	-0.82	[-4.70]	9.8
SGD	-0.02	[-0.02]	-0.63	[-3.99]	4.6	1.17	[0.57]	-0.59	[-3.35]	3.8
TRY	-0.87	[-1.08]	-0.52	[-4.11]	3.6	-0.52	[-0.28]	-0.44	[-3.06]	2.3
TWD	-0.13	[-0.15]	-0.66	[-6.49]	6.3	0.99	[0.56]	-0.57	[-5.11]	5.0
ZAR	0.41	[0.50]	-0.48	[-2.13]	2.3	2.36	[1.15]	-0.33	[-1.02]	0.7
DEV	0.45	[0.71]	-0.74	[-6.70]	6.7	1.79	[1.27]	-0.71	[-5.59]	5.7
EME	0.94	[0.52]	-0.70	[-5.88]	6.3	4.50	[0.98]	-0.64	[-4.60]	4.4
ALL	0.44	[0.69]	-0.71	[-6.72]	6.6	1.75	[1.22]	-0.66	[-5.36]	4.9

Table A2. Principal Components on All Portfolios sorted on Implied Volatility Slopes

This table presents the loadings for the first (PC_1), second (PC_2) and third (PC_3) principal component for the 20 slope-sorted portfolios (five portfolios for each of the four maturity pair) presented in Table 3. The last row reports the cumulative share of total variance (CV) explained by the common factors. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table A25 in the Internet Appendix displays results for a cross-section of 10 developed countries.

Loadings	P_1	P_2	P_3	P_4	P_5
		Panel A: 1/3 month			
PC_1	0.37	0.34	0.32	0.29	0.32
PC_2	-0.67	-0.09	-0.04	0.00	0.35
PC_3	-0.37	0.30	0.37	0.23	-0.38
		Panel B: 3/6 month			
PC_1	0.21	0.24	0.18	0.18	0.19
PC_2	-0.24	0.08	0.08	0.11	0.31
PC_3	-0.21	0.13	0.16	0.11	-0.28
		Panel C: 6/12 month			
PC_1	0.16	0.20	0.15	0.14	0.16
PC_2	-0.19	0.07	0.05	0.08	0.24
PC_3	-0.10	0.12	0.13	0.10	-0.23
		Panel D: 12/24 month			
PC_1	0.15	0.18	0.14	0.14	0.15
PC_2	-0.12	0.08	0.08	0.12	0.31
PC_3	-0.11	0.13	0.13	0.08	-0.32
CV	0.76	0.83	0.88	0.91	0.94

Table A3. Composition of Slope-sorted Portfolios

This table reports the percentage composition of the slope-sorted implied volatility portfolios presented in Tables 3. The first portfolio contains forward volatility agreements with the highest implied volatility slopes whereas the last portfolio contains forward volatility agreements with the lowest implied volatility slopes. The portfolios are rebalanced monthly from January 1996 to December 2015. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	P_1	P_2	P_3	P_4	P_5
AUD	3	19	26	15	37
CAD	9	13	27	22	29
CHF	5	25	19	26	26
DKK	2	15	39	29	15
EUR	7	35	22	24	11
GBP	29	39	18	8	5
JPY	22	26	15	16	21
NZD	0	10	24	22	44
NOK	0	9	33	30	28
SEK	0	10	23	38	28
BRL	41	28	14	7	10
CZK	1	10	13	43	34
HUF	10	26	25	29	9
KRW	39	33	9	4	15
MXN	36	34	13	16	1
PLN	3	16	28	24	29
SGD	52	32	13	3	0
TRY	79	16	1	1	3
TWD	73	12	9	4	2
ZAR	26	33	20	11	10

Table A4. Slope-sorted Portfolios and Bid-ask Spreads

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their implied volatility slopes. Volatility excess returns are computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). Slopes are computed using 3 month and 24 month model-free implied volatility. The first (last) portfolio P_1 (P_5) contains forward volatility agreements with the highest (lowest) implied volatility slopes. LEV denotes a strategy that equally invests in all five portfolios whereas VCA is a long-short strategy that buys P_5 and sells P_1. The table also reports the Sharpe ratio (SR), the first order autocorrelation coefficient ac_1, and the frequency of portfolio switches ($freq$). t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Excess returns are net of bid-ask spreads and expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	P_1	P_2	P_3	P_4	P_5	LEV	VCA
				Panel A: 1/3 month			
$mean$	-4.17	-3.58	-2.96	-3.03	-0.01	-2.75	4.16
	[-3.49]	[-3.32]	[-2.73]	[-3.24]	[-0.01]	[-2.65]	[4.67]
$sdev$	16.38	14.06	13.37	12.13	14.19	12.72	12.41
$skew$	2.22	2.76	2.17	1.67	2.48	2.47	-1.34
$SR \times \sqrt{12}$	-0.88	-0.88	-0.77	-0.87	0.00	-0.75	1.16
ac_1	0.18	0.19	0.23	0.14	0.30	0.25	0.09
				Panel B: 3/6 month			
$mean$	-0.48	-0.08	0.06	-0.09	1.40	0.16	1.88
	[-0.75]	[-0.11]	[0.09]	[-0.17]	[1.98]	[0.27]	[4.03]
$sdev$	9.46	10.16	7.83	7.83	8.88	8.00	7.19
$skew$	1.64	5.23	1.64	1.31	2.31	2.73	-0.16
$SR \times \sqrt{12}$	-0.17	-0.03	0.03	-0.04	0.55	0.07	0.90
ac_1	0.08	0.17	0.21	0.02	0.18	0.18	0.02
				Panel C: 6/12 month			
$mean$	-0.87	-0.39	-0.51	-0.45	0.81	-0.28	1.68
	[-1.80]	[-0.63]	[-1.05]	[-1.07]	[1.38]	[-0.58]	[4.20]
$sdev$	7.31	8.45	6.50	6.47	7.50	6.49	6.17
$skew$	1.26	5.57	1.37	1.18	2.71	2.66	0.43
$SR \times \sqrt{12}$	-0.41	-0.16	-0.27	-0.24	0.37	-0.15	0.94
ac_1	0.08	0.19	0.18	0.00	0.20	0.18	0.02
				Panel D: 12/24 month			
$mean$	-0.19	0.05	0.00	0.27	1.83	0.39	2.02
	[-0.40]	[0.09]	[-0.01]	[0.66]	[3.13]	[0.86]	[4.44]
$sdev$	7.04	8.03	6.39	6.44	8.17	6.32	7.02
$skew$	1.82	4.90	1.57	1.05	2.83	2.99	1.44
$SR \times \sqrt{12}$	-0.09	0.02	0.00	0.15	0.78	0.21	0.99
ac_1	0.08	0.12	0.12	-0.04	0.14	0.14	-0.02
$freq$	0.26	0.47	0.56	0.56	0.32		

Table A5. Slope-sorted Portfolios and Largest Bid-ask Spreads

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their implied volatility slopes. Volatility excess returns are computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). Slopes are computed using 3 month and 24 month model-free implied volatility. The first (last) portfolio P_1 (P_5) contains forward volatility agreements with the highest (lowest) implied volatility slopes. LEV denotes a strategy that equally invests in all five portfolios whereas VCA is a long-short strategy that buys P_5 and sells P_1. The table also reports the Sharpe ratio (SR), the first order autocorrelation coefficient ac_1, and the frequency of portfolio switches ($freq$). t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Excess returns are net of the largest bid-ask spreads (for a given maturity) and expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	P_1	P_2	P_3	P_4	P_5	LEV	VCA
				Panel A: 1/3 month			
$mean$	-3.93	-3.87	-3.24	-3.31	-0.25	-2.92	3.68
	[-3.28]	[-3.59]	[-3.00]	[-3.54]	[-0.19]	[-2.81]	[4.12]
$sdev$	16.40	14.04	13.37	12.12	14.21	12.72	12.43
$skew$	2.21	2.77	2.18	1.66	2.48	2.47	-1.37
$SR \times \sqrt{12}$	-0.83	-0.95	-0.84	-0.95	-0.06	-0.79	1.03
ac_1	0.18	0.19	0.23	0.14	0.30	0.25	0.10
				Panel B: 3/6 month			
$mean$	-0.26	-0.35	-0.23	-0.37	1.16	-0.01	1.42
	[-0.41]	[-0.47]	[-0.37]	[-0.74]	[1.64]	[-0.02]	[3.05]
$sdev$	9.49	10.14	7.82	7.83	8.91	8.01	7.23
$skew$	1.62	5.25	1.66	1.31	2.30	2.72	-0.16
$SR \times \sqrt{12}$	-0.10	-0.12	-0.10	-0.17	0.45	0.00	0.68
ac_1	0.08	0.17	0.21	0.03	0.18	0.18	0.02
				Panel C: 6/12 month			
$mean$	-0.72	-0.62	-0.76	-0.72	0.61	-0.44	1.32
	[-1.47]	[-0.99]	[-1.57]	[-1.71]	[1.04]	[-0.90]	[3.30]
$sdev$	7.33	8.43	6.50	6.47	7.51	6.49	6.20
$skew$	1.24	5.59	1.39	1.18	2.72	2.66	0.42
$SR \times \sqrt{12}$	-0.34	-0.25	-0.40	-0.38	0.28	-0.23	0.74
ac_1	0.08	0.19	0.17	0.01	0.20	0.18	0.02
				Panel D: 12/24 month			
$mean$	-0.07	-0.15	-0.22	0.04	1.68	0.26	1.74
	[-0.14]	[-0.26]	[-0.49]	[0.10]	[2.85]	[0.56]	[3.82]
$sdev$	7.06	8.02	6.39	6.45	8.19	6.32	7.05
$skew$	1.80	4.92	1.58	1.05	2.83	2.99	1.42
$SR \times \sqrt{12}$	-0.03	-0.06	-0.12	0.02	0.71	0.14	0.86
ac_1	0.08	0.12	0.11	-0.04	0.14	0.14	-0.02
$freq$	0.26	0.47	0.56	0.56	0.32		

