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: Forward Volatility Agreement, Foreign Exchange Volatility, Risk Premium, Term Structure.

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1. Introduction

The foreign exchange (FX) markets have gone through extremely volatile periods over recent decades. As a result, volatility derivatives have become a popular instrument for both hedging and speculative reasons. An effective way for market participants to gain exposure to future volatility is to trade a forward volatility agreement (FVA) – a forward contract that delivers the difference between the spot implied volatility of an exchange rate observed on the maturity date and the forward implied volatility determined at the inception date.[1] While excess returns from investing in spot and forward implied volatilities of different currencies and maturities can be economically large (Knauf 2003; Della Corte, Sarno, and Tsiakas 2011), little is known about their time-series and cross-sectional properties. This paper attempts to fill the gap by showing that volatility excess returns exhibit a strong co-movement, and also that a common risk factor explains both their time-series and cross-sectional dimension.

We start our analysis by showing that forward implied volatility is a biased predictor of future spot implied volatility for a wide set of currency options. As a result, buying (selling) FVAs when the term structure of implied volatility is downward (upward) sloping will generate, on average, positive excess returns. This is equivalent to saying that an investor can engage in a profitable strategy by buying implied volatilities at discount and selling implied volatilities at premium, and then reversing the positions in the future with spot implied volatilities. This finding is very much like the well known spot-forward exchange rate relationship (e.g., Bilson 1981; Fama 1984) which gives rise to the traditional carry trade strategy whereby an investor sells currencies at premium (low-yielding) and buys currencies at discount (high-yielding) against their corresponding spot exchange rates in the future (e.g., Lustig, Roussanov, and Verdelhan 2011; Menkhoff, Sarno, Schmeling, and Schrimpf 2012; Lettau, Maggiori, and Weber 2014). This biased relationship between spot and forward prices, moreover, persists across a broad range of maturity combinations. Hence, selling (buying) a FVA with a positive (negative) forward volatility premium is tantamount to having a short (long) position on a

[1] The FVA is simply a forward contract on the future spot implied volatility. The volatility swap, in contrast, is a forward contract on the future realized volatility and delivers the difference between the realized volatility measured ex-post and the spot implied volatility observed ex-ante. The FVA is quoted over-the-counter in the currency option market, the largest and most liquid market of its kind with a daily average turnover equal to $254 billion as of April 2016 (BIS 2016b), and a notional amounts outstanding of $11.7 trillion as of June 2016 (BIS 2016a).

FVA when the implied volatility curve is upward (downward) sloping.[2]

Motivated by this empirical evidence, we identify a common factor by forming portfolios of FVAs sorted by their implied volatility slopes. The implied volatility slope is measured using the 24 month and 3 month spot implied volatility. Following the pioneering work of Lustig and Verdelhan (2007), we group our FVAs into five portfolios at the end of each month. The first portfolio contains the FVAs with the highest implied volatility slopes. Similar to the work of Lustig, Roussanov, and Verdelhan (2011), we find that the first two principal components of our implied volatility portfolio returns explains most of the time series variation in volatility excess returns. The first principal component is essentially a level factor as all portfolios load with similar weights on it, and can be approximated as the average excess return on all implied volatility portfolios. We call this level factor LEV. The second principal component is a slope factor, its weights increase monotonically from negative to positive when moving from the first to the last portfolio. This factor resembles a zero-cost strategy that sells the first portfolio and buys the last portfolio. We call this factor the volatility carry factor or VCA. This evidence speaks in favor of the presence of a factor structure in the cross-section of volatility excess returns. Our paper is the first to document this common factor in the excess returns to trading FVAs on currencies.

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 studied in this paper. Moreover, existing currency risk factors such as those associated with carry, global imbalance, global FX volatility and liquidity risk cannot explain the variation of our implied volatility portfolios returns. These results use monthly data from January 1996 to December 2015. They hold for a cross-section of 20 developed and emerging market countries and for maturities ranging from 1 month to 24 months.

We compare our findings with the predictions from existing international asset pricing models. We show that our results strongly suggest that national economies have time-varying

[2] In our analysis, we compute spot and forward implied volatility using the model-free approach of Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). Our results, however, remain robust to using different interpolation methods (e.g., Castagna and Mercurio 2007) as well as a model-free approach that is robust to price jumps (e.g., Martin 2013).

exposure to risks that are correlated across countries. While jumps in state variables and asymmetries in parameters across countries are important for matching other features of the data, they are not sufficient to account for the time-series and cross-sectional variation in the volatility risk premia that we observe. Furthermore, we establish an important implication: the size of the volatility risk premium both over time and in the cross-section should be driven by the distance between the states of the two economies at the time.

We take this prediction to the data and show that the volatility risk in the currency market is related to macro-economic factors. We decompose the implied volatility slopes into macro-related and residual components and build portfolios that capture the decomposition. 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. Specifically, up to 72% of the excess return of the volatility carry strategy is explained by the squared difference in the growth rate, while up to 38% is explained by the difference in volatilities of economic growth. This is consistent with the models of Bansal and Shaliastovich (2013) and Lustig, Roussanov, and Verdelhan (2011). 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 paper belongs to different areas of the literature. First, we build on the recent line of research that seeks to explain currency risk premia in a cross-sectional asset pricing setting.[3] 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. We show that the traditional carry and volatility carry factors are nearly uncorrelated and our slope-sorted implied volatility portfolios have little exposure to the traditional carry trade risk factor. Furthermore, Menkhoff, Sarno, Schmeling, and Schrimpf (2012) find that currency excess returns provide compensation for exposure to global FX volatility risk. In our empirical exercise, we show that FX volatility risk has negligible explanatory power. More recently, guided by the insights of Gabaix and Maggiori (2015) theory of exchange rate determination, Della Corte, Riddiough, and Sarno (2016) provide evidence that exposure to countries' external imbalances explains

[3] 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, Rancire, and Verdelhan (2015), Colacito, Croce, Gavazzoni, and Ready (2016), Bekaert and Panayotov (2016), Colacito, Croce, Gavazzoni, and Ready (2016), and Richmond (2016).

the cross-sectional variation of currency excess returns. Their global imbalance risk factor, however, is only weakly related to our volatility excess returns.

Second, our paper also contributes to the literature on the volatility risk premium in the equity, fixed income, and currency markets (e.g., Coval and Shumway 2001; Bakshi and Kapadia 2003; Low and Zhang 2005; Broadie, Chernov, and Johannes 2009; Carr and Wu 2009; Christoffersen, Heston, and Jacobs 2009; Kozhan, Neuberger, and Schneider 2013; Ammann and Buesser 2013; Della Corte, Ramadorai, and Sarno 2016; Londono and Zhou 2016). Whereas much of the literature focuses on the difference between implied and realized volatility, our focus is on the risk premia in the term structure of implied volatility. A related literature documents that the term structure of volatility risk premia is typically downward sloping. Dew-Becker, Giglio, Le, and Rodriguez (2016), Eraker and Wu (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 risk premia embedded into the term structure of currency options' implied volatility exhibit a similar pattern. These premia naturally come into play when considering volatility carry strategies at different maturities. While the volatility carry premium decreases with the maturity of the underlying instrument, it remains both statistically and economically large in our exercise.

Finally, our exercise also speaks to the 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 idea that the term structure carries information about future risk premia is not new in the literature. In the fixed income literature, for instance, the slope of the term structure predicts future bond returns (see, for instance, Fama and Bliss 1987; Campbell and Shiller 1991; Cochrane and Piazzesi 2005). As the term structure of interest rates reflects both expectations of future interest rates and bond risk premia, so the term structure of implied volatility reflect expectations of future volatilities and volatility risk premia. Feunou, Fontaine, Taamouti, and Tdongap (2014) and Johnson (2016), moreover, show that the volatility term structure predicts future volatility returns across both time and maturities in equity markets. We find a similar result which we augment with a strong cross-sectional predictability. Using a simple decomposition as in Hassan and Mano (2015), we find evidence supporting both time-series and cross-sectional predictability of implied volatility slopes onto future volatility excess returns at all maturities.

The paper is organized as follows. Section 2 sets the theoretical framework for our paper and describes the data set we use. Section 3 provides details of how the implied volatility portfolios are constructed and shows that a volatility carry strategy provides statistically and economically significant excess returns. Section 4 shows that a single factor, VCA, explains most of the cross-sectional variation in volatility excess returns. In Section 5 we perform some further analysis by testing whether the volatility return predictability comes from cross-section of time-series. We also look at the term structure of volatility premia by adding spot volatility premium. Section 6 reviews a number of existing models and relate the volatility carry risk to macroeconomic fundamentals before concluding in Section 7. A separate Internet Appendix provides additional robustness tests and supporting analyses.

2. The Relation between Spot and Forward Implied Volatility

This section describes the link between spot and forward implied volatility which arises naturally from the forward volatility agreement (FVA) – an over-the-counter volatility derivative used in the foreign exchange (FX) market. We show how to synthesize these agreements using currency option data and present some empirical evidence 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

The 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.[4]

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

$$\left(SVOL_{t+\tau_1}^{\tau_2} - FVOL_{t,\tau_1}^{\tau_2}\right) \times M, \tag{1}$$

where $SVOL_{t+\tau_1}^{\tau_2}$ is the spot implied volatility observed at time $t+\tau_1$ and defined over the time interval between times $t+\tau_1$ and $t+\tau$, $FVOL_{t,\tau_1}^{\tau_2}$ 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 Constructing Spot and Forward Implied Volatility

We compute the implied volatilities from over-the-counter currency options using the model-free approach of Britten-Jones and Neuberger (2000) which builds on the seminal contribution of Breeden and Litzenberger (1978). The method is based on no-arbitrage conditions without imposing any specific option pricing model.

Spot Implied Volatility. The risk-neutral expectation of the integrated variance between two dates t and $t+\tau$ can be calculated by integrating over an infinite range of the strike prices

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

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 $t+\tau$.[5]

The model-free implied variance in Equation (2) requires the existence of a continuum in the cross section of option prices at time t with maturity date τ. In the FX market, over-the-counter (OTC) options are generally quoted in terms of Garman and Kohlhagen (1983) implied volatilities at fixed deltas and liquidity is generally spread across five levels of deltas. Following Jiang and Tian (2005) and Kozhan, Neuberger, and Schneider (2013), we first extract five strike prices corresponding to five plain vanilla options and then use a cubic spline around these five implied volatility points. This interpolation method is standard in the literature and has the advantage that the implied volatility smile is smooth between the maximum and minimum available strikes. Finally, we compute the option values using the Garman and Kohlhagen (1983) valuation formula and solve the integral in Equation (2) via trapezoidal integration.[6]

Even though the implied variance emerges naturally from a portfolio of options, FX participants prefer to trade volatility derivatives as opposed to variance derivatives. This is because the payoff of a variance derivative is convex in volatility and large swings in volatility, as observed during the recent financial crisis, are more likely to cause large profits and losses to counterparties. 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., $SVOL_t^\tau = \sqrt{SVAR_t^\tau}$.

[5] 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).

[6] 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.

Forward Implied Volatility. The forward implied volatility can be constructed using spot implied variances defined over different intervals. Specifically, consider the integrated variance of a risk-neutral exchange rate process measured between the current date t and the future date $t+\tau$ (i.e., an integrated variance with maturity τ). Since variance is additive in the time dimension, one can decompose it as the sum of the current variance measured between times t and $t+\tau_1$ and the future variance measured between times $t+\tau_1$ and $t+\tau$ (e.g., Carr and Wu 2009). By taking risk-neutral expectations and then employing the model-free implied variances, we can obtain the following relation:

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

where $SVAR_t^{\tau}$ ($SVAR_t^{\tau_1}$) is the spot implied variance in annual terms defined between times t and $t+\tau$ ($t+\tau_1$). $FVAR_{t,\tau_1}^{\tau_2}$ is the forward implied variance in annual terms determined at time t but defined over the future interval between times $t+\tau_1$ and $t+\tau$, which is equivalent to the risk-neutral expectation of the future spot implied variance. The forward implied volatility is then calculated as $FVOL_{t,\tau_1}^{\tau_2} = \sqrt{FVAR_{t,\tau_1}^{\tau_2}}$, a method 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).[7]

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

[7] 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.

Garman and Kohlhagen (1983) implied volatilities at fixed deltas and for constant maturities. For a given maturity, quotes are available for at-the-money, 10 delta call and put, and 25 delta call and put options. 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.[8] 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, 12 month and 24 month. We then construct spot and forward implied volatilities using the methodology presented above.

2.3 Testing the Spot-Forward Implied Volatility Relation

Armed with spot and forward implied volatilities, we move to testing their relationship empirically. We first summarize the testing framework and then present the empirical evidence.

Testing Framework. 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)

$$E_t\left[SVOL_{t+\tau_1}^{\tau_2}\right] = FVOL_{t,\tau_1}^{\tau_2}, \tag{4}$$

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.

Della Corte, Sarno, and Tsiakas (2011) test this unbiasedness hypothesis employing the analogue of the Fama (1984) predictive regressions. They focus on 1 month forward and spot implied volatilities for a cross-section of nine currency pairs and find statistical evidence that the forward volatility premium is a biased predictor of the future implied volatility change. We revisit and extend their analysis in different dimensions and use it as a preliminary investigation that motivates the core exercise presented in the following sections. Specifically,

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

we use a larger cross-section of 20 currency pairs from January 1996 to December 2015, employ different maturity combinations ranging from 1 to 24 months, and derive the analogue of the Fama (1984) predictive regression for non-overlapping monthly returns as

$$\frac{FVOL^{\tau_2}_{t+1,\tau_1-1} - FVOL^{\tau_2}_{t,\tau_1}}{FVOL^{\tau_2}_{t,\tau_1-1}} = \alpha + \gamma \left(\frac{FVOL^{\tau_2}_{t,\tau_1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}} \right) + \varepsilon_{t+1} \tag{5}$$

where the left-hand-side is the monthly volatility excess return from holding an FVA between times t and $t+1$ and the right-hand-side is the corresponding monthly forward volatility premium.

When the unbiasedness hypothesis holds, the volatility excess return is unpredictable by the forward volatility premium and the excess return is zero on average, i.e., $\alpha = 0$, $\gamma = 0$, and ε_{t+1} is serially uncorrelated. In contrast, a negative estimate of γ would be associated with the rejection of the unbiasedness hypothesis and the presence of a positive, time-varying and predictable risk premium. Intuitively, a positive forward volatility premium is likely to force down the price of an FVA contract and induce a negative correlation between the dependent and the independent variables. This would translate into a negative value of γ. Internet Appendix A shows how closely the regression relates to the Fama (1984) regressions that are conventionally used to explore the relation between spot and forward exchange rates (e.g., Della Corte, Sarno, and Tsiakas 2011).

Empirical Evidence. 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 1 about here

Panel A of Table 1 presents cross-currency pooled regressions of monthly volatility excess returns on the lagged monthly forward volatility premia, and strongly rejects the unbiasedness hypothesis for all maturity combinations. We report least-squares estimates of α and γ with

t-stat (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 statistically insignificant, the slope coefficient γ is always negative and statistically significant for the full sample period between January 1996 and December 2015. The estimate of γ ranges between -0.67 (with a t-stat of -5.44) for 1/3 mth and -1.42 (with a t-stat of -3.79) for 12/24 mth. In addition to reporting results for the entire sample, we also consider the pre- and post-crisis period (excludes data from January 2007 to December 2008) and the crisis period (only uses data from January 2007 to December 2008). The point estimates of γ are largely comparable for the pre- and post-crisis sample but are more pronounced for the crisis period (except for 12/24 mth).

In Panel B, we check the extent to which our results are affected by the convexity bias discussed in the Section 2.2. We run cross-currency pooled regressions of variance (as opposed to volatility) excess returns on the lagged forward variance premia. The estimates reported in Panel B remain qualitatively identical with respect to Panel A, thus suggesting that our results are not purely explained by the convexity bias.

Table 2 about here

We further check that our results are not driven by just a few currency pairs by running country-by-country pooled (by maturities) predictive regressions. We report these results in Table 2. The left-hand side panel displays the estimates of α and γ for the full sample period. While the coefficient α is always statistically insignificant, the slope coefficient γ turns out to be always negative and statistically different from zero. For developed countries, the estimate of γ ranges between -0.88 for the Australian dollar and -0.59 for the Swiss franc. Turning to emerging market countries, the estimates remain qualitatively similar as the estimate of γ varies between -1.11 for the South Korean won and -0.48 for the South African rand. Overall, the size and the sign of the estimates of γ are largely comparable across developed and emerging markets, and unlikely to be driven by currency specific factors such as liquidity and volatility.

We also find negative and generally statistically significant estimates for γ for the subsample periods. The few instances arise where γ is negative but insignificant, likely due to lack of power. The estimates of γ during the crisis period are substantially larger in absolute value than in the pre- and post crisis subsample. This suggests that deviations from the unbiasedness hypothesis tend to widen during periods of global financial crisis, the opposite of what we typically observe for the spot-forward exchange rate relationship – a phenomenon known as the unwinding of the carry trade.

Taken together, the results in Table 1 and Table 2 suggest that there exists a negative and statistically significant estimate of γ (and an insignificant estimate of α) which translates into a biased relationship between spot and forward prices. As a result, the volatility excess return is expected to be negative (positive) when the implied volatility is at premium (discount) in the forward market. In the next section we build on this finding and check whether investing in spot and forward implied volatilities generates economically valuable excess returns.

3. Trading Spot versus Forward Implied Volatility

The forward volatility premium predicts the future volatility excess return with a negative slope coefficient. As a result, an investor could engage into a profitable strategy by selling implied volatilities at premium and buying implied volatilities at discount in the forward market, and then reversing the positions in the future spot implied volatility market. This finding is very much alike the spot-forward exchange rate relationship which gives rise to the carry trade strategy whereby an investor sells currencies at premium (low-yielding) and buys currencies at discount (high-yielding) in the forward market against their corresponding future spot exchange rates (e.g., Lustig, Roussanov, and Verdelhan 2011; Menkhoff, Sarno, Schmeling, and Schrimpf 2012). The profitability of this strategy builds on the fact that the forward premium predicts the future currency excess return with a negative slope coefficient, a stylized fact known as "forward premium puzzle" (e.g., Fama 1984). Following this literature, we construct portfolios of FVAs and then analyze their empirical properties. In the next section, we will study such excess returns in a cross-sectional asset pricing framework.

3.1 Volatility Excess Returns

We compute monthly excess returns from buying a FVA at time t and selling it at time $t+1$ as (we ignore any currency subscript for easy notation)

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

where $FVOL^{\tau_2}_{t,\tau_1}$ is the τ_2 period forward implied volatility determined at time t but defined between times $t+\tau_1$ and $t+\tau$ (or $t+\tau_1+\tau_2$), $FVOL^{\tau_2}_{t+1,\tau_1-1}$ is the τ_2 period forward implied volatility at time $t+1$ for the same future time interval, and $FVOL^{\tau_2}_{t,\tau_1-1}$ is its 1 month lagged value. Holding, for example, a 3 month FVA written on 3 month implied volatility for a month between times t and $t+1$ is equivalent to buying this contract at time t and then selling at time $t+1$ a 2 month FVA written on 3 month implied volatility. By combining the long position (with a payoff of $SVOL^3_{t+3} - FVOL^3_{t,3}$) and the short position (with a payoff of $FVOL^3_{t+1,2} - SVOL^3_{t+3}$), we obtain a net payoff of $FVOL^3_{t+1,2} - FVOL^3_{t,3}$. The excess return $RX_{t+1} = (FVOL^3_{t+1,2} - FVOL^3_{t,3})/FVOL^3_{t,2}$ is then obtained by using the lagged value of $FVOL^3_{t+1,2}$ as scaling factor.

3.2 Implied Volatility Portfolios

The previous section shows that forward volatility premia are informative of future volatility excess returns. Motivated by this finding, we construct portfolios of FVAs sorted by their forward volatility premia defined as

$$FVP^{\tau_2}_{t,\tau_1} = \frac{FVOL^{\tau_2}_{t,\tau_1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}}. \tag{7}$$

At the end of period t, we allocate the FVAs to five baskets using the forward volatility premia observed on date t. We rank these portfolios from high to low forward volatility premia such that Portfolio 1 contains the 20% of all FVAs with the highest forward volatility premia whereas Portfolio 5 comprises the 20% of all FVAs with the lowest forward volatility premia. 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.

