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(not for publication)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.

Contents

A. Synthesizing the Forward Volatility Agreement (FVA)

We compute spot implied variance from OTC currency options using the model-free approach of Britten-Jones and Neuberger (2000). The risk-neutral expectation of the integrated variance between two dates t and $t+\tau$ can be calculated by integrating over an infinite range of strike prices from European call and put options expiring on these dates as

$$SVAR_t^{\tau} = \frac{2}{B_t^{\tau}} \left\{ \int_0^{F_t^{\tau}} \frac{P_t^{\tau}(K)}{K^2} dK + \int_{F_t^{\tau}}^{\infty} \frac{C_t^{\tau}(K)}{K^2} dK \right\}, \tag{A.1}$$

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 $t+\tau$.[1] In the FX market, OTC options are generally quoted in terms of Garman and Kohlhagen (1983) implied volatilities at fixed deltas. Following Jiang and Tian (2005) and Kozhan, Neuberger, and Schneider (2013), we infer the strike prices corresponding to the deltas, use a cubic spline to interpolate between these strikes, and set implied volatility to be constant outside the range of strikes. This interpolation method is standard in the literature. Finally, we compute the option values using the Garman and Kohlhagen (1983) valuation formula and solve the integral in Equation (A.1) via trapezoidal integration.[2]

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

$$SVAR_t^{\tau} = \frac{\tau_1}{\tau} SVAR_t^{\tau_1} + \frac{\tau_2}{\tau} FVAR_{t,\tau_1}^{\tau_2}, \tag{A.2}$$

[1] 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) relax the diffusion assumptions of Britten-Jones and Neuberger (2000) and demonstrate that the model-free method is valid even when the underlying price exhibits jumps.

[2] 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.

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

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

The forward implied volatility is then calculated as $FVOL_{t,\tau_1}^{\tau_2} = \sqrt{FVAR_{t,\tau_1}^{\tau_2}}$, an approximation that is widely used in the academic literature (e.g., Della Corte, Sarno, and Tsiakas 2011; Glasserman and Wu 2011) and among practitioners (e.g., Knauf 2003; Donner and Vibhor 2015; Iqbal 2018). This approach is subject to bias since expected volatility is generally less than the square root of expected variance. We show that the impact of the convexity bias is negligible in our empirical analysis.

B. Predictive Regressions for Implied Volatilities

This section reviews the analog 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.

B.1. 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)

$$E_t\left[SVOL^{\tau_2}_{t+\tau_1}\right] = FVOL^{\tau_2}_{t,\tau_1}, \tag{B.3}$$

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

The pricing condition presented in Equation (B.3) can be equivalently represented in a return space as

$$E_t\left[\frac{SVOL^{\tau_2}_{t+\tau_1} - SVOL^{\tau_2}_t}{SVOL^{\tau_2}_t}\right] = \frac{FVOL^{\tau_2}_{t,\tau_1} - SVOL^{\tau_2}_t}{SVOL^{\tau_2}_t} \tag{B.4}$$

by first subtracting and then dividing by the lagged value of the spot implied volatility observed at time t. In Equation (B.4), 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, Della Corte, Sarno, and Tsiakas (2011) define the equivalent predictive regressions for the spot-forward implied volatility relationship.

Starting from Equation (B.4) and using ex-post returns, the predictive regressions are easily derived as

$$\frac{SVOL^{\tau_2}_{t+\tau_1} - SVOL^{\tau_2}_t}{SVOL^{\tau_2}_t} = \alpha + \beta\left(\frac{FVOL^{\tau_2}_{t,\tau_1} - SVOL^{\tau_2}_t}{SVOL^{\tau_2}_t}\right) + \varepsilon_{t+\tau_1} \tag{B.5}$$

$$\frac{SVOL^{\tau_2}_{t+\tau_1} - FVOL^{\tau_1,\tau_2}_t}{SVOL^{\tau_2}_t} = \alpha + \gamma\left(\frac{FVOL^{\tau_2}_{t,\tau_1} - SVOL^{\tau_2}_t}{SVOL^{\tau_2}_t}\right) + \varepsilon_{t+\tau_1}. \tag{B.6}$$

While the first predictive regression follows naturally from Equation (B.3), 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 $\gamma = \beta - 1 = 0$.

B.2. Predictive Regressions with Non-overlapping Returns

The predictive regressions defined in Equations (B.5)-(B.6) 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

$$E_t[SVOL^{\tau_2}_{t+\tau_1}] = E_t[E_{t+1}(SVOL^{\tau_2}_{t+\tau_1})] = E_t[FVOL^{\tau_2}_{t+1,\tau_1-1}] \tag{B.7}$$

and then redefine the pricing condition in Equation (B.3) as

$$E_t[FVOL^{\tau_2}_{t+1,\tau_1-1}] = FVOL^{\tau_2}_{t,\tau_1}. \tag{B.8}$$

Similar to before, subtract and divide by the lagged value of the forward implied volatility observed at time t, and rewrite Equation (B.8) in return space as

$$E_t\left[\frac{FVOL^{\tau_2}_{t+1,\tau_1-1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}}\right] = \frac{FVOL^{\tau_2}_{t,\tau_1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}} \tag{B.9}$$

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 analog of the Fama (1984) predictive regressions are then easily obtained as

$$\frac{FVOL^{\tau_2}_{t+1,\tau_1-1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}} = \alpha + \beta\left(\frac{FVOL^{\tau_2}_{t,\tau_1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}}\right) + \varepsilon_{t+1} \tag{B.10}$$

$$\frac{FVOL^{\tau_2}_{t+1,\tau_1-1} - FVOL^{\tau_2}_{t,\tau_1}}{FVOL^{\tau_2}_{t,\tau_1-1}} = \alpha + \gamma\left(\frac{FVOL^{\tau_2}_{t,\tau_1} - FVOL^{\tau_2}_{t,\tau_1-1}}{FVOL^{\tau_2}_{t,\tau_1-1}}\right) + \varepsilon_{t+1} \tag{B.11}$$

where $\gamma = \beta - 1$ by construction. In our empirical analysis, we only focus on the second regression.[3]

[3] 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

The predictive regressions presented in Equations (B.10)-(B.11) are equivalent to the predictive regressions in Equations (B.5)-(B.6) when $\tau_1 = \tau_2 = 1$. To show this, rewrite the regressions in Equations (B.10)-(B.11) by setting $\tau_1 = 1$ (while removing the superscript $\tau_2 = 1$ for easy notation) as

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

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

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

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

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

which are equivalent to the predictive regressions defined in Equations (B.5)-(B.6).

