Carry Trades and Global Foreign Exchange Volatility

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Motivation

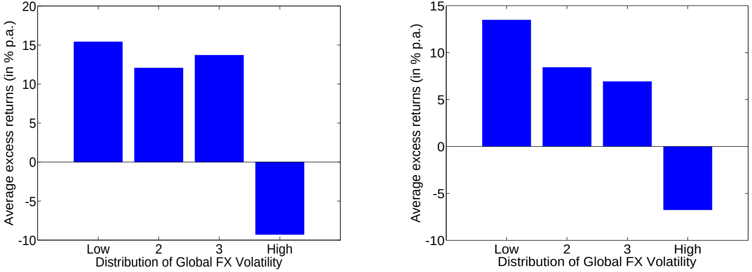
- We study the **risk-return** profile of **carry trades** in FX markets:
  - Borrow money in low interest rate currencies (e.g. JPY).
  - Invest in high interest rate currencies (e.g. AUD).
- Uncovered interest parity (UIP) suggests that changes in the exchange rates will eliminate this interest rate margin.
- However, this mechanism fails on a grand scale:
  - "forward premium puzzle" (Hansen, Hodrick 1980, 1983; Fama, 1984).
  - considerable returns to currency speculation (e.g. Lustig, Verdelhan, 2007; Burnside et al., 2008, 2009; Lustig, Roussanov, Verdelhan, 2009).

⇒ **This paper**: cross-section of carry trade returns can be explained by **exposure** to global FX **volatility risk**.

Preview: Excess returns and volatility states

Figure : Excess Returns on Carry Trade (H/L) Portfolio and Volatility

(a) All Countries (b) Developed Countries



Motivation for volatility risk

- Intertemporal CAPM (ICAPM):
  - According to ICAPM theory (Merton, 1973; Campbell, 1993), investors are concerned about deteriorations of the investment opportunities set.
  - Chen (2003) and Ang et al. (2006): volatility as a state variable affecting the evolution of future investment opportunities

    ⇒ (unexpected) market volatility as a **systematic risk factor**.
- Implications related to Coskew (Harvey and Siddique, 1999), non-linear pricing kernels (Dittmar, 2005).
- This paper takes a cross-sectional asset pricing / SDF route to explain the returns to currency speculation.

Recent literature

- Lustig and Verdelhan (2007) were the first to look at a cross-section of carry trade portfolios – offer a consumption-based explanation.
- Brunnermeier et al. (2008): currency crashes and funding liquidity.
- Burnside et al. (2008, 2009): role of Peso problems, standard risk factors fail to explain returns to currency speculation.
- Lustig, Roussanov, and Verdelhan (LRV, 2009) study an empirically derived "slope factor" to price the cross-section of currency returns
    - Two important factors: a level (Dollar risk) and a slope (HML_{FX}) factor.

Overview of main results

1. Global FX volatility accounts for the cross-sectional spread in expected carry trade returns.

2. Sorting currencies by their exposure to past volatility innovations "reproduces" the cross-section of carry trade portfolios.

3. Volatility dominates liquidity risk in horse races.
   - suggests systematic results across asset classes (e.g. Ang et al. 2006; Bandi et al. 2008; Da, Schaumburg, 2009).

4. Proposed risk factor is also helpful for pricing other assets as well.

$\Rightarrow$ Overall, the results in this paper suggest that there is a meaningful **risk-return relation** in the FX market.

Data

- We use data on forward rates (f) and spot rates (s) from BBI and Reuters/WMF (via Datastream).
- Total sample consists of 48 countries. Countries
- We also use a smaller sample of 15 developed countries.
- Sample period: 11/1983 – 08/2009 (monthly).

Currency excess returns

- We calculate excess returns for a US investor.
- USD excess return to investing in foreign currency k:

$$rx_{t+1}^{k} = i_t^k - i_t^{US} - \triangle s_{t+1}^{k}$$

s_t^k: log spot exchange rate (foreign currency per one unit USD)
(s increases – USD appreciates).

- Since the (log) forward discount $f_t^k - s_t^k \simeq i_t^k - i_t^{US}$ (CIP):

$$rx_{t+1}^{k} = f_t^k - s_{t+1}^{k}$$

Currency portfolios

- Sort currencies into five portfolios based on (lagged) forward discounts (i.e. interest rate differentials):
  - Portfolio 1: 20% of all currencies with lowest forward discounts – i.e. lowest interest rates relative to the US.
  - ...
  - Portfolio 5: 20% of all currencies with highest forward discounts – i.e. highest interest rates.
- Monthly re-balancing; transaction-cost adjusted returns. TC
- Two important portfolios (LRV 2009):
  - Average of five portfolios: "Dollar Risk"-factor (DOL)
  - Portfolio 5 minus Portfolio 1: "Carry Trade"-factor (HML_{FX})