Sorting on forward volatility premia 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 also build portfolios of FVAs using the slopes of the implied volatility curves as key sorting variable. Specifically, we measure the slope of the implied volatility curve for each currency on date t as

$$SLOPE_t = \frac{SVOL_t^{24} - SVOL_t^{3}}{SVOL_t^{3}}, \tag{8}$$

where $SVOL_t^{24}$ ($SVOL_t^{3}$) denote the 24 month (3 month) spot implied volatility on date t, and then group the FVAs into five baskets from high to low slopes such that Portfolio 1 contains FVAs with the highest slopes whereas Portfolio 5 comprises the FVAs with the lowest slopes. As before, we re-balance the portfolios monthly from January 1996 to December 2015, compute equally weighted excess returns within each basket and repeat the exercise for each maturity combination using the same samples of countries. Empirically, these set of portfolios will be qualitatively identical to each other. However, while the portfolios sorted by forward volatility premia use a maturity-specific sorting variable, the portfolios sorted by implied volatility slopes use the same sorting indicator across all maturity combinations.

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.

3.3 Descriptive Statistics

We now describe the properties of the volatility portfolios from the perspective of a US investor. Table 3 presents, for each maturity combination τ_1/τ, summary statistics for the five portfolios of FVAs sorted by forward volatility premia. In brackets, we report t-stat 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. For instance, the average monthly excess return on Portfolio 1 (Portfolio 5) is about -6.95% (0.90%) in Panel A (1/3 mth) and -0.31% (2.08%) 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 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 -2.81% (in Panel A) to -0.06% per month (in Panel C) but it is statistically significant only for 1/3 mth. This result differs from the literature on volatility swaps where an investor typically earns an excess return by simply selling such derivatives contracts. In contrast, the average excess return for the VCA strategy – long a portfolio of FVAs with the lowest forward volatility premia and short a portfolio of FVAs with the highest forward volatility premia – is always positive and highly statistically significant. We uncover an average excess return that ranges between 7.84% (with a t-stat of 7.67) and 2.39% (with a t-stat of 4.93) per month for 1/3 mth and 12/24 mth, respectively. The corresponding annualized Sharpe ratios are also monotonically decreasing from 1.77 to 1.09. 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.

Table 4 about here

As pointed out earlier, sorting on forward volatility premia should be equivalent to sorting on the implied volatility slopes.[9] We present summary statistics for these portfolio in Table 4 and find qualitatively similar results. For instance, the average excess return of the LEV

[9] Table A10 in the Internet Appendix presents percentages that each currency pair falls into one of the five slope-sorted portfolios.

portfolio ranges between 2.39% (in Panel A) and −0.03% (in Panel C) per month and is only statistically significant for the shortest maturity combination. The average excess return of the VCA portfolio, moreover, is always statistically significant and equals 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 slope sorted portfolios exhibit a slightly lower excess return than premium sorted portfolios. However, sorting on the slopes produces a slightly lower turnover than sorting on the forward premia, and in the presence of transaction costs that would erode the slightly higher return from premium sorted portfolios. This is further corroborated by the average correlation between the two set of portfolios which ranges between 83% (for 1/3 mth contracts) and 86% (for 12/24 mth). Overall, our descriptive statistics confirm that forward volatility premia or implied volatility slopes have the ability to predict both statistically and economically future volatility excess returns, consistent with the evidence reported in the previous section. Since the two set of portfolios display similar properties, we will focus our analysis on the slope-sorted portfolios.

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 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).

4. Common Risk Factors 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.

4.1 Principal Component Analysis

We examine 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 principle 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 5 about here

Table 5 presents, for different maturity combinations, the loadings of our volatility portfolios on each of the principal components as well as the fraction of the total variance (in bold) of portfolio returns associated with each principal component. For instance, in Panel A, the first principal component explains 82% of the common variation in portfolio returns whereas the second principal component captures an additional 8%. 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 whereas the second one can be approximated by the return difference between Portfolio 5 and Portfolio

1. In Section 3, we referred to the average excess return across all portfolios as LEV and denoted the long-short strategy involving the corner portfolios as VCA or volatility carry factor. LEV 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. VCA 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.[10] We now turn to a more formal investigation using standard asset pricing methods.

4.2 Asset Pricing Methods

We denote the discrete excess returns on portfolio j in period t as RX_t^j (we omit the maturity subscript for ease of notation). In the absence of arbitrage opportunities, risk-adjusted excess returns have a price of zero and satisfy the following Euler equation $E_t[M_{t+1}RX_{t+1}^j] = 0$ with a stochastic discount factor (SDF) linear in the pricing factors f_{t+1} given by

$$M_{t+1} = 1 - b' \left(f_{t+1} - \mu \right) \tag{9}$$

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. $\Sigma_f = E\left[\left(f_t - \mu \right) \left(f_t - \mu \right)' \right]$ is the variance-covariance matrix of the risk factors, and β^j are the regression coefficients of each portfolio's excess return RX_{t+1}^j on the risk factors f_{t+1}.

The factor loadings b are estimated via the Generalized Method of Moments (GMM) of Hansen (1982). To implement GMM, we use the pricing errors as a set of moments and a

[10] 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.

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 tables report estimates of b and implied λ, and standard errors based on Newey and West (1987) with optimal lag length selection set according to Andrews (1991). 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. 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).[11]

The estimation of the portfolio betas β^j and factor risk price λ is also undertaken using a two-pass ordinary least squares regression following Fama and MacBeth (1973). In the first step, we run time-series regressions of portfolio excess returns against a constant and the risk factors, and estimate the betas β^j. In the second step, we run cross-sectional regressions of portfolio returns on the betas, and estimate the factor risk prices λ.[12] We report t-stat based on Newey and West (1987) and Shanken (1992) standard errors with lag length determined according to Andrews (1991).

4.3 Cross-Sectional Regressions

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

$$M_{t+1} = 1 - b_{LEV}\left(LEV_{t+1} - \mu_{LEV}\right) - b_{VCA}\left(VCA_{t+1} - \mu_{VCA}\right), \tag{10}$$

[11]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.

[12]Note that in the second stage of Fama-MacBeth regressions we do not add any constant to capture the common over- or under-pricing in the cross section of returns. This is because LEV has no cross-sectional relation with volatility excess returns, and it works as a constant that allows for a common mispricing.

and present asset pricing tests on the cross-sections of volatility portfolios as test assets in Table 6. 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 6 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 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 additional maturity combinations (see Panels B to D of Table 6) remain qualitatively very similar.

Table 6 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). This begs the question of whether the LEV factor carries pricing power for our implied volatility portfolios. In the context of multiple factors, Cochrane (2005) points out that λ_i captures whether factor f_i is priced whereas b_i reflects whether factor f_i is marginally useful in pricing assets given the other factors. Putting it differently, while b_i gives the multiple regression coefficient of the SDF on the corresponding factor given the presence of other factors, λ_i gives the single regression coefficient of the SDF on the corresponding factor without taking other factors into account. 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 6, 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.

4.4 Time-Series Regressions

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)

$$RX_{t+1}^{j} = \alpha^{j} + \beta_{LEV}^{j} LEV_{t+1} + \beta_{VCA}^{j} VCA_{t+1} + \varepsilon_{t+1}^{j} \tag{11}$$

We present the least squares estimates of these regressions in Table 7. 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_{α}^{2} 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 7 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 7.

4.5 Global Currency Risk Factors

We also check if the volatility carry factor explains the cross-section of our implied volatility portfolios beyond what is explained by traditional currency factors such as 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.

Table 8 about here

Armed with these currency factors, we run time-series regressions and present the least-squares estimates in Table 8. We regress the volatility excess return for each of the 20 implied volatility portfolios on a constant, the level factor and the currency factors outlined above. While the LEV factor is always highly statistical significant (with a t-stat larger than 8.55), the explanatory power of the traditional currency 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. Moreover, the alphas are statistically significant in 14 out 20 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 currency risk factors are unable to fully explain the variation in the excess returns of our implied volatility volatility portfolios.

4.6 Global Equity Risk Factors

We also test if the exposure to any of the global equity factors can empirically rationalize our volatility excess returns. We regress the volatility excess return for each of the 20 implied volatility portfolios on a constant, the level factor and the Fama and French (2016) global equity factors, i.e., global equity (MKT), size (SMB), value (HML), profitability (RMW) and investment (CMA) risk factors.[13] We present the least-squares estimates in Table 9.

TABLE 9 ABOUT HERE

The global equity premium is uncorrelated with slope sorted portfolios for each maturity pair. The SMB factor is negatively correlated with the lowest implied volatility slope portfolios whereas the HML and the RMW factors have some explanatory power for middle-range implied volatility slope portfolios. The empirical evidence in favour of the global equity risk factors, however, is fairly weak as the alphas are statistically significant in 15 out 20 cases, the null hypothesis that the intercepts are jointly equal to zero is reject at 1% significance level, and R^2 (based on all factors) and R^2_{LEV} (based on the level factor only) are practically indistinguishable from each other. These results lead to the conclusions that global equity risk factors do not explain the variation in the excess returns of our implied volatility volatility portfolios.

5. Further Analysis

In this section, we present a number of additional exercises that extend and further corroborate the results reported earlier.

5.1 Dissecting Time-Series and Cross-Sectional Predictability

We take a closer look on whether the predictability of FVA returns comes from time-series or cross-sectional dimension. We also relate the forward volatility risk premia to its spot counterpart. Our results show that conditioning on the implied volatility slopes produces sizeable

[13]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.

future volatility excess returns. This predictability could arise from the time-series and/or the cross-sectional dimension. We answer this question by employing the decomposition of a portfolio strategy into cross-sectional and time-series components by Hassan and Mano (2015). We first review this method and then present our empirical evidence. Specifically, let f_t^i and rx_{t+1}^i be the predictive fundamental and the excess return for country i at times t and $t+1$, respectively. We then decompose the covariance between rx_{t+1}^i and f_t^i as follows

$$\begin{aligned} cov(rx_{t+1}^i, f_t^i) &= E[(rx_{t+1}^i - r)(f_t^i - f)] \\ &= \underbrace{E[rx_{t+1}^i(f^i - f)]}_{Static} + \underbrace{E[rx_{t+1}^i(f_t^i - f_t - (f^i - f))]}_{Dynamic} + \underbrace{E[rx_{t+1}^i(f_t - f)]}_{Dollar}, \end{aligned}$$

where

$$f_t = \frac{1}{N}\sum_{j=1}^{N} f_t^i, \quad f_i = \frac{1}{T}\sum_{t=1}^{T} f_t^i, \quad f = \frac{1}{T}\sum_{t=1}^{T}\left(\frac{1}{N}\sum_{j=1}^{N} f_t^i\right),$$

f_t denotes the average fundamental across countries at time t, f^i is the average fundamental over time for country i, and f is the unconditional average of the fundamental over time and across countries.[14]

This decomposition gives rise to three different investment strategies, each one with an intuitive interpretation. The "static trade", with weights equal to $(f^i - f)$, exploits the cross-country variation of the fundamentals, and it is long all countries that have an unconditionally high fundamental and short all countries that have an unconditionally low fundamental. The "dynamic trade", with weights given by $(f_t^i - f_t - (f^i - f))$, trades on the between time and country variation in fundamentals, and it is long countries that have high fundamentals relative to the time average fundamental of all countries and relative to their country-specific average fundamental. It can be seen as the incremental benefit of re-weighting the portfolio strategy every month. The "dollar trade", with portfolio weights equal to $(f_t - f)$, is based on the cross-time variation in the average fundamental of all countries against the US. This strategy goes long all countries when the average fundamental is high relative to its unconditional average and vice versa.

The sum of the static and dynamic trades capture the cross-sectional dimension of pre-

[14]Note that we focus on the in-sample decomposition, which holds exactly, to reduce any estimation error.

dictability with portfolio weights equal to $(f_t^i - f_t)$ as

$$E\left[rx_{t+1}^i(f_t^i - f_t)\right] = \underbrace{E[rx_{t+1}^i(f^i - f)]}_{Static} + \underbrace{E[rx_{t+1}^i(f_t^i - f_t - (f^i - f))]}_{Dynamic},$$

whereas the sum of the dollar and dynamic trades captures the pure time-series dimension with weights equal to $(f_t^i - f^i)$ as

$$E[rx_{t+1}^i(f_t^i - f^i)] = \underbrace{E[rx_{t+1}^i(f_t - f)]}_{Dollar} + \underbrace{E[rx_{t+1}^i(f_t^i - f_t - (f^i - f))]}_{Dynamic}.$$

In the cross-sectional strategy, the portfolio weight of country i depends on the difference between the fundamental for country i and time t and the average fundamental across all countries at time t. This strategy is identical to going long and short assets depending on whether their fundamental is high or low in the cross-section. In the time-series strategy, moreover, the portfolio weight of country i depends on the country's fundamental at time t relative to its own time-series mean. Such a portfolio results in a time-series trading strategy which is alike a time-series predictability test.

Table 10 about here

In our empirical analysis, we dissect the covariance between the implied volatility slopes and the future volatility excess returns using full-sample estimates of f^i, f_t and f. Moreover, since our strategy implies buying (selling) FVAs with low (high) implied volatility slopes, we multiply by minus one the proportional portfolio weights presented above. Table 10 displays the average volatility excess returns of the dynamic (DYN), static (STA), dollar (DOL), cross-sectional (CRS) and time-series (TMS) trade, respectively. Note that we scale the excess returns to have the same standard deviation of the corresponding VCA strategy reported in Table 4 for easy comparison. In our analysis, both cross-sectional and time-series strategies yield statistically significant average excess returns. The statistical and economic significance, however, becomes more pronounced in favour of the cross-sectional dimension as we increase the maturity combination of our FVAs. For 1/3 mth, for instance, CRS produces an average monthly excess return of 2.78% (with a t-stat of 3.59) per month whereas TMS generates an average excess return of 2.12% (with a t-stat of 2.26) per month. In contrast, for 12/24 mth, we uncover an average excess return of 1.77% (with a t-stat of 4.01) per month for CRS, and an average excess return of 0.85% (with a t-stat of 1.63) for TMS. In conclusion, both cross-sectional and time-series predictability matter in our portfolio setting.

5.2 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 evolves around 100 *bps* for the shortest maturity and 80 *bps* for the longest maturity in our sample. While the profitability of our volatility carry strategies drops on average by 24%, it remains both economically and statistically significant (see Tables A11-A14 in the Internet Appendix).

5.3 Spot Volatility Risk Premia

We have explored the behaviour of 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. Consider the following two strategies:

1. Go long a 3/6 mth FVA, and hold till it matures in three months. The payoff is the three month implied volatility in three months' time minus the fixed leg.

2. Go long a 6 month volatility swap, liquidating after three months, and go short a 3 month volatility swap, holding till maturity. The payoff on the 6 month volatility swap

is the three month realized volatility plus the three month implied, minus the fixed leg. The short 3 month volatility swap pays the fixed leg minus the three month realized volatility. The net payoff is the three month implied volatility in three months' time, minus the difference in the fixed legs.

Ignoring the time value of money, the payoffs are the same. The VCA is equivalent to a calendar spread in the volatility swap market. The expected return on such a contract can be regarded as a forward volatility risk premium, and it is this premium we have been investigating. Most of the literature on the volatility risk premium has concentrated on the difference between implied and realized volatility. This can be termed the spot volatility risk premium. It is the expected return on a single volatility swap contract, typically the one month contract. It can be seen as the limit case of a FVA – the 0/1 mth FVA.

Does the spot volatility risk premium behave in a similar fashion to the forward premium? To keep comparability with the previous results, we again construct five slope sorted portfolios, and construct the average portfolio (LEV) and the high-low portfolio (VCA).[15] As shown in Panel A of Figure 3, the average spot volatility risk premium (LEV) is significantly negative; the forward volatility risk premium is also significantly negative at the 1/3 mth horizon, but the magnitude is smaller than the spot premium. Beyond 3 months, the average forward volatility risk premium is insignificantly different from zero. The VCA behaves rather differently; while the absolute magnitude of the VCA declines with maturity, so does its risk, so its Sharpe ratio is substantially independent of maturity, and the expected return remains significantly positive at all maturities.

Figure 3 about here

Do the asset pricing results that we have established for the forward premium also apply to the spot volatility risk premium? There are good reasons why one would not necessarily expect them to. Principal component analysis done on the monthly returns to the different maturity VCA strategies suggests that the spot and forward strategies are exposed to rather

[15]See the tabulated results in Table A15 in the Internet Appendix.

different risks. As can be seen in Panel B of Figure 3, the spot strategy loads very heavily on the first component; the forward strategies all load much less on the first component, but load much more on the second component on which the spot strategy has a negative loading. This is not entirely surprising; factors that might give rise to risk premia in the spot market (such as dealer inventories and hedging costs) may have quite different impact in the forward market.

The analogy with the interest rate market may be pertinent. 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.

If we apply the same asset pricing test to the spot premia as we did in Table 6 to the forward premia, we find contrasting results (see Table A16 in the Internet Appendix). Now the LEV factor is significant, while the VCA factor is significant only in some of the specifications.

5.4 Additional Exercises

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

6. Towards an Understanding of FX Volatility Risk

The main purpose of this paper is to demonstrate the existence of the 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? Is it connected to other pricing regularities in the currency and international asset markets? Can one link the global volatility risk factors we have identified to macro-economic variables?

We do not presume to resolve these questions comprehensively, but rather seek to relate our findings to existing models of exchange rates. We show that some of the models capture, at least in qualitative terms, the properties of the risk premia we have documented. The models also suggest macro-economic variables that might plausibly be related to the volatility risk premium. In the second part of this section, we examine a number of these variables to test whether they do in fact have explanatory power.

6.1 Modelling the Volatility Risk Premium

We start by constructing a generic, complete market model set in continuous time, and show how the specification of pricing kernels in the different countries determines the behaviour of volatility risk premia. The pricing kernel is represented by a diffusion process as

$$dm_t^j = -\mu(z_t^j)dt - \lambda(z_t^j)dz_t^j, \qquad (12)$$

where m_t^j is the log of the nominal stochastic discount factor (SDF) in country j, z_t^j is the state variable (or a vector of state variables), $\lambda\left(z_t^j\right)$ is the price of risk in the economy, and $j = 1, \ldots, J$. For example, z_t^j may include the level, volatility and growth rate of consumption and inflation.[16]

We now focus on two specific countries: h is the home country of the investor (i.e., the US in our empirical work) and f is the foreign country. With complete markets, the evolution of the log of the exchange rate in country f (in dollars per unit of foreign currency) is given by

[16] In reduced form models, Equation (12) is specified exogenously, and the state variables are not identified; in general equilibrium models it is derived from preferences of the representative agent and the dynamics of consumption and prices.

the difference in the log SDFs (Backus, Foresi, and Telmer 2001).

$$dq_t^f = dm_t^f - dm_t^h = \left[\mu(z_t^h) - \mu(z_t^f)\right] dt + \left[\lambda(z_t^h) dz_t^h - \lambda(z_t^f) dz_t^f\right]. \tag{13}$$

It then follows that the variance of the exchange rate is computed as follows

$$V_t^f = var\left[\lambda(z_t^h) dz_t^h - \lambda(z_t^f) dz_t^f\right] / dt, \tag{14}$$

whereas the variance risk premium is given by

$$E_t\left[dRX_t^f\right] = E_t\left[dV_t^f dm_t^h\right]. \tag{15}$$

We now compare this generic model with five recent models. Bakshi, Carr, and Wu (2008) have a reduced form model with both global and local state variables. The state variables have time varying volatility, and are subject to jumps. The price of local risk does not depend on the global state variable, and nor does the price of global risk depend on the local state variable. In the symmetric form of their model, global risk enters equally into the home and foreign SDF's, and so does not affect the exchange rate between them. The variance of the exchange rate is therefore additively separable into a term that reflects home country local risk, and one that reflects foreign country local risk. Both are time varying, but the latter is not priced by the home country investor. So while there is a time varying volatility risk premium, it depends only on the level of the local home state variable, and is common across currencies.

