The Cross-Section of Currency Volatility Premia

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Introduction

- ✓ **Carry trade** is the most popular currency investment strategy:
  - An investor sells currencies at premium (low-yielding) and buys currencies at discount (higher-yielding) in the forward market: Bilson (1981), Fama (1984).
  - Short Japanese yen and long Aussie dollar is an example of a carry trade.

- ✓ Investment currencies can suddenly depreciate, thus causing large losses:
  - **carry returns** understood as compensation for **global risk**: Lustig, Roussanov and Verdelhan (2011), Menkhoff, Sarno, Schmeling and Schrimpf (2012),
  - **carry returns** decrease significantly with bond maturity: Lustig, Stathopoulos and Verdelhan (2018).

- ✓ **Global Imbalances** are a key driver of currency excess returns
  - Gabaix and Maggiori (2015), Della Corte, Riddiough and Sarno (2016), and Colacito, Croce, Gavazzoni and Ready (2018).

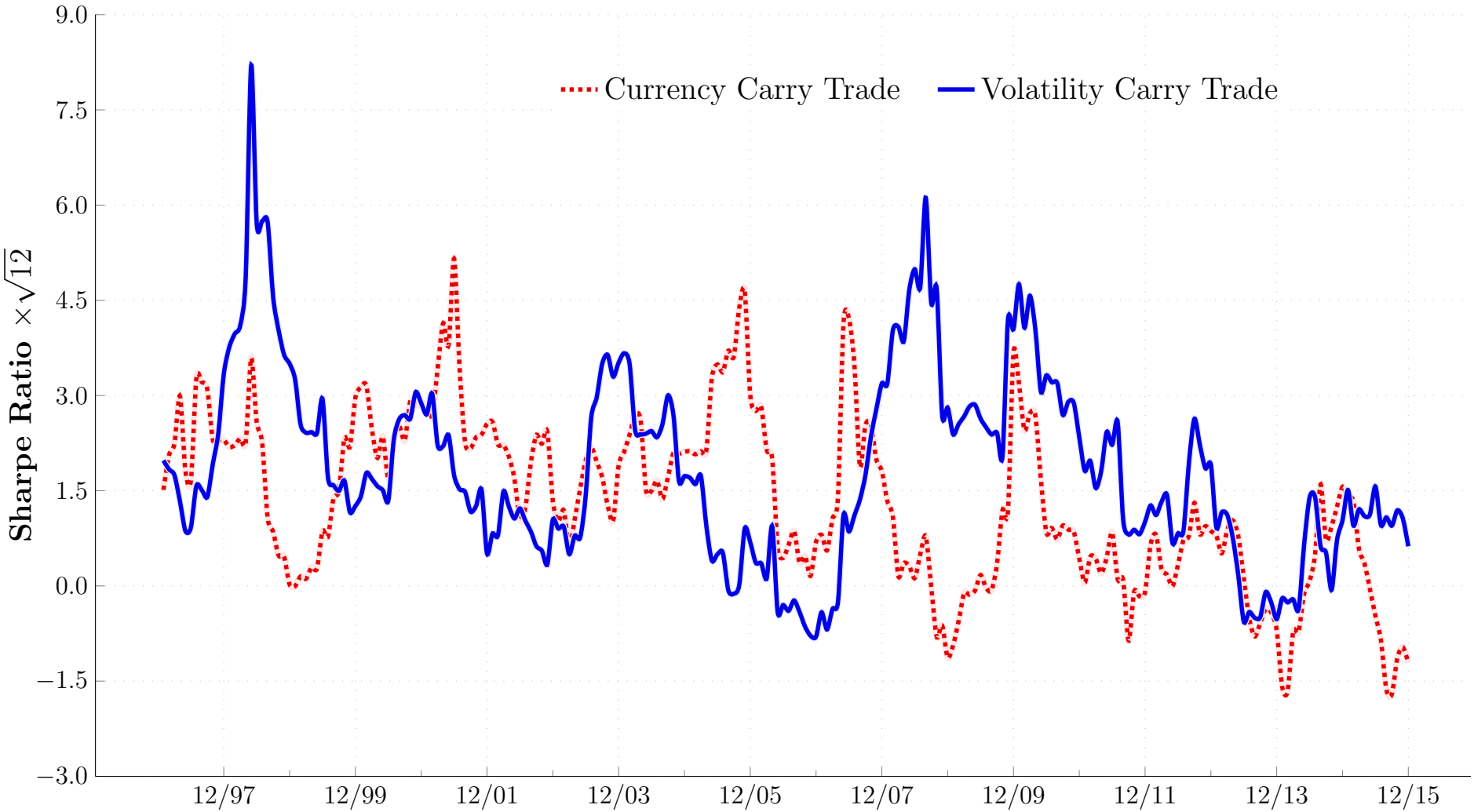
Motivations

- ✓ We can also engage into a **volatility carry trade** strategy
  - An investor sells implied volatilities at premium and buys implied volatilities at discount in the forward market.
  - There exists an OTC derivative – **forward volatility agreement** or FVA – that trades forward versus future spot implied volatility (e.g., Knauf, 2003).
  - Dew-Becker, Giglio, Le, and Rodriguez (2016) show that equity variance risk premia are small at maturities larger than two months.

- ✓ Little is known about the properties of these excess returns:
  - Are they compensation for exposure to risk?
  - Do existing currency risk factors play a role?
  - Do existing models help explain carry in volatility?