Currency portfolios: Excess returns

All countries (with b-a)							
Portfolio	1	2	3	4	5	Avg.	H/L
Mean	-1.46	-0.10	2.65	3.18	5.76	2.01	7.23
Sharpe Ratio	-0.17	-0.01	0.33	0.38	0.54	0.27	0.74
Developed countries (with b-a)							
Portfolio	1	2	3	4	5	Avg.	H/L
Mean	-0.82	1.55	1.98	2.82	4.90	2.09	5.72
Sharpe Ratio	-0.08	0.16	0.21	0.30	0.45	0.24	0.56

Notes: The sample period is 11/1983 – 08/2009, annualized monthly returns

A parsimonious linear two-factor SDF

- Chen (2003) extends discrete-time ICAPM of Campbell (1993,1996) by time-varying volatility ▸ ICAPM

  ⇒ covariance with innovations to aggregate vol. as additional source of risk.

- Negative volatility risk premium:
  - High unexpected volatility ("bad" state of the world).
  - Assets covarying positively with market vol. innovations provide a good hedge ⇒ low expected return.

- A parsimonious two-factor SDF in line with the literature on equity markets (Ang et al. 2006):

$$m_{t+1} = 1 - b_1 r^e_{m,t+1} - b_2 \Delta V_{t+1}$$

FX Volatility proxy

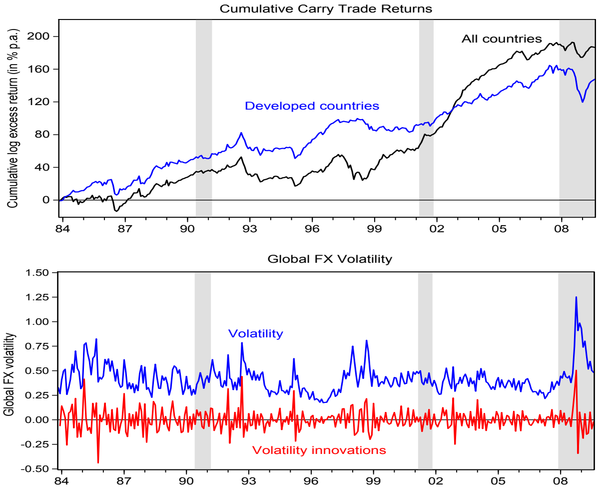
$$\sigma_t^{FX} = \frac{1}{T_t} \sum_{\tau \in T_t} \left[\sum_{k \in K_\tau} \left(\frac{|r_\tau^k|}{K_\tau} \right) \right]$$

- r_τ^k – return of currency k on day τ (daily spot rate change Δs_τ).
- K_τ – number of available currencies on day τ.
- T_t – number of trading days in month t.

  $\Rightarrow$ Average of daily absolute returns (across countries), averaged over the month.

- According to the ICAPM, only *unexpected* volatility should be priced - volatility innovations obtained from a simple AR(1).
- Carry trades perform poorly when global FX vol. is high: $Corr(\Delta\sigma_t^{FX}, HML_{FX,t}) \simeq -0.30$

Carry trades and global FX volatility



Empirical methodology: GMM

- Basic no-arbitrage pricing equation

$$\mathbb{E}[m_{t+1} rx^i_{t+1}] = 0, \quad i = 1, \ldots, N$$

with a linear SDF $m_t = 1 - b'(h_t - \mu)$.

- Estimation via GMM

$$g(z_t, \theta) = \begin{bmatrix} [1 - b'(h_t - \mu)]\, rx_t \\ h_t - \mu \\ (h_t - \mu)(h_t - \mu)' - \Sigma_h \end{bmatrix}$$

- We report b, implied λs, cross-sectional R^2s, and HJ-dist with simulated p-values.

Further methodological details

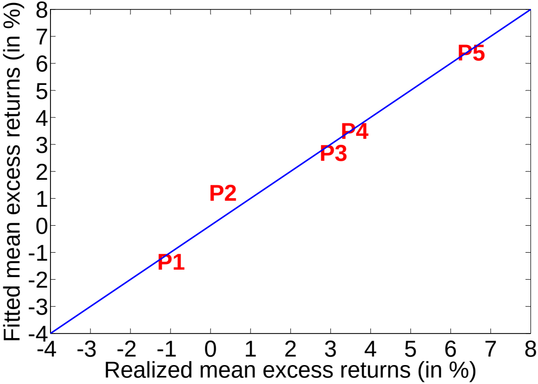
Overview of major results

1. Volatility risk captures the spread in cross-sectional carry trade excess returns.
2. Sorting currencies on past volatility-betas reproduces the cross-section of carry trade portfolios.
3. Volatility risk dominates in horse races with liquidity proxies.