C. 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

implied variances) as in Carr and Wu (2009).

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 a 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 (2018).

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.

D. 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 (2017) which is robust to price jumps (see Table A7 for portfolio results). Secondly, we replace the cubic spline interpolation method with the vanna-volga method presented in Castagna and Mercurio (2007). This procedure uses only three plain-vanilla option quotes – typically the delta-neutral straddle and the 25-delta call and put options – to construct the volatility smile, and is popular among FX brokers and market makers when there less trading activity on deep out-of-the-money options (see Table A6 for the results). Finally, there is evidence that FVAs can also be written on at-the-money implied volatilities, in which case the smile is irrelevant (e.g., Knauf 2003). In Table A8, we present the summary statistics of slopedsorted 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.[4]

E. 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 A18 presents equally-weighted (in Panel A) and GDP-weighted (in Panel B) average volatility excess returns based on forward volatility agreements and show that they exhibit similar term structure patterns as the corresponding returns based on the 20 countries. Table A19 presents the country-fixed effects predictive regressions of monthly volatility excess returns on the lagged monthly forward volatility premia pooled across countries and confirms the rejection of the unbiasedness hypothesis using both discrete and log returns. Table A20 displays summary statistics of the returns on implied volatility portfolios sorted on the volatility slope: the average excess returns increase monotonically from Portfolio 1 to Portfolio 5 for all maturities and the profitability of the VCA strategy remain both statistically and economically significant. For example, the average excess return amounts to 4.00% and 2.18% per month for 1/3 months and 12/24 months, respectively. Finally, Tables A21 through A34 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.

[4]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).

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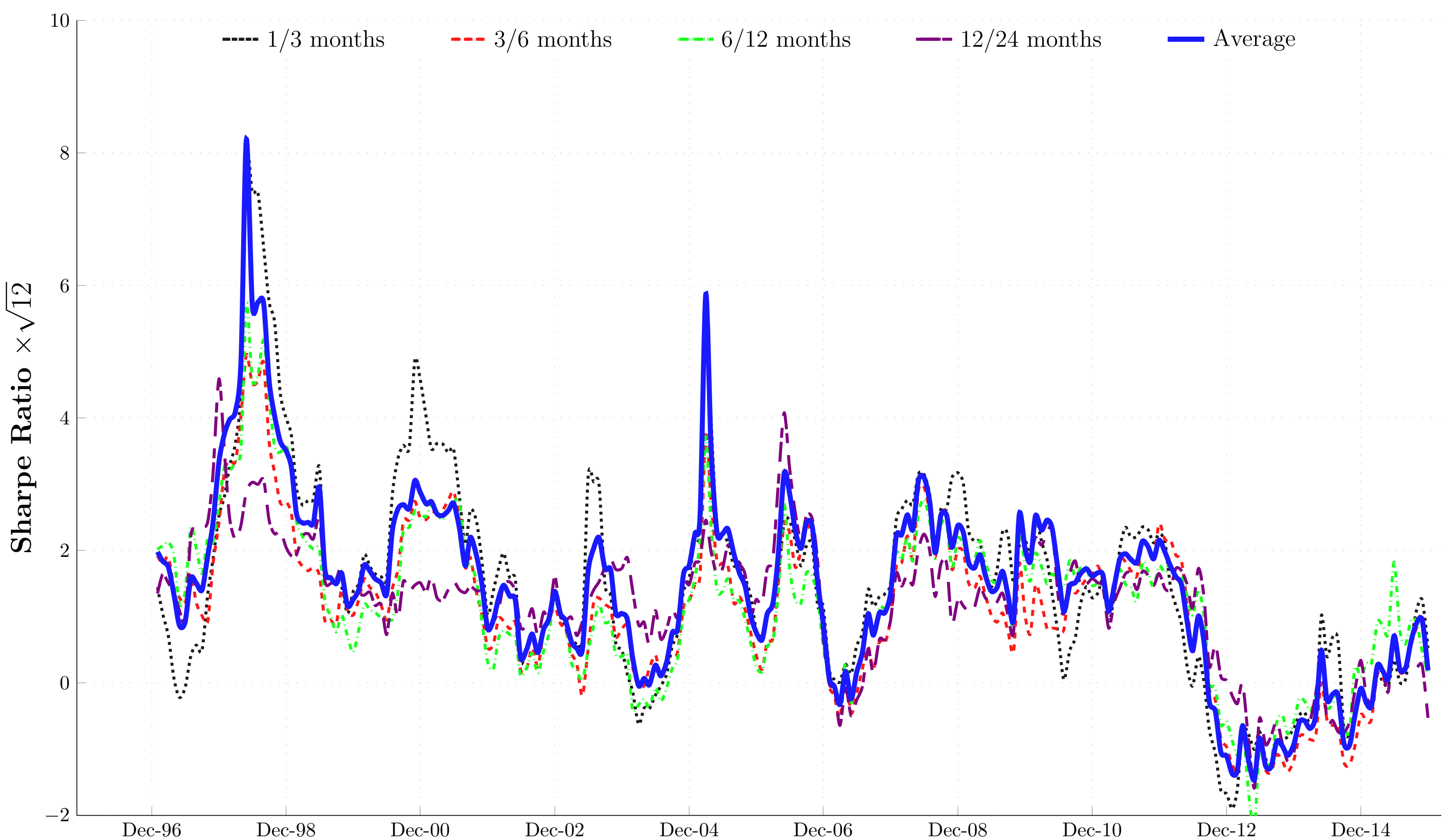