Table A6. Descriptive Statistics: Vanna-Volga Method

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their implied volatility slopes. Volatility excess returns are computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) via the vanna-volga method (e.g., Castagna and Mercurio 2007). Slopes are computed using 3 month and 24 month model-free implied volatility. The first (last) portfolio P_1 (P_5) contains forward volatility agreements with the highest (lowest) implied volatility slopes. LEV denotes a strategy that equally invests in all five portfolios whereas VCA is a long-short strategy that buys P_5 and sells P_1. The table also reports the Sharpe ratio (SR), the first order autocorrelation coefficient ac_1, and the frequency of portfolio switches ($freq$). t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	P_1	P_2	P_3	P_4	P_5	LEV	VCA
			Panel A: 1/3 month				
$mean$	-4.44	-2.93	-2.51	-2.39	0.37	-2.38	4.82
	[-3.80]	[-2.83]	[-2.34]	[-2.59]	[0.29]	[-2.34]	[5.64]
$sdev$	15.96	13.65	13.32	11.83	14.06	12.50	11.97
$skew$	2.26	2.74	2.19	1.66	2.42	2.47	-1.30
$SR \times \sqrt{12}$	-0.96	-0.74	-0.65	-0.70	0.09	-0.66	1.39
ac_1	0.19	0.18	0.22	0.17	0.30	0.25	0.08
			Panel B: 3/6 month				
$mean$	-0.77	0.39	0.50	0.50	1.81	0.49	2.58
	[-1.25]	[0.54]	[0.79]	[1.01]	[2.66]	[0.81]	[5.88]
$sdev$	9.13	9.77	7.86	7.60	8.64	7.80	6.78
$skew$	1.62	5.06	1.67	1.21	2.10	2.57	-0.07
$SR \times \sqrt{12}$	-0.29	0.14	0.22	0.23	0.73	0.22	1.32
ac_1	0.09	0.17	0.22	0.02	0.17	0.18	0.01
			Panel C: 6/12 month				
$mean$	-1.06	-0.05	-0.15	-0.03	1.09	-0.04	2.15
	[-2.27]	[-0.09]	[-0.32]	[-0.07]	[1.95]	[-0.09]	[5.54]
$sdev$	7.00	8.01	6.46	6.39	7.23	6.28	5.92
$skew$	1.22	5.19	1.42	1.00	2.38	2.37	0.63
$SR \times \sqrt{12}$	-0.53	-0.02	-0.08	-0.02	0.52	-0.02	1.26
ac_1	0.07	0.19	0.18	0.00	0.18	0.17	0.03
			Panel D: 12/24 month				
$mean$	-0.25	0.48	0.44	1.03	2.30	0.80	2.55
	[-0.52]	[0.88]	[0.96]	[2.51]	[4.01]	[1.79]	[5.55]
$sdev$	7.13	7.76	6.50	6.33	8.24	6.27	7.22
$skew$	1.89	4.22	1.46	0.87	2.58	2.56	1.60
$SR \times \sqrt{12}$	-0.12	0.21	0.24	0.56	0.97	0.44	1.22
ac_1	0.06	0.13	0.12	-0.01	0.11	0.13	-0.03
$freq$	0.26	0.45	0.54	0.56	0.32		

Table A7. Descriptive Statistics: Simple-Variance Method

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their implied volatility slopes. Volatility excess returns are computed using spot and forward simple implied volatilities constructed as in Martin (2013) via the cubic spline interpolation method (e.g., Jiang and Tian 2005). Slopes are computed using 3 month and 24 month model-free implied volatility. The first (last) portfolio P_1 (P_5) contains forward volatility agreements with the highest (lowest) implied volatility slopes. LEV denotes a strategy that equally invests in all five portfolios whereas VCA is a long-short strategy that buys P_5 and sells P_1. The table also reports the Sharpe ratio (SR), the first order autocorrelation coefficient ac_1, and the frequency of portfolio switches ($freq$). t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	P_1	P_2	P_3	P_4	P_5	LEV	VCA
			Panel A: 1/3 month				
$mean$	-4.40	-2.69	-2.07	-2.46	0.91	-2.14	5.31
	[-3.77]	[-2.75]	[-1.89]	[-2.47]	[0.76]	[-2.12]	[6.48]
$sdev$	15.98	12.83	14.01	12.29	13.75	12.46	12.30
$skew$	2.05	2.05	2.53	2.11	2.26	2.43	-1.24
$SR \times \sqrt{12}$	-0.95	-0.73	-0.51	-0.69	0.23	-0.60	1.50
ac_1	0.17	0.16	0.22	0.22	0.27	0.25	0.06
			Panel B: 3/6 month				
$mean$	-0.74	0.32	0.74	0.30	1.97	0.52	2.71
	[-1.25]	[0.53]	[1.03]	[0.54]	[3.01]	[0.88]	[6.07]
$sdev$	8.93	7.86	9.13	7.77	8.19	7.60	6.80
$skew$	1.23	1.78	3.92	1.60	1.86	2.33	-0.04
$SR \times \sqrt{12}$	-0.29	0.14	0.28	0.13	0.83	0.24	1.38
ac_1	0.06	0.15	0.22	0.09	0.18	0.18	0.03
			Panel C: 6/12 month				
$mean$	-1.04	-0.20	0.19	-0.20	1.23	0.00	2.27
	[-2.38]	[-0.42]	[0.32]	[-0.46]	[2.33]	[-0.01]	[5.94]
$sdev$	6.65	6.41	7.25	6.53	6.70	6.01	5.76
$skew$	0.79	2.09	3.14	1.53	1.85	2.04	0.54
$SR \times \sqrt{12}$	-0.54	-0.11	0.09	-0.11	0.64	0.00	1.37
ac_1	0.03	0.14	0.23	0.06	0.19	0.17	0.05
			Panel D: 12/24 month				
$mean$	-0.39	0.22	0.55	0.56	1.97	0.58	2.36
	[-0.96]	[0.52]	[1.06]	[1.31]	[3.81]	[1.41]	[5.58]
$sdev$	6.23	6.31	6.95	6.62	7.45	5.82	6.65
$skew$	1.01	2.02	3.00	1.45	2.09	2.31	1.66
$SR \times \sqrt{12}$	-0.21	0.12	0.27	0.29	0.92	0.35	1.23
ac_1	0.00	0.06	0.16	0.02	0.10	0.12	-0.04
$freq$	0.27	0.49	0.57	0.57	0.31		

Table A8. Descriptive Statistics: At-the-Money Implied Volatilities

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their implied volatility slopes. Volatility excess returns are computed using spot and forward at-the-money implied volatilities. Slopes are computed using 3 month and 24 month model-free implied volatility. The first (last) portfolio P_1 (P_5) contains forward volatility agreements with the highest (lowest) implied volatility slopes. LEV denotes a strategy that equally invests in all five portfolios whereas VCA is a long-short strategy that buys P_5 and sells P_1. The table also reports the Sharpe ratio (SR), the first order autocorrelation coefficient ac_1, and the frequency of portfolio switches ($freq$). t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	P_1	P_2	P_3	P_4	P_5	LEV	VCA
Panel A: 1/3 month							
$mean$	-3.16	-1.89	-1.43	-1.81	1.66	-1.33	4.82
	[-2.68]	[-1.83]	[-1.35]	[-1.96]	[1.35]	[-1.31]	[5.87]
$sdev$	16.18	13.48	13.71	11.71	14.22	12.53	12.32
$skew$	2.05	2.35	2.17	1.62	2.42	2.37	-0.99
$SR \times \sqrt{12}$	-0.68	-0.49	-0.36	-0.54	0.40	-0.37	1.36
ac_1	0.18	0.18	0.19	0.17	0.27	0.24	0.06
Panel B: 3/6 month							
$mean$	-0.74	0.42	0.57	0.21	1.88	0.47	2.61
	[-1.20]	[0.59]	[0.93]	[0.43]	[2.90]	[0.80]	[6.18]
$sdev$	9.13	9.30	7.99	7.33	8.24	7.59	6.54
$skew$	1.43	4.08	1.35	1.02	1.52	2.03	-0.24
$SR \times \sqrt{12}$	-0.28	0.16	0.25	0.10	0.79	0.21	1.39
ac_1	0.09	0.19	0.18	0.06	0.15	0.18	0.01
Panel C: 6/12 month							
$mean$	-0.96	0.07	0.10	-0.17	1.24	0.05	2.20
	[-2.11]	[0.12]	[0.21]	[-0.42]	[2.40]	[0.12]	[6.23]
$sdev$	6.85	7.66	6.45	6.09	6.74	6.00	5.47
$skew$	1.01	4.32	0.91	0.83	1.57	1.71	0.54
$SR \times \sqrt{12}$	-0.49	0.03	0.05	-0.10	0.64	0.03	1.40
ac_1	0.06	0.21	0.15	0.05	0.15	0.17	0.00
Panel D: 12/24 month							
$mean$	-0.57	0.21	0.19	0.00	1.57	0.28	2.14
	[-1.31]	[0.41]	[0.44]	[-0.01]	[3.14]	[0.69]	[5.39]
$sdev$	6.57	7.22	6.33	5.99	7.37	5.79	6.30
$skew$	1.40	3.78	1.30	0.69	1.94	2.12	0.97
$SR \times \sqrt{12}$	-0.30	0.10	0.10	0.00	0.74	0.17	1.18
ac_1	0.04	0.12	0.07	-0.09	0.07	0.10	-0.05
$freq$	0.28	0.53	0.58	0.57	0.33		