The model does, however, explicitly envisage differences in a scale parameter across countries. With economies affected to varying degrees by global shocks, the global state variable does enter into the exchange rate in this asymmetric model, and it is a priced risk. The premium is of the form $\alpha_t + \gamma^f \beta_t$, where α_t is the time-varying premium compensating for local risk in the home country, β_t is compensation for global risk, and γ^f is a country specific constant that reflects the difference in exposure to the global factor between the home country and the foreign country. With asymmetry, the volatility risk premium does vary both over time and cross-sectionally. But the ranking of countries by premium is invariant over time, which is not what we observe in the data.

Colacito and Croce (2011) have a representative agent economy with Epstein-Zin preferences and long run risk. Shocks come from changes in consumption and changes in consumption growth. These shocks can be correlated across countries. But the prices of risk, and the size of shocks are both constant over time. The volatility of the exchange rate is therefore also constant, and there is no volatility risk premium.

Du (2013) has a consumption based general equilibrium symmetric multi-country model where consumption follows a jump diffusion process. Jumps have time varying intensity, with both local (affecting one country) and global (equally affecting all countries) jumps. Global jumps do not affect the exchange rate. Foreign jumps do affect the exchange rate, but they are not priced by the home country investor. So there is a time varying foreign exchange volatility risk premium which varies according to the intensity of jump risk in the home country, but the premium is common to all currencies.

The last two models we examine can generate substantial variation over time both in the cross-section and in the time series. Bansal and Shaliastovich (2013) is a symmetric two country model with long run risk and Epstein-Zin preferences. Consumption and inflation evolve jointly with time varying growth rates; and the volatility of the growth rate is also time varying. To explain the implications of their model for the volatility risk premium, it is helpful to focus on a simplified version where inflation is non-stochastic. The variance of the exchange rate can be written as

$$V_t^f = \alpha_0 + \alpha_1 \left(\sigma_t^{f2} + \sigma_t^{h2} - 2\tau_x \sigma_t^f \sigma_t^h \right) . \tag{16}$$

The α's are constants, σ_t^j is the volatility of consumption growth (proxied empirically by real economic growth) in country j at time t, and τ_x is the correlation between shocks to consumption growth in the two countries – in the paper, the correlation is estimated at 0.82. The variance is stochastic, and is affected by shocks to the volatility of consumption growth in both countries. The volatility risk premium takes the form

$$E_t \left[\frac{dRX_t^j}{dt} \right] \propto f \left(\frac{\sigma_t^f}{\sigma_t^h} \right), \text{ where } f(z) = \left(1 - \frac{\tau_x}{z} \right) + \tau_\sigma \left(1 - \tau_x z \right) .$$

τ_σ is the correlation between shocks to the volatility of consumption growth in the two countries – in the paper, the correlation is estimated at 0.94. The function f is shaped like an inverted U. It goes to minus infinity as z goes to 0 or infinity. So the premium is large and negative when there is a large difference between foreign and home volatility – irrespective of which is larger. The premium reaches a maximum when the ratio z is equal to $z = 1/\sqrt{\tau_\sigma}$, which is close to $z = 1$. At $z = 1$, when home and foreign consumption growth volatility are equal, the risk premium is positive.

This simplified version of the Bansal-Shaliastovich model suggests that the variance risk premium should be locally quadratic in the ratio of the volatilities of consumption growth of the two countries concerned. If we now include the impact of the volatility of inflation, since inflation and consumption follow similar processes in the model (albeit with different parameters), we can draw similar conclusions about the impact of differences in inflation growth volatility.

Finally we examine the model of Lustig, Roussanov, and Verdelhan (2011). It is a reduced form model with global and local 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:

$$-\,dm_t^j = (\alpha + \chi z_t^j + \tau z_t^w)dt + \sqrt{\gamma z_t^j}du_t^i + \sqrt{\kappa z_t^j + \delta^j z_t^w}du_t^w. \tag{17}$$

z_t^w is a global variable which enters the SDF of all countries; u_t^w and u_t^i are uncorrelated standard Brownian processes that capture global and local shocks. The effect of this is that the volatility risk premium includes compensation for global risk, and the exposure to global risk depends on the difference between the level of the home and foreign countries' state variables. This model too delivers volatility risk premia that vary both in the time series and the cross-section.

The state variables are not explicitly related to macro-economic variables and follow identical (but uncorrelated) square root processes

$$\begin{aligned} dz_t^j &= \beta(\theta - z_t^j)dt - \sigma\sqrt{z_t^j}du_t^j \\ dz_t^w &= \beta^w(\theta - z_t^w)dt - \sigma^w\sqrt{z_t^w}du_t^w. \end{aligned} \tag{18}$$

The instantaneous variance of the exchange rate f in this case is

$$V_t^f = \gamma\left(z_t^f + z_t^h\right) + \left(\sqrt{\kappa z_t^f + \delta z_t^w} - \sqrt{\kappa z_t^h + \delta z_t^w}\right)^2. \tag{19}$$

Exchange rate volatility depends not only on the level of state variables in the two countries, but also on the distance between them. The risk premium

$$\begin{aligned} E_t\left[\frac{dRX_t^f}{dt}\right] &= -\sigma z_t^h \gamma^{1/2}\left(\gamma - \kappa\left(\sqrt{\frac{\kappa z_t^f + \delta z_t^w}{\kappa z_t^h + \delta z_t^w}} - 1\right)\right) \\ &+ \sigma\delta\sqrt{\frac{z_t^w}{\kappa z_t^f + \delta z_t^w}}\left(\sqrt{\kappa z_t^f + \delta z_t^w} - \sqrt{\kappa z_t^h + \delta z_t^w}\right)^2. \end{aligned} \tag{20}$$

The variance V_t^f in Equation (19) shows that it is exposed to country f risk, to the local risk of home country (US), and to global risk. Country f risk is not priced by the dollar based investor. The risk premium in Equation (20) contains two terms. The first term, which is the compensation for US local risk, is locally linear in $z_t^f - z_t^h$. The second term, which is the compensation for global risk, is locally proportional to $\left(z_t^f - z_t^h\right)^2$.

The generic model shows that to match our findings on the volatility risk premium at least in qualitative terms, it is necessary that national economies have time-varying exposure to risks that are correlated across countries. While jumps in state variables and asymmetries in parameters across countries may be important for matching other features of the data, they are not sufficient to account for what we have found. The other implication of our brief survey of the theoretical literature is that the size of the volatility risk premium both over time and in the cross-section is driven by the distance between the states of the two economies at the time. Depending on the exact model specification, the size of the premium may be correlated with the signed distance or the absolute distance between the two economies.

6.2 Understanding Global Risk

Both Bansal and Shaliastovich (2013) and Lustig, Roussanov, and Verdelhan (2011) suggest a strong link between volatility risk premia and macroeconomic state variables. In this section we examine whether our empirical findings can be explained by macroeconomic factors.

To do so, we decompose volatility slopes into macro-related signals and residual components by following the methodology from Menkhoff, Sarno, Schmeling, and Schrimpf (2016) and Della Corte, Sarno, Schmeling, and Wagner (2016). 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.

The next step is to fix the m macro variables of interest. For each period we regress the DSP weight for each country on the macro variable of interest. This allows us to construct a portfolio of currencies for each variable which has weights proportional to that macro variable, 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 G.

Bansal and Shaliastovich (2013) identifies the difference in the volatility of inflation and consumption (proxied by real economic growth) of the foreign and home country as the driver of volatility risk premia. To this end, we collect monthly data on year-on-year inflation and industrial production growth rates for all countries in our sample, and then estimate volatility using stochastic volatility model as in Jurado, Ludvigson, and Ng (2015). We construct two macroeconomic variables for each country and period: the log of the difference of the volatility of inflation between the country and the US, and a similar variable for industrial production. We use the log difference as opposed to the simple ratio of volatilities as the former displays better statistical properties.

Table 11 about here

In Panel A of Table 11, 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. We find that the volatility of real economic growth is both statistically and economically an important driver of volatility risk premia. For 1/3 mth, the overall excess return of the DSP is 4.61% per month (with a t-stat of 5.97). This is quite similar to the 5.15% return on the VCA reported in Table 4. The decomposition into macro volatility related and residual components reveals that up to 38% of this excess return is explained by the difference in the volatility of real economic growth (i.e., an average excess return of 1.77% per month with a t-stat of 2.16) and 53% by the residual component (i.e., an average excess return of 2.44% per month with a t-stat of 2.17). The volatility of inflation, in contrast, plays no significant role. Overall, results remain qualitatively similar for the other maturity combinations.

As we have shown, Lustig, Roussanov, and Verdelhan (2011) implies that volatility risk premia for different counties are proportional to the squared difference between the domestic and foreign (the US) state 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). We source all our data from OECD and IMF and report our results in Panel B of Table 11.

Our empirical evidence suggests that the implied volatility slopes are both statistically and economically related to changes in economic growth. For the 1/3 mth, for instance, the overall excess return is 4.52% per month with a t-stat of 5.86. The decomposition into macro-related and residual components, then, reveals that up to 72% of this excess return is explained by the lagged changes in economic growth (i.e., an average excess return of 3.24% per month with a t-stat of 3.52) and 23% by the residual component (i.e., an average excess return of 1.03% per month with a t-stat of 1.37). 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 2.16% per month with a

t-stat of 5.30. The lagged changes in economic growth can explain up to 42% of this excess return (i.e., an average excess return of 0.90% per month with a t-stat of 2.37) and 56% by the residual component (i.e., an average excess return of 1.20% per month with a t-stat of 3.48). 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 substantially explain our volatility risk premia in line with the model of Bansal and Shaliastovich (2013) and Lustig, Roussanov, and Verdelhan (2011). In particular, the log difference of real economic growth volatility and the squared difference in real economic growth shocks display an average cross-sectional correlation of more than 40%, thus suggesting that these models share similar information.

7. 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.

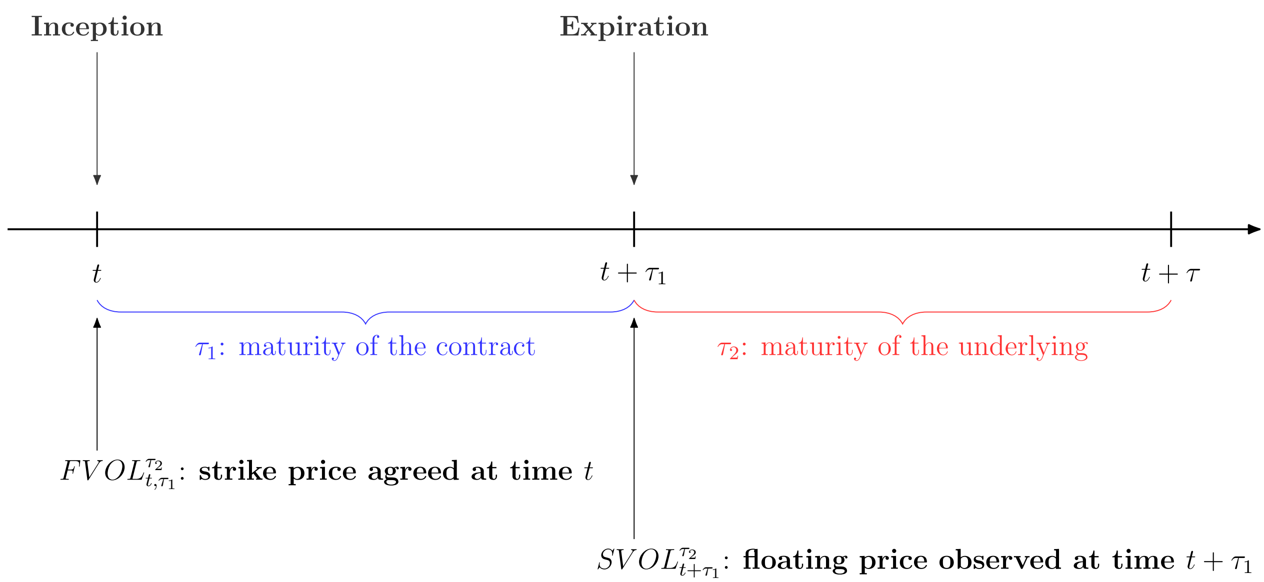

Figure 1. Forward Volatility Agreement

This figures describes a forward volatility agreement written at time t and expiring at time $t+\tau_1$. This is a forward contract that exchanges the τ_2 period implied volatility observed at time $t+\tau_1$ (*spot implied volatility*) against the τ_2 period implied volatility determined today but defined over the same future time interval (*forward implied volatility*). The buyer of this contract receives on the maturity date $t+\tau_1$ a payoff equals to $(SVOL_{t+\tau_1}^{\tau_2} - FVOL_{t,\tau_1}^{\tau_2}) \times M$, where $SVOL_{t+\tau_1}^{\tau_2}$ is the spot implied volatility observed at time $t+\tau_1$ and defined over the time interval between times $t+\tau_1$ and $t+\tau$, $FVOL_{t,\tau_1}^{\tau_2}$ 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 forward volatility agreement and τ_2 is the maturity of the underlying financial instrument (spot implied volatility). The time interval between times t and $t+\tau$ is such that $\tau = \tau_1 + \tau_2$ and $t < t+\tau_1 < t+\tau$.

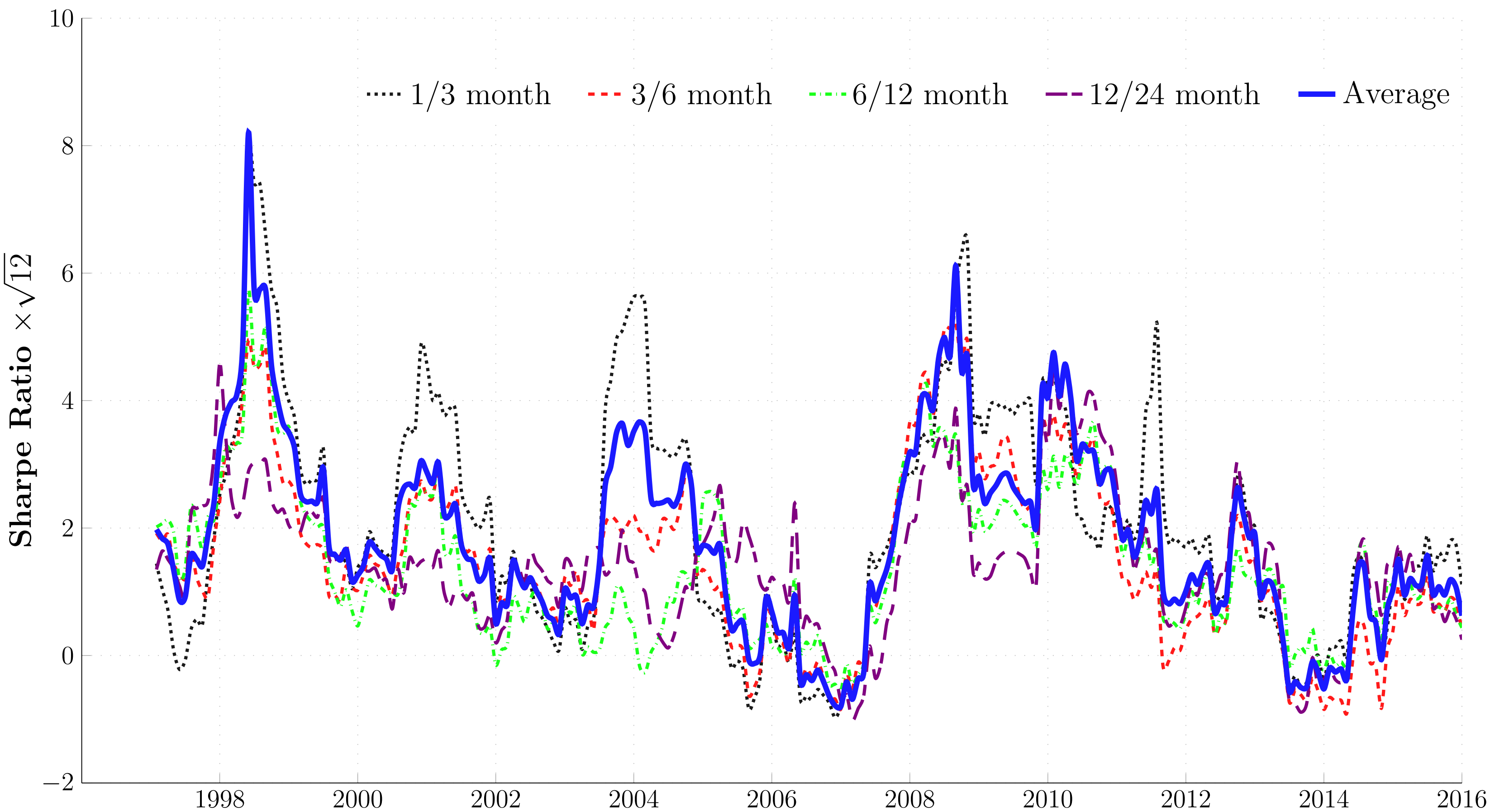

Figure 2. Rolling Sharpe Ratios of Volatility Carry Strategies

This figures displays the annualized 1-year rolling Sharpe ratios for the volatility carry (VCA) strategies described in Table 4. 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 constructed via the cubic spline interpolation method as in 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 A1 in the Internet Appendix displays results for a cross-section of 10 developed countries.

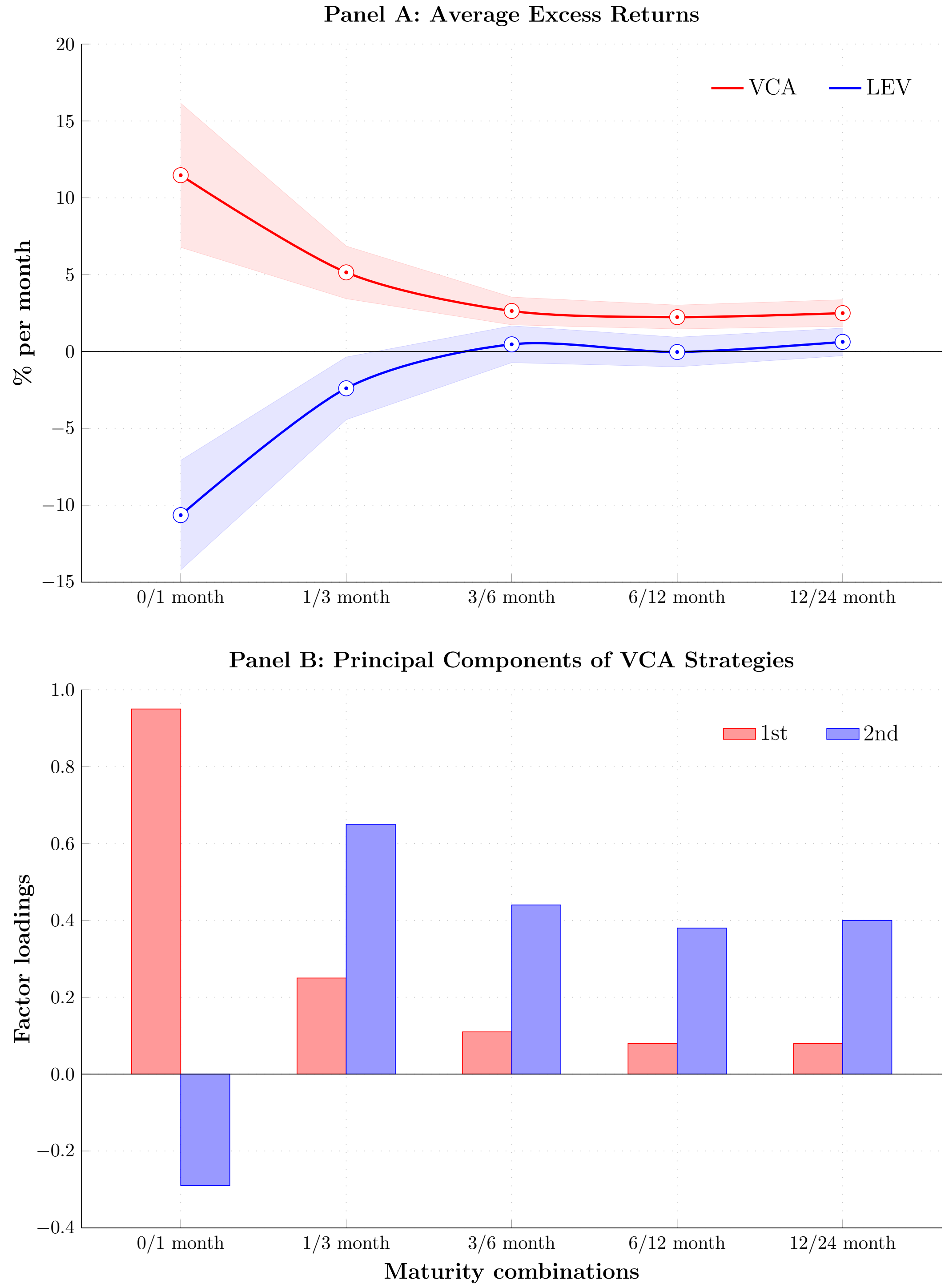

Figure 3. Principal Components of Volatility Carry Strategies

This figure reports average excess returns in Panel A, and factor loadings from principal component analysis in Panel B. VCA and LEV denote strategies based on portfolios of (i) forward volatility agreements from 1/3 month (mth) to 12/24 mth (see Table 4), and (ii) volatility swaps for 0/1 mth (see Table A15 in the Internet Appendix). Figure A2 in the Internet Appendix displays results for a cross-section of 10 developed countries.