Figure A1. The Sharpe Ratios of Volatility Carry Strategies (Developed)

This figure displays the annualized 1-year rolling Sharpe ratios of the volatility carry (VCA) strategies. 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. The implied volatilities are model-free as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). Each slope is based on the 24-month and 3-month implied volatility. *Average* denotes the rolling Sharpe ratio of an equally-weighted basket of volatility carry strategies. The volatility carry strategies are rebalanced monthly. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

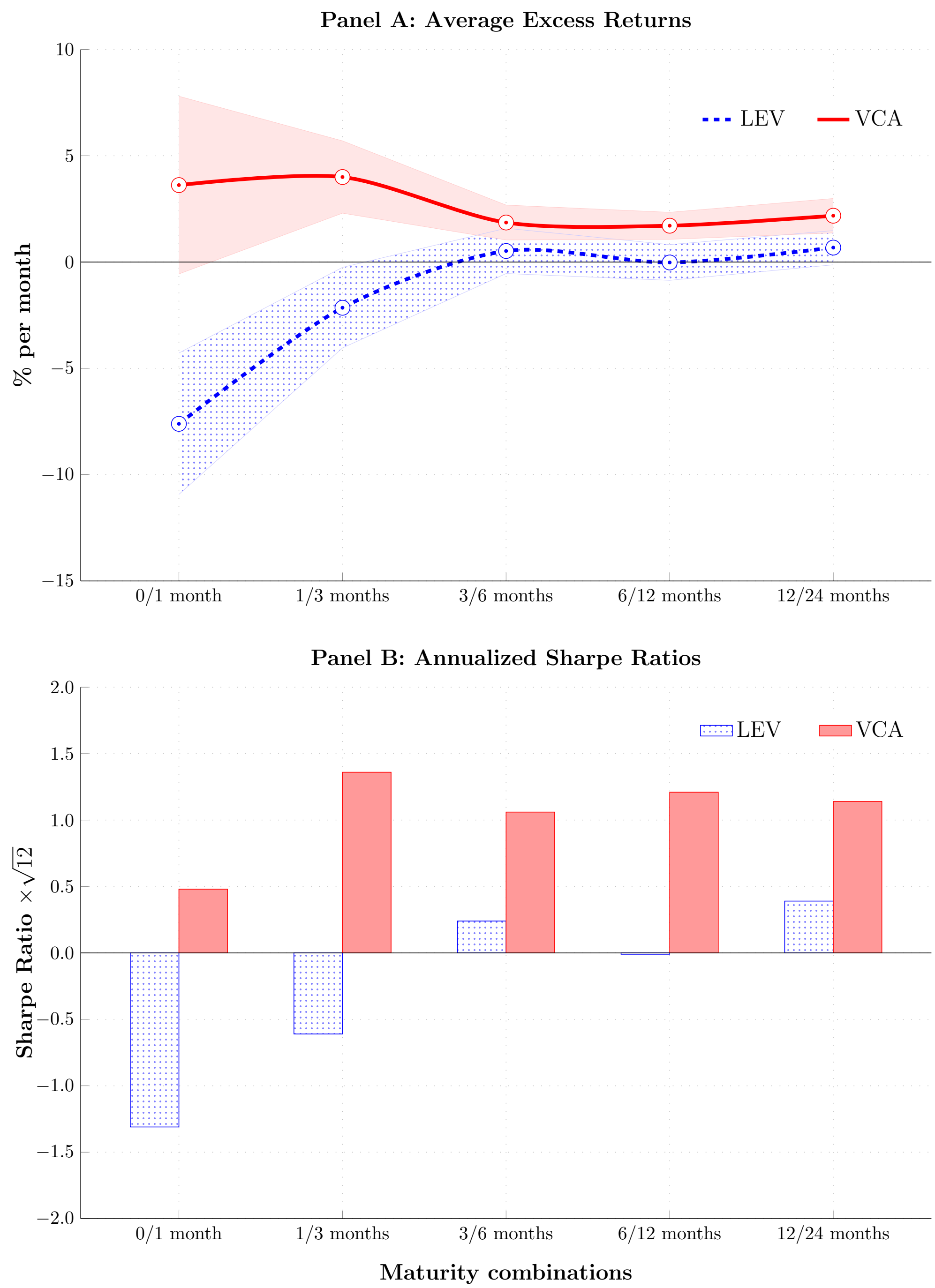

Figure A2. Performance of Volatility Carry Strategies (Developed)

This figure reports average excess returns (Panel A) and annualized Sharpe Ratios (Panel B) of LEV and VCA, respectively. These are strategies based on slope-sorted portfolios of (i) volatility swaps for 0/1 month, and (ii) forward volatility agreements from 1/3 months to 12/24 months. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

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

This table presents estimates of country-level regressions. The dependent variable is the volatility excess return whereas the explanatory variable is the lagged forward volatility premium, both computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). The coefficient estimates α and γ should be equal to zero under the null hypothesis. t-statistics (reported in brackets) are based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. Excess returns are expressed in percentage per month and the sample runs from January 1996 to December 2015. Data on over-the-counter currency options are from JP Morgan and Bloomberg.