Volatility risk: Cross-sectional asset pricing tests

Factor Betas				
All countries (with b-a)				
PF	α	DOL	VOL	R^2
1	-0.29	1.01	4.34	0.76
2	-0.15	0.84	1.00	0.74
3	0.05	0.97	-0.30	0.79
4	0.09	1.02	-1.06	0.83
5	0.30	1.15	-3.98	0.67
Factor Prices and Loadings				
All countries (with b-a)				
GMM	DOL	VOL	R^2	HJ-dist
b	0.00	-7.15	0.97	0.08
s.e.	(0.05)	(2.96)		(0.79)
λ	0.21	-0.07		
s.e.	(0.25)	(0.03)		
FMB	DOL	VOL	χ^2_{SH}	χ^2_{NW}
λ	0.21	-0.07	1.35	0.94
(Sh)	(0.15)	(0.02)	(0.72)	(0.82)
(NW)	(0.12)	(0.03)		

Volatility risk: Cross-sectional asset pricing tests



Volatility risk: Factor-mimicking portfolio

- Global FX volatility innovations are not a traded risk factor (unlike market excess return in a standard CAPM or LRV's HML_{FX}).
- We also build a factor-mimicking portfolio for the volatility factor by projecting volatility innovations on the five currency portfolios:

This yields a factor-mimicking portfolio:

$$rx_{t+1}^{FM} = 0.202 rx_{t+1}^{1} - 0.054 rx_{t+1}^{2} - 0.063 rx_{t+1}^{3} - 0.068 rx_{t+1}^{4} - 0.071 rx_{t+1}^{5}$$

Average return: $\overline{rx}_{t+1}^{FM} = -0.107\%$ p.m. ($\approx -1.3\%$ p.a.).

Advantages:

- Tradable risk factor.
- Check for plausibility of prices of risk.

Volatility risk: Factor mimicking portfolio – Results

Panel A: Factor Prices and Loadings				
All countries (with b-a)				
GMM	DOL	VOL_{FM}	R^2	HJ-dist
b	0.00	-0.71	0.97	0.08
s.e.	(0.03)	(0.23)		(0.64)
λ	0.21	-0.10		
s.e.	(0.15)	(0.03)		
FMB	DOL	VOL_{FM}	χ^2_{SH}	χ^2_{NW}
λ	0.21	-0.10	1.89	4.59
(Sh)	(0.13)	(0.02)	(0.60)	(0.20)
(NW)	(0.12)	(0.02)		

⇒ Factor price estimate for the FM portfolio: -1.22% p.a., close to the average return p.a. on the FM PF.

Volatility risk: Factor risk price – FX option markets

- JP Morgan data on FX options, maturity one month.
- 29 currencies quoted against the USD, sample period: 1996-2009.

⇒ How does our factor risk price estimate compare to estimates from option markets?

⇒ Build a zero-beta straddle portfolio (long calls, long puts – equal weights) in the spirit of Coval/Shumway (2002)

- Loads on volatility risk but not market risk.
- Average return on the straddle portfolio $\simeq$ -1.2% p.a.
  - Close to our estimates based on the FM PF.
  - Close in magnitude to factor risk price for stock markets of -1% p.a. reported by Ang et al. (2006)

Volatility risk: Beta sorts

⇒ Sort currencies into five portfolios based on their past betas with global FX vol. innovations, 36 months rolling window.

All countries							
Portfolio	1	2	3	4	5	Avg.	H/L
Mean	4.67	3.78	2.73	1.43	0.25	2.57	4.43
Sharpe Ratio	0.53	0.49	0.41	0.20	0.03	0.39	0.52
pre-f. $f - s$	3.71	3.20	1.35	0.28	0.41		
post-f. $f - s$	4.26	2.63	1.36	0.70	0.58		

- Currencies with low vol-betas (PF 1) – low payoffs in times of high vol. innovations: high excess returns and high $f - s$.
- Currencies with high vol-betas (PF 5) – hedge against vol. risk: low excess returns and low $f - s$.

⇒ Carry Trade selects currencies subject to high volatility risk.

Volatility versus liquidity risk

(II-)Liquidity proxies

- Global foreign exchange bid-ask spreads:

$$\psi_t^{FX} = \frac{1}{T_t} \sum_{\tau \in T_t} \left[\sum_{k \in K_\tau} \left(\frac{\psi_\tau^k}{K_\tau} \right) \right]$$

- TED spread: 3M interbank rate (LIBOR) minus 3M T-Bill rate (Brunnermeier, Nagel, Pedersen, 2008).
- U.S. stock market liquidity measure (Pastor/Stambaugh, 2003).
- FX vol. is correlated with illiquidity proxies ▸ Correlations

Volatility versus liquidity risk: Liquidity risk

Example: Bid-ask spreads

Panel A: Factor Prices and Loadings – Global bid-ask spreads									
All countries (with b-a)					Developed countries (with b-a)				
GMM	DOL	BAS	R^2	HJ-dist	GMM	DOL	BAS	R^2	HJ-dist
b	0.00	-54.06	0.74	0.19	b	0.02	-36.68	0.58	0.13
s.e.	(0.05)	(26.48)		(0.16)	s.e.	(0.03)	(22.63)		(0.36)
λ	0.21	-0.03			λ	0.22	-0.02		
s.e.	(0.24)	(0.01)			s.e.	(0.21)	(0.01)		