Table 1. Predictive Regressions

This table presents estimates of the unbiasedness hypothesis between spot and forward implied volatility (or variance) for a cross-section of 20 developed and emerging market countries. We run cross-country pooled regressions of monthly volatility excess returns on the lagged monthly forward implied volatility premia. α and β are both equal to zero under the null that the hypothesis holds. Implied volatilities are model-free as in Britten-Jones and Neuberger (2000) and are constructed using the cubic spline interpolation method (e.g., Jiang and Tian 2005). t-statistics (reported in brackets) are based on Driscoll and Kraay (1998) standard errors that are heteroscedasticity consistent and robust to very general forms of cross-sectional and temporal dependence. The full sample runs at monthly frequency from January 1996 to December 2015. The crisis (pre- and post-crisis) sub-sample uses (excludes) data from January 2007 to December 2008. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table A1 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	Panel A: Spot and Forward Implied Volatility											
Sample	1/3 month			3/6 month			6/12 month			12/24 month		
	α	γ	$R^2(\%)$	α	γ	$R^2(\%)$	α	γ	$R^2(\%)$	α	γ	$R^2(\%)$
Full	0.00	-0.67	7.6	0.00	-0.80	2.5	0.01	-1.39	1.8	0.00	-1.42	1.7
	[-0.29]	[-5.44]		[0.68]	[-3.42]		[1.08]	[-3.58]		[0.67]	[-3.79]	
Pre- and Post-Crisis	-0.02	-0.52	5.1	0.00	-0.51	1.1	0.00	-1.12	1.4	0.00	-1.63	2.9
	[-2.85]	[-6.72]		[-0.64]	[-2.52]		[-0.33]	[-2.81]		[-0.61]	[-4.35]	
Crisis	0.06	-1.10	11.7	0.04	-1.83	6.9	0.04	-2.39	2.3	0.04	-0.56	0.1
	[1.62]	[-3.10]		[1.72]	[-5.16]		[2.54]	[-2.71]		[1.91]	[-0.40]	
	Panel B: Spot and Forward Implied Variance											
Full	0.01	-0.65	5.6	0.02	-0.78	2.0	0.02	-1.35	1.5	0.01	-1.39	1.4
	[0.53]	[-4.35]		[1.36]	[-3.09]		[1.57]	[-3.41]		[1.22]	[-3.44]	
Pre- and Post-Crisis	-0.02	-0.47	3.5	0.00	-0.46	0.8	0.00	-1.06	1.2	0.00	-1.64	2.7
	[-1.67]	[-5.52]		[0.20]	[-2.24]		[0.31]	[-2.63]		[0.07]	[-4.16]	
Crisis	0.17	-1.30	9.7	0.09	-1.98	5.8	0.10	-2.46	1.9	0.09	-0.13	0.0
	[1.71]	[-2.63]		[1.79]	[-4.51]		[2.56]	[-2.54]		[1.94]	[-0.08]	

Table 2. Country-level Predictive Regressions

This table presents estimates of the unbiasedness hypothesis between spot and forward implied volatility for different maturity combinations. We run country-level pooled (by maturities) regressions of monthly volatility excess returns on the lagged monthly forward implied volatility premia. α and β are both equal to zero under the null that the hypothesis holds. Implied volatilities are model-free as in Britten-Jones and Neuberger (2000) and are constructed using the cubic spline interpolation method (e.g., Jiang and Tian 2005). t-statistics (reported in brackets) are based on Driscoll and Kraay (1998) standard errors that are heteroscedasticity consistent and robust to very general forms of cross-sectional and temporal dependence. DEV denotes the cross-section of 10 developed countries, EME the cross-section of 10 emerging market countries, and ALL the entire cross-section of 20 countries. The full sample runs at monthly frequency from January 1996 to December 2015. The crisis (pre- and post-crisis) sub-sample uses (excludes) data from January 2007 to December 2008. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table A2 in the Internet Appendix displays results for implied variances.

Sample	Full					Pre- and Post-Crisis					Crisis				
	α		γ		$R^2(\%)$	α		γ		$R^2(\%)$	α		γ		$R^2(\%)$
AUD	0.01	[0.81]	-0.88	[-5.84]	10.7	0.00	[-0.18]	-0.79	[-5.29]	10.2	0.05	[1.70]	-1.26	[-2.63]	10.4
BRL	0.01	[0.43]	-0.70	[-3.22]	6.1	-0.01	[-1.12]	-0.51	[-3.41]	4.0	0.06	[1.42]	-0.98	[-1.81]	7.1
CAD	0.01	[0.88]	-0.85	[-5.53]	7.2	0.00	[-0.15]	-0.74	[-4.45]	6.2	0.05	[1.66]	-1.19	[-3.98]	8.3
CHF	0.00	[0.05]	-0.59	[-3.79]	3.6	-0.01	[-1.31]	-0.47	[-3.18]	2.5	0.04	[2.29]	-1.10	[-1.94]	5.8
CZK	0.00	[0.26]	-0.79	[-4.00]	6.7	-0.01	[-1.25]	-0.58	[-3.46]	4.0	0.04	[1.72]	-1.27	[-3.35]	12.4
DKK	0.00	[0.01]	-0.67	[-6.19]	5.4	-0.01	[-1.21]	-0.60	[-5.61]	4.7	0.05	[1.99]	-1.03	[-3.06]	7.9
EUR	0.00	[0.07]	-0.66	[-5.06]	5.1	-0.01	[-1.26]	-0.56	[-4.32]	4.1	0.04	[2.02]	-1.05	[-3.10]	8.5
GBP	0.00	[-0.24]	-0.68	[-3.64]	5.9	-0.01	[-1.60]	-0.60	[-3.21]	5.2	0.04	[1.75]	-1.08	[-2.08]	6.5
HUF	0.00	[-0.12]	-0.74	[-6.59]	7.6	-0.01	[-1.24]	-0.70	[-6.47]	7.0	0.03	[1.79]	-0.30	[-0.89]	0.9
JPY	0.00	[-0.01]	-0.66	[-4.53]	4.9	-0.01	[-1.33]	-0.55	[-4.36]	3.8	0.05	[2.75]	-0.43	[-0.81]	1.1
KRW	0.02	[0.83]	-1.11	[-3.23]	10.0	-0.02	[-1.88]	-0.54	[-3.06]	3.5	0.09	[1.69]	-2.10	[-2.76]	14.6
MXN	0.00	[-0.44]	-0.72	[-4.51]	7.6	-0.02	[-2.12]	-0.59	[-5.07]	6.1	0.06	[1.34]	-3.07	[-2.31]	26.2
NOK	0.00	[0.53]	-0.73	[-5.34]	5.4	0.00	[-0.57]	-0.63	[-4.91]	4.4	0.04	[1.88]	-1.31	[-2.98]	9.9
NZD	0.01	[1.11]	-0.85	[-7.05]	11.2	0.00	[0.45]	-0.84	[-6.41]	11.9	0.04	[1.52]	-0.88	[-2.12]	6.4
PLN	0.00	[-0.09]	-0.84	[-5.19]	10.6	-0.01	[-2.01]	-0.63	[-5.60]	7.4	0.04	[1.59]	-1.64	[-4.02]	15.7
SEK	0.00	[0.20]	-0.63	[-5.78]	4.7	0.00	[-0.92]	-0.54	[-5.23]	3.8	0.04	[1.88]	-1.16	[-3.34]	9.7
SGD	0.00	[-0.02]	-0.63	[-3.99]	4.6	-0.01	[-1.78]	-0.47	[-3.62]	3.0	0.06	[2.06]	-1.91	[-2.96]	15.1
TRY	-0.01	[-1.08]	-0.52	[-4.11]	3.6	-0.01	[-1.16]	-0.62	[-4.97]	5.7	0.00	[-0.13]	0.21	[0.68]	0.4
TWD	0.00	[-0.15]	-0.66	[-6.49]	6.3	-0.01	[-1.16]	-0.63	[-6.11]	6.5	0.04	[1.61]	-0.65	[-1.66]	2.7
ZAR	0.00	[0.50]	-0.48	[-2.13]	2.3	0.00	[0.04]	-0.47	[-2.03]	2.5	0.03	[1.17]	-0.08	[-0.12]	0.0
DEV	0.01	[0.33]	-0.73	[-6.25]	6.4	0.00	[-1.28]	-0.62	[-6.51]	5.3	0.02	[2.01]	-0.99	[-3.09]	6.8
EME	0.01	[0.32]	-0.72	[-7.17]	6.5	0.00	[-1.28]	-0.62	[-8.07]	5.8	0.03	[1.72]	-1.29	[-3.45]	8.3
ALL	0.01	[0.33]	-0.72	[-7.21]	6.5	0.00	[-1.31]	-0.62	[-8.18]	5.7	0.02	[1.86]	-1.15	[-3.49]	7.6

Table 3. 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. 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). For each maturity combination, the forward volatility premia are computed using the corresponding forward and spot implied volatilities. The first (last) portfolio P_1 (P_5) contains forward volatility agreements 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. 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 A3 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-6.95	-4.05	-2.22	-1.75	0.90	-2.81	7.84	-1.22	-0.08	0.17	0.88	2.27	0.40	3.49
	[-5.51]	[-3.91]	[-2.18]	[-1.61]	[0.71]	[-2.75]	[7.67]	[-1.71]	[-0.14]	[0.30]	[1.23]	[3.18]	[0.66]	[6.61]
$sdev$	18.21	13.59	13.16	13.88	14.29	12.73	15.33	10.47	7.56	7.49	9.98	9.18	8.01	7.90
$skew$	1.98	2.12	2.11	3.81	2.18	2.57	-0.90	1.61	1.52	1.33	5.10	2.39	2.74	-0.04
$kurt$	9.81	11.86	12.94	33.42	13.43	17.72	8.49	9.26	9.10	9.35	52.92	15.31	21.58	3.79
$SR \times \sqrt{12}$	-1.32	-1.03	-0.58	-0.44	0.22	-0.77	1.77	-0.40	-0.04	0.08	0.31	0.86	0.17	1.53
ac_1	0.11	0.19	0.18	0.22	0.33	0.24	0.07	0.12	0.17	0.13	0.12	0.20	0.19	0.07
$freq$	0.42	0.62	0.70	0.67	0.47			0.46	0.70	0.72	0.73	0.60		
	Panel C: 6/12 month							Panel D: 12/24 month						
$mean$	-1.13	-0.54	-0.28	0.24	1.43	-0.06	2.56	-0.31	-0.01	0.60	0.71	2.08	0.61	2.39
	[-1.72]	[-1.21]	[-0.59]	[0.51]	[2.27]	[-0.11]	[6.34]	[-0.56]	[-0.03]	[1.24]	[1.61]	[4.31]	[1.34]	[4.93]
$sdev$	9.75	6.39	6.64	6.19	7.86	6.53	7.12	8.38	7.01	7.29	6.12	7.22	6.32	7.61
$skew$	4.52	1.76	1.53	1.18	2.45	2.66	-1.12	3.72	2.20	2.92	1.99	1.72	2.97	0.63
$kurt$	41.09	10.83	10.24	6.17	17.15	21.05	12.56	34.47	14.89	24.33	15.52	8.89	24.33	15.21
$SR \times \sqrt{12}$	-0.40	-0.29	-0.14	0.14	0.63	-0.03	1.25	-0.13	-0.01	0.28	0.40	1.00	0.34	1.09
ac_1	0.10	0.12	0.11	0.18	0.22	0.20	-0.11	0.06	0.16	0.05	0.16	0.07	0.14	-0.03
$freq$	0.36	0.65	0.68	0.69	0.52			0.20	0.40	0.48	0.51	0.33		

Table 4. Descriptive Statistics: Portfolios sorted on Implied Volatility Slopes

This table reports descriptive statistics for five portfolios of forward volatility agreements 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). Each slope is based on the 24 month and 3 month 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 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. 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 A4 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-4.66	-3.02	-2.35	-2.42	0.49	-2.39	5.15	-0.83	0.37	0.58	0.44	1.81	0.47	2.64
	[-3.91]	[-2.82]	[-2.17]	[-2.61]	[0.38]	[-2.31]	[5.91]	[-1.31]	[0.50]	[0.93]	[0.86]	[2.58]	[0.78]	[5.75]
$sdev$	16.33	14.08	13.41	12.13	14.16	12.72	12.25	9.42	10.18	7.85	7.82	8.86	8.00	7.09
$skew$	2.20	2.76	2.18	1.66	2.51	2.48	-1.34	1.64	5.22	1.63	1.30	2.34	2.73	-0.16
$kurt$	12.31	20.12	13.35	10.72	17.35	17.29	11.62	9.87	53.77	10.26	8.32	16.10	21.61	4.35
$SR \times \sqrt{12}$	-0.99	-0.74	-0.61	-0.69	0.12	-0.65	1.46	-0.30	0.13	0.26	0.19	0.71	0.21	1.29
ac_1	0.19	0.18	0.23	0.14	0.30	0.25	0.08	0.08	0.17	0.21	0.02	0.18	0.18	0.00
$freq$	0.26	0.47	0.56	0.56	0.32			0.26	0.47	0.56	0.56	0.32		

	Panel C: 6/12 month							Panel D: 12/24 month						
$mean$	-1.13	-0.04	-0.08	-0.01	1.11	-0.03	2.24	-0.40	0.38	0.37	0.68	2.10	0.63	2.50
	[-2.34]	[-0.06]	[-0.17]	[-0.03]	[1.92]	[-0.06]	[5.67]	[-0.86]	[0.67]	[0.83]	[1.67]	[3.63]	[1.37]	[5.67]
$sdev$	7.28	8.47	6.51	6.47	7.49	6.49	6.12	7.01	8.05	6.39	6.42	8.14	6.31	6.95
$skew$	1.27	5.56	1.36	1.18	2.72	2.65	0.43	1.82	4.89	1.57	1.04	2.85	2.98	1.45
$kurt$	8.04	59.44	8.73	6.91	19.83	21.36	5.21	12.99	49.31	10.41	7.81	17.75	24.39	10.88
$SR \times \sqrt{12}$	-0.54	-0.02	-0.04	-0.01	0.52	-0.02	1.27	-0.20	0.16	0.20	0.37	0.89	0.34	1.25
ac_1	0.08	0.19	0.18	0.00	0.20	0.18	0.01	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			0.26	0.47	0.56	0.56	0.32		

Table 5. Principal Components: Portfolios sorted on Implied Volatility Slopes

This table presents the loadings c_i on the principal components of the slope-sorted portfolios presented in Table 4. In each panel, the last row reports cumulative percentage share of total variance 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 A5 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	Panel A: 1/3 month					Panel B: 3/6 month				
	c_1	c_2	c_3	c_4	c_5	c_1	c_2	c_3	c_4	c_5
P_1	0.52	-0.82	-0.25	0.09	0.01	0.46	-0.79	-0.40	-0.04	0.02
P_2	0.46	0.10	0.33	-0.81	0.00	0.53	0.01	0.65	-0.54	0.07
P_3	0.43	0.20	0.45	0.45	0.61	0.40	0.08	0.21	0.54	-0.70
P_4	0.40	0.20	0.24	0.35	-0.79	0.40	0.18	0.07	0.56	0.70
P_5	0.42	0.49	-0.76	-0.01	0.10	0.44	0.58	-0.61	-0.30	-0.10
Cum. Var.	**0.82**	**0.90**	**0.96**	**0.98**	**1.00**	**0.81**	**0.89**	**0.94**	**0.98**	**1.00**
	Panel C: 6/12 month					Panel D: 12/24 month				
P_1	0.43	-0.76	-0.39	0.29	0.01	0.42	-0.36	-0.80	-0.26	0.02
P_2	0.54	-0.04	0.81	0.20	0.14	0.52	-0.26	0.15	0.72	-0.33
P_3	0.41	0.02	-0.01	-0.53	-0.74	0.40	-0.22	0.35	-0.07	0.81
P_4	0.40	0.13	-0.23	-0.59	0.65	0.40	-0.10	0.45	-0.64	-0.47
P_5	0.45	0.63	-0.38	0.50	-0.08	0.48	0.86	-0.14	0.02	0.06
Cum. Var.	**0.80**	**0.88**	**0.93**	**0.98**	**1.00**	**0.76**	**0.88**	**0.93**	**0.97**	**1.00**

Table 6. Asset Pricing Tests: Risk Prices

This table presents cross-sectional asset pricing tests for a linear factor model that uses the five slope-sorted portfolios presented in Table 4 as test assets and the level (LEV) and volatility carry (VCA) strategies as pricing factors. The table reports GMM (first and second-stage) and Fama-MacBeth (FMB) 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. For FMB, we also report t-statistics based on Shanken (1992) corrected standard errors in brackets (second row). χ^2 denotes the test statistics (with p-values in parentheses) for the null hypothesis that all pricing errors are jointly zero. 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 A6 in the Internet Appendix displays results for a cross-section of 10 developed countries.

	Panel A: 1/3 month						Panel B: 3/6 month					
	b_{LEV}	b_{VCA}	λ_{LEV}	λ_{VCA}	$R^2(\%)$	HJ	b_{LEV}	b_{VCA}	λ_{LEV}	λ_{VCA}	$R^2(\%)$	HJ
GMM_1	-0.01	0.03	-2.37	4.75	84.1	0.23	0.01	0.05	0.47	2.59	96.8	0.11
	[-1.31]	[2.67]	[-2.20]	[4.86]		(0.43)	[1.31]	[5.19]	[0.76]	[5.45]		(0.66)
GMM_2	-0.02	0.04	-2.30	4.86	73.0		0.01	0.06	0.38	2.61	89.3	
	[-1.92]	[4.33]	[-2.45]	[5.63]			[1.07]	[6.16]	[0.75]	[5.78]		
FMB	-0.01	0.03	-2.37	4.75	84.1		0.01	0.05	0.47	2.59	96.8	
	[-1.66]	[4.79]	[-2.20]	[4.86]			[1.09]	[5.61]	[0.76]	[5.45]		
	[-2.11]	[5.57]	[-2.88]	[5.89]			[1.24]	[5.69]	[0.91]	[5.62]		
$mean$			**-2.39**	**5.15**					**0.47**	**2.64**		
	Panel C: 6/12 month						Panel D: 12/24 month					
GMM_1	0.00	0.06	-0.03	2.23	99.0	0.05	0.01	0.05	0.62	2.51	98.6	0.07
	[-0.41]	[5.61]	[-0.05]	[5.52]		(0.93)	[1.24]	[5.11]	[1.33]	[5.98]		(0.87)
GMM_2	0.00	0.07	-0.16	2.19	97.8		0.01	0.05	0.55	2.40	97.8	
	[-0.33]	[6.48]	[-0.39]	[5.88]			[1.31]	[5.73]	[1.40]	[6.13]		
FMB	0.00	0.06	-0.03	2.23	99.0		0.01	0.05	0.62	2.51	98.6	
	[-0.35]	[5.81]	[-0.05]	[5.52]			[0.97]	[6.13]	[1.33]	[5.98]		
	[-0.40]	[5.62]	[-0.06]	[5.61]			[1.06]	[5.34]	[1.51]	[5.44]		
$mean$			**-0.03**	**2.24**					**0.63**	**2.50**		

Table 7. Asset Pricing Tests: Factor Betas

This table presents time-series asset pricing tests for a linear factor model that uses the five slope-sorted portfolios presented in Table 4 as test assets and the level (LEV) and volatility carry (VCA) strategies as pricing factors. The table reports least-squares estimates of time series regressions. 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 A7 in the Internet Appendix displays results for a cross-section of 10 developed countries.