	α		γ		$R^2(\%)$	α		γ		$R^2(\%)$
	Panel A: Implied Volatilities					Panel B: Implied Variances				
AUD	0.50	[1.53]	-0.88	[-6.83]	10.7	1.90	[2.52]	-0.84	[-5.17]	8.3
CAD	0.52	[1.61]	-0.85	[-5.71]	7.2	1.91	[2.71]	-0.83	[-5.22]	6.2
CHF	0.02	[0.09]	-0.59	[-3.98]	3.6	0.82	[1.34]	-0.57	[-3.58]	3.1
DKK	0.01	[0.02]	-0.67	[-6.05]	5.4	0.72	[1.18]	-0.65	[-5.56]	4.9
EUR	0.04	[0.13]	-0.66	[-5.12]	5.1	0.78	[1.13]	-0.63	[-4.30]	4.6
GBP	-0.14	[-0.41]	-0.68	[-3.77]	5.9	0.33	[0.44]	-0.60	[-2.73]	4.4
JPY	-0.01	[-0.02]	-0.66	[-5.21]	4.9	0.79	[1.27]	-0.67	[-4.83]	4.9
NOK	0.27	[0.95]	-0.73	[-5.15]	5.4	1.36	[2.06]	-0.71	[-4.45]	4.3
NZD	0.60	[2.13]	-0.85	[-8.66]	11.2	2.00	[3.16]	-0.83	[-7.21]	9.6
SEK	0.09	[0.38]	-0.63	[-5.65]	4.7	0.86	[1.57]	-0.61	[-5.00]	4.0
BRL	0.58	[0.70]	-0.70	[-3.19]	6.1	2.78	[1.48]	-0.65	[-2.81]	4.4
CZK	0.22	[0.53]	-0.79	[-4.44]	6.7	1.27	[1.39]	-0.79	[-4.31]	6.3
HUF	-0.08	[-0.22]	-0.74	[-5.55]	7.6	0.51	[0.65]	-0.72	[-5.28]	6.8
KRW	1.75	[1.58]	-1.11	[-4.50]	10.0	6.55	[2.28]	-1.12	[-3.82]	7.6
MXN	-0.49	[-0.70]	-0.72	[-4.78]	7.6	0.62	[0.33]	-0.67	[-3.41]	5.5
PLN	-0.07	[-0.16]	-0.84	[-6.35]	10.6	0.58	[0.61]	-0.82	[-5.77]	9.8
SGD	-0.02	[-0.03]	-0.63	[-4.11]	4.6	1.17	[1.00]	-0.59	[-3.33]	3.8
TRY	-0.87	[-1.56]	-0.52	[-3.34]	3.6	-0.52	[-0.42]	-0.44	[-2.52]	2.3
TWD	-0.13	[-0.25]	-0.66	[-6.13]	6.3	0.99	[0.91]	-0.57	[-4.76]	5.0
ZAR	0.41	[0.76]	-0.48	[-2.07]	2.3	2.36	[1.72]	-0.33	[-1.02]	0.7

Table A2. Slope-sorted Portfolios: Composition

This table reports the percentage composition of the slope-sorted implied volatility portfolios. 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 and excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging currencies.

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

Table A3. Principal Components: All Slope-sorted Portfolios

This table presents the loadings for the first (PC_1), second (PC_2) and third (PC_3) principal components for the 20 slope-sorted portfolios (five portfolios for each of the four maturity pairs). The last row reports the cumulative share of the total variance (CV) explained by the common factors. The portfolios are rebalanced monthly and excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging currencies.

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

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

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

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

Table A5. Volatility Excess Returns: Reverse Currency Pairs

This table presents panel regression estimates. The dependent variable is the volatility excess returns whereas the independent variable is the reverse currency volatility excess returns. The set of control variable includes the spot exchange rate return, volatility level factor, implied volatility slope in deviation from the cross-country median value (lagged by 1 month), and 1-month realized volatility (lagged by 1 month). We also include currency, maturity, and time (monthly) fixed effects. t-statistics (reported in brackets) are based on standard errors robust to heteroscedasticity, cross-sectional, and temporal dependence as in Driscoll and Kraay (1998) and Vogelsang (2012). Excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging currencies.

	(1)	(2)	(3)	(4)	(5)	(6)
Volatility Excess Returns	0.97	0.97	0.97	0.96	0.97	0.97
	[99.42]	[115.01]	[112.90]	[67.37]	[72.89]	[72.91]
Volatility Level				0.01	0.04	0.05
				[0.95]	[1.68]	[2.08]
FX Returns				0.05	0.04	0.04
				[5.56]	[7.61]	[7.61]
Lagged Implied Slope				0.16	−0.11	−0.11
				[0.76]	[−0.61]	[−0.62]
Lagged Realized Volatility				0.01	0.01	0.01
				[1.83]	[0.81]	[0.81]
RMSE	0.70	0.63	0.63	0.69	0.61	0.61
R^2(%)	99.7	99.7	99.7	99.7	99.7	99.7
# Observations	15,940	15,940	15,940	14,560	14,560	14,560
Currency fe		Yes	Yes		Yes	Yes
Time fe		Yes	Yes		Yes	Yes
Maturity fe			Yes			Yes

Table A6. Descriptive Statistics: Vanna-Volga Method

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

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

Table A7. Descriptive Statistics: Simple-Variance Method

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their implied volatility slopes. Volatility excess returns are computed using spot and forward simple implied volatilities constructed as in Martin (2017) via the cubic spline interpolation method (e.g., Jiang and Tian 2005). Slopes are computed using 3 months and 24 months model-free implied volatility. The first (last) portfolio P_1 (P_5) contains forward volatility agreements with the highest (lowest) implied volatility slopes. LEV denotes a strategy that equally invests in all five portfolios whereas VCA is a long-short strategy that buys P_5 and sells P_1. The table also reports the Sharpe ratio (SR), the first-order autocorrelation coefficient ac_1, and the frequency of portfolio switches ($freq$). t-statistics (reported in brackets) are based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. The portfolios are rebalanced monthly and excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging currencies.

