Common Risk Factors in Currency Markets
Separate Appendix *

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May 3, 2011

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Abstract

In this separate appendix, we first report in Section 1 the asset pricing results obtained with the first principal components of our currency portfolios. We then check in Section 2 that our betas are driven by exchange rate changes, not interest rate variations. Section 3 reports an additional robustness check: we split the sample of countries in two groups and show that risk factors built using currencies that do not belong to the portfolios used as test assets can still price these assets. Section 4 checks that our two risk factors (RX and HML_{FX}) in the model price the cross-section of simulated portfolios and replicate the asset pricing tests on individual currencies. Finally, Section 5 focuses on portfolios of countries sorted by their global equity volatility betas.

1 Principal Components as Asset Pricing Factors

The paper presents our main asset pricing estimates. In this appendix, we first build some intuition for why the second principal component is a good candidate risk factor. Following Cochrane and Piazzesi (2008), we compute the covariance of each principal component with the currency portfolio returns, and we compare these covariances (indicated by triangles) with the average currency excess returns (indicated by squares) for each portfolio. Figure 1 illustrates that the second principal component is the only promising candidate. Its covariance with currency excess returns increases monotonically as we go from portfolio 1 to 6.[1] This is not the case for any of the other principal components. As a result, in the space of portfolio returns, the second principal component is crucial.

[Figure 1 about here.]

We thus can use the two first principal components themselves as risk factors. The results are reported in Table 1. The risk price of the carry factor (the second principal component) is 4.16 % per annum and the risk price of the dollar factor (the first principal component) is 3.46 % per annum. The risk-adjusted return on HML_{FX} is -21 basis points per annum. The only portfolio with a statistically significant positive risk-adjusted return is the fourth one. However, the null that the α's are jointly zero cannot be rejected.[2] All of the statistics of fit are virtually identical to those that we obtained we when we used HML_{FX} and RX_{FX} as factors.

[Table 1 about here.]

2 Exchange Rate Betas

A natural question is whether the unconditional betas of our main asset pricing experiment are driven by the covariance between exchange rate changes and risk factors, or between interest rate changes and risk factors. This is important because the conditional covariance between the log currency returns and the carry trade risk factor obviously only depends on the spot exchange rate changes:

$$cov_t \left[rx^j_{t+1}, HML_{FX,t+1} \right] = -cov_t \left[\Delta s^j_{t+1}, HML_{FX,t+1} \right].$$

The regression of the log changes in spot rates for each portfolio on the factors reveals that these conditional betas are almost identical to the unconditional ones (with a minus sign), as expected. Table 2 in this appendix shows the currency betas. Low interest currencies offer a hedge against carry trade risk because they appreciate when the carry return is low, not because the interest rates on these currencies increase. High interest rate currencies expose investors to more carry risk, because they depreciate when the carry return is low, not because the interest rates on these currencies decline. This is exactly the pattern that our no-arbitrage model delivers. Our analysis within the context of the model focuses on conditional betas.

[Table 2 about here.]

3 Robustness Check: Splitting Samples

To guard against a mechanical relation between the returns and the factors, we randomly split our large sample of developed and emerging countries into two sub-samples.

To do so, we sort countries alphabetically and consider two groups. Table 3 reports market prices of risk and factor betas. The panel on the left uses countries A to M as test assets; the panel on the right uses countries N to Z as test assets. We use two risk factors: the return on high interest rate minus low interest rate countries and the average return on currency markets. On the left panel, risk factors are built from portfolios of countries N to Z. On the right panel, risk factors are built from portfolios of countries A to M. As a result, test assets and risk factors belong to two non-overlapping sets of countries.

Clearly, risk factors built using currencies that do not belong to the portfolios used as test assets can still explain currency excess returns. However, the market price of risk appears higher and less precisely estimated than on the full sample, and thus further from its sample mean. This happens because, by splitting the sample, we introduce more measurement error in HML_{FX}. This shrinks the betas in absolute value (towards zero), lowers the spread in betas between high and low interest rate portfolios and hence inflates the risk price estimates. However, portfolio betas increase monotonically from the first to the last portfolio, showing that common risk factors are at work on currency markets.

[Table 3 about here.]

We also bootstrapped the sample-splitting experiment. For each run of the bootstrap, we draw randomly two sub-samples of countries. We build four portfolios on each sub-sample. We use the first set of portfolios as test assets and we build two risk factors out of the second set of portfolios: the dollar and carry trade risk factors. Again, test assets and risk factors belong to two non-overlapping sets of countries. We do not take into account bid-ask spreads. We repeat the estimation 1,000 times. The estimated risk price for HML_{FX} is

18.11 with a standard deviation of 6, compared to mean of HML_{FX} of 6.77 with a standard deviation of 1.45. This seems to confirm that splitting the sample introduces more noise in the factors and shrinks the betas.