Table A9. Descriptive Statistics: Volatility Swaps

This table reports descriptive statistics for five portfolios of volatility swaps sorted by their implied volatility slopes. The implied volatilities are model-free as in Britten-Jones and Neuberger (2000) and constructed via the cubic spline interpolation method (e.g., Jiang and Tian 2005). The realized volatilities are based on daily forward exchange rate returns as in Kozhan, Neuberger, and Schneider (2013). Each slope is based on the 24 month and 3 month implied volatility. The first (last) portfolio P_1 (P_5) contains volatility swaps with the highest (lowest) forward implied volatility premia. LEV denotes a strategy that equally invests in all five portfolios whereas VCA is a long-short strategy that buys P_5 and sells P_1. The table also reports the first order autocorrelation coefficient (ac_1), the Sharpe ratio (SR) and the frequency of portfolio switches ($freq$). t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries in *Panel A* and 10 developed countries in *Panel B*. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	P_1	P_2	P_3	P_4	P_5	LEV	VCA
			Panel A: Developed and Emerging				
$mean$	-18.30	-10.75	-8.14	-9.19	-6.83	-10.64	11.47
	[-6.19]	[-4.90]	[-4.17]	[-5.55]	[-3.50]	[-5.85]	[4.80]
$sdev$	36.67	25.00	24.79	22.63	27.76	21.83	33.93
$skew$	2.41	1.91	0.91	1.33	2.31	1.46	-1.59
$SR \times \sqrt{12}$	-1.73	-1.49	-1.14	-1.41	-0.85	-1.69	1.17
ac_1	0.24	0.33	0.19	0.12	0.13	0.27	0.12
$freq$	0.26	0.47	0.56	0.56	0.32		
			Panel B: Developed				
$mean$	-9.78	-7.09	-6.38	-8.62	-6.16	-7.61	3.62
	[-4.21]	[-3.70]	[-3.24]	[-5.06]	[-3.29]	[-4.49]	[1.70]
$sdev$	26.33	22.66	27.18	21.30	26.77	20.12	26.35
$skew$	0.73	0.73	2.97	0.56	2.05	0.96	1.19
$SR \times \sqrt{12}$	-1.29	-1.08	-0.81	-1.40	-0.80	-1.31	0.48
ac_1	0.30	0.25	0.11	0.21	0.09	0.21	0.21
$freq$	0.31	0.52	0.61	0.56	0.33		

Table A10. Slope-sorted Portfolios of Volatility Swap

This table presents cross-sectional asset pricing tests. Both test assets (slope-sorted portfolios of volatility swaps) and pricing factors (level and volatility carry) are presented in Table A9 in the Internet Appendix. The table reports GMM (first and second-stage) estimates of the factor loadings b, the market price of risk λ, and the cross-sectional R^2. t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. HJ refers to the Hansen and Jagannathan (1997) distance (with simulated p-values in parentheses) for the null hypothesis that the pricing errors per unit of norm is equal to zero. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries in *Panel A* and 10 developed countries in *Panel B*. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	b_{LEV}	b_{VCA}	λ_{LEV}	λ_{VCA}	$R^2(\%)$	HJ
			Panel A: Developed and Emerging			
GMM_1	-0.02	0.01	-10.61	11.11	93.7	0.17
	[-3.35]	[1.36]	[-5.55]	[4.08]		(0.59)
GMM_2	-0.02	0.01	-10.31	10.14	79.5	
	[-3.20]	[2.87]	[-5.63]	[4.43]		
			-10.64	**11.47**		
			Panel B: Developed			
GMM_1	-0.02	0.00	-7.54	2.78	5.9	0.21
	[-3.42]	[0.80]	[-4.14]	[1.24]		(0.34)
GMM_2	-0.02	0.01	-7.57	3.61	-31.4	
	[-3.81]	[1.28]	[-4.21]	[1.70]		
			-7.61	**3.62**		

Table A11. Country-level Asset Pricing Tests

This table presents country-level cross-sectional tests. The test assets are implied volatility excess returns for a cross-section of 20 developed and emerging market countries in *Panel A*, and a cross-section of 10 developed economies in *Panel B*. These excess returns are constructed by going long (short) forward volatility agreements with implied volatility slopes lower (higher) than the median implied volatility slope. The pricing factors are the level (LEV) and the volatility carry (VCA) factors described in Table 3 and Table A23, respectively. The implied volatilities are model-free as in Britten-Jones and Neuberger (2000) and constructed via the cubic spline interpolation method as in Jiang and Tian (2005). The table reports Fama-MacBeth estimates of the factor price of risk λ, the cross-sectional R^2, and the t-statistic based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection in brackets. A bolded λ denotes statistical significance at 5% (or lower) obtained via 10,000 stationary bootstrap repetitions (e.g., Politis and Romano 1994). Excess returns are expressed in percentage per month and rebalanced monthly from January 1996 to December 2015. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	Panel A: Developed and Emerging					Panel B: Developed				
	λ_{LEV}		λ_{VCA}		$R^2(\%)$	λ_{LEV}		λ_{VCA}		$R^2(\%)$
1/3 month	-2.94	[-2.05]	**9.13**	[4.29]	48.9	-2.54	[-1.38]	**7.21**	[3.69]	57.0
3/6 month	-0.46	[-0.62]	**3.96**	[3.72]	76.0	-0.29	[-0.39]	**2.46**	[3.00]	68.5
6/12 month	0.17	[0.29]	**1.93**	[2.25]	75.2	-0.44	[-0.71]	**2.10**	[3.03]	71.2
12/24 month	0.66	[1.10]	**2.19**	[2.82]	67.5	-0.06	[-0.09]	**2.23**	[2.86]	66.3

Table A12. Asset Pricing Tests: S&P 500 Variance Swap Returns

5This table presents time-series asset pricing tests. The test assets (slope-sorted portfolios) are presented in Table 3. The set of traded pricing factors includes the level (LEV), and the S&P 500 variance swap returns ranging from 1-month (R_1) to 12-month (R_{12}). The superscripts ***, **, and * denote statistical significance at the 1%, 5%, and 10%, respectively, based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. Excess returns are expressed in percentage per month and range from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. The variance swap returns are from Travis Johnson's website. Table A32 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	α	LEV	R_1	R_2	R_3	R_6	R_9	R_{12}	$R^2_{LEV}(\%)$	$R^2_{ALL}(\%)$	χ^2_α
					Panel A: 1/3 month						
P_1	−3.66***	1.58***	0.00	0.07	0.01	−0.07	−0.09	0.07	69.4	69.4	(<.01)
P_2	−2.74***	1.56***	−0.01	−0.03	0.00	−0.02	0.19**	−0.09**	83.7	83.8	
P_3	−1.60***	1.48***	0.03	−0.04	−0.09	0.24**	−0.17	0.07	80.8	82.0	
P_4	−1.82***	1.29***	0.01	0.00	−0.02	0.00	0.08	−0.02	82.0	81.8	
P_5	1.24*	1.45***	−0.02	0.09	0.00	−0.14	0.10	−0.06	75.1	75.3	
					Panel B: 3/6 month						
P_1	−0.48	0.98***	0.01	−0.02	0.02	0.01	−0.12	0.11**	72.8	73.0	
P_2	0.36	1.15***	−0.03	0.00	0.06*	−0.09	0.18*	−0.14	83.3	84.7	
P_3	0.75***	0.91***	0.01	−0.03	−0.02	0.15***	−0.19***	0.10***	82.9	84.1	
P_4	0.61**	0.88***	0.01	−0.03	0.01	0.02	−0.08	0.07***	81.7	81.9	
P_5	2.23***	0.95***	0.00	0.04	−0.02	−0.12***	0.07	0.01	75.3	75.4	
					Panel C: 6/12 month						
P_1	−0.94***	0.73***	0.01	−0.04	0.02	0.00	0.02	0.01	68.4	68.0	
P_2	−0.01	0.94***	−0.02	0.00	0.05*	−0.06	0.19*	−0.15*	81.1	82.9	
P_3	0.06	0.74***	0.00	−0.01	−0.03	0.13***	−0.17***	0.07**	78.5	79.4	
P_4	0.22	0.71***	0.01	−0.02	0.00	0.03	−0.07	0.05*	77.1	77.0	
P_5	1.62***	0.79***	0.00	0.04	−0.03	−0.09**	0.10*	−0.04	75.8	76.2	
					Panel D: 12/24 month						
P_1	−0.09	0.71***	0.01	−0.03	0.04	−0.07	0.05	−0.01	70.5	70.3	
P_2	0.47*	0.90***	−0.02	0.00	0.03	−0.02	0.12	−0.13**	81.1	82.5	
P_3	0.49**	0.75***	0.00	−0.02	−0.03	0.10***	−0.13***	0.07***	78.4	79.3	
P_4	0.82***	0.70***	0.01	−0.02	0.00	0.03	−0.06	0.05	73.3	73.2	
P_5	2.46***	0.79***	−0.01	0.04	−0.01	−0.03	−0.01	−0.03	58.4	58.4	