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

Table 8. Asset Pricing Tests: Currency Risk Factors

This table presents time-series asset pricing tests using the slope-sorted portfolios presented in Table 4 as test assets, and the level (LEV), carry (CAR), global imbalance (IMB), foreign exchange volatility (VOL), and liquidity (LIQ) as pricing factors. LEV denotes the average excess returns across all slope-sorted portfolios. 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 countries. Excess returns are expressed in percentage per month. Table A8 in the Internet Appendix displays results for a cross-section of 10 developed countries.

Portfolios		α	LEV	DOL	CAR	IMB	VOL	LIQ	$R^2(\%)$	$R^2_{LEV}(\%)$	χ^2_α
1/3 month	P_1	-3.76	1.70	0.21	-0.35	-0.25	0.51	-0.21	69.5	69.4	(<.01)
		[-4.13]	[15.09]	[0.77]	[-0.60]	[-0.71]	[0.91]	[-0.65]			
	P_2	-2.38	1.59	-0.02	-0.07	-0.20	0.31	-0.03	83.6	83.7	
		[-6.53]	[26.80]	[-0.12]	[-0.35]	[-0.81]	[1.71]	[-0.21]			
	P_3	-1.63	1.46	0.18	-0.18	-0.17	0.06	-0.05	80.7	80.8	
		[-3.41]	[17.84]	[1.20]	[-0.87]	[-0.79]	[0.31]	[-0.23]			
	P_4	-1.96	1.38	0.35	0.20	-0.11	-0.14	-0.34	82.4	82.0	
		[-5.69]	[22.62]	[1.74]	[0.86]	[-0.43]	[-0.68]	[-2.38]			
	P_5	0.73	1.57	-0.09	-0.01	0.27	0.26	0.12	75.0	75.1	
		[1.21]	[18.03]	[-0.36]	[-0.04]	[0.89]	[0.85]	[0.55]			
3/6 month	P_1	-0.48	0.99	0.00	0.13	-0.13	0.03	-0.13	72.4	72.8	
		[-1.33]	[14.23]	[-0.01]	[0.56]	[-0.69]	[0.13]	[-0.82]			
	P_2	0.63	1.13	-0.16	0.02	0.00	0.03	0.35	83.7	83.3	
		[2.61]	[10.39]	[-1.37]	[0.14]	[0.01]	[0.32]	[2.63]			
	P_3	0.92	0.85	-0.09	-0.04	-0.04	-0.02	0.06	82.7	82.9	
		[3.76]	[14.52]	[-0.79]	[-0.33]	[-0.33]	[-0.13]	[0.56]			
	P_4	0.73	0.87	0.08	-0.03	0.09	-0.05	-0.14	81.6	81.7	
		[3.00]	[15.11]	[0.57]	[-0.19]	[0.62]	[-0.39]	[-0.96]			
	P_5	1.94	0.93	-0.31	0.00	0.31	-0.05	0.08	75.7	75.3	
		[5.64]	[18.72]	[-2.15]	[-0.02]	[1.47]	[-0.26]	[0.68]			
6/12 month	P_1	-0.92	0.74	0.02	0.20	-0.07	-0.12	-0.15	68.2	68.4	
		[-3.23]	[12.16]	[0.11]	[1.06]	[-0.47]	[-0.65]	[-1.19]			
	P_2	0.17	0.92	-0.09	0.05	-0.02	-0.07	0.32	81.6	81.1	
		[0.88]	[8.77]	[-0.79]	[0.32]	[-0.12]	[-0.72]	[2.34]			
	P_3	0.13	0.69	-0.02	-0.01	0.02	-0.06	0.12	78.3	78.5	
		[0.66]	[12.28]	[-0.19]	[-0.13]	[0.17]	[-0.64]	[1.10]			
	P_4	0.24	0.70	0.06	-0.08	0.12	-0.05	-0.11	77.0	77.1	
		[1.19]	[12.72]	[0.51]	[-0.60]	[1.05]	[-0.43]	[-0.92]			
	P_5	1.31	0.79	-0.20	-0.07	0.16	0.01	0.10	75.7	75.8	
		[4.78]	[15.06]	[-1.59]	[-0.41]	[0.92]	[0.07]	[0.91]			
12/24 month	P_1	-0.19	0.72	0.03	0.11	-0.01	-0.10	-0.12	70.2	70.5	
		[-0.73]	[17.50]	[0.19]	[0.66]	[-0.05]	[-0.63]	[-1.06]			
	P_2	0.66	0.84	-0.05	0.14	-0.13	-0.26	0.18	81.5	81.1	
		[3.03]	[9.30]	[-0.48]	[0.92]	[-1.20]	[-2.93]	[1.48]			
	P_3	0.62	0.67	0.08	0.10	-0.09	-0.23	0.03	78.5	78.4	
		[3.00]	[14.26]	[0.73]	[0.99]	[-0.88]	[-1.95]	[0.33]			
	P_4	0.90	0.67	0.21	0.02	0.12	-0.25	-0.18	74.1	73.3	
		[3.68]	[14.78]	[1.45]	[0.17]	[0.79]	[-2.20]	[-1.46]			
	P_5	2.33	0.77	-0.19	-0.13	0.12	0.18	0.09	58.0	58.4	
		[6.44]	[10.16]	[-1.18]	[-0.57]	[0.48]	[0.75]	[0.62]			

Table 9. Asset Pricing Tests: Global Equity Risk Factors

This table presents time-series asset pricing tests using the slope-sorted portfolios presented in Table 4 as test assets, and the level (LEV) and the Fama-French global equity factors – market excess return (MKT), size (SMB), value (HML), profitability (RMW), and investment (CMA) – as pricing factors. LEV denotes the average excess returns across all slope-sorted portfolios. 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 countries. Excess returns are expressed in percentage per month. Table A9 in the Internet Appendix displays results for a cross-section of 10 developed countries.

Portfolios		α	LEV	MKT	SMB	HML	RMW	CMA	R^2(%)	R^2_{LEV}(%)	χ^2_α
1/3 month	P_1	-4.06	1.68	-0.07	-0.01	0.46	-0.11	-0.51	68.9	69.4	(<.01)
		[-5.68]	[16.03]	[-0.31]	[-0.05]	[1.44]	[-0.24]	[-1.23]			
	P_2	-2.46	1.64	0.08	0.23	0.32	-0.30	-0.21	83.8	83.7	
		[-6.97]	[28.74]	[0.74]	[1.34]	[1.06]	[-0.97]	[-0.58]			
	P_3	-2.05	1.47	0.07	0.48	-0.34	0.46	0.29	81.1	80.8	
		[-4.94]	[27.04]	[0.69]	[2.86]	[-0.69]	[1.68]	[0.43]			
	P_4	-2.06	1.39	0.01	0.47	0.52	0.12	-0.55	82.6	82.0	
		[-6.05]	[27.42]	[0.09]	[3.21]	[2.09]	[0.56]	[-1.84]			
	P_5	1.26	1.52	-0.09	-0.41	0.46	-0.56	-0.58	75.3	75.1	
		[1.82]	[17.91]	[-0.74]	[-1.65]	[1.77]	[-1.32]	[-1.79]			
3/6 month	P_1	-0.40	0.98	-0.04	-0.06	0.09	-0.18	-0.13	72.3	72.8	
		[-1.17]	[14.43]	[-0.41]	[-0.43]	[0.44]	[-0.85]	[-0.47]			
	P_2	0.79	1.15	0.03	-0.06	0.05	-0.23	0.09	83.2	83.3	
		[3.18]	[10.39]	[0.34]	[-0.46]	[0.25]	[-1.24]	[0.40]			
	P_3	0.76	0.86	0.05	0.08	-0.47	0.39	0.32	83.8	82.9	
		[3.85]	[16.34]	[0.71]	[0.82]	[-2.91]	[2.16]	[1.58]			
	P_4	0.59	0.88	0.05	0.00	0.05	0.30	-0.10	81.7	81.7	
		[3.17]	[14.46]	[0.69]	[0.03]	[0.48]	[2.01]	[-0.70]			
	P_5	2.30	0.92	-0.11	-0.42	0.12	-0.23	-0.26	75.7	75.3	
		[6.15]	[17.93]	[-1.20]	[-2.42]	[0.51]	[-0.89]	[-0.79]			
6/12 month	P_1	-0.85	0.71	-0.10	0.04	-0.04	0.03	0.00	68.0	68.4	
		[-2.95]	[11.77]	[-1.17]	[0.36]	[-0.19]	[0.16]	[-0.01]			
	P_2	0.26	0.93	0.03	-0.02	-0.15	-0.07	0.31	80.9	81.1	
		[1.32]	[8.75]	[0.41]	[-0.22]	[-0.74]	[-0.47]	[1.39]			
	P_3	0.09	0.69	0.03	0.06	-0.35	0.30	0.16	79.3	78.5	
		[0.45]	[14.78]	[0.45]	[0.65]	[-2.61]	[2.19]	[0.90]			
	P_4	0.19	0.69	-0.02	-0.02	0.00	0.13	-0.08	76.8	77.1	
		[0.95]	[12.32]	[-0.24]	[-0.23]	[-0.02]	[0.87]	[-0.57]			
	P_5	1.46	0.77	-0.06	-0.24	-0.22	-0.07	0.17	75.9	75.8	
		[4.91]	[15.85]	[-0.71]	[-2.04]	[-1.26]	[-0.32]	[0.66]			
12/24 month	P_1	-0.05	0.69	-0.07	-0.11	-0.15	-0.23	0.21	70.3	70.5	
		[-0.18]	[19.22]	[-1.07]	[-1.03]	[-0.85]	[-1.33]	[0.96]			
	P_2	0.62	0.88	0.07	-0.03	-0.19	-0.05	0.41	81.0	81.1	
		[2.97]	[10.16]	[0.97]	[-0.30]	[-1.32]	[-0.35]	[2.47]			
	P_3	0.50	0.69	0.10	0.12	-0.37	0.26	0.31	79.0	78.4	
		[2.42]	[16.71]	[1.29]	[1.38]	[-2.92]	[1.87]	[1.81]			
	P_4	0.79	0.70	0.07	0.19	0.17	0.07	-0.01	73.4	73.3	
		[3.17]	[14.26]	[1.00]	[2.40]	[1.19]	[0.43]	[-0.03]			
	P_5	2.32	0.74	-0.02	-0.28	0.06	-0.02	0.16	58.5	58.4	
		[6.43]	[11.47]	[-0.21]	[-1.68]	[0.19]	[-0.06]	[0.44]			

Table 10. Time-series vs. Cross-sectional Predictability

This table reports descriptive statistics for the decomposition of the covariance between implied volatility slopes and future implied volatility excess returns into three components: the conditional component or "dynamic trade" (DYN), the unconditional component or "static trade" (STA) and the cross-time variation in the average implied volatility slope or "dollar trade" (DOL). The combination of the static and dynamic trade yields a cross-sectional strategy (CRS) which exploits persistent differences in the cross-section of implied volatility slopes. The combination of the dynamic and dollar trade yields a time-series strategy (TMS) which exploits variation in implied volatility slopes over time. The decomposition is based on Hassan and Mano (2015) and uses portfolio weights proportional to the covariance decomposition. For each maturity combination, we scale excess returns to have the same standard deviation of the corresponding VCA strategy reported in Table 4. The table also reports the Sharpe ratio (SR) and the t-statistic based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection in brackets. Excess returns are expressed in percentage per month and run monthly from January 1996 to December 2015. The sample 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.

	DYN	STA	DOL	CRS	TMS
			1/3 month		
mean	-0.60	2.46	2.38	2.78	2.12
	[-0.57]	[2.58]	[2.48]	[3.59]	[2.26]
$SR \times \sqrt{12}$	-0.17	0.70	0.67	0.79	0.60
			3/6 month		
mean	0.84	0.16	0.75	1.54	0.98
	[1.40]	[0.30]	[1.46]	[3.44]	[1.73]
$SR \times \sqrt{12}$	0.41	0.08	0.37	0.75	0.48
			6/12 month		
mean	0.73	0.19	0.85	1.52	1.02
	[1.39]	[0.41]	[1.80]	[3.83]	[2.01]
$SR \times \sqrt{12}$	0.41	0.10	0.48	0.86	0.57
			12/24 month		
mean	0.84	0.17	0.61	1.77	0.85
	[1.55]	[0.35]	[1.26]	[4.01]	[1.63]
$SR \times \sqrt{12}$	0.42	0.09	0.30	0.88	0.42

Table 11. Understanding Global Risk

This table presents descriptive statistics of signal-weighted implied volatility strategies decomposed into macro and residual components. In *Panel A*, we first run in each month t cross-sectional regressions of implied volatility slopes on the deviation between local and US macro volatilities (in logs) and then construct proportional linear portfolio weights. We compute macro volatility using a stochastic volatility model as in Jurado, Ludvigson, and Ng (2015). In *Panel B*, we first run in each month t cross-sectional regressions of implied volatility slopes on the squared deviation between shocks to local and US macro variables and then construct proportional linear portfolio weights. The table also reports the annualized Sharpe ratio (SR) and the t-statistic based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection in brackets. Excess returns are expressed in percentage per month and the sample runs monthly from January 1996 to December 2015. The sample 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.

	Panel A: Bansal and Shaliastovich (2012)				Panel B: Lustig, Roussanov and Verdelhan (2011)					
	Total	Inflation Rate	Economic Growth	Residual	Total	Inflation Rate	Economic Growth	Trade Balance	Term Spread	Residual
	1/3 month				1/3 month					
mean	4.61	0.40	1.77	2.44	4.52	0.80	3.24	-1.05	0.50	1.03
	[5.97]	[0.76]	[2.16]	[2.17]	[5.86]	[1.08]	[3.52]	[-1.56]	[0.65]	[1.37]
$SR \times \sqrt{12}$	1.37	0.21	0.42	0.47	1.34	0.23	0.88	-0.30	0.12	0.33
	3/6 month				3/6 month					
mean	2.46	-0.06	0.79	1.73	2.33	0.00	1.40	-0.25	0.04	1.15
	[5.31]	[-0.24]	[2.15]	[2.95]	[5.02]	[0.00]	[2.90]	[-0.62]	[0.08]	[2.60]
$SR \times \sqrt{12}$	1.17	-0.05	0.41	0.65	1.10	0.00	0.67	-0.14	0.02	0.56
	6/12 month				6/12 month					
mean	1.90	0.04	0.79	1.07	1.80	0.02	1.28	-0.19	-0.09	0.79
	[5.05]	[0.21]	[2.30]	[2.33]	[4.74]	[0.05]	[3.43]	[-0.55]	[-0.22]	[2.10]
$SR \times \sqrt{12}$	1.10	0.05	0.50	0.50	1.03	0.01	0.79	-0.12	-0.05	0.47
	12/24 month				12/24 month					
mean	2.18	-0.14	0.69	1.63	2.16	-0.03	0.90	0.26	-0.18	1.20
	[5.17]	[-0.70]	[2.36]	[3.54]	[5.30]	[-0.08]	[2.37]	[0.70]	[-0.32]	[3.48]
$SR \times \sqrt{12}$	1.10	-0.16	0.49	0.72	1.11	-0.01	0.55	0.16	-0.07	0.73

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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.

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. The pricing condition presented in Equation (4) can be equivalently represented in a return space as

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

by first subtracting and then dividing by the lagged value of the spot implied volatility observed at time t. In Equation (A1), 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 (A1) and using ex-post returns, the predictive regressions are easily derived as

$$\frac{SVOL_{t+\tau_1}^{\tau_2}-SVOL_t^{\tau_2}}{SVOL_t^{\tau_2}} = \alpha+\beta\left(\frac{FVOL_{t,\tau_1}^{\tau_2}-SVOL_t^{\tau_2}}{SVOL_t^{\tau_2}}\right)+\varepsilon_{t+\tau_1} \tag{A2}$$

$$\frac{SVOL_{t+\tau_1}^{\tau_2}-FVOL_t^{\tau_1,\tau_2}}{SVOL_t^{\tau_2}} = \alpha+\gamma\left(\frac{FVOL_{t,\tau_1}^{\tau_2}-SVOL_t^{\tau_2}}{SVOL_t^{\tau_2}}\right)+\varepsilon_{t+\tau_1}. \tag{A3}$$

While the first predictive regression follows naturally from Equation (4), 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 (A2)-(A3) 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

$$E_t[SVOL^{\tau_2}_{t+\tau_1}] = E_t[E_{t+1}(SVOL^{\tau_2}_{t+\tau_1})] = E_t[FVOL^{\tau_2}_{t+1,\tau_1-1}] \tag{A4}$$

and then redefine the pricing condition in Equation (4) as

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

Similar to before, subtract and divide by the lagged value of the forward implied volatility observed at time t, and rewrite Equation(A5) in return space as

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

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

$$\frac{FVOL^{\tau_2}_{t+1,\tau_1-1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}} = \alpha + \beta\left(\frac{FVOL^{\tau_2}_{t,\tau_1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}}\right) + \varepsilon_{t+1} \tag{A7}$$

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

where $\gamma = \beta - 1$ by construction. In our empirical analysis, we only focus on the second regression.[17]

The predictive regressions presented in Equations (A7)-(A8) are equivalent to the predictive regressions in Equations (A2)-(A3) when $\tau_1 = \tau_2 = 1$. To show this, rewrite the regressions in Equations (A7)-(A8) by setting $\tau_1 = 1$ (while removing the superscript $\tau_2 = 1$

[17] 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).

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 (A2)-(A3).

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).[18]

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

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

closes at time $t+1$ a position already existing at time t. Table A11 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 A12).

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 A1 presents the 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 A3 displays summary statistics of the implied volatility portfolios sorted on forward volatility premia: 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 4.61% and 2.48% per month for 1/3 mth and 12/24 mth, respectively. Moreover, results stay very similar when FVAs are sorted by implied volatility slopes (see Table A4) since the average correlation between these two set of portfolios ranges between 92% for 1/3 mth and 86% for 12/24 mth. Finally, Tables A5 through A9 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 A17 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.[19]

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 of Martin (2013) which is robust to price jumps (see Table A18 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 A19 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 A20, 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.[20]

[19] 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.

[20] 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).

G. Decomposition of Dynamic Slope-sorted Portfolios

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

$$y_{i,t} = \alpha + \sum_{s=1}^{m} \beta^s x^s_{i,t} + \varepsilon_{i,t} \tag{G9}$$

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, $x^s_{i,t}$ 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

$$w^s_{i,t} = K^s_{i,t}/c_t,$$

where c_t is a scaling factor such that the positive and negative weights sum to one and minus one, respectively, and $K^s_{i,t}$ is the signal extracted from the cross-sectional regression at time t corresponding to the state variable $x^s_{i,t}$. Our DSP portfolio is defined by setting up $K_{i,t} = y_{i,t}$. For the macro-related conditioning variables, we set $K^s_{i,t} = \hat{\beta}^s x^s_{i,t}$, and for the residual component portfolio we set $K^0_{i,t} = \hat{\alpha} + \hat{\varepsilon}^i_t$. 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.[21]

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

$$RX_{t+1} = \sum\nolimits_{i=1}^{N} -w^i_t rx^i_{t+1}, \tag{G10}$$

where rx^i_{t+1} is the implied volatility excess return for country i as defined by Equation (6), and w^i_t is multiplied by minus one as our strategy implies buying (selling) forward volatility agreements with low (high) implied volatility slopes.

[21] The estimate of α turns out to be negligible in our empirical exercise. As result, we run our cross-sectional regressions without the constant.