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

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

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

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

Table A9. Descriptive Statistics: Volatility Swaps

This table reports descriptive statistics for five portfolios of volatility swaps sorted by their implied volatility slopes. The implied volatilities are model-free as in Britten-Jones and Neuberger (2000) and constructed via the cubic spline interpolation method (e.g., Jiang and Tian 2005). The realized volatilities are based on daily forward exchange rate returns as in Kozhan, Neuberger, and Schneider (2013). Each slope is based on the 3 months and 24 months model-free 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 (reported in brackets) are based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. The portfolios are rebalanced monthly and excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging currencies in *Panel A* and 10 developed currencies in *Panel B*.

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

Table A10. Slope-sorted Portfolios of Volatility Swap

This table presents cross-sectional asset pricing tests. Both test assets (slope-sorted portfolios of volatility swaps) and pricing factors (level and volatility carry) are presented in Table A9 in the Internet Appendix. The table reports GMM (first and second-stage) estimates of the factor loadings b, the market price of risk λ, and the cross-sectional R^2. t-statistics (reported in brackets) are based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. 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 are equal to zero. The portfolios are rebalanced monthly and excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging currencies in *Panel A* and 10 developed currencies in *Panel B*.

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

Table A11. Asset Pricing Tests: Currency Risk Factors

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

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

Table A12. Asset Pricing Tests: Global Equity Risk Factors

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

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

Table A13. Asset Pricing Tests: S&P 500 Variance Swap Returns

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

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

Table A14. Asset Pricing Tests: VIX Futures Returns

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

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

Table A15. FVA Bid/Ask Spreads

This table presents panel regression estimates based on the following specification:

$$FVOL^T_{ij\ell,t} = \alpha + \beta D_t + \varepsilon_{ij\ell,t},$$

where $FVOL^T_{ij\ell,t}$ is either the bid or the ask tradeable forward volatility (we drop the subscript to ease the notation) on day t for currency i, dealer j, and maturity combination ℓ, D_t is a dummy variable that takes on the value of one when the dependent variable is an ask price, α is the average bid volatility in percentage per annum, and β in basis points captures the average bid-ask spread. Panel A employs bid and ask prices from all dealers whereas Panel B selects the best bid and ask prices. t-statistics (reported in brackets) are based on standard errors robust to heteroscedasticity, cross-sectional, and temporal dependence as in Driscoll and Kraay (1998) and Vogelsang (2012). The sample ranges from October 2009 to January 2014 for a cross-section of 9 developed and 6 emerging currencies. Tradeable volatilities have been manually collected from the archive of a London based hedge fund.

	α (%)		β (*bps*)		N	R^2(%)
Panel A: All Bid/Ask Forward Volatilities						
All Countries	12.5	[21.52]	60.6	[14.30]	2,237	2.03
Developed Countries	12.5	[20.21]	58.2	[15.49]	2,120	2.06
Emerging Countries	11.6	[6.22]	103.3	[12.35]	117	2.35
1/2 *month*	12.1	[15.70]	57.8	[10.58]	204	0.96
3/6 *month*	12.7	[27.00]	51.9	[14.39]	109	2.44
6/12 *month*	12.2	[12.17]	51.9	[15.92]	152	1.42
12/24 *month*	12.5	[20.23]	62.3	[12.66]	1,772	2.37
Panel B: Best Bid/Ask Forward Volatilities						
All Countries	12.9	[24.74]	30.9	[10.56]	799	0.58
Developed Countries	12.9	[23.46]	29.4	[11.65]	751	0.59
Emerging Countries	12.2	[6.81]	54.2	[2.24]	48	0.70
1/2 *month*	12.5	[17.58]	29.7	[6.52]	68	0.28
3/6 *month*	12.8	[27.16]	28.8	[3.88]	48	0.83
6/12 *month*	12.7	[18.46]	30.2	[2.62]	72	0.76
12/24 *month*	12.9	[22.68]	31.4	[8.19]	611	0.63

Table A16. Descriptive Statistics: Portfolios sorted on Forward Volatility Premia

This table reports descriptive statistics for five portfolios of forward volatility agreements sorted by their forward volatility premia. Volatility excess returns are computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). The first (last) portfolio P_1 (P_5) contains forward volatility agreements with the highest (lowest) forward 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 Sharpe ratio (SR), the first-order autocorrelation coefficient ac_1, and the frequency of portfolio switches ($freq$). t-statistics based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection are reported in brackets. Excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging countries.

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

Table A17. Principal Components: Portfolios sorted on Forward Volatility Premia

This table presents the loadings for the first (PC_1) and second (PC_2) principal components of the portfolios. In each panel, the last column reports the cumulative share of the total variance (CV) explained by the common factors. The portfolios are rebalanced monthly from January 1996 to December 2015 using a cross-section of 10 developed countries. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

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

Table A18. Descriptive Statistics: Volatility Excess Returns

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

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

Table A19. Predictive Regressions: Volatility Excess Returns

This table presents panel regression estimates with currency fixed effects. In Panel A, the dependent variable is the volatility excess return whereas the explanatory variable is the lagged forward implied volatility premium, both computed using spot and forward model-free implied volatilities constructed as in Britten-Jones and Neuberger (2000) and Jiang and Tian (2005). In Panel B, implied volatilities are replaced with implied variances. The coefficient estimates α and γ should be equal to zero under the null hypothesis. t-statistics (reported in brackets) are based on standard errors robust to heteroscedasticity, cross-sectional, and temporal dependence as in Driscoll and Kraay (1998) and Vogelsang (2012). Excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