Table A13. Asset Pricing Tests: Currency Risk Factors

This table presents time-series asset pricing tests. The test assets (slope-sorted portfolios) are presented in Table 3. The set of traded pricing factors includes the level (LEV), dollar (DOL), carry (CAR), global imbalance (IMB), foreign exchange volatility (VOL), and liquidity (LIQ) factors. The superscripts ***, **, and * denote statistical significance at the 1%, 5%, and 10%, respectively, based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. R^2_{LEV} is the R^2 due to the level factor only and R^2_{ALL} denoted the total R^2 coefficient. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. Excess returns are expressed in percentage per month and range from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Table A29 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	α	LEV	DOL	CAR	IMB	VOL	LIQ	$R^2_{LEV}(\%)$	$R^2_{ALL}(\%)$	χ^2_α
				Panel A: 1/3 month						
P_1	−3.76***	1.70***	0.21	−0.35	−0.25	0.51	−0.21	69.4	69.5	(<.01)
P_2	−2.38***	1.59***	−0.02	−0.07	−0.20	0.31	−0.03	83.7	83.6	
P_3	−1.63***	1.46***	0.18	−0.18	−0.17	0.06	−0.05	80.8	80.7	
P_4	−1.96***	1.38***	0.35*	0.20	−0.11	−0.14	−0.34**	82.0	82.4	
P_5	0.73	1.57***	−0.09	−0.01	0.27	0.26	0.12	75.1	75.0	
				Panel B: 3/6 month						
P_1	−0.48	0.99***	0.00	0.13	−0.13	0.03	−0.13	72.8	72.4	
P_2	0.63**	1.13***	−0.16	0.02	0.00	0.03	0.35***	83.3	83.7	
P_3	0.92***	0.85***	−0.09	−0.04	−0.04	−0.02	0.06	82.9	82.7	
P_4	0.73***	0.87***	0.08	−0.03	0.09	−0.05	−0.14	81.7	81.6	
P_5	1.94***	0.93***	−0.31**	0.00	0.31	−0.05	0.08	75.3	75.7	
				Panel C: 6/12 month						
P_1	−0.92***	0.74***	0.02	0.20	−0.07	−0.12	−0.15	68.4	68.2	
P_2	0.17	0.92***	−0.09	0.05	−0.02	−0.07	0.32**	81.1	81.6	
P_3	0.13	0.69***	−0.02	−0.01	0.02	−0.06	0.12	78.5	78.3	
P_4	0.24	0.70***	0.06	−0.08	0.12	−0.05	−0.11	77.1	77.0	
P_5	1.31***	0.79***	−0.20*	−0.07	0.16	0.01	0.10	75.8	75.7	
				Panel D: 12/24 month						
P_1	−0.19	0.72***	0.03	0.11	−0.01	−0.10	−0.12	70.5	70.2	
P_2	0.66***	0.84***	−0.05	0.14	−0.13	−0.26**	0.18	81.1	81.5	
P_3	0.62***	0.67***	0.08	0.10	−0.09	−0.23*	0.03	78.4	78.5	
P_4	0.90***	0.67***	0.21	0.02	0.12	−0.25**	−0.18	73.3	74.1	
P_5	2.33***	0.77***	−0.19	−0.13	0.12	0.18	0.09	58.4	58.0	

Table A14. Asset Pricing Tests: Global Equity Risk Factors

This table presents time-series asset pricing tests. The test assets (slope-sorted portfolios) are presented in Table 3. The set of traded pricing factors includes the level (LEV) and the Fama-French global equity factors, i.e., market excess return (MKT), size (SMB), value (HML), profitability (RMW), and investment (CMA). The superscripts ***, **, and * denote statistical significance at the 1%, 5%, and 10%, respectively, based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. R^2_{LEV} is the R^2 due to the level factor only and R^2_{ALL} denoted the total R^2 coefficient. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. Excess returns are expressed in percentage per month and range from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. The Fama-French factors are from Kenneth French's website. Table A30 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	α	LEV	MKT	SMB	HML	RMW	CMA	$R^2_{LEV}(\%)$	$R^2_{ALL}(\%)$	χ^2_α
					Panel A: 1/3 month					
P_1	−4.06***	1.68***	−0.07	−0.01	0.46	−0.11	−0.51	69.4	68.9	(<.01)
P_2	−2.46***	1.64***	0.08	0.23	0.32	−0.30	−0.21	83.7	83.8	
P_3	−2.05***	1.47***	0.07	0.48	−0.34	0.46*	0.29	80.8	81.1	
P_4	−2.06***	1.39***	0.01	0.47***	0.52	0.12	−0.55	82.0	82.6	
P_5	1.26*	1.52***	−0.09	−0.41*	0.46*	−0.56	−0.58*	75.1	75.3	
					Panel B: 3/6 month					
P_1	−0.40	0.98***	−0.04	−0.06	0.09	−0.18	−0.13	72.8	72.3	
P_2	0.79***	1.15***	0.03	−0.06	0.05	−0.23	0.09	83.3	83.2	
P_3	0.76***	0.86***	0.05	0.08	−0.47	0.39	0.32	82.9	83.8	
P_4	0.59***	0.88***	0.05	0.00	0.05	0.30**	−0.10	81.7	81.7	
P_5	2.30***	0.92***	−0.11	−0.42**	0.12	−0.23	−0.26	75.3	75.7	
					Panel C: 6/12 month					
P_1	−0.85***	0.71***	−0.10	0.04	−0.04	0.03	0.00	68.4	68.0	
P_2	0.26	0.93***	0.03	−0.02	−0.15	−0.07	0.31	81.1	80.9	
P_3	0.09	0.69***	0.03	0.06	−0.35**	0.30**	0.16	78.5	79.3	
P_4	0.19	0.69***	−0.02	−0.02	0.00	0.13	−0.08	77.1	76.8	
P_5	1.46***	0.77***	−0.06	−0.24**	−0.22	−0.07	0.17	75.8	75.9	
					Panel D: 12/24 month					
P_1	−0.05	0.69***	−0.07	−0.11	−0.15	−0.23	0.21	70.5	70.3	
P_2	0.62***	0.88***	0.07	−0.03	−0.19	−0.05	0.41**	81.1	81.0	
P_3	0.50**	0.69***	0.10	0.12	−0.37***	0.26*	0.31*	78.4	79.0	
P_4	0.79***	0.70***	0.07	0.19**	0.17	0.07	−0.01	73.3	73.4	
P_5	2.32***	0.74***	−0.02	−0.28*	0.06	−0.02	0.16	58.4	58.5	

Table A15. Asset Pricing Tests: VIX Futures Returns

This table presents time-series asset pricing tests. The test assets (slope-sorted portfolios) are presented in Table 3. The set of traded pricing factors includes the level (LEV), and the VIX futures returns ranging from 1-month (R_1) to 6-month (R_6). The superscripts ***, **, and * denote statistical significance at the 1%, 5%, and 10%, respectively, based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. R^2_{LEV} is the R^2 due to the level factor only and R^2_{ALL} denoted the total R^2 coefficient. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. Excess returns are expressed in percentage per month and range from April 2004 to December 2015 using a cross-section of 20 developed and emerging market countries. The VIX futures returns are from Travis Johnson's website. Table A31 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	α	LEV	R_1	R_2	R_3	R_4	R_5	R_6	R^2_{LEV}(%)	R^2_{ALL}(%)	χ^2_α
					Panel A: 1/3 month						
P_1	−2.65**	1.61***	−0.31	0.57	0.13	−0.38*	−0.08	0.09	75.5	76.2	(<.01)
P_2	−3.07***	1.53***	−0.15	0.07	0.02	0.15	0.02	−0.09	87.9	87.7	
P_3	−2.06***	1.44***	−0.03	0.16	−0.06	−0.02	−0.10	−0.03	90.0	90.0	
P_4	−2.33***	1.27***	0.07	−0.11	0.03	−0.03	0.02	0.04	87.7	87.3	
P_5	0.01	1.55***	−0.09	0.31	−0.14	−0.37**	0.24**	0.02	85.4	86.0	
					Panel B: 3/6 month						
P_1	0.23	0.94***	0.05	−0.07	0.09	0.07	−0.12	0.04	80.8	80.8	
P_2	−2.65**	1.17***	0.20	−0.30	0.00	0.20**	0.07	−0.19**	86.5	87.8	
P_3	1.01***	0.91***	−0.04	0.03	−0.02	0.10	−0.14	0.07	87.3	87.4	
P_4	0.68***	0.85***	0.11	−0.27**	0.11**	0.07	−0.11	0.13**	85.6	87.0	
P_5	1.90***	1.03***	−0.02	0.04	−0.01	−0.16*	0.11*	0.05	88.2	88.2	
					Panel C: 6/12 month						
P_1	−0.16*	0.68***	−0.06	0.07	−0.02	0.14	−0.10	0.03	76.7	77.1	
P_2	0.17	0.94***	0.13	−0.20	−0.04	0.15	0.13**	−0.19**	83.0	84.6	
P_3	0.30	0.75***	−0.08	0.06	−0.03	0.04	−0.08	0.07*	83.7	83.8	
P_4	0.16	0.66***	0.05	−0.16**	0.06	0.02	−0.02	0.10**	83.3	84.4	
P_5	1.35***	0.84***	−0.09	0.14	−0.09	−0.13*	0.18**	−0.01	84.5	84.9	
					Panel D: 12/24 month						
P_1	0.25	0.70***	0.00	0.00	0.03	0.14*	−0.12*	−0.04	82.9	83.4	
P_2	−2.65**	0.90***	0.17	−0.23	−0.04	0.14	0.10	−0.17**	83.8	85.7	
P_3	−2.65**	0.72***	−0.05	0.02	−0.02	0.05	−0.06	0.04	84.1	83.8	
P_4	0.72***	0.65***	0.11	−0.18**	0.06	0.03	−0.08	0.07***	82.1	82.4	
P_5	1.99***	0.88***	0.04	0.04	−0.07	−0.20*	0.13	−0.03	81.9	83.4	

Table A16. Understanding Global Risk: Linear Component

This table presents descriptive statistics of implied volatility strategies decomposed into macro and residual components. In each month t, we run the following cross-sectional regression with multiple regressors

$$y_{i,t} = \sum_s \beta^s (x^s_{i,t} - x^s_{us,t}) + \varepsilon_{i,t},$$

where $y_{i,t}$ is the implied volatility slope at time t for country i in deviation from the cross-sectional median value, $x^s_{i,t}$ is the shock to the macro variable s for country i, $x^s_{us,t}$ is the corresponding component for the US, and $\varepsilon_{i,t}$ captures the error term unrelated to economic fundamentals. The least-squares estimates of β^s are used to construct the linear portfolio weights at time t whereas the portfolio returns are realized at time $t+1$. Shocks to macro variables are computed as first linear difference. The portfolio return based on the implied volatility slopes is, by construction, equal to the sum of all macro-based components plus the residual component. The table reports the average return in percentage per annum, the annualized Sharpe ratio, and the average least-squares estimates of β^s. t-statistic based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The sample runs monthly from January 1996 to December 2015, and includes a cross-section of 20 developed and emerging market countries. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Macro data are from the OECD and IMF. Table A17 in the Internet Appendix reports the decomposition performed for each component separately.