4 Model

In our model, the two asset pricing factors RX and HML_{FX} completely explain the cross-sectional variation in average excess returns on the currency portfolios – this is true by construction. For completeness, we report these asset pricing results obtained on simulated data in Table 4. In the cross-sectional asset pricing tests, the estimated market price of the carry trade factor HML_{FX} is 5.91% per annum, very close to the sample mean. The price of the aggregate market return RX is -0.38% and not statistically significant. This is due to the fact that we assigned the home country's pricing kernel an "average" loading on the global risk factor. Due to the cross-sectional heterogeneity in the loadings on the world risk factor, our model is able to reproduce the variation in average returns on currency portfolios, and in particular the large average return on the carry trade factor. The bottom panel in Table 4 reports the loadings of different currency portfolio returns on the two factors. As can be seen from the pattern in the betas, our model reproduces the common factor structure in currency portfolio returns and hence in exchange rates.

[Table 4 about here.]

We also replicate the asset pricing tests on individual currencies. One difference between the simulated and the actual data is that in the model we have a balanced panel whereas in the data some currencies only appear in the sample in the later years, while others disappear over time. Nevertheless, as shown in Table 5, the model closely matches the empirical evidence. The price of carry risk estimated using the cross-sectional Fama-MacBeth regressions using both unconditional and conditional betas is close to the sample mean of the factor, and the model is able to explain roughly $60-70\%$ of sample variation in average currency returns.

[Table 5 about here.]

5 Global Volatility Betas

As a robustness check, we sort countries on their global equity volatility betas (as we did for HML_{FX} betas). For each date t, we first regress each currency i log change in exchange rate Δs^i on a constant and Vol_{Equity} using a 36-month rolling window that ends in period $t-1$. This gives us currency i's exposure to Vol_{Equity}, and we denote it $\beta_t^{i,Vol}$. It only uses information available at date t. We then sort currencies into six groups at time t based on these slope coefficients $\beta_t^{i,Vol}$. In constructing these portfolios, we do not use any information on interest rates. The first portfolio contains currencies with the lowest βs. The last portfolio contains currencies with the highest βs. Table 6 reports summary statistics on these portfolios. The first panel reports average changes in exchange rates. The second panel shows that average forward discounts increase monotonically from the first portfolio to the last portfolio. Again, we have not used any information on exchange rates or interest rates to obtain these portfolios. Yet, they deliver a clear cross-section of interest rates. The third panel reports the average log excess returns. In both samples, they are monotonically increasing. The last three panels report pre- and post-formation betas. Pre-formation betas (obtained over short windows) are more volatile than post-formation betas (obtained over the entire sample). These post-formation volatility betas are not significant, across portfolios and for both samples. However, using HML_{FX}, the post-formation betas that we obtain over the entire sample are significant, and we recover a monotonic cross-section. Countries that load more on global volatility offer higher excess returns because they bear more HML_{FX} risk.

[Table 6 about here.]

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Table 1: Asset Pricing — US Investor — Principal Components

Panel I: Factor Prices and Loadings														
	All Countries							Developed Countries						
	λ_c	λ_d	b_c	b_d	R^2	$RMSE$	χ^2	λ_2	λ_1	b_c	b_d	R^2	$RMSE$	χ^2
GMM_1	4.16	3.46	0.73	0.10	76.15	0.86		2.45	4.26	0.41	0.09	72.43	0.56	
	[1.63]	[4.48]	[0.29]	[0.13]			20.62%	[1.83]	[4.94]	[0.30]	[0.11]			57.37%
GMM_2	4.17	0.96	0.73	0.03	42.27	1.33		3.06	6.64	0.51	0.14	−31.67	1.23	
	[1.47]	[4.25]	[0.26]	[0.12]			23.48%	[1.72]	[4.51]	[0.28]	[0.10]			65.21%
FMB	4.16	3.46	0.73	0.10	76.15	0.86		2.45	4.26	0.40	0.09	72.43	0.56	
	[1.35]	[3.32]	[0.24]	[0.10]			16.50%	[1.39]	[3.87]	[0.23]	[0.08]			50.74%
	(1.35)	(3.32)	(0.24)	(0.10)			17.89%	(1.39)	(3.87)	(0.23)	(0.08)			51.34%
$Mean$	**4.16**	**3.46**						**2.45**	**4.26**					

Panel II: Factor Betas												
	All Countries						Developed Countries					
$Portfolio$	α_0^j	β_c^j	β_d^j	R^2	$\chi^2(\alpha)$	$p-value$	α_0^j	β_d^j	β_c^j	R^2	$\chi^2(\alpha)$	$p-value$
1	−0.31	−0.43	0.42	86.41			0.38	−0.66	0.44	91.77		
	[0.67]	[0.03]	[0.01]				[0.63]	[0.04]	[0.01]			
2	−1.17	−0.24	0.38	79.85			−0.86	−0.25	0.45	83.17		
	[0.71]	[0.03]	[0.02]				[0.80]	[0.05]	[0.02]			
3	−0.06	−0.29	0.38	80.08			0.65	−0.02	0.46	86.81		
	[0.73]	[0.04]	[0.01]				[0.78]	[0.04]	[0.01]			
4	1.53	−0.04	0.38	74.92			−0.47	0.27	0.44	85.23		
	[0.77]	[0.04]	[0.02]				[0.80]	[0.04]	[0.02]			
5	0.55	0.08	0.43	77.38			0.27	0.66	0.45	93.86		
	[0.83]	[0.05]	[0.02]				[0.55]	[0.04]	[0.01]			
6	−0.52	0.81	0.45	96.81								
	[0.36]	[0.02]	[0.01]									
All					5.49	48.23					2.14	83.00