Carry Strategies

1-year Rolling Sharpe Ratios

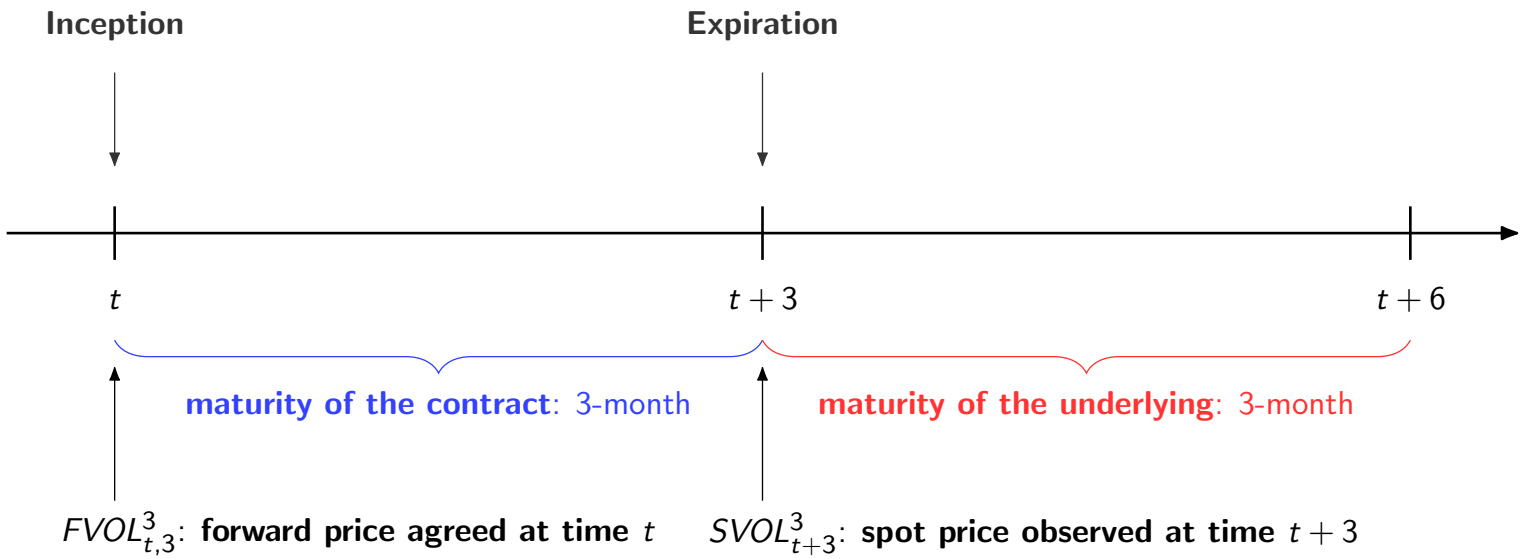


Overview of this Paper

- ✓ We construct FVAs for a cross-section of 20 countries:
  - We synthesize model-free implied volatilities using currency option data for maturities between 1-month and 24-month (e.g., Britten-Jones and Neuberger, 2000; Jiang and Tian, 2005).
  - Forward implied volatility is a **biased predictor** of the future implied volatility (e.g., Campa and Chang, 1995; Della Corte, Sarno and Tsiakas, 2011).
  - Long FVAs with low forward volatility premia and short FVAs high forward volatility premia generates significant excess returns.
- ✓ Our analysis suggests:
  - Excess returns are unrelated to existing risk factors but are explained by two pervasive – level and carry volatility – factors.
  - A reduced-form model shows that excess returns are reward for exposure to **global risk** (e.g., Lustig, Roussanov and Verdelhan, 2011).
  - Shocks to economic growth are the key economic driver of our excess returns.

Forward Volatility Agreement (or simply FVA)

✓ A 3-month forward contract on the future 3-month implied volatility

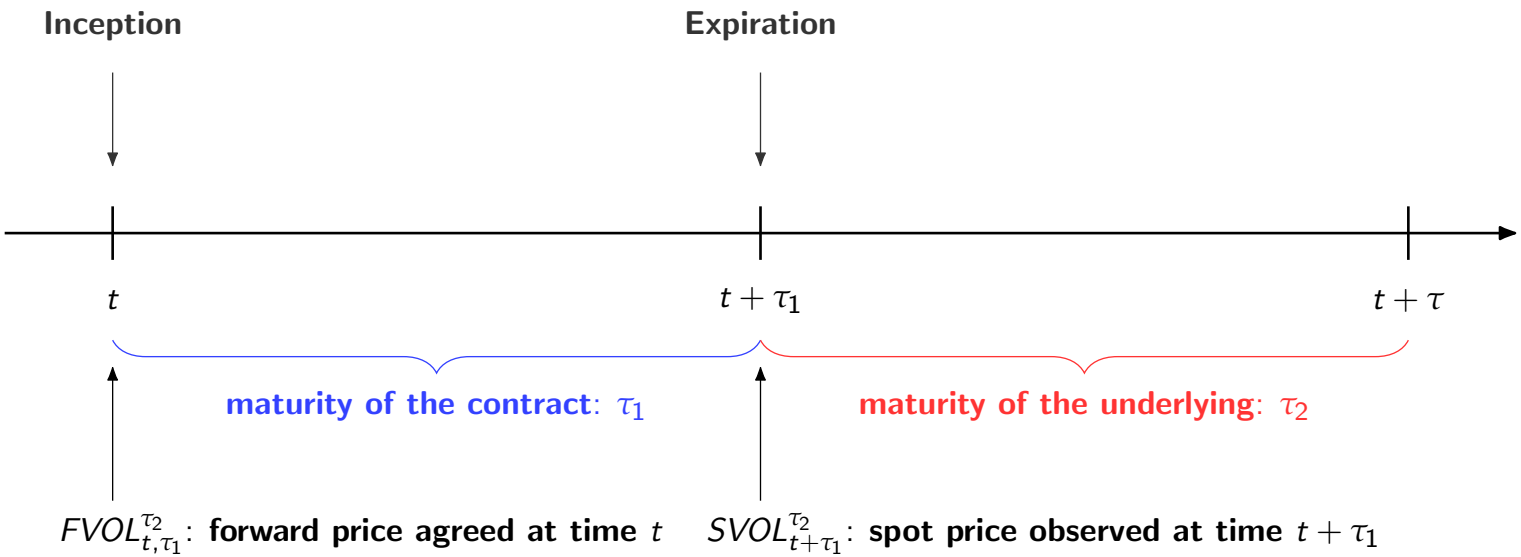


✓ The **payoff** on the maturity date $t+3$ is given by

$$\left(SVOL^3_{t+3} - FVOL^3_{t,3}\right) \times M,$$

Forward Volatility Agreement (or simply FVA)