	Implied Slope	Economic Growth	Inflation Rate	Trade Balance	Term Spread	Residual
			Panel A: 1/3 month			
mean	4.57	1.59	2.04	0.23	-0.44	1.14
	[5.18]	[2.91]	[2.94]	[0.59]	[-0.45]	[1.35]
$SR \times \sqrt{12}$	1.16	0.58	0.66	0.13	-0.10	0.30
			Panel B: 3/6 month			
mean	2.42	0.66	0.77	0.20	-0.30	1.09
	[4.96]	[2.05]	[1.95]	[0.95]	[-0.50]	[2.29]
$SR \times \sqrt{12}$	1.08	0.40	0.44	0.19	-0.11	0.52
			Panel C: 6/12 month			
mean	1.97	0.56	0.51	0.31	-0.16	0.75
	[5.00]	[1.85]	[1.45]	[1.64]	[-0.33]	[1.82]
$SR \times \sqrt{12}$	1.10	0.41	0.32	0.36	-0.07	0.43
			Panel D: 12/24 month			
mean	2.21	0.42	0.43	0.18	0.13	1.06
	[5.05]	[1.60]	[1.30]	[0.91]	[0.25]	[2.78]
$SR \times \sqrt{12}$	1.09	0.33	0.29	0.20	0.05	0.62
β^s		0.11	-0.57	0.01	-5.23	
		[0.48]	[-0.97]	[0.04]	[-1.19]	

Table A17. Understanding Global Risk: Linear Component

This table presents descriptive statistics of implied volatility strategies decomposed into macro and residual components. In each month t, we run the following cross-sectional regression

$$y_{i,t} = \beta^s(x^s_{i,t} - x^s_{us,t}) + \varepsilon_{i,t},$$

where $y_{i,t}$ is the implied volatility slope at time t for country i in deviation from the cross-sectional median value, $x^s_{i,t}$ is the shock to the macro variable s for country i, $x^s_{us,t}$ is the corresponding component for the US, and $\varepsilon_{i,t}$ captures the error term unrelated to economic fundamentals. The least-squares estimates of β^s are used to construct the linear portfolio weights at time t whereas the portfolio returns are realized at time $t+1$. Shocks to macro variables are computed as first linear difference. The table reports the average return in percentage per annum, the annualized Sharpe ratio, and the average least-squares estimates of β^s. t-statistic based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The sample runs monthly from January 1996 to December 2015, and includes a cross-section of 20 developed and emerging market countries. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Macro data are from the OECD and IMF. Table A16 reports the decomposition performed for all components jointly.

	Economic Growth	Residual	Inflation Rate	Residual	Trade Balance	Residual	Term Spread	Residual
				Panel A: 1/3 month				
mean	1.38	3.18	2.20	2.36	0.34	4.23	0.64	3.93
	[3.20]	[3.61]	[3.54]	[2.46]	[0.98]	[4.54]	[1.07]	[3.86]
$SR \times \sqrt{12}$	0.77	0.81	0.81	0.55	0.22	1.02	0.24	0.89
				Panel B: 3/6 month				
mean	0.53	1.89	0.67	1.75	0.24	2.18	-0.06	2.48
	[2.05]	[3.76]	[1.97]	[3.37]	[1.23]	[4.03]	[-0.18]	[4.30]
$SR \times \sqrt{12}$	0.47	0.83	0.44	0.73	0.28	0.90	-0.04	0.96
				Panel C: 6/12 month				
mean	0.40	1.58	0.53	1.44	0.30	1.67	0.01	1.97
	[1.79]	[3.81]	[1.78]	[3.49]	[1.92]	[3.90]	[0.03]	[4.30]
$SR \times \sqrt{12}$	0.43	0.85	0.40	0.76	0.43	0.87	0.01	0.96
				Panel D: 12/24 month				
mean	0.23	1.97	0.41	1.80	0.30	1.91	0.13	2.08
	[1.06]	[4.28]	[1.52]	[4.11]	[2.51]	[4.37]	[0.55]	[4.35]
$SR \times \sqrt{12}$	0.24	0.94	0.34	0.89	0.55	0.94	0.12	0.95
β^s	0.18		-0.14		-0.11		-5.05	
	[0.99]		[-0.37]		[-0.37]		[-1.08]	

Table A18. Understanding Global Risk: Squared Component

This table presents descriptive statistics of implied volatility strategies decomposed into macro and residual components. In each month t, we run the following cross-sectional regression

$$y_{i,t} = \beta^s (x^s_{i,t} - x^s_{us,t})^2 + \varepsilon_{i,t},$$

where $y_{i,t}$ is the implied volatility slope at time t for country i in deviation from the cross-sectional median value, $x^s_{i,t}$ is the shock to the macro variable s for country i, $x^s_{us,t}$ is the corresponding component for the US, and $\varepsilon_{i,t}$ captures the error term unrelated to economic fundamentals. The least-squares estimates of β^s are used to construct the linear portfolio weights at time t whereas the portfolio returns are realized at time $t+1$. Shocks to macro variables are computed as first linear difference. The table reports the average return in percentage per annum, the annualized Sharpe ratio, and the average least-squares estimates of β^s. t-statistic based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The sample runs monthly from January 1996 to December 2015, and includes a cross-section of 20 developed and emerging market countries. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Macro data are from the OECD and IMF. Table 9 reports the decomposition performed for all components jointly.

	Economic Growth	Residual	Inflation Rate	Residual	Trade Balance	Residual	Term Spread	Residual
				Panel A: 1/3 month				
mean	2.76	1.81	1.86	2.71	0.94	3.63	1.16	3.41
	[4.91]	[1.96]	[2.75]	[2.70]	[1.74]	[3.68]	[2.00]	[3.30]
$SR \times \sqrt{12}$	1.32	0.45	0.61	0.67	0.40	0.82	0.45	0.77
				Panel B: 3/6 month				
mean	1.00	1.42	0.36	2.06	0.25	2.17	-0.02	2.44
	[3.76]	[2.80]	[0.94]	[3.64]	[1.03]	[4.28]	[-0.07]	[4.39]
$SR \times \sqrt{12}$	0.86	0.63	0.21	0.89	0.21	0.91	-0.02	0.98
				Panel C: 6/12 month				
mean	0.92	1.06	0.43	1.54	0.28	1.69	0.03	1.95
	[4.01]	[2.59]	[1.34]	[3.39]	[1.44]	[4.00]	[0.10]	[4.24]
$SR \times \sqrt{12}$	0.94	0.58	0.30	0.77	0.32	0.90	0.02	0.97
				Panel D: 12/24 month				
mean	0.60	1.61	0.16	2.04	0.16	2.04	-0.18	2.39
	[3.48]	[3.52]	[0.53]	[4.48]	[1.38]	[4.73]	[-0.71]	[4.76]
$SR \times \sqrt{12}$	0.78	0.79	0.12	1.00	0.28	1.00	-0.17	1.07
β^s	2.86		1.47		-1.00		9.94	
	[5.01]		[0.51]		[-1.15]		[0.98]	

H.2 Portfolios sorted on Forward Volatility Premia

Table A19. Descriptive Statistics: Portfolios sorted on Forward Volatility Premia

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their forward volatility premia. Volatility excess returns are computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). Slopes are computed using 3 month and 24 month model-free implied volatility. The first (last) portfolio P_1 (P_5) contains forward volatility agreements with the highest (lowest) implied volatility slopes. LEV denotes a strategy that equally invests in all five portfolios whereas VCA is a long-short strategy that buys P_5 and sells P_1. The table also reports the Sharpe ratio (SR), the first order autocorrelation coefficient ac_1, and the frequency of portfolio switches ($freq$). t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 20 developed and emerging market countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	P_1	P_2	P_3	P_4	P_5	LEV	VCA
			Panel A: 1/3 month				
$mean$	-6.95	-4.05	-2.22	-1.75	0.90	-2.81	7.84
	[-5.51]	[-3.91]	[-2.18]	[-1.61]	[0.71]	[-2.75]	[7.67]
$sdev$	18.21	13.59	13.16	13.88	14.29	12.73	15.33
$skew$	1.98	2.12	2.11	3.81	2.18	2.57	-0.90
$SR \times \sqrt{12}$	-1.32	-1.03	-0.58	-0.44	0.22	-0.77	1.77
ac_1	0.11	0.19	0.18	0.22	0.33	0.24	0.07
$freq$	0.42	0.62	0.70	0.67	0.47		
			Panel B: 3/6 month				
$mean$	-1.22	-0.08	0.17	0.88	2.27	0.40	3.49
	[-1.71]	[-0.14]	[0.30]	[1.23]	[3.18]	[0.66]	[6.61]
$sdev$	10.47	7.56	7.49	9.98	9.18	8.01	7.90
$skew$	1.61	1.52	1.33	5.10	2.39	2.74	-0.04
$SR \times \sqrt{12}$	-0.40	-0.04	0.08	0.31	0.86	0.17	1.53
ac_1	0.12	0.17	0.13	0.12	0.20	0.19	0.07
$freq$	0.46	0.70	0.72	0.73	0.60		
			Panel C: 6/12 month				
$mean$	-1.13	-0.54	-0.28	0.24	1.43	-0.06	2.56
	[-1.72]	[-1.21]	[-0.59]	[0.51]	[2.27]	[-0.11]	[6.34]
$sdev$	9.75	6.39	6.64	6.19	7.86	6.53	7.12
$skew$	4.52	1.76	1.53	1.18	2.45	2.66	-1.12
$SR \times \sqrt{12}$	-0.40	-0.29	-0.14	0.14	0.63	-0.03	1.25
ac_1	0.10	0.12	0.11	0.18	0.22	0.20	-0.11
$freq$	0.36	0.65	0.68	0.69	0.52		
			Panel D: 12/24 month				
$mean$	-0.31	-0.01	0.60	0.71	2.08	0.61	2.39
	[-0.56]	[-0.03]	[1.24]	[1.61]	[4.31]	[1.34]	[4.93]
$sdev$	8.38	7.01	7.29	6.12	7.22	6.32	7.61
$skew$	3.72	2.20	2.92	1.99	1.72	2.97	0.63
$SR \times \sqrt{12}$	-0.13	-0.01	0.28	0.40	1.00	0.34	1.09
ac_1	0.06	0.16	0.05	0.16	0.07	0.14	-0.03
$freq$	0.20	0.40	0.48	0.51	0.33		