Volatility versus liquidity risk: Horse races

Panel A: Volatility and global bid-ask spreads					
GMM	DOL	BAS	VOL	R^2	HJ-dist
b	0.01	18.23	-8.11	0.98	0.06
s.e.	(0.07)	(36.08)	(4.24)		(0.82)
λ	0.21	0.01	-0.08		
s.e.	(0.31)	(0.02)	(0.04)		
Panel B: Volatility and TED spread					
GMM	DOL	TED	VOL	R^2	HJ-dist
b	0.01	-1.03	-6.17	0.98	0.07
s.e.	(0.05)	(2.94)	(3.28)		(0.66)
λ	0.21	-0.08	-0.06		
s.e.	(0.25)	(0.24)	(0.03)		
Panel C: Volatility and P/S liquidity measure					
GMM	DOL	PS	VOL	R^2	HJ-dist
b	-0.01	-1.65	-7.46	0.97	0.08
s.e.	(0.07)	(10.36)	(3.82)		(0.65)
λ	0.18	-0.01	-0.08		
s.e.	(0.29)	(0.04)	(0.04)		

Overview of further results

1. Extreme observations: winsorized series and estimation by empirical likelihood approach.
2. Volatility risk ($\Delta\sigma^{FX}$) is related, but not equivalent to the carry trade factor HML_{FX}.
3. Our volatility risk factor is also priced in other cross-sections: FX momentum, U.S. equity momentum, U.S. corporate bonds and individual FX returns.
4. Further assets (FX options, int. bond portfolios) and more robustness tests.

Rare events

- Impact of extreme observations?
- GMM treats observations symmetrically.
- Empirical likelihood
  - Information in extreme observations (endogeneously) receives different weight than "normal" observations.
  - Attractive estimation approach in the presence of rare events or peso problems (Ghosh/Julliard 2008).
- Effect on factor risk prices?

Extreme observations – Empirical Likelihood

Panel A: All countries									
	EL estimates					Blockwise – EL estimates			
	b_{DOL}	b_{VOL}	λ_{DOL}	λ_{VOL}		b_{DOL}	b_{VOL}	λ_{DOL}	λ_{VOL}
coeff.	0.01	-6.79	0.25	-0.07	coeff	0.01	-6.53	0.24	-0.07
s.e.	(0.05)	(2.52)	(0.24)	(0.03)	s.e.	(0.05)	(2.54)	(0.27)	(0.03)
OIR-Test	1.33				OIR-Test	3.37			
p-value	(0.72)				p-value	(0.34)			
Panel B: Developed countries									
	EL estimates					Blockwise – EL estimates			
	b_{DOL}	b_{VOL}	λ_{DOL}	λ_{VOL}		b_{DOL}	b_{VOL}	λ_{DOL}	λ_{VOL}
coeff.	0.03	-5.32	0.28	-0.06	coeff	0.02	-5.27	0.27	-0.06
s.e.	(0.04)	(3.09)	(0.21)	(0.03)	s.e.	(0.04)	(3.08)	(0.24)	(0.04)
OIR-Test	0.76				OIR-Test	5.55			
p-value	(0.86)				p-value	(0.14)			

Global FX volatility innovations and HML_{FX}

A non-traded factor *cannot* beat a (return-based) factor mimicking portfolio factor in a horse race (Cochrane 2005).

⇒ A level playing field:

Horse races between (return-based) VOL_{FM} and HML_{FX}.

- HML_{FX} (2nd PC of CT returns) and VOL_{FM} – no clear winner (some multi-collinearity). Res1
- Orthogonal component of HML_{FX} does not contain explanatory power once considered jointly with VOL_{FM}. Res2

⇒ Both global FX vol. risk and HML_{FX} are powerful factors to explain the cross-section of FX risk premia.

Other assets: FX momentum, U.S. corporate bonds

- 5 FX momentum portfolios (sorted on returns over past 12 months), 11/1983-08/2009.
- 6 corporate bond portfolios (AAA-BA), duration-adjusted as in Da/Schaumburg (2009), 04/1990-08/2009.

5 Currency Momentum Portfolios					US corporate bonds				
GMM	DOL	VOL	R^2	HJ-dist	GMM	DOL	VOL	R^2	HJ-dist
b	0.05	-6.36	0.59	0.18	b	-0.39	-12.33	0.93	0.14
s.e.	(0.05)	(4.69)		(0.10)	s.e.	(0.34)	(8.38)		(0.81)
λ	0.36	-0.07			λ	-0.93	-0.10		
s.e.	(0.27)	(0.05)			s.e.	(1.31)	(0.08)		
FMB	DOL	VOL	χ^2_{SH}	χ^2_{NW}	FMB	DOL	VOL	χ^2_{SH}	χ^2_{NW}
λ	0.36	-0.07	6.79	14.35	λ	-0.93	-0.10	1.91	1.64
(Sh)	(0.15)	(0.03)	(0.08)	(0.00)	(Sh)	(1.08)	(0.04)	(0.75)	(0.89)
(NW)	(0.15)	(0.04)			(NW)	(1.30)	(0.07)		

Other assets: U.S. equity momentum

- 10 U.S. equity momentum portfolios (K. French's website).