✓ A τ_1-period forward contract on the future τ_2-period implied volatility



✓ The **payoff** on the maturity date $t+\tau_1$ is given by

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

Relation between Spot and Forward Volatility

✓ No arbitrage condition dictates (under risk-neutrality) that

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

✓ It can be equivalently written in return space as

$$\underbrace{E_t\left[\frac{SVOL_{t+\tau_1}^{\tau_2} - SVOL_t^{\tau_2}}{SVOL_t^{\tau_2}}\right]}_{\textit{Implied Volatility Return}} = \underbrace{\frac{FVOL_{t,\tau_1}^{\tau_2} - SVOL_t^{\tau_2}}{SVOL_t^{\tau_2}}}_{\textit{Forward Volatility Premium}}$$

or alternatively as

$$\underbrace{E_t\left[\frac{SVOL_{t+\tau_1}^{\tau_2} - FVOL_{t,\tau_1}^{\tau_2}}{SVOL_t^{\tau_2}}\right]}_{\textit{Volatility Excess Return}} = 0.$$

Predictive Regressions

✓ The analogue of the Fama (1984) **predictive regressions** for exchange rates:

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

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

✓ Under the null hypothesis

1. $\alpha = 0$ and $\beta = 1$: forward volatility premia predict implied volatility returns,
2. $\alpha = 0$ and $\gamma = 0$: volatility excess returns are zero on average,
3. $\gamma = \beta - 1$ by construction.

Model-Free Implied Volatility

✓ We use the model-free approach of Britten-Jones and Neuberger (2000):

- The annualized spot implied variance based on ∞ range of option strikes

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

- $P_t^\tau(K)$ and $C_t^\tau(K)$: put and call prices with strike K and maturity τ
- B_t^τ: price of a domestic bond with maturity τ,
- We approximate the model-free variance as in Jiang and Tian (2005).

✓ FX participants trade volatility as opposed to variance derivatives

- We measure model-free **spot and forward volatility** as

$$SVOL_t^\tau = \sqrt{SVAR_t^\tau}$$

$$FVOL_{t,\tau_1}^{\tau_2} = \sqrt{\frac{\tau}{\tau_2}SVAR_t^\tau - \frac{\tau_1}{\tau_2}SVAR_t^{\tau_1}}.$$

Data

✓ Country Sample

- We use sample of 20 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.

✓ Exchange Rates

- we collect spot and one-month forward exchange rates vis-à-vis the US dollar from Barclays and Reuters from 01/1996 to 12/2015 via Datastream.

✓ Currency Options

- we obtain OTC currency options data from JP Morgan and Bloomberg for the following maturities: 1-month, 3-month, 6-month, 12-month and 24-month,
- for a given maturity, quotes are available for five different combinations of plain-vanilla options: ATM delta-neutral straddles, 10 delta and 25 delta risk-reversals, and 10 delta and 25 delta butterfly spreads.

Unconditional Volatility Risk Premia

Pooling Data across All Countries

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

Predictive Regressions

All Countries: Country-Fixed Effects

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

Standard errors robust to heteroskedasticity, cross-sectional and temporal dependence.

▶ G-10 ▶ Country-Level

Trading Baskets of FVAs

Sorting from **high** (P_1) to **low** (P_5) Implied Volatility Slopes

	P_1	P_2	P_3	P_4	P_5	*LEV*	*VCA*
			Panel A: 1-month/3-month				
mean	-4.66	-3.02	-2.35	-2.42	0.49	-2.39	5.15
	[-3.91]	[-2.82]	[-2.17]	[-2.61]	[0.38]	[-2.31]	[5.91]
$SR \times \sqrt{12}$	-0.99	-0.74	-0.61	-0.69	0.12	-0.65	1.46
			Panel B: 3-month/6-month				
mean	-0.83	0.37	0.58	0.44	1.81	0.47	2.64
	[-1.31]	[0.50]	[0.93]	[0.86]	[2.58]	[0.78]	[5.75]
$SR \times \sqrt{12}$	-0.30	0.13	0.26	0.19	0.71	0.21	1.29
			Panel C: 6-month/12-month				
mean	-1.13	-0.04	-0.08	-0.01	1.11	-0.03	2.24
	[-2.34]	[-0.06]	[-0.17]	[-0.03]	[1.92]	[-0.06]	[5.67]
$SR \times \sqrt{12}$	-0.54	-0.02	-0.04	-0.01	0.52	-0.02	1.27
			Panel D: 12-month/24-month				
mean	-0.40	0.38	0.37	0.68	2.10	0.63	2.50
	[-0.86]	[0.67]	[0.83]	[1.67]	[3.63]	[1.37]	[5.67]
$SR \times \sqrt{12}$	-0.20	0.16	0.20	0.37	0.89	0.34	1.25

Newey-West t-statistics are reported in brackets.

▸ Vol Prem ▸ Composition ▸ PCA ▸ G-10 ▸ Vanna-Volga ▸ Simple ▸ ATM ▸ Bid-Ask Spread

Asset Pricing Tests

Methodology

- ✓ Under no-arbitrage, risk-adjusted excess returns have a zero price:

$$E_t[M_{t+1} RX^j_{t+1}] = 0$$

where RX^j_t is the discrete excess returns on portfolio j.

- ✓ The SDF M_{t+1} is linear in the pricing factors f_{t+1}

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

where μ is the sample mean of the pricing factors.