Table A20. Principal Components: Portfolios sorted on Forward Volatility Premia

This table presents the loadings for the first (PC_1) and second (PC_2) principal component of the portfolios presented in Table A19. In each panel, the last column reports the cumulative share of total variance (CV) explained by the common factors. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 10 developed countries. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

Loadings	P_1	P_2	P_3	P_4	P_5	CV
Panel A: 1/3 month						
PC_1	0.56	0.44	0.39	0.43	0.40	0.74
PC_2	-0.80	0.11	0.34	0.24	0.42	0.89
Panel B: 3/6 month						
PC_1	0.58	0.38	0.40	0.36	0.48	0.77
PC_2	-0.81	0.15	0.30	0.33	0.36	0.89
Panel C: 6/12 month						
PC_1	0.50	0.37	0.38	0.51	0.46	0.79
PC_2	-0.82	-0.02	0.11	0.36	0.43	0.89
Panel D: 12/24 month						
PC_1	0.51	0.44	0.47	0.39	0.41	0.76
PC_2	-0.59	-0.10	-0.06	0.13	0.79	0.88

H.3 Developed Countries

Table A21. Descriptive Statistics: Unconditional Volatility Excess Returns

This table presents descriptive statistics of equally-weighted (in Panel A) and GDP-weighted (in Panel B) volatility excess returns based on forward volatility agreements. Excess returns are computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). The table also reports the Sharpe ratio (SR) and the first order autocorrelation coefficient ac_1. t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. Excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed countries. Table 1 displays results for a cross-section of 20 developed and emerging market countries.

	1/3 month	3/6 month	6/12 month	12/24 month
Panel A: Equally-weighted				
mean	-2.19	0.49	-0.04	0.65
	[-2.42]	[0.97]	[-0.10]	[1.79]
sdev	11.42	7.09	5.80	5.50
skew	1.14	0.75	0.71	0.88
$SR \times \sqrt{12}$	-0.67	0.24	-0.02	0.41
ac_1	0.18	0.08	0.05	0.04
Panel B: GDP-weighted				
mean	-2.61	0.31	-0.09	0.50
	[-3.14]	[0.64]	[-0.24]	[1.38]
sdev	11.35	7.22	5.94	5.60
skew	0.98	0.65	0.56	0.65
$SR \times \sqrt{12}$	-0.80	0.15	-0.05	0.31
ac_1	0.13	0.07	0.00	-0.02

Table A22. Predictive Regressions: Volatility Excess Returns

This table presents country-fixed effects panel regression estimates. The dependent variable is the variance excess return whereas the explanatory variable is the lagged forward implied variance premium, both computed using spot and forward model-free implied variances constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). The coefficient estimates α and γ should equal zero under the null that the unbiasedness hypothesis holds. t-statistics (reported in brackets) are base on Driscoll and Kraay (1998) standard errors that are heteroscedasticity consistent and robust to very general forms of cross-sectional and temporal dependence. Excess returns are expressed in percentage per month and the sample runs from January 1996 to December 2015. Data on over-the-counter currency options are from JP Morgan and Bloomberg for a cross-section of 10 developed countries. Table 2 in this Appendix displays results for a cross-section of 20 developed and emerging market countries.

	α		γ		$R^2(\%)$
Panel A: Spot and Forward Implied Volatilities					
1/3 month	0.27	[0.26]	-0.68	[-5.23]	8.4
3/6 month	0.58	[0.97]	-0.68	[-2.54]	2.1
6/12 month	0.48	[0.96]	-1.38	[-2.62]	1.7
12/24 month	-0.01	[-0.01]	-1.90	[-4.09]	3.4
Panel B: Spot and Forward Implied Variances					
1/3 month	2.50	[0.98]	-0.68	[-4.36]	7.3
3/6 month	1.88	[1.47]	-0.66	[-2.36]	1.8
6/12 month	1.42	[1.32]	-1.35	[-2.54]	1.5
12/24 month	0.46	[0.36]	-1.97	[-3.95]	3.4

Table A23. Descriptive Statistics: Slope-sorted Portfolios

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their implied volatility slopes. Volatility excess returns are computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). Slopes are computed using 3 month and 24 month model-free implied volatility. The first (last) portfolio P_1 (P_5) contains forward volatility agreements with the highest (lowest) implied volatility slopes. LEV denotes a strategy that equally invests in all five portfolios whereas VCA is a long-short strategy that buys P_5 and sells P_1. The table also reports the Sharpe ratio (SR), the first order autocorrelation coefficient ac_1, and the frequency of portfolio switches ($freq$). t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 10 developed countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table 3 displays results for a cross-section of 20 developed and emerging market countries.

	P_1	P_2	P_3	P_4	P_5	LEV	VCA
			Panel A: 1/3 month				
$mean$	-3.63	-2.96	-2.22	-2.30	0.37	-2.15	4.00
	[-3.74]	[-2.83]	[-2.06]	[-2.49]	[0.32]	[-2.22]	[4.61]
$sdev$	13.04	13.38	13.33	12.56	13.78	12.14	10.19
$skew$	1.92	1.76	2.34	1.21	1.90	1.99	0.29
$SR \times \sqrt{12}$	-0.96	-0.77	-0.58	-0.63	0.09	-0.61	1.36
ac_1	0.17	0.16	0.22	0.13	0.24	0.20	0.27
			Panel B: 3/6 month				
$mean$	-0.31	0.25	0.50	0.63	1.55	0.52	1.86
	[-0.58]	[0.39]	[0.80]	[1.17]	[2.79]	[0.96]	[4.46]
$sdev$	7.77	8.27	8.06	8.36	8.31	7.49	6.10
$skew$	1.19	1.43	1.71	0.92	1.31	1.43	0.23
$SR \times \sqrt{12}$	-0.14	0.11	0.21	0.26	0.65	0.24	1.06
ac_1	0.08	0.17	0.16	0.01	0.06	0.11	0.09
			Panel C: 6/12 month				
$mean$	-0.80	-0.30	-0.06	0.16	0.91	-0.02	1.71
	[-1.98]	[-0.62]	[-0.13]	[0.35]	[1.98]	[-0.05]	[5.28]
$sdev$	6.13	6.83	6.48	7.00	6.97	6.12	4.89
$skew$	1.01	1.19	1.57	0.87	1.47	1.34	0.44
$SR \times \sqrt{12}$	-0.45	-0.15	-0.03	0.08	0.45	-0.01	1.21
ac_1	0.04	0.12	0.15	-0.01	0.04	0.08	0.05
			Panel D: 12/24 month				
$mean$	-0.24	0.27	0.49	0.91	1.94	0.68	2.18
	[-0.59]	[0.59]	[1.03]	[2.11]	[3.89]	[1.65]	[5.26]
$sdev$	6.03	6.69	6.57	6.76	7.72	5.92	6.59
$skew$	1.27	1.45	2.11	0.66	2.10	1.79	1.81
$SR \times \sqrt{12}$	-0.14	0.14	0.26	0.47	0.87	0.39	1.14
ac_1	0.04	0.09	0.13	-0.03	0.02	0.08	-0.06
$freq$	0.31	0.52	0.61	0.56	0.33		

Table A24. Portfolios sorted on Implied Volatility Slopes: Composition

This table reports the percentage composition of the slope-sorted implied volatility portfolios presented in Tables A23. The first portfolio contains forward volatility agreements with the highest implied volatility slopes whereas the last portfolio contains forward volatility agreements with the lowest implied volatility slopes. The portfolios are rebalanced monthly from January 1996 to December 2015. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg.

	P_1	P_2	P_3	P_4	P_5
AUD	16	22	14	15	32
CAD	17	24	15	17	28
CHF	10	27	22	21	20
DKK	13	17	31	31	10
EUR	27	30	19	19	5
GBP	58	23	11	5	3
JPY	37	15	15	13	20
NZD	1	13	36	26	24
NOK	8	22	13	17	40
SEK	2	13	26	38	20

Table A25. Principal Components: Portfolios sorted on Implied Volatility Slopes

This table presents the loadings for the first (PC_1) and second (PC_2) principal component of the slope-sorted portfolios presented in Table A23. In each panel, the last column reports the cumulative share of total variance (CV) explained by the common factors. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 10 developed countries. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table 4 displays results for a cross-section of 20 developed and emerging market countries.

Loadings	P_1	P_2	P_3	P_4	P_5	CV
			Panel A: 1/3 month			
PC_1	0.44	0.47	0.46	0.44	0.43	0.84
PC_2	-0.46	-0.11	-0.23	-0.01	0.85	0.91
			Panel B: 3/6 month			
PC_1	0.41	0.46	0.45	0.47	0.45	0.84
PC_2	-0.55	-0.17	-0.17	0.06	0.79	0.90
			Panel C: 6/12 month			
PC_1	0.40	0.47	0.44	0.47	0.46	0.84
PC_2	-0.55	-0.15	-0.19	0.01	0.80	0.90
			Panel D: 12/24 month			
PC_1	0.38	0.46	0.44	0.46	0.48	0.76
PC_2	-0.31	-0.20	-0.28	-0.18	0.87	0.88

Table A26. Principal Components on All Portfolios sorted on Implied Volatility Slopes

This table presents the loadings for the first (PC_1), second (PC_2) and third (PC_3) principal component for all slope-sorted portfolios presented in Table A23. The last row reports the cumulative share of total variance (CV) explained by the common factors. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 10 developed countries. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table A26 displays results for a cross-section of 20 developed and emerging market countries.