US equity momentum				
GMM	DOL	VOL	R^2	HJ-dist
b	-0.33	-13.79	0.41	0.35
s.e.	(0.54)	(7.07)		(0.01)
λ	-1.12	-0.13		
s.e.	(2.38)	(0.07)		
FMB	DOL	VOL	χ^2_{SH}	χ^2_{NW}
λ	-1.12	-0.13	12.96	11.77
(Sh)	(1.84)	(0.05)	(0.11)	(0.16)
(NW)	(2.27)	(0.06)		

HMLFX Traditional AP Models

Other assets: Individual currencies

	DOL	VOL	HML_{FX}	R^2
λ	0.25	-0.05		0.31
t-stat	[2.08]	[-3.19]		
BS p-val	(0.25)	(0.05)		(0.01)
λ	0.29		0.67	0.10
t-stat	[2.40]		[2.67]	
BS p-val	(0.16)		(0.12)	(0.79)
λ	0.25	-0.05	0.33	0.27
t-stat	[2.01]	[-2.84]	[1.09]	
BS p-val	(0.23)	(0.08)	(0.51)	(0.01)

FX Options

- JP Morgan data on FX options, maturity one month.
- 29 currencies quoted against the USD, sample period: 1996-2009.
- Quoted implied volatilities for Calls and Puts, different moneyness (ATM, 25-Delta, 10-Delta).
- IV patterns for portfolios sorted on lagged forward discounts (f-s) and lagged volatility betas. Results
- Estimation on a cross-section of portfolio returns on FX option strategies.

FX Options: Cross-sectional asset pricing tests

12 option portfolios (risk reversals, bull spreads and bear spreads).

12 Option portfolios				
GMM	DOL	VOL	R^2	HJ-dist
b	-0.08	-9.18	0.91	0.36
s.e.	(0.08)	(5.20)		(0.38)
λ	0.15	-0.08		
s.e.	(0.44)	(0.04)		
FMB	DOL	VOL	χ^2_{SH}	χ^2_{NW}
λ	0.15	-0.08	14.28	7.44
(Sh)	(0.20)	(0.02)	(0.16)	(0.68)
(NW)	(0.19)	(0.03)		

FX Opt.

FX Options: Cross-sectional asset pricing tests

12 option portfolios (risk reversals, bull spreads and bear spreads).

12 Option portfolios				
GMM	DOL	VOL	R^2	HJ-dist
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(Sh)	(0.20)	(0.02)	(0.16)	(0.68)
(NW)	(0.19)	(0.03)		

FX Opt.

More robustness tests

- Different proxies for aggregate volatility:
  - Country weights.
  - Implied volatility: CBOE VIX index and JP Morgan FX VIX. ▸ IV
- Longer maturities. ▸ Bonds
- Potential EIV problems due to pre-estimation of vol. innovations can be ruled out (GMM System approach).
- Coskewness measure of Harvey/Siddique – no monotone patterns.
- Other base currencies (GBP, CHF, JPY), i.e. other investors.
- Sub-samples analysis.
- Non-linearities.

Conclusions

1. Volatility risk matters for explaining carry trade risk premia.
   - High interest rate currencies ("investment currencies") perform particularly poorly during times of high (unexpected) volatility.
   - Low interest rate currencies ("funding currencies" in the carry trade) provide a hedge against volatility innovations.
2. Our results are in line with results for other asset classes:
   - Cross-sections of stock returns (e.g. Ang et al., 2006), stock options and corp. bonds (Da, Schaumburg, 2009).
   - Volatility risk dominates proxies for market (il)liquidity.
3. Many more results indicating that risk premia in FX markets reflect compensation for volatility risk.

$\Rightarrow$ Meaningful risk-return relation in the FX market.

Sample countries

Australia	Austria	Belgium	Brazil	Bulgaria
Canada	Croatia	Cyprus	Czech Rep.	Denmark
Egypt	Euro area	Finland	France	Germany
Greece	Hong Kong	Hungary	India	Indonesia
Ireland	Israel	Italy	Iceland	Japan
Kuwait	Malaysia	Mexico	Netherlands	N. Zealand
Norway	Philippines	Poland	Portugal	Russia
Saudi Arabia	Singapore	Slovakia	Slovenia	S. Africa
South Korea	Spain	Sweden	Switzerland	Taiwan
Thailand	Ukraine	U.K.		