- ✓ The beta pricing model is defined as

$$E[RX^j] = \lambda' \beta^j$$

where $\lambda = \Sigma_f b$ is the market price of risk.

Asset Pricing Results

Cross-Sectional Tests

	Panel A: 1-month/3-month						Panel B: 3-month/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	0.10
	[-1.31]	[2.67]	[-2.20]	[4.86]		(0.13)	[1.31]	[5.19]	[0.76]	[5.45]		(0.53)
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]		
mean			**-2.39**	**5.15**					**0.47**	**2.64**		
	Panel C: 6-month/12-month						Panel D: 12-month/24-month					
GMM_1	0.00	0.06	-0.03	2.23	99.0	0.04	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]		(0.83)
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]		
mean			**-0.03**	**2.24**					**0.63**	**2.50**		

Newey-West t-statistics are reported in brackets.

▶ Time-Series ▶ Country-level

Currency Risk Factors

Time-Series Tests

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

Newey-West t-statistics are reported in brackets.

▸ Fama-French ▸ Vol Swap: Summary ▸ Vol Swap: Tests ▸ Vol Swap: Chart

What Drives Global Risk?

- We model SDF in country i as in Lustig, Roussanov and Verdelhan (2011)

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

  - z_t^w is a global variable which enters the SDF of all countries, and can be interpreted as the degree of global risk aversion
  - z_t^j is the country specific variable that captures local risk aversion
  - u_t^w and u_t^j are standard Brownian processes that capture global and local shocks, respectively.

- The instantaneous variance is

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

  - f is the foreign country and h the home country.

What Drives Global Risk?

- The risk premium consists of two terms

$$rp_t = -\sigma z_t^h \gamma^{1/2} \left(\gamma - \kappa \left(\sqrt{\frac{\kappa z_t^f + \delta z_t^w}{\kappa z_t^h + \delta z_t^w}} - 1 \right) \right) + \sigma \delta \sqrt{\frac{z_t^w}{\kappa z_t^f + \delta z_t^w}} \left(\sqrt{\kappa z_t^f + \delta z_t^w} - \sqrt{\kappa z_t^h + \delta z_t^w} \right)^2$$

  - Compensation for **US local risk**, which is related to $z_t^f - z_t^h$,
  - Compensation for **global risk**, which is roughly proportional to $(z_t^f - z_t^h)^2$.
  - Global risk and US local risk are both priced in a country's volatility return.

- From the perspective of a US investor:
  - Buying (selling) the volatility portfolios of countries that are far from (close to) the US in terms of state variables **maximizes exposure to global risk** and minimizes exposure to US local risk.
  - The slope of the implied volatility curve captures the distance of the local economies from the US and allows us to identify global risk empirically.

What Drives Global Risk?

Decomposition of the Implied Volatility Slopes

	Total	Inflation rate	Economic growth	Trade balance	Term spread	Residual
			1-month/3-month			
mean	4.52	0.80	3.24	-1.05	0.50	1.03
	[5.86]	[1.08]	[3.52]	[-1.56]	[0.65]	[1.37]
$SR \times \sqrt{12}$	1.34	0.23	0.88	-0.30	0.12	0.33
			3-month/6-month			
mean	2.33	0.00	1.40	-0.25	0.04	1.15
	[5.02]	[0.00]	[2.90]	[-0.62]	[0.08]	[2.60]
$SR \times \sqrt{12}$	1.10	0.00	0.67	-0.14	0.02	0.56
			6-month/12-month			
mean	1.80	0.02	1.28	-0.19	-0.09	0.79
	[4.74]	[0.05]	[3.43]	[-0.55]	[-0.22]	[2.10]
$SR \times \sqrt{12}$	1.03	0.01	0.79	-0.12	-0.05	0.47
			12-month/24-month			
mean	2.16	-0.03	0.90	0.26	-0.18	1.20
	[5.30]	[-0.08]	[2.37]	[0.70]	[-0.32]	[3.48]
$SR \times \sqrt{12}$	1.11	-0.01	0.55	0.16	-0.07	0.73

Newey-West t-statistics are reported in brackets.

Methods

Conclusion

- We construct a zero-cost portfolio strategy that buys FVA of currencies with negative slopes and sells FVAs with positive implied volatility slopes.
- We identify a risk factor – forward volatility premium – that fully explains FVA cross-sectional variation.
- The lower is the slope of the implied volatility curve, the more FVA return is exposed to this forward volatility premium.
- We present evidence that results are driven by exposure to global volatility risk.
- In the data, shocks to economic growth are an important driver of volatility carry trade returns.

Predictive Regressions

Developed Countries: Country-Fixed Effects

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

Standard errors robust to heteroskedasticity, cross-sectional and temporal dependence.