Loadings	P_1	P_2	P_3	P_4	P_5
			Panel A: 1/3 month		
PC_1	0.33	0.35	0.34	0.33	0.33
PC_2	-0.44	-0.22	-0.30	-0.13	0.43
PC_3	-0.05	-0.36	-0.22	-0.14	-0.49
			Panel B: 3/6 month		
PC_1	0.18	0.21	0.20	0.21	0.19
PC_2	-0.11	0.02	0.00	0.09	0.38
PC_3	0.27	0.13	0.19	0.28	0.03
			Panel C: 6/12 month		
PC_1	0.14	0.17	0.16	0.17	0.16
PC_2	-0.09	0.04	0.01	0.07	0.29
PC_3	0.21	0.12	0.18	0.28	0.04
			Panel D: 12/24 month		
PC_1	0.14	0.16	0.16	0.16	0.15
PC_2	-0.06	0.05	0.03	0.12	0.42
CV	0.77	0.84	0.88	0.91	0.94

Table A27. Asset Pricing Tests: Risk Prices

This table presents cross-sectional asset pricing tests. Both test assets (slope-sorted portfolios) and pricing factors (level and volatility carry strategies) are presented in Table A23. The table reports GMM (first and second-stage) estimates of the factor loadings b, the market price of risk λ, and the cross-sectional R^2. t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. HJ refers to the Hansen and Jagannathan (1997) distance (with simulated p-values in parentheses) for the null hypothesis that the pricing errors per unit of norm is equal to zero. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 10 developed countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table 5 displays results for a cross-section of 20 developed and emerging market countries.

	b_{LEV}	b_{VCA}	λ_{LEV}	λ_{VCA}	$R^2(\%)$	HJ
			Panel A: 1/3 month			
GMM_1	-0.02	0.04	-2.15	4.04	92.3	0.18
	[-1.80]	[5.13]	[-2.13]	[4.30]		(0.54)
GMM_2	-0.02	0.04	-2.12	3.90	78.4	
	[-2.21]	[4.91]	[-2.33]	[4.51]		
			-2.15	**4.00**		
			Panel B: 3/6 month			
GMM_1	0.01	0.05	0.52	1.88	96.9	0.08
	[0.68]	[4.69]	[0.91]	[4.14]		(0.83)
GMM_2	0.01	0.05	0.45	1.84	92.3	
	[0.70]	[4.77]	[0.90]	[4.17]		
			0.52	**1.86**		
			Panel C: 6/12 month			
GMM_1	-0.01	0.07	-0.02	1.72	94.8	0.10
	[-0.88]	[6.20]	[-0.05]	[5.07]		(0.70)
GMM_2	-0.01	0.07	-0.05	1.70	91.9	
	[-0.90]	[6.20]	[-0.13]	[5.07]		
			-0.02	**1.71**		
			Panel D: 12/24 month			
GMM_1	0.01	0.05	0.68	2.12	92.1	0.15
	[1.12]	[4.76]	[1.63]	[5.20]		(0.42)
GMM_2	0.01	0.05	0.64	2.08	88.0	
	[1.00]	[5.77]	[1.70]	[5.47]		
			0.68	**2.18**		

Table A28. Asset Pricing Tests: Factor Betas

The table reports least-squares estimates of time series regressions. Both test assets (slope-sorted portfolios) and pricing factors (level and volatility carry strategies) are presented in Table A23. t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 10 developed countries. Excess returns are expressed in percentage per month. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table 6 in the Internet Appendix displays results for a cross-section of 20 developed and merging market countries.

	α		β_{LEV}		β_{VCA}		$R^2(\%)$	χ^2_α
				Panel A: 1/3 month				
P_1	0.30	[1.18]	0.98	[37.50]	-0.46	[-14.33]	93.4	(0.46)
P_2	-0.61	[-1.75]	1.04	[41.15]	-0.03	[-0.79]	89.2	
P_3	0.28	[0.66]	1.02	[21.55]	-0.08	[-1.74]	86.1	
P_4	-0.28	[-0.86]	0.97	[20.43]	0.02	[0.49]	88.4	
P_5	0.30	[1.18]	0.98	[37.50]	0.54	[17.14]	94.1	
				Panel B: 3/6 month				
P_1	0.06	[0.47]	0.96	[56.65]	-0.47	[-13.36]	93.3	(0.94)
P_2	-0.21	[-1.12]	1.04	[32.86]	-0.04	[-1.41]	88.2	
P_3	0.05	[0.27]	1.00	[22.81]	-0.04	[-1.01]	86.1	
P_4	0.03	[0.16]	1.05	[19.20]	0.03	[0.84]	87.9	
P_5	0.06	[0.47]	0.96	[56.65]	0.53	[15.03]	94.2	
				Panel C: 6/12 month				
P_1	0.01	[0.11]	0.95	[46.44]	-0.47	[-14.69]	92.9	(0.80)
P_2	-0.23	[-1.50]	1.05	[36.35]	-0.03	[-0.80]	87.9	
P_3	0.03	[0.19]	0.99	[20.65]	-0.04	[-0.94]	85.8	
P_4	0.17	[1.02]	1.06	[17.73]	0.00	[0.12]	85.7	
P_5	0.01	[0.11]	0.95	[46.44]	0.53	[16.89]	94.5	
				Panel D: 12/24 month				
P_1	-0.08	[-0.57]	0.94	[33.68]	-0.36	[-9.91]	89.0	(0.46)
P_2	-0.26	[-1.58]	1.06	[35.52]	-0.09	[-3.20]	85.9	
P_3	0.04	[0.22]	1.02	[18.35]	-0.11	[-2.51]	82.8	
P_4	0.37	[1.91]	1.04	[14.67]	-0.08	[-2.02]	82.0	
P_5	-0.08	[-0.57]	0.94	[33.68]	0.64	[17.33]	93.3	

Table A29. Asset Pricing Tests: Currency Risk Factors

This table presents time-series asset pricing tests. The test assets (slope-sorted portfolios) are presented in Table A23. The set of traded pricing factors includes the level (LEV), dollar (DOL), carry (CAR), global imbalance (IMB), foreign exchange volatility (VOL), and liquidity (LIQ) factors. The superscripts ***, **, and * denote statistical significance at the 1%, 5%, and 10%, respectively, based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. R^2_{LEV} is the R^2 due to the level factor only and R^2_{ALL} denoted the total R^2 coefficient. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. TExcess returns are expressed in percentage per month and range from January 1996 to December 2015 using a cross-section of 10 developed countries. Table A13 displays results for a cross-section of 20 developed and emerging market countries.

	α	LEV	DOL	CAR	IMB	VOL	LIQ	$R^2_{LEV}(\%)$	$R^2_{ALL}(\%)$	χ^2_α
					Panel A: 1/3 month					
P_1	−3.18***	1.46***	0.21	−0.01	−0.01	−0.15	−0.20	76.7	76.7	(<.01)
P_2	−2.49***	1.57***	0.10	−0.19	0.00	0.11	−0.21	82.7	82.6	
P_3	−1.88***	1.54***	−0.03	0.53	−0.52	−0.19	0.16	78.0	78.3	
P_4	−1.98***	1.54***	0.08	0.04	0.00	0.07	0.08	83.8	83.6	
P_5	0.71	1.55***	−0.16	−0.16	0.36	0.03	−0.09	74.1	73.8	
					Panel B: 3/6 month					
P_1	−0.07	0.87***	0.02	−0.15	0.00	0.11	0.00	74.1	73.6	
P_2	0.55**	0.98***	−0.01	−0.33**	0.05	0.21*	−0.05	84.8	85.1	
P_3	0.68***	0.97***	−0.19**	0.13	−0.15	0.05	0.16**	82.9	83.5	
P_4	0.85***	0.99***	−0.07	−0.11	0.03	0.06	0.16	83.7	83.7	
P_5	1.75***	0.96***	−0.17	−0.12	0.09	0.19	−0.03	75.3	75.3	
					Panel C: 6/12 month					
P_1	−0.62***	0.69***	0.13	0.04	−0.02	−0.08	−0.04	74.1	73.9	
P_2	−0.09	0.81***	0.08	−0.19**	0.14	0.08	−0.06	83.3	83.4	
P_3	0.09	0.76***	−0.20**	0.09	−0.06	0.01	0.05	81.5	81.7	
P_4	0.34	0.79***	−0.02	−0.08	0.02	−0.03	0.19**	78.0	78.0	
P_5	1.08***	0.80***	−0.03	0.02	0.03	−0.05	0.08	76.7	76.4	
					Panel D: 12/24 month					
P_1	−0.06	0.66***	0.17	0.06	0.01	−0.08	−0.09	69.1	69.1	
P_2	0.53***	0.78***	0.10	−0.01	−0.01	−0.01	−0.24***	81.7	82.5	
P_3	0.64***	0.76***	−0.05	0.27*	−0.13	−0.10	−0.03	76.8	76.9	
P_4	1.07***	0.77***	0.04	0.11	−0.09	−0.06	0.13	75.6	75.4	
P_5	2.08***	0.75***	0.01	0.04	0.24	−0.17	0.00	54.8	54.3	

Table A30. Asset Pricing Tests: Global Equity Risk Factors

This table presents time-series asset pricing tests. The test assets (slope-sorted portfolios) are presented in Table A23. The set of traded pricing factors includes the level (LEV) and the Fama-French global equity factors, i.e., market excess return (MKT), size (SMB), value (HML), profitability (RMW), and investment (CMA). The superscripts ***, **, and * denote statistical significance at the 1%, 5%, and 10%, respectively, based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. R^2_{LEV} is the R^2 due to the level factor only and R^2_{ALL} denoted the total R^2 coefficient. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. Excess returns are expressed in percentage per month and range from January 1996 to December 2015 using a cross-section of 10 developed countries. The Fama-French factors are from Kenneth French's website. Table A14 displays results for a cross-section of 20 developed and emerging market countries.