	α		γ		$R^2(\%)$
Panel A: Implied Volatilities					
1/3 months	-0.20	[-0.23]	-0.68	[-5.25]	8.4
3/6 months	0.38	[0.79]	-0.68	[-2.55]	2.1
6/12 months	0.38	[0.98]	-1.38	[-2.63]	1.7
12/24 months	-0.06	[-0.14]	-1.90	[-4.10]	3.4
Panel B: Implied Variances					
1/3 months	1.24	[0.60]	-0.68	[-4.38]	7.3
3/6 months	1.44	[1.41]	-0.66	[-2.37]	1.8
6/12 months	1.20	[1.49]	-1.35	[-2.55]	1.5
12/24 months	0.30	[0.33]	-1.97	[-3.97]	3.4

Table A20. Descriptive Statistics: Slope-sorted Portfolios

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

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

Table A21. Principal Components: Slope-sorted Portfolios

This table presents the loadings for the first (PC_1) and second (PC_2) principal components of the slope-sorted portfolios. In each panel, the last column reports the cumulative share of the total variance (CV) explained by the common factors. The portfolios are rebalanced monthly and excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

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

Table A22. Asset Pricing Tests: Risk Prices

This table presents cross-sectional asset pricing tests. Test assets are slope-sorted portfolios and pricing factors (level and volatility carry strategies). The table reports GMM (first and second-stage) estimates of the factor loadings b, the market price of risk λ, and the cross-sectional R^2. t-statistics (reported in brackets) are based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. 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 are equal to zero. The portfolios are rebalanced monthly and excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

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

Table A23. Country-level Asset Pricing Tests

This table presents country-level cross-sectional tests. The test assets are implied volatility excess returns 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 volatility level (LEV) and the volatility carry (VCA) factors. The table reports Fama-MacBeth estimates of the factor price of risk λ and the cross-sectional R^2. t-statistics (reported in brackets) are based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. We bold λ when its statistical significance is at 5% (or lower) via 10,000 stationary bootstrap repetitions (e.g., Politis and Romano 1994). Excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

	λ_{LEV}		λ_{VCA}		$R^2(\%)$
1/3 months	-2.54	[-1.38]	**7.21**	[3.69]	57.0
3/6 months	-0.29	[-0.39]	**2.46**	[3.00]	68.5
6/12 months	-0.44	[-0.71]	**2.10**	[3.03]	71.2
12/24 months	-0.06	[-0.09]	**2.23**	[2.86]	66.3

Table A24. Asset Pricing Tests: Factor Betas

The table reports least-squares estimates of time-series regressions. Test assets are slope-sorted portfolios and pricing factors (level and volatility carry strategies). t-statistics (reported in brackets) are based on Newey and West (1987) standard errors with Andrews (1991) optimal lag selection. χ^2_α denotes the test statistics (with p-values in parentheses) for the null hypothesis that all intercepts α are jointly zero. The portfolios are rebalanced monthly and excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 20 developed and emerging currencies.

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

Table A25. Exposure to Volatility Carry Risk

This table presents panel estimates from the following specification:

$$rx_{i\ell,t} = \alpha + \beta LEV_{i\ell,t} + \gamma VCA_{i\ell,t} + \phi X_{i,t-1} + \delta LEV_{i\ell,t} \times X_{i,t-1} + \lambda VCA_{i\ell,t} \times X_{i,t-1} + fe + \varepsilon_{i\ell,t},$$

where $rx_{i\ell}$ is the volatility excess return for currency i and maturity combination ℓ, $LEV_{i\ell}$ and $VCA_{i\ell}$ are the volatility level and volatility carry factors while excluding currency i, X_i is the implied volatility slope for currency i in deviation from the cross-country median value, and fe refers to currency, time (monthly) and maturity fixed effects. t-statistics (reported in brackets) are based on standard errors robust to heteroscedasticity, cross-sectional, and temporal dependence as in Driscoll and Kraay (1998) and Vogelsang (2012). $W_{\gamma\lambda}$ is the Wald test for the null hypothesis that γ and λ are jointly zero. The superscripts ***, **, and * denote rejection of the null hypothesis at the 1%, 5%, and 10% confidence level, respectively. Returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

	(1)	(2)	(3)	(4)	(5)	(6)
$LEV_{i\ell,t}$	0.95	0.73	0.69	0.95	0.73	0.69
	[98.94]	[19.17]	[13.23]	[110.28]	[19.56]	[13.55]
$VCA_{i\ell,t}$	0.05	0.06	0.07	0.05	0.06	0.07
	[3.44]	[2.33]	[2.63]	[3.38]	[2.18]	[2.50]
$X_{i,t-1}$	−0.08	−0.08	−0.08	−0.08	−0.09	−0.08
	[−4.78]	[−4.13]	[−4.13]	[−4.85]	[−4.13]	[−4.14]
$LEV_{i\ell,t} \times X_{i,t-1}$				−0.48	−0.47	−0.46
				[−2.20]	[−2.11]	[−2.08]
$VCA_{i\ell,t} \times X_{i,t-1}$	−1.33	−1.35	−1.36	−1.33	−1.35	−1.36
	[−3.92]	[−3.80]	[−3.86]	[−4.02]	[−3.87]	[−3.93]
$W_{\gamma\lambda}$	***	***	***	***	***	***
$R^2(\%)$	67.7	67.9	68.0	67.7	67.9	68.0
# Observations	9,416	9,416	9,416	9,416	9,416	9,416
Time fe		Yes	Yes		Yes	Yes
Currency fe		Yes	Yes		Yes	Yes
Maturity fe			Yes			Yes