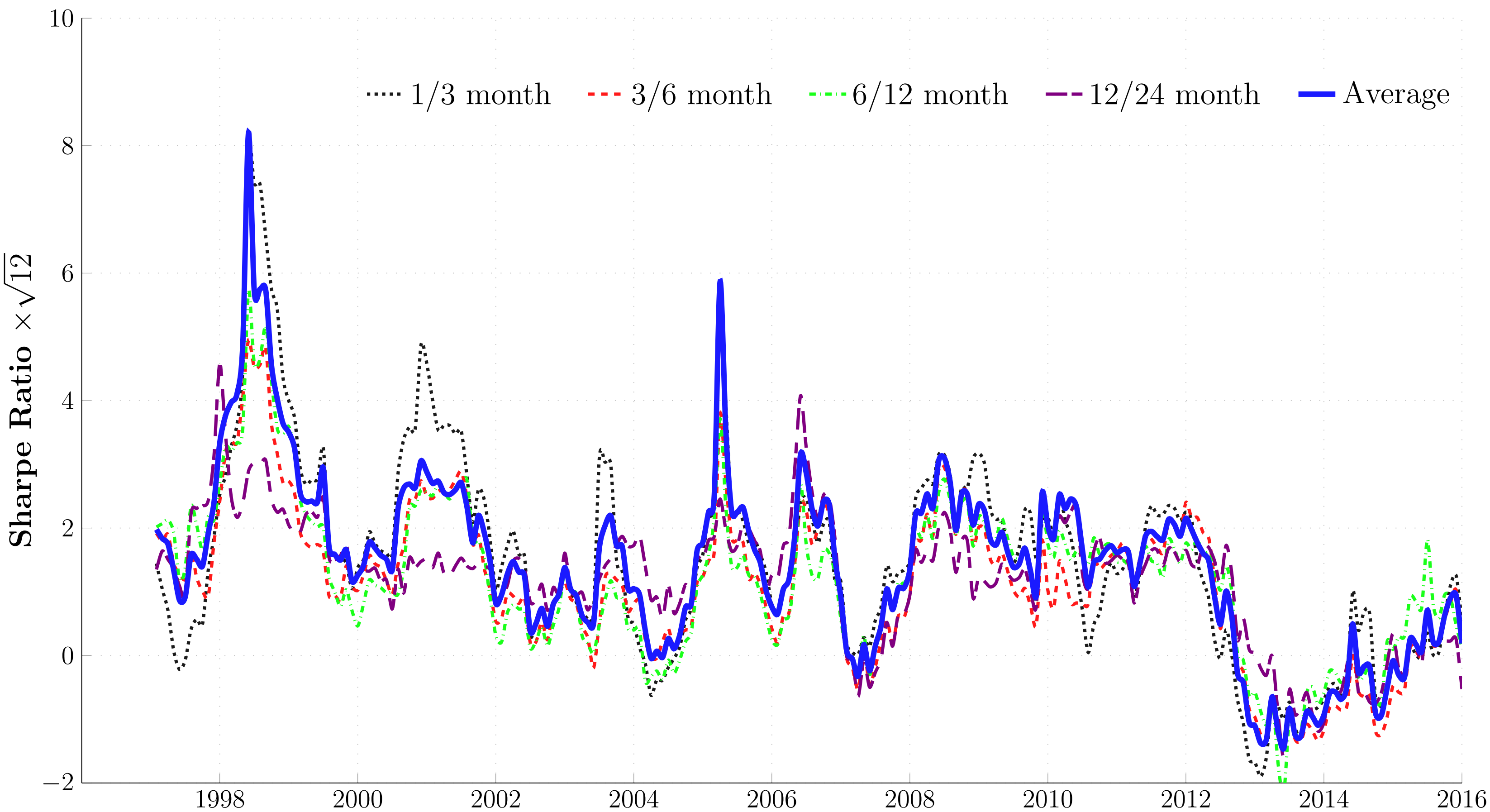

Figure A1. Rolling Sharpe Ratios of Volatility Carry Strategies: Developed Countries

This figures displays the annualized 1-year rolling Sharpe ratios for the volatility carry (VCA) strategies described in Table A4. 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 constructed via the cubic spline interpolation method as in 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

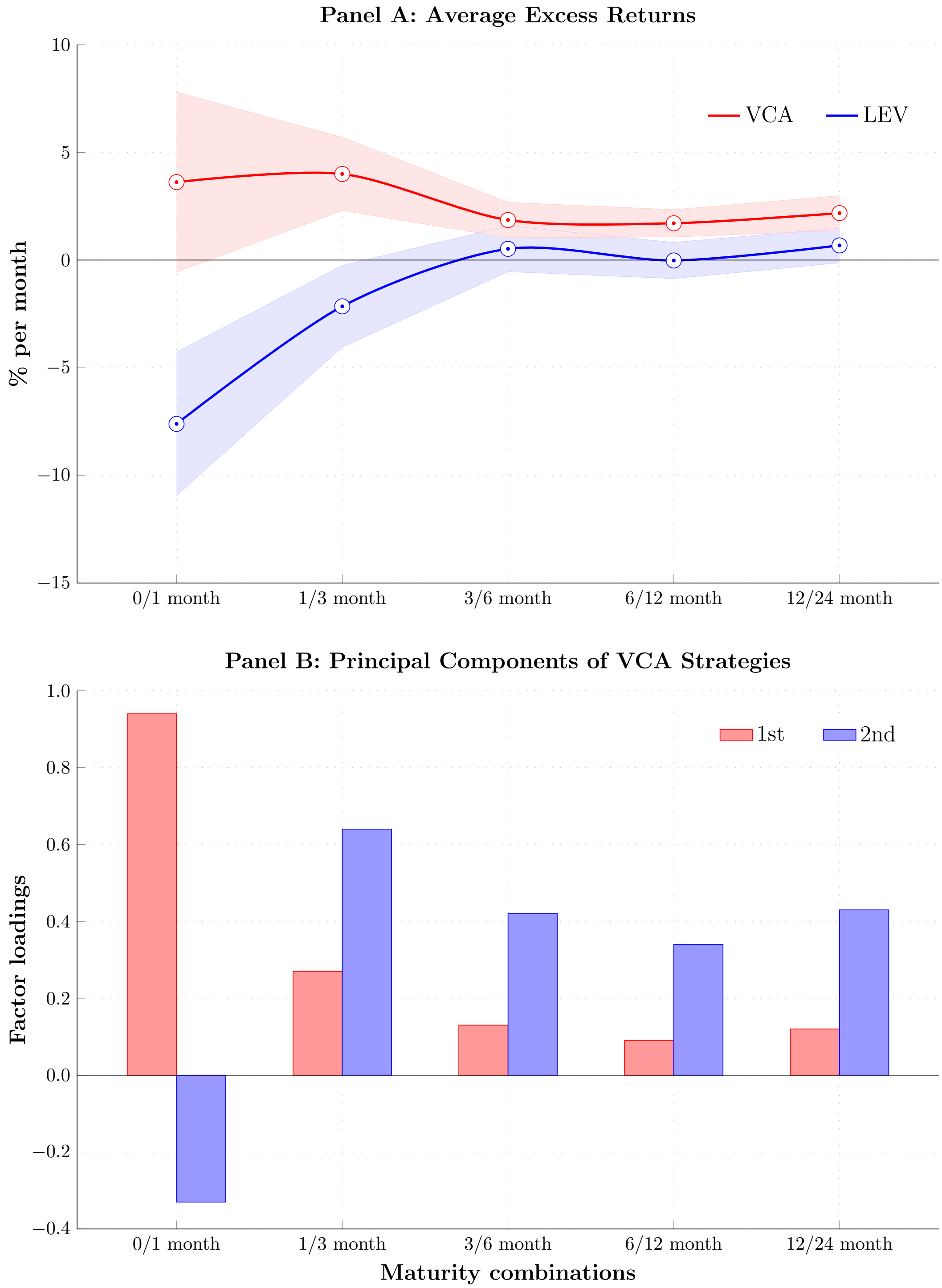

Figure A2. Principal Components of Volatility Carry Strategies

This figure reports average excess returns in Panel A, and factor loadings from principal component analysis in Panel B. *VCA* and *LEV* denote strategies based on portfolios of (i) forward volatility agreements from 1/3 month (mth) to 12/24 mth (see Table A4), and (ii) volatility swaps for 0/1 mth (see Table A15). Figure 3 displays results for a cross-section of 20 developed and emerging market countries.

Table A1. Predictive Regressions

This table presents estimates of the unbiasedness hypothesis between spot and forward implied volatility (or variance) for a cross-section of 10 developed countries. We run cross-country pooled regressions of monthly volatility excess returns on the lagged monthly forward implied volatility premia. α and β are both equal to zero under the null that the hypothesis holds. Implied volatilities are model-free as in Britten-Jones and Neuberger (2000) and are constructed using the cubic spline interpolation method (e.g., Jiang and Tian 2005). t-statistics (reported in brackets) are based on Driscoll and Kraay (1998) standard errors that are heteroscedasticity consistent and robust to very general forms of cross-sectional and temporal dependence. The full sample runs at monthly frequency from January 1996 to December 2015. The crisis (pre- and post-crisis) sub-sample uses (excludes) data from January 2007 to December 2008. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table 1 displays results for a cross-section of 20 developed and emerging market countries.

	Panel A: Spot and Forward Implied Volatility											
Sample	1/3 month			3/6 month			6/12 month			12/24 month		
	α	γ	$R^2(\%)$	α	γ	$R^2(\%)$	α	γ	$R^2(\%)$	α	γ	$R^2(\%)$
Full	0.00	-0.69	8.3	0.00	-0.69	2.0	0.00	-1.38	1.6	0.00	-1.86	3.4
	[-0.19]	[-5.47]		[0.78]	[-2.64]		[0.98]	[-2.65]		[-0.11]	[-4.30]	
Pre- and Post-Crisis	-0.01	-0.57	6.1	0.00	-0.45	1.0	0.00	-1.20	1.5	-0.01	-2.04	4.9
	[-1.87]	[-5.20]		[-0.25]	[-1.75]		[-0.29]	[-2.24]		[-1.43]	[-4.71]	
Crisis	0.06	-1.01	11.3	0.04	-1.42	4.7	0.04	-2.03	1.1	0.04	0.85	0.1
	[1.61]	[-2.85]		[1.81]	[-3.31]		[2.54]	[-1.19]		[1.83]	[0.34]	
	Panel B: Spot and Forward Implied Variance											
Full	0.01	-0.70	7.2	0.01	-0.67	1.8	0.01	-1.35	1.5	0.00	-1.93	3.3
	[0.64]	[-4.55]		[1.40]	[-2.46]		[1.49]	[-2.57]		[0.37]	[-4.14]	
Pre- and Post-Crisis	-0.01	-0.54	4.9	0.00	-0.42	0.8	0.00	-1.16	1.3	-0.01	-2.12	5.0
	[-0.98]	[-4.51]		[0.42]	[-1.58]		[0.29]	[-2.15]		[-0.90]	[-4.56]	
Crisis	0.15	-1.26	11.6	0.09	-1.45	4.0	0.09	-2.05	0.9	0.09	1.13	0.1
	[1.74]	[-2.69]		[1.88]	[-3.20]		[2.58]	[-1.12]		[1.89]	[0.41]	

Table A2. Country-level Predictive Regressions

This table presents estimates of the unbiasedness hypothesis between spot and forward implied variance for different maturity combinations. We run country-level pooled (by maturities) regressions of monthly variance excess returns on the lagged monthly forward implied variance premia. α and β are both equal to zero under the null that the hypothesis holds. Implied variances are model-free as in Britten-Jones and Neuberger (2000) and are constructed using the cubic spline interpolation method (e.g., Jiang and Tian 2005). t-statistics (reported in brackets) are based on Driscoll and Kraay (1998) standard errors that are heteroscedasticity consistent and robust to very general forms of cross-sectional and temporal dependence. DEV denotes the cross-section of 10 developed countries, EME the cross-section of 10 emerging market countries, and ALL the entire cross-section of 20 countries. The full sample runs at monthly frequency from January 1996 to December 2015. The crisis (pre- and post-crisis) sub-sample uses (excludes) data from January 2007 to December 2008. Implied volatility data from over-the-counter currency option market are obtained by JP Morgan and Bloomberg. Table 2 displays results for implied volatilities.

Sample	Full					Pre- and Post-Crisis					Crisis				
	α		γ		$R^2(\%)$	α		γ		$R^2(\%)$	α		γ		$R^2(\%)$
AUD	0.02	[1.36]	-0.84	[-4.54]	8.3	0.00	[0.41]	-0.70	[-4.17]	7.6	0.12	[1.79]	-1.64	[-2.55]	11.2
BRL	0.03	[0.89]	-0.65	[-2.74]	4.4	-0.01	[-0.38]	-0.47	[-2.74]	2.9	0.15	[1.52]	-0.96	[-1.36]	4.6
CAD	0.02	[1.47]	-0.83	[-4.91]	6.2	0.01	[0.52]	-0.71	[-3.93]	5.2	0.12	[1.74]	-1.25	[-3.66]	7.0
CHF	0.01	[0.73]	-0.57	[-3.40]	3.1	-0.01	[-0.57]	-0.44	[-2.82]	2.1	0.10	[2.37]	-1.29	[-1.84]	6.2
CZK	0.01	[0.72]	-0.79	[-3.82]	6.3	-0.01	[-0.67]	-0.57	[-3.42]	3.8	0.10	[1.83]	-1.42	[-3.01]	12.1
DKK	0.01	[0.63]	-0.65	[-5.54]	4.9	-0.01	[-0.55]	-0.57	[-5.06]	4.3	0.11	[2.03]	-1.13	[-2.73]	7.4
EUR	0.01	[0.61]	-0.63	[-4.44]	4.6	-0.01	[-0.67]	-0.52	[-3.78]	3.6	0.10	[2.07]	-1.14	[-2.77]	8.0
GBP	0.00	[0.26]	-0.60	[-2.56]	4.4	-0.01	[-1.11]	-0.50	[-2.16]	3.6	0.10	[1.87]	-1.36	[-1.77]	7.5
HUF	0.01	[0.36]	-0.72	[-6.19]	6.8	-0.01	[-0.70]	-0.67	[-6.10]	6.5	0.07	[1.81]	-0.27	[-0.72]	0.6
JPY	0.01	[0.73]	-0.67	[-4.18]	4.9	-0.01	[-0.66]	-0.53	[-3.99]	3.5	0.10	[2.77]	-0.67	[-1.08]	2.0
KRW	0.07	[1.22]	-1.12	[-2.70]	7.6	-0.02	[-0.97]	-0.49	[-2.66]	2.5	0.23	[1.77]	-2.64	[-2.32]	11.9
MXN	0.01	[0.22]	-0.67	[-3.25]	5.5	-0.02	[-1.27]	-0.51	[-3.33]	4.1	0.20	[1.44]	-4.40	[-1.99]	28.1
NOK	0.01	[1.18]	-0.71	[-4.36]	4.3	0.00	[0.15]	-0.58	[-4.11]	3.4	0.10	[1.88]	-1.61	[-2.42]	9.6
NZD	0.02	[1.69]	-0.83	[-6.17]	9.6	0.01	[1.03]	-0.79	[-5.55]	10.0	0.09	[1.66]	-1.11	[-2.44]	7.7
PLN	0.01	[0.33]	-0.82	[-4.70]	9.8	-0.02	[-1.52]	-0.61	[-5.28]	6.9	0.09	[1.65]	-1.91	[-3.47]	14.8
SEK	0.01	[0.86]	-0.61	[-4.98]	4.0	0.00	[-0.23]	-0.51	[-4.62]	3.2	0.09	[1.92]	-1.31	[-2.78]	8.9
SGD	0.01	[0.57]	-0.59	[-3.35]	3.8	-0.01	[-0.98]	-0.42	[-2.87]	2.3	0.14	[2.07]	-2.10	[-2.47]	14.6
TRY	-0.01	[-0.28]	-0.44	[-3.06]	2.3	-0.01	[-0.54]	-0.54	[-3.64]	3.9	0.02	[0.26]	0.26	[0.77]	0.4
TWD	0.01	[0.56]	-0.57	[-5.11]	5.0	-0.01	[-0.37]	-0.55	[-4.80]	5.2	0.10	[1.79]	-0.55	[-1.14]	1.6
ZAR	0.02	[1.15]	-0.33	[-1.02]	0.7	0.01	[0.66]	-0.30	[-0.92]	0.7	0.10	[1.25]	-0.34	[-0.51]	0.1
DEV	0.01	[0.97]	-0.69	[-5.27]	5.3	0.00	[-0.33]	-0.53	[-5.93]	3.8	0.11	[2.08]	-1.12	[-2.61]	6.3
EME	0.02	[1.00]	-0.65	[-5.36]	4.5	0.00	[-0.33]	-0.53	[-5.93]	3.8	0.13	[1.74]	-1.50	[-2.75]	6.9
ALL	0.01	[1.00]	-0.66	[-5.70]	4.8	0.00	[-0.41]	-0.55	[-6.53]	4.0	0.12	[1.90]	-1.32	[-2.85]	6.5

Table A3. 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 for a cross-section of 10 developed countries. 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). For each maturity combination, the forward volatility premia are computed using the corresponding forward and spot implied volatilities. The first (last) portfolio P_1 (P_5) contains forward volatility agreements 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. 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.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
mean	-4.34	-2.56	-2.88	-1.25	0.27	-2.15	4.61	0.02	-0.17	0.49	0.63	1.75	0.55	1.73
	[-3.91]	[-2.75]	[-2.99]	[-1.23]	[0.22]	[-2.22]	[5.30]	[0.04]	[-0.31]	[0.91]	[1.20]	[2.65]	[1.00]	[3.70]
sdev	14.34	12.83	12.64	13.23	13.24	12.19	10.59	8.33	7.95	8.13	7.91	8.36	7.52	6.10
skew	1.87	1.47	1.63	1.97	1.99	1.98	-0.18	1.50	0.91	1.56	1.21	1.12	1.42	0.18
kurt	10.22	8.29	11.43	13.27	13.06	13.46	4.82	9.14	5.78	11.82	8.28	6.03	9.44	3.78
$SR \times \sqrt{12}$	-1.05	-0.69	-0.79	-0.33	0.07	-0.61	1.51	0.01	-0.08	0.21	0.28	0.73	0.25	0.98
ac_1	0.18	0.13	0.15	0.14	0.31	0.20	0.20	0.07	0.08	0.07	0.06	0.19	0.11	0.17
freq	0.49	0.68	0.69	0.71	0.48			0.63	0.72	0.72	0.72	0.59		
	Panel C: 6/12 month							Panel D: 12/24 month						
mean	-0.63	-0.16	-0.05	0.11	0.84	0.02	1.48	-0.33	0.01	0.79	0.80	2.15	0.69	2.48
	[-1.29]	[-0.37]	[-0.11]	[0.24]	[1.91]	[0.05]	[4.33]	[-0.69]	[0.02]	[1.72]	[1.87]	[4.55]	[1.67]	[5.57]
sdev	6.95	6.71	6.60	6.82	6.70	6.18	5.28	6.61	6.72	6.62	6.42	7.32	5.93	6.99
skew	1.79	1.57	1.35	1.13	0.71	1.33	0.10	1.84	1.30	2.04	1.52	1.44	1.78	1.57
kurt	13.17	11.20	7.74	6.91	3.84	8.78	6.69	13.78	10.26	15.15	10.04	7.64	12.66	14.35
$SR \times \sqrt{12}$	-0.32	-0.08	-0.03	0.05	0.44	0.01	0.97	-0.17	0.00	0.41	0.43	1.02	0.40	1.23
ac_1	0.13	0.06	0.07	0.03	0.05	0.08	0.01	0.12	0.00	0.08	0.07	0.02	0.08	-0.03
freq	0.56	0.71	0.70	0.77	0.54			0.27	0.50	0.59	0.57	0.37		

Table A4. Descriptive Statistics: Portfolios sorted on Implied Volatility Slopes

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their implied volatility slopes for a cross-section of 10 developed countries. 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). Each slope is based on the 24 month and 3 month 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 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. 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 4 displays results for a cross-section of 20 developed and emerging market countries.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-3.63	-2.96	-2.22	-2.30	0.37	-2.15	4.00	-0.31	0.25	0.50	0.63	1.55	0.52	1.86
	[-3.74]	[-2.83]	[-2.06]	[-2.49]	[0.32]	[-2.22]	[4.61]	[-0.58]	[0.39]	[0.80]	[1.17]	[2.79]	[0.96]	[4.46]
$sdev$	13.04	13.38	13.33	12.56	13.78	12.14	10.19	7.77	8.27	8.06	8.36	8.31	7.49	6.10
$skew$	1.92	1.76	2.34	1.21	1.90	1.99	0.29	1.19	1.43	1.71	0.92	1.31	1.43	0.23
$kurt$	11.63	11.52	15.86	6.69	12.29	13.64	4.73	6.77	9.77	12.33	4.96	8.48	9.59	4.43
$SR \times \sqrt{12}$	-0.96	-0.77	-0.58	-0.63	0.09	-0.61	1.36	-0.14	0.11	0.21	0.26	0.65	0.24	1.06
ac_1	0.17	0.16	0.22	0.13	0.24	0.20	0.27	0.08	0.17	0.16	0.01	0.06	0.11	0.09
$freq$	0.31	0.52	0.61	0.56	0.33			0.31	0.52	0.61	0.56	0.33		

	Panel C: 6/12 month							Panel D: 12/24 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-0.80	-0.30	-0.06	0.16	0.91	-0.02	1.71	-0.24	0.27	0.49	0.91	1.94	0.68	2.18
	[-1.98]	[-0.62]	[-0.13]	[0.35]	[1.98]	[-0.05]	[5.28]	[-0.59]	[0.59]	[1.03]	[2.11]	[3.89]	[1.65]	[5.26]
$sdev$	6.13	6.83	6.48	7.00	6.97	6.12	4.89	6.03	6.69	6.57	6.76	7.72	5.92	6.59
$skew$	1.01	1.19	1.57	0.87	1.47	1.34	0.44	1.27	1.45	2.11	0.66	2.10	1.79	1.81
$kurt$	6.56	8.41	12.08	4.29	9.58	9.02	3.87	8.89	9.88	16.33	4.73	12.53	12.71	12.46
$SR \times \sqrt{12}$	-0.45	-0.15	-0.03	0.08	0.45	-0.01	1.21	-0.14	0.14	0.26	0.47	0.87	0.39	1.14
ac_1	0.04	0.12	0.15	-0.01	0.04	0.08	0.05	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			0.31	0.52	0.61	0.56	0.33		

Table A5. Principal Components: Portfolios sorted on Implied Volatility Slopes

This table presents the loadings c_i on the principal components of the slope-sorted portfolios presented in Table A4. In each panel, the last row reports percentage share of total variance explained by each common factor. Excess returns are expressed in percentage per month. 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 5 displays results for a cross-section of 20 developed and emerging market countries.