Go back

Predictive Regressions

Country-level: Pooling Data across Different Maturities

Sample	Full			Pre- and Post-Crisis			Crisis		
	α	γ	R^2	α	γ	R^2	α	γ	R^2
AUD	0.01	-0.88***	10.7	0.00	-0.79***	10.2	0.05*	-1.26***	10.4
BRL	0.01	-0.70***	6.1	-0.01	-0.51***	4.0	0.06	-0.98*	7.1
CAD	0.01	-0.85***	7.2	0.00	-0.74***	6.2	0.05*	-1.19***	8.3
CHF	0.00	-0.59***	3.6	-0.01	-0.47***	2.5	0.04**	-1.10*	5.8
CZK	0.00	-0.79***	6.7	-0.01	-0.58***	4.0	0.04*	-1.27***	12.4
DKK	0.00	-0.67***	5.4	-0.01	-0.60***	4.7	0.05**	-1.03***	7.9
EUR	0.00	-0.66***	5.1	-0.01	-0.56***	4.1	0.04**	-1.05***	8.5
GBP	0.00	-0.68***	5.9	-0.01	-0.60***	5.2	0.04*	-1.08**	6.5
HUF	0.00	-0.74***	7.6	-0.01	-0.70***	7.0	0.03*	-0.30	0.9
JPY	0.00	-0.66***	4.9	-0.01	-0.55***	3.8	0.05***	-0.43	1.1
KRW	0.02	-1.11***	10.0	-0.02*	-0.54***	3.5	0.09*	-2.10***	14.6
MXN	0.00	-0.72***	7.6	-0.02**	-0.59***	6.1	0.06	-3.07**	26.2
NOK	0.00	-0.73***	5.4	0.00	-0.63***	4.4	0.04*	-1.31***	9.9
NZD	0.01	-0.85***	11.2	0.00	-0.84***	11.9	0.04	-0.88**	6.4
PLN	0.00	-0.84***	10.6	-0.01**	-0.63***	7.4	0.04	-1.64***	15.7
SEK	0.00	-0.63***	4.7	0.00	-0.54***	3.8	0.04*	-1.16***	9.7
SGD	0.00	-0.63***	4.6	-0.01*	-0.47***	3.0	0.06**	-1.91***	15.1
TRY	-0.01	-0.52***	3.6	-0.01	-0.62***	5.7	0.00	0.21	0.4
TWD	0.00	-0.66***	6.3	-0.01	-0.63***	6.5	0.04	-0.65*	2.7
ZAR	0.00	-0.48**	2.3	0.00	-0.47**	2.5	0.03	-0.08	0.0

Robust standard errors to heteroskedasticity, cross-sectional and temporal dependence.

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Portfolios' Composition

	Panel A: Actual					Panel B: Percentage				
	P_1	P_2	P_3	P_4	P_5	P_1	P_2	P_3	P_4	P_5
AUD	6	46	62	37	88	3	19	26	15	37
BRL	49	33	17	8	12	41	28	14	7	10
CAD	21	32	64	53	69	9	13	27	22	29
CHF	12	59	46	61	61	5	25	19	26	26
CZK	1	12	15	51	40	1	10	13	43	34
DKK	4	36	94	70	35	2	15	39	29	15
EUR	15	72	45	48	23	7	35	22	24	11
GBP	70	94	44	20	11	29	39	18	8	5
HUF	11	28	27	31	10	10	26	25	29	9
JPY	53	62	35	39	50	22	26	15	16	21
KRW	46	39	11	5	18	39	33	9	4	15
MXN	43	41	15	19	1	36	34	13	16	1
NOK	0	22	78	71	68	0	9	33	30	28
NZD	1	24	58	52	104	0	10	24	22	44
PLN	4	19	33	28	35	3	16	28	24	29
SEK	1	24	55	91	68	0	10	23	38	28
SGD	62	38	15	4	0	52	32	13	3	0
TRY	94	19	1	1	4	79	16	1	1	3
TWD	131	21	16	8	3	73	12	9	4	2
ZAR	44	55	33	19	16	26	33	20	11	10

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Principle Components Analysis

✓ Do slope-sorted portfolios display a strong factor structure?

- $corr(PrC_1, LEV) \approx 1$ and $corr(PrC_2, VCA) \approx 0.95$.

	Panel A: 1-month/3-month					Panel B: 3-month/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-month/12-month					Panel D: 12-month/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**

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Trading Baskets of FVAs

Sorting from **high** (P_1) to **low** (P_5) Forward Volatility Premia

	P_1	P_2	P_3	P_4	P_5	*LEV*	*VCA*
				Panel A: 1-month/3-month			
mean	-6.95	-4.05	-2.22	-1.75	0.90	-2.81	7.84
	[-5.51]	[-3.91]	[-2.18]	[-1.61]	[0.71]	[-2.75]	[7.67]
$SR \times \sqrt{12}$	-1.32	-1.03	-0.58	-0.44	0.22	-0.77	1.77
				Panel B: 3-month/6-month			
mean	-1.22	-0.08	0.17	0.88	2.27	0.40	3.49
	[-1.71]	[-0.14]	[0.30]	[1.23]	[3.18]	[0.66]	[6.61]
$SR \times \sqrt{12}$	-0.40	-0.04	0.08	0.31	0.86	0.17	1.53
				Panel C: 6-month/12-month			
mean	-1.13	-0.54	-0.28	0.24	1.43	-0.06	2.56
	[-1.72]	[-1.21]	[-0.59]	[0.51]	[2.27]	[-0.11]	[6.34]
$SR \times \sqrt{12}$	-0.40	-0.29	-0.14	0.14	0.63	-0.03	1.25
				Panel D: 12-month/24-month			
mean	-0.31	-0.01	0.60	0.71	2.08	0.61	2.39
	[-0.56]	[-0.03]	[1.24]	[1.61]	[4.31]	[1.34]	[4.93]
$SR \times \sqrt{12}$	-0.13	-0.01	0.28	0.40	1.00	0.34	1.09

Newey-West t-statistics are reported in brackets.

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Trading Baskets of FVAs

Sorting on Implied Volatility Slopes: Developed Countries

	P_1	P_2	P_3	P_4	P_5	*LEV*	*VCA*
				Panel A: 1-month/3-month			
mean	-3.63	-2.96	-2.22	-2.30	0.37	-2.15	4.00
	[-3.74]	[-2.83]	[-2.06]	[-2.49]	[0.32]	[-2.22]	[4.61]
$SR \times \sqrt{12}$	-0.96	-0.77	-0.58	-0.63	0.09	-0.61	1.36
				Panel B: 3-month/6-month			
mean	-0.31	0.25	0.50	0.63	1.55	0.52	1.86
	[-0.58]	[0.39]	[0.80]	[1.17]	[2.79]	[0.96]	[4.46]
$SR \times \sqrt{12}$	-0.14	0.11	0.21	0.26	0.65	0.24	1.06
				Panel C: 6-month/12-month			
mean	-0.80	-0.30	-0.06	0.16	0.91	-0.02	1.71
	[-1.98]	[-0.62]	[-0.13]	[0.35]	[1.98]	[-0.05]	[5.28]
$SR \times \sqrt{12}$	-0.45	-0.15	-0.03	0.08	0.45	-0.01	1.21
				Panel D: 12-month/24-month			
mean	-0.24	0.27	0.49	0.91	1.94	0.68	2.18
	[-0.59]	[0.59]	[1.03]	[2.11]	[3.89]	[1.65]	[5.26]
$SR \times \sqrt{12}$	-0.14	0.14	0.26	0.47	0.87	0.39	1.14

Newey-West t-statistics are reported in brackets.