Table A26. Asset Pricing Tests: Currency Risk Factors

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

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

Table A27. Asset Pricing Tests: Global Equity Risk Factors

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

	α	LEV	MKT	SMB	HML	RMW	CMA	$R^2_{LEV}(\%)$	$R^2_{ALL}(\%)$	χ^2_α
					Panel A: 1/3 months					
P_1	−3.28***	1.53***	0.12	−0.03	0.04	−0.11	0.01	76.7	76.3	(<.01)
P_2	−2.55***	1.59***	−0.05	0.27	0.08	−0.03	−0.10	82.7	82.5	
P_3	−1.88***	1.50***	−0.08	0.42**	−0.25	0.08	0.37	78.0	78.3	
P_4	−1.90***	1.55***	−0.01	0.31**	0.56**	−0.18	−0.56**	83.8	84.3	
P_5	1.12*	1.55***	−0.22*	−0.44*	0.67**	−0.67*	−0.85**	74.1	74.6	
					Panel B: 3/6 months					
P_1	−0.12	0.88***	0.06	−0.04	−0.07	−0.03	0.12	74.1	73.6	
P_2	0.53**	0.97***	−0.06	0.01	−0.15	−0.02	0.17	84.8	84.7	
P_3	0.67***	0.92***	−0.01	0.02	−0.32*	0.25	0.26	82.9	83.2	
P_4	0.81***	1.02***	0.09	−0.11	−0.04	0.14	−0.04	83.7	83.6	
P_5	1.85***	0.95***	−0.06	−0.29	0.34	−0.06	−0.50	75.3	75.9	
					Panel C: 6/12 months					
P_1	−0.67***	0.69***	0.04	0.07	−0.13	0.11	0.08	74.1	73.7	
P_2	−0.11	0.79***	−0.04	0.06	−0.10	0.05	0.13	83.3	83.2	
P_3	0.15	0.72***	−0.08	−0.04	−0.25*	0.14	0.10	81.5	81.9	
P_4	0.36	0.81***	0.03	−0.12	−0.12	0.04	0.04	78.0	77.8	
P_5	1.11***	0.80***	−0.02	−0.12	0.05	0.09	−0.19	76.7	76.6	
					Panel D: 12/24 months					
P_1	−0.16	0.67***	0.13**	−0.01	−0.22	0.04	0.34	69.1	69.1	
P_2	0.42**	0.77***	0.00	0.04	−0.17	0.05	0.29*	81.7	81.7	
P_3	0.61***	0.74***	0.03	0.07	−0.30*	0.13	0.35*	76.8	76.9	
P_4	1.01***	0.80***	0.12*	0.09	0.05	−0.03	0.15	75.6	75.5	
P_5	2.072***	0.76***	0.00	−0.17	0.33	0.00	−0.19	54.8	54.8	

Table A28. Asset Pricing Tests: VIX Futures Returns

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

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

Table A29. Asset Pricing Tests: S&P 500 Variance Swap Returns

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

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

Table A30. Traded vs. Quoted Implied Volatility

This table presents panel regression estimates based on the following specification:

$$IVOL^T_{ik\tau,t} = \alpha + \beta\, IVOL_{ik\tau,t} + \gamma' X_{i,t} + fe + \varepsilon_{ik\tau,t},$$

where $IVOL^T_{ik\tau,t}$ is the traded implied volatility for currency i, strike k, and maturity τ on day t, $IVOL_{ik\tau,t}$ is the corresponding quoted implied volatility, $X_{i,t}$ denotes a set of currency-specific variables (option notional value, interest rate differential, foreign exchange liquidity, and spot rate return), and fe refers to hour, currency, maturity, and time (monthly) fixed effects. t_β denotes t-statistics for the null hypothesis that β is equal to one. Implied volatilities are expressed in percentage per annum and their maturity ranges between one month and two years. t-statistics (reported in brackets) are based on standard errors by currency and time (month) dimension. The sample ranges from March 2013 and April 2019 using a cross-section of 10 developed currencies. Traded options are collected from the Depository Trust & Clearing Corporation (DTCC) whereas quoted implied volatilities are provided by JP Morgan and Bloomberg.

	(1)	(2)	(3)	(4)	(5)	(6)
IVOL	1.00	1.00	1.00	1.00	1.00	0.99
	[154.16]	[118.46]	[129.91]	[156.78]	[121.22]	[132.59]
t_β	[0.32]	[0.51]	[0.16]	[−0.46]	[−0.36]	[−0.72]
Option Volume				0.07	−0.08	−0.14
				[0.12]	[−0.16]	[−0.29]
Interest Rate Differential				0.03	0.05	0.04
				[3.62]	[9.21]	[10.27]
FX Liquidity				−0.56	0.18	0.18
				[−1.77]	[0.49]	[0.49]
FX Returns				−0.01	0.01	0.01
				[−1.59]	[0.45]	[0.44]
RMSE	2.29	2.29	2.28	2.29	2.29	2.28
R^2(%)	47.6	47.7	47.9	47.6	47.7	47.9
# Observations	820,453	820,453	820,453	820,453	820,453	820,453
Hour fe		Yes	Yes		Yes	Yes
Time fe		Yes	Yes		Yes	Yes
Currency fe		Yes	Yes		Yes	Yes
Maturity fe			Yes			Yes

Table A31. Traded vs. Quoted Forward Volatility

This table presents panel regression estimates based on the following specification:

$$FVOL^{T}_{ij\ell,t} = \alpha + \beta\, FVOL_{i\ell,t} + \gamma\, Spread_{ij\ell,t} + fe + \varepsilon_{ij\ell,t},$$

where $FVOL^{T}_{ij\ell,t}$ is the tradeable forward implied volatility on day t for currency i, dealer j, and maturity combination ℓ, $FVOL_{i\ell,t}$ is the synthetic forward implied volatility for currency i and maturity ℓ, $Spread_{ij\ell,t}$ is the bid-ask spread on the tradeable volatility, and fe refers to dealer, currency, maturity, and time (monthly) fixed effects. t_β denotes t-statistics for the null hypothesis that β is equal to one. t-statistics (reported in brackets) are based on standard errors robust to heteroscedasticity, cross-sectional, and temporal dependence as in Driscoll and Kraay (1998) and Vogelsang (2012). Volatilities are expressed in percentage per annum and the sample ranges from October 2009 to January 2014 for a cross-section of 9 developed countries. Tradeable volatilities have been manually collected from the archive of a London based hedge fund. Mid synthetic volatilities are computed using data provided by JP Morgan and Bloomberg.