Total sample consists of 48 countries. Developed country sample: 15 countries highlighted in red

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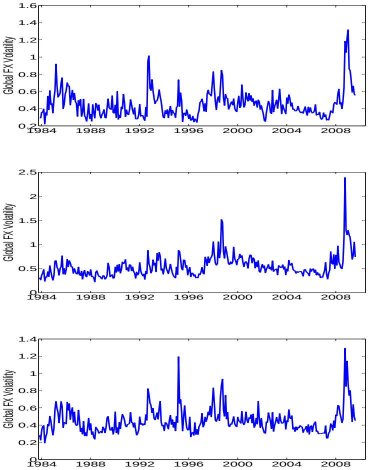
Other base currencies: FX volatility proxy



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Currency excess returns

Transaction costs

- Long position (sell USD forward in t, buy spot USD in $t+1$):

$$rx^{l}_{t+1} = f^{b}_{t} - s^{a}_{t+1}$$

- Short position (buy USD forward in t, sell spot USD in $t+1$):

$$rx^{s}_{t+1} = -f^{a}_{t} + s^{b}_{t+1}$$

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Volatility versus liquidity risk: Correlations

Correlation coefficients				
	VOL	BAS	TED	-PS
VOL	1.000	0.365	0.357	0.116
BAS		1.000	-0.034	0.062
TED			1.000	0.097
-PS				1.000

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Volatility versus liquidity risk: Liquidity risk

Panel A: Factor Prices and Loadings – Global bid-ask spreads

All countries (with b-a)					Developed countries (with b-a)				
GMM	DOL	BAS	R^2	HJ-dist	GMM	DOL	BAS	R^2	HJ-dist
b	0.00	-54.06	0.74	0.19	b	0.02	-36.68	0.58	0.13
s.e.	(0.05)	(26.48)		(0.16)	s.e.	(0.03)	(22.63)		(0.36)
λ	0.21	-0.03			λ	0.22	-0.02		
s.e.	(0.24)	(0.01)			s.e.	(0.21)	(0.01)		

Panel B: Factor Prices and Loadings – TED spread

All countries (with b-a)					Developed countries (with b-a)				
GMM	DOL	TED	R^2	HJ-dist	GMM	DOL	TED	R^2	HJ-dist
b	0.04	-4.38	0.73	0.13	b	0.03	-2.44	0.81	0.66
s.e.	(0.07)	(3.35)		(0.53)	s.e.	(0.04)	(2.06)		(0.16)
λ	0.21	-0.36			λ	0.22	-0.20		
s.e.	(0.30)	(0.28)			s.e.	(0.24)	(0.17)		

Panel C: Factor Prices and Loadings – Pastor/Stambaugh liquidity measure

All countries (with b-a)					Developed countries (with b-a)				
GMM	DOL	PS	R^2	HJ-dist	GMM	DOL	PS	R^2	HJ-dist
b	0.06	12.89	0.70	0.19	b	0.05	12.24	0.97	0.05
s.e.	(0.05)	(8.29)		(0.09)	s.e.	(0.04)	(9.05)		(0.94)
λ	0.18	0.05			λ	0.18	0.05		
s.e.	(0.22)	(0.03)			s.e.	(0.23)	(0.03)		

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Empirical methodology

The baseline SDF specification is given as

$$m_{t+1} = 1 - b_{DOL}(DOL_{t+1} - \mu_{DOL}) - b_{VOL}\triangle\sigma^{FX}_{t+1}.$$

A few further details:

- Estimation by pre-specified weighting matrix, equal weights for the test asset returns.
- HAC standard errors – Newey-West with optimal lag selection by Andrews (1991).
- Factor risk prices λ backed out from the SDF slope parameters.
- We also report results from traditional FMB OLS two-pass regressions (incl. Shanken adjustments) – i.e. beta-pricing framework.

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ICAPM motivation of volatility risk

- Asset pricing in the discrete-time ICAPM (Campbell, 1993/1996 and extended by Chen 2003)

$$E_t\left(r^e_{i,t+1}\right) + \frac{V_{ii,t}}{2} = \gamma V_{im,t} + (\gamma - 1)\, V_{ih,t} - \frac{(\gamma-1)^2}{2} V_{i\nu,t}$$

Three sources of risk premia:

1. $V_{im,t} \equiv Cov_t\left(r^e_{i,t+1}, r_{m,t+1}\right)$, $r_{m,t+1}$ is the market return.
2. $V_{ih,t} \equiv Cov_t\left(r^e_{i,t+1}, r_{h,t+1}\right)$, $r_{h,t+1} \equiv (E_{t+1} - E_t)\sum_{j=1}^{\infty} \rho^j r_{m,t+1+j}$ (changes in forecasts of future market returns).
3. $V_{i\nu,t} \equiv Cov_t\left(r^e_{i,t+1}, r_{\nu,t+1}\right)$, $r_{\nu,t+1} \equiv (E_{t+1} - E_t)\sum_{j=1}^{\infty} \rho^j\, Var_{t+j}\left(r_{m,t+j+1} + r_{h,t+j+1}\right)$ (changes in forecasts of future market variances).