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Trading Baskets of FVAs

Sorting on Implied Volatility Slopes: Vanna-Volga

	P_1	P_2	P_3	P_4	P_5	*LEV*	*VCA*
				Panel A: 1-month/3-month			
mean	-4.44	-2.93	-2.51	-2.39	0.37	-2.38	4.82
	[-3.80]	[-2.83]	[-2.34]	[-2.59]	[0.29]	[-2.34]	[5.64]
$SR \times \sqrt{12}$	-0.96	-0.74	-0.65	-0.70	0.09	-0.66	1.39
				Panel B: 3-month/6-month			
mean	-0.77	0.39	0.50	0.50	1.81	0.49	2.58
	[-1.25]	[0.54]	[0.79]	[1.01]	[2.66]	[0.81]	[5.88]
$SR \times \sqrt{12}$	-0.29	0.14	0.22	0.23	0.73	0.22	1.32
				Panel C: 6-month/12-month			
mean	-1.06	-0.05	-0.15	-0.03	1.09	-0.04	2.15
	[-2.27]	[-0.09]	[-0.32]	[-0.07]	[1.95]	[-0.09]	[5.54]
$SR \times \sqrt{12}$	-0.53	-0.02	-0.08	-0.02	0.52	-0.02	1.26
				Panel D: 12-month/24-month			
mean	-0.25	0.48	0.44	1.03	2.30	0.80	2.55
	[-0.52]	[0.88]	[0.96]	[2.51]	[4.01]	[1.79]	[5.55]
$SR \times \sqrt{12}$	-0.12	0.21	0.24	0.56	0.97	0.44	1.22

Newey-West t-statistics are reported in brackets.

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Trading Baskets of FVAs

Sorting on Implied Volatility Slopes: Simple

	P_1	P_2	P_3	P_4	P_5	*LEV*	*VCA*
				Panel A: 1-month/3-month			
mean	-3.57	-2.70	-2.27	-1.97	0.25	-2.05	3.82
	[-3.77]	[-2.88]	[-2.21]	[-1.89]	[0.22]	[-2.15]	[4.27]
$SR \times \sqrt{12}$	-0.98	-0.73	-0.58	-0.51	0.06	-0.59	1.31
				Panel B: 3-month/6-month			
mean	-0.33	0.24	0.59	0.54	1.58	0.52	1.91
	[-0.66]	[0.41]	[1.00]	[0.95]	[2.75]	[0.98]	[4.63]
$SR \times \sqrt{12}$	-0.15	0.10	0.25	0.22	0.69	0.25	1.12
				Panel C: 6-month/12-month			
mean	-0.80	-0.30	-0.05	0.01	0.98	-0.03	1.78
	[-2.06]	[-0.71]	[-0.10]	[0.03]	[2.12]	[-0.07]	[5.55]
$SR \times \sqrt{12}$	-0.46	-0.16	-0.02	0.01	0.52	-0.02	1.32
				Panel D: 12-month/24-month			
mean	-0.30	0.17	0.48	0.83	1.96	0.63	2.26
	[-0.76]	[0.41]	[1.13]	[1.71]	[4.03]	[1.61]	[5.58]
$SR \times \sqrt{12}$	-0.17	0.09	0.26	0.39	0.93	0.37	1.20

Newey-West t-statistics are reported in brackets.

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Trading Baskets of FVAs

Sorting on Implied Volatility Slopes: ATM

	P_1	P_2	P_3	P_4	P_5	*LEV*	*VCA*
				Panel A: 1-month/3-month			
mean	-3.16	-1.89	-1.43	-1.81	1.66	-1.33	4.82
	[-2.68]	[-1.83]	[-1.35]	[-1.96]	[1.35]	[-1.31]	[5.87]
$SR \times \sqrt{12}$	-0.68	-0.49	-0.36	-0.54	0.40	-0.37	1.36
				Panel B: 3-month/6-month			
mean	-0.74	0.42	0.57	0.21	1.88	0.47	2.61
	[-1.20]	[0.59]	[0.93]	[0.43]	[2.90]	[0.80]	[6.18]
$SR \times \sqrt{12}$	-0.28	0.16	0.25	0.10	0.79	0.21	1.39
				Panel C: 6-month/12-month			
mean	-0.96	0.07	0.10	-0.17	1.24	0.05	2.20
	[-2.11]	[0.12]	[0.21]	[-0.42]	[2.40]	[0.12]	[6.23]
$SR \times \sqrt{12}$	-0.49	0.03	0.05	-0.10	0.64	0.03	1.40
				Panel D: 12-month/24-month			
mean	-0.57	0.21	0.19	0.00	1.57	0.28	2.14
	[-1.31]	[0.41]	[0.44]	[-0.01]	[3.14]	[0.69]	[5.39]
$SR \times \sqrt{12}$	-0.30	0.10	0.10	0.00	0.74	0.17	1.18

Newey-West t-statistics are reported in brackets.