	α	LEV	MKT	SMB	HML	RMW	CMA	$R^2_{LEV}(\%)$	$R^2_{ALL}(\%)$	χ^2_α
					Panel A: 1/3 month					
P_1	−3.28***	1.53***	0.12	−0.03	0.04	−0.11	0.01	76.7	76.3	
P_2	−2.55***	1.59***	−0.05	0.27	0.08	−0.03	−0.10	82.7	82.5	
P_3	−1.88***	1.50***	−0.08	0.42**	−0.25	0.08	0.37	78.0	78.3	
P_4	−1.90***	1.55***	−0.01	0.31**	0.56**	−0.18	−0.56**	83.8	84.3	
P_5	1.12*	1.55***	−0.22*	−0.44*	0.67**	−0.67*	−0.85**	74.1	74.6	
					Panel B: 3/6 month					
P_1	−0.12	0.88***	0.06	−0.04	−0.07	−0.03	0.12	74.1	73.6	
P_2	0.53**	0.97***	−0.06	0.01	−0.15	−0.02	0.17	84.8	84.7	
P_3	0.67***	0.92***	−0.01	0.02	−0.32*	0.25	0.26	82.9	83.2	
P_4	0.81***	1.02***	0.09	−0.11	−0.04	0.14	−0.04	83.7	83.6	
P_5	1.85***	0.95***	−0.06	−0.29	0.34	−0.06	−0.50	75.3	75.9	
					Panel C: 6/12 month					
P_1	−0.67***	0.69***	0.04	0.07	−0.13	0.11	0.08	74.1	73.7	
P_2	−0.11	0.79***	−0.04	0.06	−0.10	0.05	0.13	83.3	83.2	
P_3	0.15	0.72***	−0.08	−0.04	−0.25*	0.14	0.10	81.5	81.9	
P_4	0.36	0.81***	0.03	−0.12	−0.12	0.04	0.04	78.0	77.8	
P_5	1.11***	0.80***	−0.02	−0.12	0.05	0.09	−0.19	76.7	76.6	
					Panel D: 12/24 month					
P_1	−0.16	0.67***	0.13**	−0.01	−0.22	0.04	0.34	69.1	69.1	
P_2	0.42**	0.77***	0.00	0.04	−0.17	0.05	0.29*	81.7	81.7	
P_3	0.61***	0.74***	0.03	0.07	−0.30*	0.13	0.35*	76.8	76.9	
P_4	1.01***	0.80***	0.12*	0.09	0.05	−0.03	0.15	75.6	75.5	
P_5	2.072***	0.76***	0.00	−0.17	0.33	0.00	−0.19	54.8	54.8	

Table A31. Asset Pricing Tests: VIX Futures Returns

This table presents time-series asset pricing tests. The test assets (slope-sorted portfolios) are presented in Table A23. The set of traded pricing factors includes the level (LEV), and the VIX futures returns ranging from 1-month (R_1) to 6-month (R_6). The superscripts ***, **, and * denote statistical significance at the 1%, 5%, and 10%, respectively, based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. R^2_{LEV} is the R^2 due to the level factor only and R^2_{ALL} denoted the total R^2 coefficient. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. Excess returns are expressed in percentage per month and range from April 2004 to December 2015 using a cross-section of 10 developed countries. The VIX futures returns are from Travis Johnson's website. Table A15 in the Internet Appendix displays results for a cross-section of 20 developed and emerging market countries.

	α	LEV	R_1	R_2	R_3	R_4	R_5	R_6	$R^2_{LEV}(\%)$	$R^2_{ALL}(\%)$	χ^2_α
					Panel A: 1/3 month						
P_1	−2.89***	1.48***	0.01	−0.01	0.13	0.08	−0.04	−0.25***	84.4	85.6	(<.01)
P_2	−2.61***	1.48***	0.09	0.07	0.03	−0.18	0.08	−0.11	86.0	86.2	
P_3	−2.28***	1.33***	0.06	0.00	−0.17	0.16	0.12	−0.09	84.9	85.3	
P_4	−1.77***	1.46***	−0.04	0.08	0.02	−0.14	0.01	0.07	86.6	86.2	
P_5	0.10	1.52***	−0.04	0.40*	−0.15	−0.41***	0.18*	0.02	84.5	85.7	
					Panel B: 3/6 month						
P_1	0.07	0.96***	−0.04	−0.08	0.05	0.22**	−0.12	−0.08	80.8	81.8	
P_2	0.22**	0.97***	0.06	−0.09	0.06	0.10	−0.09	−0.01	88.3	88.2	
P_3	0.22**	0.92***	0.08	−0.15	−0.06	0.22**	−0.07	0.06	86.5	87.7	
P_4	1.10***	1.04***	−0.10	−0.07	0.13**	0.02	−0.11	0.16***	86.2	88.1	
P_5	1.45***	1.05***	−0.03	0.06	0.00	−0.17***	0.04	0.10***	89.8	90.4	
					Panel C: 6/12 month						
P_1	0.22**	0.75***	−0.04	−0.03	0.00	0.12	−0.05	−0.06*	79.7	80.3	
P_2	−0.10	0.79***	0.08	−0.10	0.07*	0.02	−0.06	−0.01	86.0	85.7	
P_3	0.12	0.72***	0.00	−0.06	−0.07	0.16*	0.03	0.03	87.2	88.6	
P_4	0.22**	0.84***	−0.18	0.04	0.04	−0.01	−0.02	0.15***	81.6	84.1	
P_5	0.98***	0.88***	−0.12	0.15*	−0.06	−0.16***	0.12**	0.05	85.8	86.5	
					Panel D: 12/24 month						
P_1	0.22	0.73***	0.00	−0.03	−0.02	0.13*	−0.04	−0.11***	77.0	78.9	
P_2	0.22**	0.74***	0.17**	−0.15	0.06	0.00	−0.05	−0.02	85.9	86.1	
P_3	0.22**	0.69***	0.09	−0.12	−0.01	0.10	−0.01	−0.02	81.1	81.2	
P_4	1.07***	0.80***	−0.11	0.01	0.02	0.00	−0.03	0.09*	81.0	82.0	
P_5	1.79***	0.86***	0.04	0.08	−0.08	−0.25*	0.10	0.02	77.2	79.0	

Table A32. Asset Pricing Tests: S&P 500 Variance Swap Returns

5This table presents time-series asset pricing tests. The test assets (slope-sorted portfolios) are presented in Table A23. The set of traded pricing factors includes the level (LEV), and the S&P 500 variance swap returns ranging from 1-month (R_1) to 12-month (R_{12}). The superscripts ***, **, and * denote statistical significance at the 1%, 5%, and 10%, respectively, based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. Excess returns are expressed in percentage per month and range from January 1996 to December 2015 using a cross-section of 10 developed countries. The variance swap returns are from Travis Johnson's website. Table A12 in the Internet Appendix displays results for a cross-section of 20 developed and and emerging market countries.

	α	LEV	R_1	R_2	R_3	R_6	R_9	R_{12}	$R^2_{LEV}(\%)$	$R^2_{ALL}(\%)$	χ^2_α
					Panel A: 1/3 month						
P_1	−3.19***	1.51***	−0.01	0.04	−0.01	−0.06	0.02	−0.02	76.7	76.4	$(<.01)$
P_2	−2.59***	1.57***	−0.01	0.02	0.00	0.00	−0.01	0.01	82.7	82.3	
P_3	−1.64***	1.43***	0.00	−0.01	−0.05	0.12	0.12	−0.10	78.0	79.1	
P_4	−1.68***	1.46***	0.01	0.03	−0.05	−0.04	0.11	−0.03	83.8	83.7	
P_5	1.07*	1.45***	−0.02	0.09	0.02	−0.09	0.05	−0.04	74.1	74.6	
					Panel B: 3/6 month						
P_1	−0.23	0.91***	0.00	0.00	0.00	−0.02	−0.04	0.05	74.1	73.9	
P_2	0.31	1.01***	0.00	−0.04	0.06	0.00	−0.07	0.05	84.8	85.1	
P_3	0.59**	0.93***	0.00	−0.04	0.02	0.08*	−0.02	0.00	82.9	83.3	
P_4	0.78***	1.03***	0.01	−0.03	0.00	−0.01	−0.02	0.05	83.7	83.8	
P_5	1.75***	0.95***	−0.01	0.03	−0.01	−0.06	0.01	0.03	75.3	75.0	
					Panel C: 6/12 month						
P_1	−0.66***	0.73***	0.00	0.00	−0.01	0.00	0.00	−0.01	74.1	74.0	
P_2	−0.25	0.82***	0.00	−0.03	0.04*	0.03	−0.09	0.05	83.3	83.5	
P_3	0.06	0.74***	0.00	−0.02	0.01	0.05	0.01	−0.02	81.5	81.5	
P_4	0.38*	0.84***	0.02	−0.03	−0.01	0.01	−0.02	0.03	78.0	78.1	
P_5	1.18***	0.80***	0.00	0.03	−0.03	−0.05	0.06	−0.03	76.7	76.6	
					Panel D: 12/24 month						
P_1	−0.06	0.70***	0.01	−0.01	0.00	−0.03	0.00	0.00	69.1	69.1	
P_2	0.37	0.80***	0.00	−0.01	0.02	0.08**	−0.13**	0.04	81.7	81.9	
P_3	0.64**	0.74***	0.00	−0.02	0.01	0.01	0.05	−0.03	76.8	76.5	
P_4	1.03***	0.81***	0.01	−0.02	−0.01	−0.01	−0.01	0.03	75.6	75.8	
P_5	2.14***	0.78***	−0.01	0.03	0.00	0.01	−0.02	−0.04	54.8	54.7	