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Horse-Races – Interpretation

- A non-traded factor cannot beat a (return-based) factor mimicking portfolio factor in a horse race (e.g. Cochrane 2005).
- A level playing field: Horse races between the (return-based) VOL_{FM} and HML_{FX}.
  - HML_{FX} (essentially the second PC of CT returns) and VOL_{FM} – no clear winner (some multi-collinearity).
  - Orthogonal component of HML_{FX} does not contain explanatory power once included jointly with VOL_{FM}.
- Individual currencies, economic magnitude of pricing errors: $\Rightarrow$ points towards an important role of volatility risk.

$\Rightarrow$ Both HML_{FX} and global FX vol. risk are powerful factors to explain the cross-section of FX risk premia.

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Global FX volatility innovations and HML_{FX}

⇒ A non-traded factor can never beat a (return-based) factor mimicking portfolio in a horse race (e.g. Cochrane 2005).

⇒ A level playing field: Horse races between (return-based) vol. innovations factor mimicking portfolio VOL_{FM} and HML_{FX}.

Panel A: Volatility innovations and HML_{FX}					
GMM	DOL	VOL	HML_{FX}	R^2	HJ-dist
b	0.01	-6.60	0.01	0.97	0.08
s.e.	(0.06)	(6.06)	(0.07)		(0.63)
λ	0.21	-0.07	0.65		
s.e.	(0.27)	(0.06)	(0.33)		
Panel B: Factor-mimicking portfolio and HML_{FX}					
GMM	DOL	VOL_{FM}	HML_{FX}	R^2	HJ-dist
b	0.06	-2.54	-0.06	0.98	0.06
s.e.	(0.05)	(1.52)	(0.09)		(0.69)
λ	0.17	-0.04	0.59		
s.e.	(0.18)	(0.01)	(0.27)		

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Global FX volatility innovations and HML_{FX}

HML_{FX} ($\sim$ 2nd PC of CT returns) and VOL_{FM} are strongly related

$\Rightarrow$ multicollinearity issues when considering both at the same time.

$\Rightarrow$ orthogonalizing VOL_{FM} and HML_{FX} against each other.

Panel C: Factor-mimicking portfolio (orth.) and HML_{FX}					
GMM	DOL	$\text{VOL}_{FM}^{Orth.}$	HML_{FX}	R^2	HJ-dist
b	0.00	-6.67	0.08	0.97	0.08
s.e.	(0.04)	(4.34)	(0.03)		(0.46)
λ	0.21	-0.02	0.65		
s.e.	(0.16)	(0.01)	(0.24)		
Panel D: Factor-mimicking portfolio and HML_{FX} (orth.)					
GMM	DOL	VOL_{FM}	$HML_{FX}^{Orth.}$	R^2	HJ-dist
b	0.00	-0.70	0.01	0.97	0.08
s.e.	(0.04)	(0.27)	(0.06)		(0.51)
λ	0.21	-0.10	0.07		
s.e.	(0.19)	(0.04)	(1.09)		

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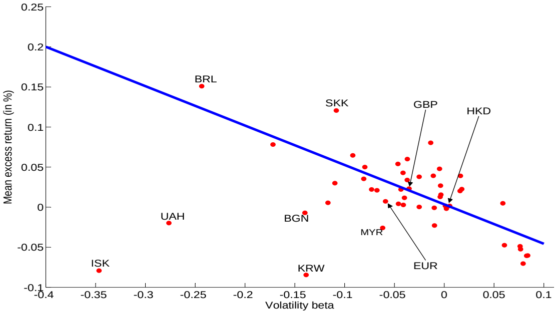
Other test assets: Individual currencies



Notes: This figure cross-plots individual currencies' volatility betas (horizontal axis) against mean excess returns (vertical axis). The red line shows the linear relation between betas and returns from a robust regression of returns on betas. Returns and betas for each currencies are calculated over the full available sample for that currency.

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Implied volatility indices

Factor Betas									
JPM G-7 Currency VIX					S&P 500 VIX				
PF	α	DOL	$\triangle VIX$	R^2	PF	α	DOL	$\triangle VIX$	R^2
1	-0.31	0.90	0.48	0.69	1	-0.31	0.97	0.07	0.71
	(0.09)	(0.06)	(0.06)			(0.09)	(0.05)	(0.02)	
2	-0.15	0.85	0.12	0.73	2	-0.17	0.84	0.01	0.73
	(0.07)	(0.05)	(-0.16)			(0.06)	(0.04)	(-0.02)	
3	0.07	1.00	0.03	0.77	3	0.07	1.02	0.01	0.81
	(0.07)	(0.05)	(0.08)			(0.06)	(0.04)	(0.02)	
4	0.03	1.02	-0.16	0.80	4	0.07	1.05	-0.02	0.83
	(0.07)	(0.05)	(0.08)			(0.06)	(0.04)	(0.02)	
5	0.37	1.24	-0.46	0.67	5	0.34	1.13	-0.09	0.65
	(0.13)	(0.10)	(0.14)			(0.12)	(0.07)	(0.03)	

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FX Option Portfolios

- Risk Reversals: long 25-Delta Put, short 25-Delta Call
- Bull spreads: long ATM Call, short 25-Delta Call
- Bear spreads: long ATM Put, short 25-Delta Put
- 4 portfolios for each strategy depending on lagged forward discount.