	Panel A: 1/3 month					Panel B: 3/6 month				
	c_1	c_2	c_3	c_4	c_5	c_1	c_2	c_3	c_4	c_5
P_1	0.44	-0.46	-0.73	0.22	0.15	0.41	-0.55	0.62	-0.31	-0.22
P_2	0.47	-0.11	0.06	-0.84	-0.23	0.46	-0.17	0.08	0.70	0.51
P_3	0.46	-0.23	0.60	0.17	0.60	0.45	-0.17	-0.59	0.18	-0.63
P_4	0.44	-0.01	0.26	0.46	-0.73	0.47	0.06	-0.38	-0.61	0.50
P_5	0.43	0.85	-0.21	0.06	0.20	0.45	0.79	0.35	0.02	-0.22
Cum. Var.	**0.84**	**0.91**	**0.95**	**0.98**	**1.00**	**0.84**	**0.90**	**0.94**	**0.98**	**1.00**
	Panel C: 6/12 month					Panel D: 12/24 month				
P_1	0.40	-0.55	-0.48	0.50	-0.25	0.38	-0.31	-0.76	-0.36	0.24
P_2	0.47	-0.15	-0.31	-0.52	0.62	0.46	-0.20	-0.15	0.51	-0.68
P_3	0.44	-0.19	0.37	-0.51	-0.62	0.44	-0.28	0.34	0.44	0.64
P_4	0.47	0.01	0.67	0.45	0.36	0.46	-0.18	0.53	-0.64	-0.24
P_5	0.46	0.80	-0.32	0.12	-0.20	0.48	0.87	-0.09	0.00	0.09
Cum. Var.	**0.84**	**0.90**	**0.94**	**0.98**	**1.00**	**0.76**	**0.88**	**0.93**	**0.97**	**1.00**

Table A6. Asset Pricing Tests: Risk Prices

This table presents cross-sectional asset pricing tests for a linear factor model that uses the five slope-sorted portfolios presented in Table A4 as test assets and the level (LEV) and volatility carry (VCA) strategies as pricing factors. The table reports GMM (first and second-stage) and Fama-MacBeth (FMB) 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. For FMB, we also report t-statistics based on Shanken (1992) corrected standard errors in brackets (second row). χ^2 denotes the test statistics (with p-values in parentheses) for the null hypothesis that all pricing errors are jointly zero. 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 6 displays results for a cross-section of 20 developed and emerging market countries.

	Panel A: 1/3 month						Panel B: 3/6 month					
	b_{LEV}	b_{VCA}	λ_{LEV}	λ_{VCA}	$R^2(\%)$	HJ	b_{LEV}	b_{VCA}	λ_{LEV}	λ_{VCA}	$R^2(\%)$	HJ
GMM_1	-0.02	0.04	-2.15	4.04	92.3	0.18	0.01	0.05	0.52	1.88	96.9	0.08
	[-1.80]	[5.13]	[-2.13]	[4.30]		(0.54)	[0.68]	[4.69]	[0.91]	[4.14]		(0.83)
GMM_2	-0.02	0.04	-2.12	3.90	78.4		0.01	0.05	0.45	1.84	92.3	
	[-2.21]	[4.91]	[-2.33]	[4.51]			[0.70]	[4.77]	[0.90]	[4.17]		
FMB	-0.02	0.04	-2.15	4.04	92.3		0.01	0.05	0.52	1.88	96.9	
	[-2.43]	[4.64]	[-2.13]	[4.30]			[0.64]	[4.19]	[0.91]	[4.14]		
	[-3.01]	[6.19]	[-2.74]	[6.07]			[0.72]	[4.68]	[1.08]	[4.75]		
$mean$			**-2.15**	**4.00**					**0.52**	**1.86**		
	Panel C: 6/12 month						Panel D: 12/24 month					
GMM_1	-0.01	0.07	-0.02	1.72	94.8	0.10	0.01	0.05	0.68	2.12	92.1	0.15
	[-0.88]	[6.20]	[-0.05]	[5.07]		(0.54)	[1.12]	[4.76]	[1.63]	[5.20]		(0.42)
GMM_2	-0.01	0.07	-0.05	1.70	91.9		0.01	0.05	0.64	2.08	88.0	
	[-0.90]	[6.20]	[-0.13]	[5.07]			[1.00]	[5.77]	[1.70]	[5.47]		
FMB	-0.01	0.07	-0.02	1.72	94.8		0.01	0.05	0.68	2.12	92.1	
	[-0.90]	[5.29]	[-0.05]	[5.07]			[0.96]	[5.18]	[1.63]	[5.20]		
	[-0.95]	[5.50]	[-0.05]	[5.42]			[1.00]	[4.60]	[1.77]	[4.82]		
$mean$			**-0.02**	**1.71**					**0.68**	**2.18**		

Table A7. Asset Pricing Tests: Factor Betas

This table presents time-series asset pricing tests for a linear factor model that uses the five slope-sorted portfolios presented in Table A4 as test assets and the level (LEV) and volatility carry (VCA) strategies as pricing factors. The table reports least-squares estimates of time series regressions. 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 7 in the Internet Appendix displays results for a cross-section of 20 developed and merging market countries.

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

Table A8. Asset Pricing Tests: Currency Risk Factors

This table presents time-series asset pricing tests using the slope-sorted portfolios presented in Table A4 as test assets, and the level (LEV), carry (CAR), global imbalance (IMB), foreign exchange volatility (VOL), and liquidity (LIQ) as pricing factors. LEV denotes the average excess returns across all slope-sorted portfolios. 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. Table 8 displays results for a cross-section of 20 developed and emerging market countries.

Portfolios		α	LEV	DOL	CAR	IMB	VOL	LIQ	$R^2(\%)$	$R^2_{LEV}(\%)$	χ^2_α
1/3 month	P_1	-3.18	1.46	0.21	-0.01	-0.01	-0.15	-0.20	76.7	76.7	(<.01)
		[-6.41]	[19.50]	[1.02]	[-0.03]	[-0.04]	[-0.61]	[-1.11]			
	P_2	-2.49	1.57	0.10	-0.19	0.00	0.11	-0.21	82.6	82.7	
		[-5.96]	[25.97]	[0.69]	[-0.92]	[0.01]	[0.46]	[-1.10]			
	P_3	-1.88	1.54	-0.03	0.53	-0.52	-0.19	0.16	78.3	78.0	
		[-4.25]	[17.39]	[-0.15]	[1.58]	[-1.16]	[-0.93]	[1.05]			
	P_4	-1.98	1.54	0.08	0.04	0.00	0.07	0.08	83.6	83.8	
		[-5.09]	[24.57]	[0.55]	[0.22]	[0.01]	[0.36]	[0.54]			
	P_5	0.71	1.55	-0.16	-0.16	0.36	0.03	-0.09	73.8	74.1	
		[1.26]	[15.70]	[-0.72]	[-0.57]	[1.12]	[0.13]	[-0.37]			
3/6 month	P_1	-0.07	0.87	0.02	-0.15	0.00	0.11	0.00	73.6	74.1	
		[-0.29]	[19.54]	[0.14]	[-1.14]	[0.01]	[0.84]	[0.01]			
	P_2	0.55	0.98	-0.01	-0.33	0.05	0.21	-0.05	85.1	84.8	
		[2.22]	[25.65]	[-0.15]	[-2.34]	[0.26]	[1.74]	[-0.48]			
	P_3	0.68	0.97	-0.19	0.13	-0.15	0.05	0.16	83.5	82.9	
		[2.87]	[26.11]	[-2.08]	[0.96]	[-0.91]	[0.44]	[2.02]			
	P_4	0.85	0.99	-0.07	-0.11	0.03	0.06	0.16	83.7	83.7	
		[3.55]	[13.38]	[-0.61]	[-0.63]	[0.16]	[0.44]	[1.57]			
	P_5	1.75	0.96	-0.17	-0.12	0.09	0.19	-0.03	75.3	75.3	
		[5.84]	[24.31]	[-1.27]	[-0.79]	[0.43]	[1.45]	[-0.21]			
12/24 month	P_1	-0.62	0.69	0.13	0.04	-0.02	-0.08	-0.04	73.9	74.1	
		[-3.27]	[18.13]	[1.19]	[0.33]	[-0.12]	[-0.68]	[-0.42]			
	P_2	-0.09	0.81	0.08	-0.19	0.14	0.08	-0.06	83.4	83.3	
		[-0.51]	[26.39]	[1.02]	[-2.08]	[1.31]	[0.97]	[-0.76]			
	P_3	0.09	0.76	-0.20	0.09	-0.06	0.01	0.05	81.7	81.5	
		[0.52]	[26.64]	[-2.23]	[0.88]	[-0.42]	[0.10]	[0.76]			
	P_4	0.34	0.79	-0.02	-0.08	0.02	-0.03	0.19	78.0	78.0	
		[1.61]	[12.45]	[-0.27]	[-0.62]	[0.12]	[-0.19]	[2.33]			
	P_5	1.08	0.80	-0.03	0.02	0.03	-0.05	0.08	76.4	76.7	
		[4.67]	[21.25]	[-0.22]	[0.20]	[0.23]	[-0.45]	[0.89]			
12/24 month	P_1	-0.06	0.66	0.17	0.06	0.01	-0.08	-0.09	69.1	69.1	
		[-0.28]	[18.54]	[1.59]	[0.46]	[0.05]	[-0.64]	[-0.87]			
	P_2	0.53	0.78	0.10	-0.01	-0.01	-0.01	-0.24	82.5	81.7	
		[2.72]	[24.00]	[1.29]	[-0.12]	[-0.09]	[-0.10]	[-4.23]			
	P_3	0.64	0.76	-0.05	0.27	-0.13	-0.10	-0.03	76.9	76.8	
		[2.67]	[16.83]	[-0.47]	[1.95]	[-1.10]	[-0.79]	[-0.27]			
	P_4	1.07	0.77	0.04	0.11	-0.09	-0.06	0.13	75.4	75.6	
		[4.25]	[14.98]	[0.46]	[0.97]	[-0.54]	[-0.50]	[1.43]			
	P_5	2.08	0.75	0.01	0.04	0.24	-0.17	0.00	54.3	54.8	
		[6.34]	[12.03]	[0.05]	[0.23]	[0.84]	[-0.98]	[0.03]			

Table A9. Asset Pricing Tests: Global Equity Risk Factors

This table presents time-series asset pricing tests using the slope-sorted portfolios presented in Table A4 as test assets, and the level (LEV) and the Fama-French global equity factors – market excess return (MKT), size (SMB), value (HML), profitability (RMW), and investment (CMA) – as pricing factors. LEV denotes the average excess returns across all slope-sorted portfolios. 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. Table 9 displays results for a cross-section of 20 developed and emerging market countries.

Portfolios		α	LEV	MKT	SMB	HML	RMW	CMA	$R^2(\%)$	$R^2_{LEV}(\%)$	χ^2_α
1/3 month	P_1	-3.28	1.53	0.12	-0.03	0.04	-0.11	0.01	76.3	76.7	(<.01)
		[-6.30]	[22.51]	[0.83]	[-0.14]	[0.12]	[-0.32]	[0.03]			
	P_2	-2.55	1.59	-0.05	0.27	0.08	-0.03	-0.10	82.5	82.7	
		[-5.70]	[28.67]	[-0.44]	[1.56]	[0.32]	[-0.10]	[-0.34]			
	P_3	-1.88	1.50	-0.08	0.42	-0.25	0.08	0.37	78.3	78.0	
		[-4.47]	[21.86]	[-0.79]	[2.12]	[-0.51]	[0.28]	[0.56]			
	P_4	-1.90	1.55	-0.01	0.31	0.56	-0.18	-0.56	84.3	83.8	
		[-4.78]	[30.91]	[-0.07]	[2.02]	[2.38]	[-0.89]	[-2.06]			
	P_5	1.12	1.55	-0.22	-0.44	0.67	-0.67	-0.85	74.6	74.1	
		[1.73]	[17.26]	[-1.68]	[-1.69]	[2.52]	[-1.78]	[-2.52]			
3/6 month	P_1	-0.12	0.88	0.06	-0.04	-0.07	-0.03	0.12	73.6	74.1	
		[-0.41]	[18.67]	[0.86]	[-0.31]	[-0.36]	[-0.15]	[0.49]			
	P_2	0.53	0.97	-0.06	0.01	-0.15	-0.02	0.17	84.7	84.8	
		[2.21]	[27.83]	[-0.72]	[0.10]	[-0.72]	[-0.11]	[0.71]			
	P_3	0.67	0.92	-0.01	0.02	-0.32	0.25	0.26	83.2	82.9	
		[3.36]	[24.23]	[-0.20]	[0.15]	[-1.90]	[1.35]	[1.09]			
	P_4	0.81	1.02	0.09	-0.11	-0.04	0.14	-0.04	83.6	83.7	
		[3.30]	[14.79]	[1.05]	[-1.05]	[-0.30]	[0.98]	[-0.25]			
	P_5	1.85	0.95	-0.06	-0.29	0.34	-0.06	-0.50	75.9	75.3	
		[5.40]	[22.28]	[-0.75]	[-1.49]	[1.62]	[-0.25]	[-1.46]			
6/12 month	P_1	-0.67	0.69	0.04	0.07	-0.13	0.11	0.08	73.7	74.1	
		[-2.96]	[18.64]	[0.59]	[0.73]	[-0.84]	[0.80]	[0.39]			
	P_2	-0.11	0.79	-0.04	0.06	-0.10	0.05	0.13	83.2	83.3	
		[-0.69]	[25.28]	[-0.67]	[0.61]	[-0.68]	[0.47]	[0.72]			
	P_3	0.15	0.72	-0.08	-0.04	-0.25	0.14	0.10	81.9	81.5	
		[0.86]	[25.04]	[-1.43]	[-0.39]	[-1.77]	[1.01]	[0.55]			
	P_4	0.36	0.81	0.03	-0.12	-0.12	0.04	0.04	77.8	78.0	
		[1.55]	[13.82]	[0.49]	[-1.33]	[-0.95]	[0.30]	[0.25]			
	P_5	1.11	0.80	-0.02	-0.12	0.05	0.09	-0.19	76.6	76.7	
		[4.36]	[20.33]	[-0.22]	[-0.97]	[0.31]	[0.51]	[-0.82]			
12/24 month	P_1	-0.16	0.67	0.13	-0.01	-0.22	0.04	0.34	69.1	69.1	
		[-0.61]	[18.58]	[2.16]	[-0.06]	[-1.49]	[0.33]	[1.81]			
	P_2	0.42	0.77	0.00	0.04	-0.17	0.05	0.29	81.7	81.7	
		[2.03]	[24.37]	[0.03]	[0.39]	[-1.32]	[0.43]	[1.69]			
	P_3	0.61	0.74	0.03	0.07	-0.30	0.13	0.35	76.9	76.8	
		[2.59]	[17.56]	[0.58]	[0.65]	[-1.85]	[0.91]	[1.89]			
	P_4	1.01	0.80	0.12	0.09	0.05	-0.03	0.15	75.5	75.6	
		[3.94]	[16.52]	[1.66]	[1.11]	[0.31]	[-0.20]	[0.77]			
	P_5	2.07	0.76	0.00	-0.17	0.33	0.00	-0.19	54.8	54.8	
		[6.13]	[12.44]	[-0.01]	[-0.91]	[1.14]	[0.01]	[-0.54]			

Table A10. Portfolios sorted on Implied Volatility Slopes: Composition

This table reports the percentage composition of the slope-sorted implied volatility portfolios presented in Tables 4 and A4, respectively. The portfolios are constructed by sorting forward volatility agreements 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 as in Jiang and Tian (2005). Each slope is based on the 24 month and 3 month implied volatility. 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.