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Trading Baskets of FVAs

Sorting on Implied Volatility Slopes: Net of Bid-Ask Spreads

	P_1	P_2	P_3	P_4	P_5	*LEV*	*VCA*
				Panel A: 1-month/3-month			
mean	-4.17	-3.58	-2.96	-3.03	-0.01	-2.75	4.16
	[-3.49]	[-3.32]	[-2.73]	[-3.24]	[-0.01]	[-2.65]	[4.67]
$SR \times \sqrt{12}$	-0.88	-0.88	-0.77	-0.87	0.00	-0.75	1.16
				Panel B: 3-month/6-month			
mean	-0.48	-0.08	0.06	-0.09	1.40	0.16	1.88
	[-0.75]	[-0.11]	[0.09]	[-0.17]	[1.98]	[0.27]	[4.03]
$SR \times \sqrt{12}$	-0.17	-0.03	0.03	-0.04	0.55	0.07	0.90
				Panel C: 6-month/12-month			
mean	-0.87	-0.39	-0.51	-0.45	0.81	-0.28	1.68
	[-1.80]	[-0.63]	[-1.05]	[-1.07]	[1.38]	[-0.58]	[4.20]
$SR \times \sqrt{12}$	-0.41	-0.16	-0.27	-0.24	0.37	-0.15	0.94
				Panel D: 12-month/24-month			
mean	-0.19	0.05	0.00	0.27	1.83	0.39	2.02
	[-0.40]	[0.09]	[-0.01]	[0.66]	[3.13]	[0.86]	[4.44]
$SR \times \sqrt{12}$	-0.09	0.02	0.00	0.15	0.78	0.21	0.99

Newey-West t-statistics are reported in brackets.

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Asset Pricing Results

Time-Series Tests

	Panel A: 1-month/3-month					Panel B: 3-month/6-month				
	α	β_{LEV}	β_{VCA}	$R^2(\%)$	χ^2_α	α	β_{LEV}	β_{VCA}	$R^2(\%)$	χ^2_α
P_1	0.81	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-month/12-month					Panel D: 12-month/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]		

Newey-West t-statistics are reported in brackets.

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Trading Baskets of FVAs

Sorting on Implied Volatility Slopes: Country-level

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

Newey-West t-statistics are reported in brackets (bootstrapped in bold)

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Fama-French Equity Risk Factors

Time-Series Tests

Portfolios		α	*LEV*	*MKT*	*SMB*	*HML*	*RMW*	*CMA*	$R^2(\%)$	$R^2_{LEV}(\%)$	χ^2_α
1m/3m	P_1	-4.06***	1.68***	-0.07	-0.01	0.46	-0.11	-0.51	68.9	69.4	(<.01)
	P_2	-2.46***	1.64***	0.08	0.23	0.32	-0.3	-0.21	83.8	83.7	
	P_3	-2.05***	1.47***	0.07	0.48***	-0.34	0.46*	0.29	81.1	80.8	
	P_4	-2.06***	1.39***	0.01	0.47***	0.52**	0.12	-0.55*	82.6	82.0	
	P_5	1.26*	1.52***	-0.09	-0.41*	0.46*	-0.56	-0.58*	75.3	75.1	
3m/6m	P_1	-0.4	0.98***	-0.04	-0.06	0.09	-0.18	-0.13	72.3	72.8	
	P_2	0.79***	1.15***	0.03	-0.06	0.05	-0.23	0.09	83.2	83.3	
	P_3	0.76***	0.86***	0.05	0.08	-0.47***	0.39***	0.32	83.8	82.9	
	P_4	0.59***	0.88***	0.05	0	0.05	0.30***	-0.1	81.7	81.7	
	P_5	2.30***	0.92***	-0.11	-0.42***	0.12	-0.23	-0.26	75.7	75.3	
6m/12m	P_1	-0.85***	0.71***	-0.1	0.04	-0.04	0.03	0	68	68.4	
	P_2	0.26	0.93***	0.03	-0.02	-0.15	-0.07	0.31	80.9	81.1	
	P_3	0.09	0.69***	0.03	0.06	-0.35***	0.30**	0.16	79.3	78.5	
	P_4	0.19	0.69***	-0.02	-0.02	0	0.13	-0.08	76.8	77.1	
	P_5	1.46***	0.77***	-0.06**	-0.24	-0.22	-0.07	0.17	75.9	75.8	
12m/24m	P_1	-0.05	0.69***	-0.07	-0.11	-0.15	-0.23	0.21	70.3	70.5	
	P_2	0.62***	0.88***	0.07	-0.03	-0.19	-0.05	0.41***	81	81.1	
	P_3	0.50**	0.69***	0.1	0.12	-0.37***	0.26*	0.31*	79	78.4	
	P_4	0.79***	0.70***	0.07	0.19**	0.17	0.07	-0.01	73.4	73.3	
	P_5	2.32***	0.74***	-0.02	-0.28*	0.06	-0.02	0.16	58.5	58.4	

Newey-West *t*-statistics are reported in brackets.

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Trading Baskets of Vol Swaps

Sorting from **high** (P_1) to **low** (P_5) Implied Volatility Slopes

	P_1	P_2	P_3	P_4	P_5	LEV	VCA
	Panel A: Developed and Emerging						
mean	-18.30	-10.75	-8.14	-9.19	-6.83	-10.64	11.47
	[-6.19]	[-4.90]	[-4.17]	[-5.55]	[-3.50]	[-5.85]	[4.80]
$SR \times \sqrt{12}$	-1.73	-1.49	-1.14	-1.41	-0.85	-1.69	1.17
	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]
$SR \times \sqrt{12}$	-1.29	-1.08	-0.81	-1.40	-0.80	-1.31	0.48

Newey-West t-statistics are reported in brackets.

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Cross-Sectional Tests

Sorting from **high** (P_1) to **low** (P_5) Implied Volatility Slopes

	b_{LEV}	b_{VCA}	λ_{LEV}	λ_{VCA}	$R^2(\%)$	HJ
Panel A: Developed and Emerging						
GMM_1	-0.02	0.01	-10.61	11.11	93.7	0.17
	[-3.35]	[1.36]	[-5.55]	[4.08]		(0.59)
GMM_2	-0.02	0.01	-10.31	10.14	79.5	
	[-3.20]	[2.87]	[-5.63]	[4.43]		
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**		

Newey-West t-statistics are reported in brackets.