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Mid Implied Forward Volatility			
FVOL	0.90	0.99	0.98	0.90	0.99	0.98
	[19.92]	[13.58]	[13.14]	[19.61]	[13.41]	[12.98]
t_β	[−2.31]	[−0.15]	[−0.21]	[−2.22]	[−0.15]	[−0.20]
Spread				2.08	−0.11	0.31
				[1.06]	[−0.12]	[0.25]
RMSE	0.59	0.36	0.36	0.58	0.36	0.36
$R^2(\%)$	92.0	97.0	97.0	92.0	97.0	97.0
			Panel B: Bid Implied Forward Volatility			
FVOL	0.88	0.98	0.98	0.88	0.97	0.96
	[20.36]	[13.79]	[13.35]	[19.88]	[13.43]	[13.00]
t_β	[−2.68]	[−0.26]	[−0.33]	[−2.73]	[−0.46]	[−0.50]
Spread				−4.51	−6.60	−6.24
				[−2.58]	[−6.85]	[−4.88]
RMSE	0.58	0.37	0.36	0.57	0.35	0.35
$R^2(\%)$	92.0	96.7	96.9	92.2	97.0	97.1
			Panel C: Ask Implied Forward Volatility			
FVOL	0.91	1.00	0.99	0.92	1.01	1.01
	[19.40]	[13.34]	[12.90]	[19.37]	[13.40]	[12.96]
t_β	[−1.95]	[−0.05]	[−0.10]	[−1.75]	[0.14]	[0.09]
Spread				8.67	6.39	6.86
				[3.94]	[7.24]	[5.37]
RMSE	0.62	0.39	0.38	0.60	0.37	0.36
$R^2(\%)$	91.2	96.6	96.8	91.9	97.0	97.0
# Observations	1,135	1,135	1,135	1,135	1,135	1,135
Dealer fe		Yes	Yes		Yes	Yes
Time fe		Yes	Yes		Yes	Yes
Currency fe		Yes	Yes		Yes	Yes
Maturity fe			Yes			Yes

Table A32. Volatility Excess Returns: Reverse Currency Pairs

This table presents panel regression estimates. The dependent variable is the volatility excess returns whereas the independent variable is the reverse currency volatility excess returns. The set of control variable includes the spot exchange rate return, volatility level factor, implied volatility slope in deviation from the cross-country median value (lagged by 1 month), and 1-month realized volatility (lagged by 1 month). We also include currency, maturity, and time (monthly) fixed effects. t-statistics (reported in brackets) are based on standard errors robust to heteroscedasticity, cross-sectional, and temporal dependence as in Driscoll and Kraay (1998) and Vogelsang (2012). Excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

	(1)	(2)	(3)	(4)	(5)	(6)
Volatility Excess Returns	0.99	0.99	1.00	0.99	0.99	0.99
	[297.75]	[797.21]	[832.79]	[319.77]	[422.13]	[424.25]
Volatility Level				0.00	0.01	0.01
				[−2.57]	[1.45]	[1.98]
FX Returns				0.00	0.00	0.00
				[−0.02]	[0.42]	[0.42]
Lagged Implied Slope				0.05	0.12	0.12
				[0.25]	[0.45]	[0.45]
Lagged Realized Volatility				0.01	0.01	0.01
				[0.95]	[1.03]	[1.03]
RMSE	0.42	0.37	0.37	0.42	0.37	0.37
R^2(%)	99.8	99.9	99.9	99.8	99.9	99.9
# Observations	9,416	9,416	9,416	9,376	9,376	9,376
Currency fe		Yes	Yes		Yes	Yes
Time fe		Yes	Yes		Yes	Yes
Maturity fe			Yes			Yes

Table A33. Slope-sorted Portfolios: Composition

This table reports the percentage composition of the slope-sorted implied volatility portfolios. 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 and excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

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

Table A34. Principal Components: All Slope-sorted Portfolios

This table presents the loadings for the first (PC_1), second (PC_2) and third (PC_3) principal components for the 20 slope-sorted portfolios (five portfolios for each of the four maturity pairs). The last row reports the cumulative share of the total variance (CV) explained by the common factors. The portfolios are rebalanced monthly and excess returns are expressed in percentage per month. The sample runs from January 1996 to December 2015 and employs over-the-counter currency options from JP Morgan and Bloomberg for a cross-section of 10 developed currencies.

	P_1	P_2	P_3	P_4	P_5
	Panel A: 1/3 month				
PC_1	0.33	0.35	0.34	0.33	0.33
PC_2	-0.44	-0.22	-0.30	-0.13	0.43
PC_3	-0.05	-0.36	-0.22	-0.14	-0.49
	Panel B: 3/6 month				
PC_1	0.18	0.21	0.20	0.21	0.19
PC_2	-0.11	0.02	0.00	0.09	0.38
PC_3	0.27	0.13	0.19	0.28	0.03
	Panel C: 6/12 month				
PC_1	0.14	0.17	0.16	0.17	0.16
PC_2	-0.09	0.04	0.01	0.07	0.29
PC_3	0.21	0.12	0.18	0.28	0.04
	Panel D: 12/24 month				
PC_1	0.14	0.16	0.16	0.16	0.15
PC_2	-0.06	0.05	0.03	0.12	0.42
PC_3	0.22	0.13	0.20	0.28	-0.08
CV	0.77	0.84	0.88	0.91	0.94

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