	Panel A: Developed and Emerging					Panel B: Developed				
	P_1	P_2	P_3	P_4	P_5	P_1	P_2	P_3	P_4	P_5
AUD	3	19	26	15	37	16	22	14	15	32
CAD	9	13	27	22	29	17	24	15	17	28
CHF	5	25	19	26	26	10	27	22	21	20
DKK	2	15	39	29	15	13	17	31	31	10
EUR	7	35	22	24	11	27	30	19	19	5
GBP	29	39	18	8	5	58	23	11	5	3
JPY	22	26	15	16	21	37	15	15	13	20
NZD	0	10	24	22	44	1	13	36	26	24
NOK	0	9	33	30	28	8	22	13	17	40
SEK	0	10	23	38	28	2	13	26	38	20
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 A11. Portfolios sorted on Implied Volatility Slopes: Net of Bid-Ask Spreads

This table reports descriptive statistics for five portfolios of forward volatility agreements 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). Each slope is based on the 24 month and 3 month 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 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 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. Table A13 displays results for a cross-section of 10 developed countries.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-4.17	-3.58	-2.96	-3.03	-0.01	-2.75	4.16	-0.48	-0.08	0.06	-0.09	1.40	0.16	1.88
	[-3.49]	[-3.32]	[-2.73]	[-3.24]	[-0.01]	[-2.65]	[4.67]	[-0.75]	[-0.11]	[0.09]	[-0.17]	[1.98]	[0.27]	[4.03]
$sdev$	16.38	14.06	13.37	12.13	14.19	12.72	12.41	9.46	10.16	7.83	7.83	8.88	8.00	7.19
$skew$	2.22	2.76	2.17	1.67	2.48	2.47	-1.34	1.64	5.23	1.64	1.31	2.31	2.73	-0.16
$kurt$	12.40	20.22	13.33	10.86	17.15	17.32	11.60	9.87	54.15	10.42	8.46	15.85	21.71	4.42
$SR \times \sqrt{12}$	-0.88	-0.88	-0.77	-0.87	0.00	-0.75	1.16	-0.17	-0.03	0.03	-0.04	0.55	0.07	0.90
ac_1	0.18	0.19	0.23	0.14	0.30	0.25	0.09	0.08	0.17	0.21	0.02	0.18	0.18	0.02
$freq$	0.26	0.47	0.56	0.56	0.32			0.26	0.47	0.56	0.56	0.32		
	Panel C: 6/12 month							Panel D: 12/24 month						
$mean$	-0.87	-0.39	-0.51	-0.45	0.81	-0.28	1.68	-0.19	0.05	0.00	0.27	1.83	0.39	2.02
	[-1.80]	[-0.63]	[-1.05]	[-1.07]	[1.38]	[-0.58]	[4.20]	[-0.40]	[0.09]	[-0.01]	[0.66]	[3.13]	[0.86]	[4.44]
$sdev$	7.31	8.45	6.50	6.47	7.50	6.49	6.17	7.04	8.03	6.39	6.44	8.17	6.32	7.02
$skew$	1.26	5.57	1.37	1.18	2.71	2.66	0.43	1.82	4.90	1.57	1.05	2.83	2.99	1.44
$kurt$	8.03	59.69	8.85	6.95	19.82	21.44	5.20	12.97	49.48	10.49	7.88	17.61	24.47	10.83
$SR \times \sqrt{12}$	-0.41	-0.16	-0.27	-0.24	0.37	-0.15	0.94	-0.09	0.02	0.00	0.15	0.78	0.21	0.99
ac_1	0.08	0.19	0.18	0.00	0.20	0.18	0.02	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			0.26	0.47	0.56	0.56	0.32		

Table A12. Portfolios sorted on Implied Volatility Slopes: Net of the Largest Bid-Ask Spreads

This table reports descriptive statistics for five portfolios of forward volatility agreements 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). Each slope is based on the 24 month and 3 month 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 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 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. Table A14 displays results for a cross-section of 10 developed countries.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-3.93	-3.87	-3.24	-3.31	-0.25	-2.92	3.68	-0.26	-0.35	-0.23	-0.37	1.16	-0.01	1.42
	[-3.28]	[-3.59]	[-3.00]	[-3.54]	[-0.19]	[-2.81]	[4.12]	[-0.41]	[-0.47]	[-0.37]	[-0.74]	[1.64]	[-0.02]	[3.05]
$sdev$	16.40	14.04	13.37	12.12	14.21	12.72	12.43	9.49	10.14	7.82	7.83	8.91	8.01	7.23
$skew$	2.21	2.77	2.18	1.66	2.48	2.47	-1.37	1.62	5.25	1.66	1.31	2.30	2.72	-0.16
$kurt$	12.37	20.28	13.37	10.87	17.14	17.30	11.64	9.75	54.29	10.53	8.46	15.86	21.68	4.40
$SR \times \sqrt{12}$	-0.83	-0.95	-0.84	-0.95	-0.06	-0.79	1.03	-0.10	-0.12	-0.10	-0.17	0.45	0.00	0.68
ac_1	0.18	0.19	0.23	0.14	0.30	0.25	0.10	0.08	0.17	0.21	0.03	0.18	0.18	0.02
$freq$	0.26	0.47	0.56	0.56	0.32			0.26	0.47	0.56	0.56	0.32		
	Panel C: 6/12 month							Panel D: 12/24 month						
$mean$	-0.72	-0.62	-0.76	-0.72	0.61	-0.44	1.32	-0.07	-0.15	-0.22	0.04	1.68	0.26	1.74
	[-1.47]	[-0.99]	[-1.57]	[-1.71]	[1.04]	[-0.90]	[3.30]	[-0.14]	[-0.26]	[-0.49]	[0.10]	[2.85]	[0.56]	[3.82]
$sdev$	7.33	8.43	6.50	6.47	7.51	6.49	6.20	7.06	8.02	6.39	6.45	8.19	6.32	7.05
$skew$	1.24	5.59	1.39	1.18	2.72	2.66	0.42	1.80	4.92	1.58	1.05	2.83	2.99	1.42
$kurt$	7.94	60.00	8.98	6.93	19.88	21.46	5.24	12.82	49.67	10.60	7.88	17.56	24.44	10.69
$SR \times \sqrt{12}$	-0.34	-0.25	-0.40	-0.38	0.28	-0.23	0.74	-0.03	-0.06	-0.12	0.02	0.71	0.14	0.86
ac_1	0.08	0.19	0.17	0.01	0.20	0.18	0.02	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			0.26	0.47	0.56	0.56	0.32		

Table A13. Portfolios sorted on Implied Volatility Slopes: Net of Bid-Ask Spreads

This table reports descriptive statistics for five portfolios of forward volatility agreements 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). Each slope is based on the 24 month and 3 month 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 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 10 developed 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. A11 displays results for a cross-section of 20 developed and emerging market countries.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-3.20	-3.46	-2.86	-2.89	-0.12	-2.50	3.08	0.02	-0.15	-0.03	0.13	1.16	0.22	1.14
	[-3.28]	[-3.30]	[-2.64]	[-3.00]	[-0.10]	[-2.54]	[3.30]	[0.04]	[-0.24]	[-0.05]	[0.24]	[2.08]	[0.41]	[2.62]
$sdev$	13.09	13.36	13.32	12.57	13.78	12.14	10.35	7.83	8.26	8.05	8.37	8.35	7.49	6.24
$skew$	1.91	1.74	2.33	1.21	1.86	1.98	0.25	1.20	1.41	1.72	0.89	1.28	1.42	0.19
$kurt$	11.58	11.35	15.93	6.78	12.03	13.60	4.75	6.74	9.58	12.56	4.96	8.28	9.55	4.46
$SR \times \sqrt{12}$	-0.85	-0.90	-0.74	-0.80	-0.03	-0.71	1.03	0.01	-0.06	-0.01	0.05	0.48	0.10	0.63
ac_1	0.17	0.16	0.22	0.14	0.24	0.20	0.28	0.09	0.17	0.16	0.02	0.06	0.11	0.12
$freq$	0.31	0.52	0.61	0.56	0.33			0.31	0.52	0.61	0.56	0.33		
	Panel C: 6/12 month							Panel D: 12/24 month						
$mean$	-0.57	-0.62	-0.50	-0.26	0.62	-0.27	1.19	-0.05	-0.01	0.11	0.51	1.69	0.45	1.74
	[-1.39]	[-1.28]	[-1.02]	[-0.58]	[1.34]	[-0.62]	[3.58]	[-0.12]	[-0.03]	[0.23]	[1.16]	[3.31]	[1.09]	[4.10]
$sdev$	6.18	6.82	6.48	7.00	7.00	6.13	4.97	6.08	6.69	6.58	6.78	7.77	5.93	6.67
$skew$	1.01	1.17	1.59	0.86	1.48	1.34	0.43	1.27	1.42	2.11	0.67	2.10	1.80	1.76
$kurt$	6.53	8.22	12.23	4.33	9.63	9.04	3.93	8.82	9.62	16.43	4.78	12.50	12.72	12.25
$SR \times \sqrt{12}$	-0.32	-0.31	-0.27	-0.13	0.31	-0.15	0.83	-0.03	-0.01	0.06	0.26	0.75	0.26	0.90
ac_1	0.05	0.12	0.16	0.00	0.04	0.08	0.07	0.06	0.09	0.13	-0.02	0.03	0.08	-0.04
$freq$	0.31	0.52	0.61	0.56	0.33			0.31	0.52	0.61	0.56	0.33		

Table A14. Portfolios sorted on Implied Volatility Slopes: Net of the Largest Bid-Ask Spreads

This table reports descriptive statistics for five portfolios of forward volatility agreements 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). Each slope is based on the 24 month and 3 month 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 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 10 developed 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. Table A12 displays results for a cross-section of 20 developed and emerging market countries.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-2.85	-3.85	-3.21	-3.22	-0.39	-2.71	2.46	0.29	-0.49	-0.34	-0.15	0.92	0.05	0.63
	[-2.93]	[-3.68]	[-2.96]	[-3.33]	[-0.33]	[-2.74]	[2.63]	[0.53]	[-0.76]	[-0.55]	[-0.27]	[1.65]	[0.09]	[1.44]
$sdev$	13.11	13.34	13.30	12.57	13.81	12.14	10.38	7.87	8.24	8.03	8.37	8.40	7.50	6.31
$skew$	1.92	1.75	2.31	1.21	1.85	1.98	0.23	1.20	1.43	1.70	0.88	1.27	1.41	0.18
$kurt$	11.60	11.45	15.88	6.81	11.98	13.61	4.71	6.77	9.69	12.55	4.92	8.26	9.57	4.44
$SR \times \sqrt{12}$	-0.75	-1.00	-0.84	-0.89	-0.10	-0.77	0.82	0.13	-0.20	-0.15	-0.06	0.38	0.02	0.35
ac_1	0.17	0.17	0.22	0.14	0.24	0.21	0.29	0.09	0.17	0.16	0.02	0.07	0.11	0.12
$freq$	0.31	0.52	0.61	0.56	0.33			0.31	0.52	0.61	0.56	0.33		
	Panel C: 6/12 month							Panel D: 12/24 month						
$mean$	-0.44	-0.80	-0.67	-0.41	0.51	-0.36	0.95	0.06	-0.18	-0.04	0.38	1.59	0.36	1.53
	[-1.07]	[-1.66]	[-1.37]	[-0.90]	[1.10]	[-0.84]	[2.84]	[0.15]	[-0.39]	[-0.09]	[0.87]	[3.12]	[0.88]	[3.60]
$sdev$	6.19	6.81	6.47	7.01	7.01	6.14	5.00	6.10	6.69	6.56	6.79	7.78	5.94	6.70
$skew$	1.01	1.18	1.58	0.87	1.47	1.34	0.42	1.27	1.44	2.11	0.67	2.09	1.80	1.74
$kurt$	6.55	8.32	12.21	4.33	9.65	9.07	3.94	8.81	9.73	16.41	4.79	12.46	12.73	12.08
$SR \times \sqrt{12}$	-0.25	-0.41	-0.36	-0.20	0.25	-0.20	0.66	0.03	-0.09	-0.02	0.19	0.71	0.21	0.79
ac_1	0.05	0.12	0.16	0.00	0.04	0.08	0.07	0.06	0.09	0.13	-0.02	0.03	0.08	-0.04
$freq$	0.31	0.52	0.61	0.56	0.33			0.31	0.52	0.61	0.56	0.33		

Table A15. 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.

	Panel A: Developed and Emerging						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-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
$kurt$	17.92	11.55	5.82	8.24	12.17	7.22	18.84
$SR \times \sqrt{12}$	-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
$kurt$	5.68	4.51	26.63	4.05	11.68	5.24	8.93
$SR \times \sqrt{12}$	-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 A16. Asset Pricing Tests: Risk Prices

This table presents cross-sectional asset pricing tests for a linear factor model that uses the five slope-sorted portfolios of volatility swaps presented in Table A15 as test assets and the level (LEV) and volatility carry (VCA) strategies as pricing factors. The table reports GMM (first and second-stage) and Fama-MacBeth (FMB) 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. For FMB, we also report t-statistics based on Shanken (1992) corrected standard errors in brackets (second row). χ^2 denotes the test statistics (with p-values in parentheses) for the null hypothesis that all pricing errors are jointly zero. 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.

	Panel A: Developed and Emerging					
	b_{LEV}	b_{VCA}	λ_{LEV}	λ_{VCA}	$R^2(\%)$	HJ
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]		
FMB	-0.02	0.01	-10.61	11.11	93.7	
	[-5.18]	[3.12]	[-5.55]	[4.08]		
	[1.26]	[1.08]	[1.35]	[1.22]		
mean			**-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]		
FMB	-0.02	0.00	-7.54	2.78	5.9	
	[-4.16]	[1.02]	[-4.14]	[1.24]		
	[1.37]	[1.23]	[1.40]	[1.27]		
mean			**-7.61**	**3.62**		

Table A17. 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 4 and Table A4, 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	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 A18. Descriptive Statistics: Simple-Variance Method

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by the slopes of their implied volatility curves. The implied volatilities are model-free as in Martin (2013) and constructed via the cubic spline interpolation method (e.g., Jiang and Tian 2005). Each slope is based on the 24 month and 3 month 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 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 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.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-4.40	-2.69	-2.07	-2.46	0.91	-2.14	5.31	-0.74	0.32	0.74	0.30	1.97	0.52	2.71
	[-3.77]	[-2.75]	[-1.89]	[-2.47]	[0.76]	[-2.12]	[6.48]	[-1.25]	[0.53]	[1.03]	[0.54]	[3.01]	[0.88]	[6.07]
$sdev$	15.98	12.83	14.01	12.29	13.75	12.46	12.30	8.93	7.86	9.13	7.77	8.19	7.60	6.80
$skew$	2.05	2.05	2.53	2.11	2.26	2.43	-1.24	1.23	1.78	3.92	1.60	1.86	2.33	-0.04
$kurt$	10.94	12.91	16.95	14.42	14.69	16.48	11.15	6.77	12.12	36.77	10.46	11.50	17.26	4.45
$SR \times \sqrt{12}$	-0.95	-0.73	-0.51	-0.69	0.23	-0.60	1.50	-0.29	0.14	0.28	0.13	0.83	0.24	1.38
ac_1	0.17	0.16	0.22	0.22	0.27	0.25	0.06	0.06	0.15	0.22	0.09	0.18	0.18	0.03
$freq$	0.27	0.49	0.57	0.57	0.31			0.27	0.49	0.57	0.57	0.31		
	Panel C: 6/12 month							Panel D: 12/24 month						
$mean$	-1.04	-0.20	0.19	-0.20	1.23	0.00	2.27	-0.39	0.22	0.55	0.56	1.97	0.58	2.36
	[-2.38]	[-0.42]	[0.32]	[-0.46]	[2.33]	[-0.01]	[5.94]	[-0.96]	[0.52]	[1.06]	[1.31]	[3.81]	[1.41]	[5.58]
$sdev$	6.65	6.41	7.25	6.53	6.70	6.01	5.76	6.23	6.31	6.95	6.62	7.45	5.82	6.65
$skew$	0.79	2.09	3.14	1.53	1.85	2.04	0.54	1.01	2.02	3.00	1.45	2.09	2.31	1.66
$kurt$	4.63	16.35	27.74	9.36	11.72	14.94	4.92	6.22	15.51	25.52	10.57	11.21	17.34	11.13
$SR \times \sqrt{12}$	-0.54	-0.11	0.09	-0.11	0.64	0.00	1.37	-0.21	0.12	0.27	0.29	0.92	0.35	1.23
ac_1	0.03	0.14	0.23	0.06	0.19	0.17	0.05	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			0.27	0.49	0.57	0.57	0.31		

Table A19. Descriptive Statistics: Vanna-Volga based Implied Volatilities

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by the slopes of their implied volatility curves. The implied volatilities are model-free as in Britten-Jones and Neuberger (2000) and constructed via the vanna-volga method (e.g., Castagna and Mercurio 2007). Each slope is based on the 24 month and 3 month 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 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 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.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
mean	-4.44	-2.93	-2.51	-2.39	0.37	-2.38	4.82	-0.77	0.39	0.50	0.50	1.81	0.49	2.58
	[-3.80]	[-2.83]	[-2.34]	[-2.59]	[0.29]	[-2.34]	[5.64]	[-1.25]	[0.54]	[0.79]	[1.01]	[2.66]	[0.81]	[5.88]
sdev	15.96	13.65	13.32	11.83	14.06	12.50	11.97	9.13	9.77	7.86	7.60	8.64	7.80	6.78
skew	2.26	2.74	2.19	1.66	2.42	2.47	-1.30	1.62	5.06	1.67	1.21	2.10	2.57	-0.07
kurt	12.57	20.11	13.41	11.05	16.65	17.12	12.02	9.19	52.41	10.58	8.12	13.82	20.05	4.47
$SR \times \sqrt{12}$	-0.96	-0.74	-0.65	-0.70	0.09	-0.66	1.39	-0.29	0.14	0.22	0.23	0.73	0.22	1.32
ac_1	0.19	0.18	0.22	0.17	0.30	0.25	0.08	0.09	0.17	0.22	0.02	0.17	0.18	0.01
$freq$	0.26	0.45	0.54	0.56	0.32			0.26	0.45	0.54	0.56	0.32		
	Panel C: 6/12 month							Panel D: 12/24 month						
mean	-1.06	-0.05	-0.15	-0.03	1.09	-0.04	2.15	-0.25	0.48	0.44	1.03	2.30	0.80	2.55
	[-2.27]	[-0.09]	[-0.32]	[-0.07]	[1.95]	[-0.09]	[5.54]	[-0.52]	[0.88]	[0.96]	[2.51]	[4.01]	[1.79]	[5.55]
sdev	7.00	8.01	6.46	6.39	7.23	6.28	5.92	7.13	7.76	6.50	6.33	8.24	6.27	7.22
skew	1.22	5.19	1.42	1.00	2.38	2.37	0.63	1.89	4.22	1.46	0.87	2.58	2.56	1.60
kurt	7.21	55.20	9.17	6.23	16.25	18.47	6.01	12.03	41.62	9.85	7.06	14.93	19.84	13.10
$SR \times \sqrt{12}$	-0.53	-0.02	-0.08	-0.02	0.52	-0.02	1.26	-0.12	0.21	0.24	0.56	0.97	0.44	1.22
ac_1	0.07	0.19	0.18	0.00	0.18	0.17	0.03	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			0.26	0.45	0.54	0.56	0.32		

Table A20. Descriptive Statistics: At-the-Money Implied Volatilities

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by the slopes of their implied volatility curves. The implied volatilities are from at-the-money currency options. Each slope is based on the 24 month and 3 month 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 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 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.

	Panel A: 1/3 month							Panel B: 3/6 month						
	P_1	P_2	P_3	P_4	P_5	LEV	VCA	P_1	P_2	P_3	P_4	P_5	LEV	VCA
$mean$	-3.16	-1.89	-1.43	-1.81	1.66	-1.33	4.82	-0.74	0.42	0.57	0.21	1.88	0.47	2.61
	[-2.68]	[-1.83]	[-1.35]	[-1.96]	[1.35]	[-1.31]	[5.87]	[-1.20]	[0.59]	[0.93]	[0.43]	[2.90]	[0.80]	[6.18]
$sdev$	16.18	13.48	13.71	11.71	14.22	12.53	12.32	9.13	9.30	7.99	7.33	8.24	7.59	6.54
$skew$	2.05	2.35	2.17	1.62	2.42	2.37	-0.99	1.43	4.08	1.35	1.02	1.52	2.03	-0.24
$kurt$	11.28	16.11	12.33	10.69	15.59	15.62	9.79	7.73	38.55	8.25	6.62	9.08	14.48	4.32
$SR \times \sqrt{12}$	-0.68	-0.49	-0.36	-0.54	0.40	-0.37	1.36	-0.28	0.16	0.25	0.10	0.79	0.21	1.39
ac_1	0.18	0.18	0.19	0.17	0.27	0.24	0.06	0.09	0.19	0.18	0.06	0.15	0.18	0.01
$freq$	0.28	0.53	0.58	0.57	0.33			0.28	0.53	0.58	0.57	0.33		
	Panel C: 6/12 month							Panel D: 12/24 month						
$mean$	-0.96	0.07	0.10	-0.17	1.24	0.05	2.20	-0.57	0.21	0.19	0.00	1.57	0.28	2.14
	[-2.11]	[0.12]	[0.21]	[-0.42]	[2.40]	[0.12]	[6.23]	[-1.31]	[0.41]	[0.44]	[-0.01]	[3.14]	[0.69]	[5.39]
$sdev$	6.85	7.66	6.45	6.09	6.74	6.00	5.47	6.57	7.22	6.33	5.99	7.37	5.79	6.30
$skew$	1.01	4.32	0.91	0.83	1.57	1.71	0.54	1.40	3.78	1.30	0.69	1.94	2.12	0.97
$kurt$	5.67	42.24	5.75	4.86	9.77	11.71	5.44	8.51	34.86	8.00	5.94	10.42	15.17	7.71
$SR \times \sqrt{12}$	-0.49	0.03	0.05	-0.10	0.64	0.03	1.40	-0.30	0.10	0.10	0.00	0.74	0.17	1.18
ac_1	0.06	0.21	0.15	0.05	0.15	0.17	0.00	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			0.28	0.53	0.58	0.57	0.33		