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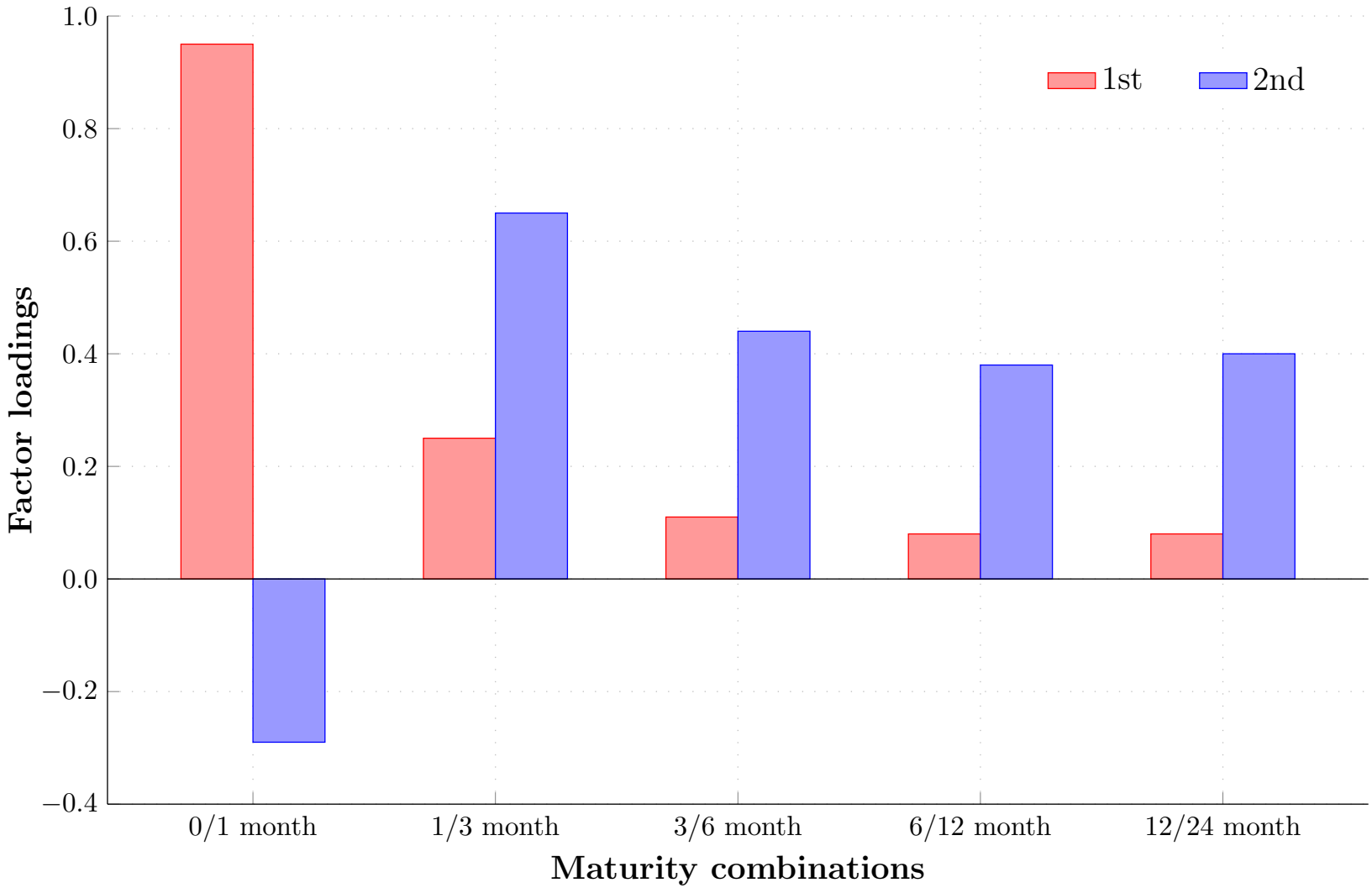
Volatility Carry Strategies

spot risk premia vs forward risk premia



What Drives Global Risk?

Decomposition of the Implied Volatility Slopes

- Every month t, we run the following cross-sectional regression:

$$y_{i,t} - y_{m,t} = \sum_{s=1}^{m} \beta^s x_{i,t}^s + \varepsilon_{i,t}$$

  - $y_{i,t} \rightarrow$ implied volatility slope at time t for country i,
  - $y_{m,t} \rightarrow$ cross-sectional median of the slopes at time t,
  - $x_{i,t}^s \rightarrow$ conditioning variable s for country i,
  - $\varepsilon_{i,t} \rightarrow$ error term unrelated to conditioning variables for country i.

- We then construct linear portfolio weights as follows

$$w_{i,t}^s = \hat{\beta}^s x_{i,t}^s / c_t, \qquad w_{i,t}^{\varepsilon} = \varepsilon_{i,t} / c_t,$$

  - $c_t \rightarrow$ scaling factor such that sum of the long (short) positions equals 1 (-1),
  - $c_t = \sum_i^N (y_t^i)^+ \rightarrow$ positive weights; $c_t = -\sum_i^N (y_t^i)^- \rightarrow$ negative weights.

What Drives Global Risk?

Decomposition of the Implied Volatility Slopes

- Finally, we calculate next month excess return as

$$RX^s_{t+1} = \sum_{i=1}^{N} -w^s_{i,t} rx_{i,t+1},$$

  - $rx^i_{t+1} \rightarrow$ implied volatility excess return for country i at time $t+1$,
  - $-w^s_{i,t} \rightarrow$ we buy (sell) FVAs with low (high) implied vol slopes,
  - similarly, for the residual component.

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