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Other test assets and canonical models of equity pricing

- 10 U.S. equity momentum portfolios.
- Traditional asset pricing models (CAPM, Fama-French 3-factor model).

Factor Prices and Loadings

US stock momentum: CAPM			
GMM	MKTRF	R^2	HJ-dist
b	0.05	-1.21	0.33
s.e.	(0.02)		(0.00)
λ	0.81		
s.e.	(0.36)		
FMB	MKTRF	χ^2_{SH}	χ^2_{NW}
λ	0.81	37.41	39.22
(Sh)	(0.27)	(0.00)	(0.00)
(NW)	(0.30)		

US stock momentum: 3-factor model					
GMM	MKTRF	SMB	HML	R^2	HJ-dist
b	0.03	-0.30	-0.28	0.50	0.31
s.e.	(0.04)	(0.18)	(0.22)		(0.02)
λ	1.12	-2.01	-1.86		
s.e.	(0.43)	(1.25)	(1.52)		
FMB	MKTRF	SMB	HML	χ^2_{SH}	χ^2_{NW}
λ	1.12	-2.01	-1.86	15.68	16.58
(Sh)	(0.28)	(0.84)	(0.98)	(0.03)	(0.01)
(NW)	(0.29)	(1.14)	(1.42)		

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Other assets: HML_{FX}

5 Currency Momentum Portfolios				
GMM	DOL	HML_{FX}	R^2	HJ-dist
b	0.07	0.03	0.01	0.18
s.e.	(0.04)	(0.05)		(0.06)
λ	0.32	0.26		
s.e.	(0.16)	(0.42)		
US stock momentum				
GMM	DOL	HML_{FX}	R^2	HJ-dist
b	-1.22	0.71	-1.26	0.37
s.e.	(1.72)	(0.85)		(0.00)
λ	-4.91	4.60		
s.e.	(7.13)	(5.46)		
US corporate bonds				
GMM	DOL	HML_{FX}	R^2	HJ-dist
b	-0.41	0.48	0.27	0.28
s.e.	(0.29)	(0.49)		(0.01)
λ	-0.79	2.93		
s.e.	(1.21)	(3.58)		

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Other assets

- 5 portfolios of international bonds of different maturities sorted on redemption yield ("bond carry trade").
- FX momentum portfolios (sorted on returns over past 12 months).

5 International Bond Portfolios					5 Currency Momentum Portfolios				
GMM	DOL	VOL	R^2	HJ-dist	GMM	DOL	VOL	R^2	HJ-dist
b	0.06	-8.57	0.68	0.20	b	0.05	-6.36	0.59	0.18
s.e.	(0.04)	(5.57)		(0.07)	s.e.	(0.05)	(4.69)		(0.10)
λ	0.46	-0.09			λ	0.36	-0.07		
s.e.	(0.31)	(0.05)			s.e.	(0.27)	(0.05)		
FMB	DOL	VOL	χ^2_{SH}	χ^2_{NW}	FMB	DOL	VOL	χ^2_{SH}	χ^2_{NW}
λ	0.46	-0.09	7.32	5.91	λ	0.36	-0.07	6.79	14.35
(Sh)	(0.21)	(0.03)	(0.06)	(0.12)	(Sh)	(0.15)	(0.03)	(0.08)	(0.00)
(NW)	(0.16)	(0.05)			(NW)	(0.15)	(0.04)		

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FX Options

IV patterns across portfolios

Panel A: Carry Trade Portfolios						
Portfolio	(low f-s)	2	3	4	(high f-s)	5-1
10-Delta Put – 10-Delta Call	-7.96	2.20	5.07	15.85	26.17	34.12
	[-3.91]	[1.47]	[1.77]	[5.50]	[9.47]	[10.11]
Panel B: Portfolios based on Volatility Betas						
Portfolio	(low beta)	2	3	4	(high beta)	5-1
10-Delta Put – 10-Delta Call	10.53	9.61	7.42	1.67	-1.19	-11.72
	[4.99]	[4.00]	[1.67]	[0.52]	[-0.56]	[-3.75]

⇒ High risk currencies (high f-s, low vol beta): higher IVs for puts than for calls

⇒ Portfolio insurance for these high risk currencies is expensive.

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