Notes: The factors are the first and the second principal components (denoted d, for the "dollar" factor, and c, for the "carry" factor, respectively). The panel on the left reports results for all countries. The panel on the right reports results for the developed countries. Panel I reports results from GMM and Fama-McBeth asset pricing procedures. Market prices of risk λ, the adjusted R^2, the square-root of mean-squared errors $RMSE$ and the p-values of χ^2 tests on pricing errors are reported in percentage points. b denotes the vector of factor loadings. Excess returns used as test assets and risk factors take into account bid-ask spreads. All excess returns are multiplied by 12 (annualized). The standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). Shanken (1992)-corrected standard errors are reported in parentheses. We do not include a constant in the second step of the FMB procedure. Panel II reports OLS estimates of the factor betas. R^2s and p-values are reported in percentage points. The χ^2 test statistic $\alpha' V_\alpha^{-1} \alpha$ tests the null that all intercepts are jointly zero. This statistic is constructed from the Newey-West variance-covariance matrix (1 lag) for the system of equations (see Cochrane (2005), p. 234). Data are monthly, from Barclays and Reuters in Datastream. The sample period is 11/1983–12/2009. The alphas are annualized and in percentage points.

Table 2: Conditional Betas — US Investor

	All Countries			Developed Countries		
Portfolio	$\beta^j_{HML_{FX}}$	β^j_{RX}	R^2	$\beta^j_{HML_{FX}}$	β^j_{RX}	R^2
1	0.38	−1.03	91.21	0.50	−0.98	93.99
	[0.02]	[0.03]		[0.03]	[0.02]	
2	0.11	−0.93	77.27	0.09	−1.00	80.10
	[0.03]	[0.04]		[0.04]	[0.04]	
3	0.14	−0.95	75.71	−0.00	−1.03	86.15
	[0.03]	[0.04]		[0.03]	[0.03]	
4	0.01	−0.94	75.02	−0.12	−0.97	81.84
	[0.03]	[0.05]		[0.04]	[0.04]	
5	−0.04	−1.05	74.29	−0.50	−0.98	93.76
	[0.03]	[0.05]		[0.02]	[0.02]	
6	−0.61	−1.05	91.48			
	[0.02]	[0.03]				

Notes: The panel on the left reports results for all countries. The panel on the right reports results for the developed countries. The table reports OLS estimates of the factor betas obtained by regressing changes in log spot exchange rates Δs^j_{t+1} on the factors. R^2s are reported in percentage points. Data are monthly, from Barclays and Reuters in Datastream. The sample period is 11/1983–12/2009. The standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991).

Table 3: Asset Pricing — Alphabetical Sorts

Panel I: Risk Prices														
	Countries A to M							Countries N to Z						
	$\lambda_{HML_{FX}}$	λ_{RX}	$b_{HML_{FX}}$	b_{RX}	R^2	$RMSE$	χ^2	$\lambda_{HML_{FX}}$	λ_{RX}	$b_{HML_{FX}}$	b_{RX}	R^2	$RMSE$	χ^2
GMM_1	17.83	5.52	1.53	0.39	79.49	0.99		11.86	1.83	1.33	0.19	97.68	0.25	
	[7.27]	[2.87]	[0.64]	[0.34]			15.97	[5.44]	[2.12]	[0.61]	[0.39]			86.60
GMM_2	16.37	5.13	1.41	0.37	78.23	1.02		12.56	1.93	1.40	0.20	96.57	0.31	
	[7.07]	[2.84]	[0.62]	[0.34]			16.32	[5.19]	[2.09]	[0.58]	[0.38]			87.38
FMB	17.83	5.52	1.53	0.39	79.49	0.99		11.86	1.83	1.32	0.19	97.69	0.25	
	[4.50]	[1.75]	[0.40]	[0.23]			8.27	[3.90]	[1.39]	[0.44]	[0.26]			84.55
	(5.02)	(1.81)	(0.45)	(0.23)			14.56	(4.14)	(1.40)	(0.47)	(0.27)			86.53
Mean	**5.51**	**2.43**						**7.04**	**2.34**					

Panel II: Factor Betas												
	Countries A to M						Countries N to Z					
Portfolio	α_0^j	$\beta_{HML_{FX}}^j$	β_{RX}^j	R^2	$\chi^2(\alpha)$	$p-value$	α_0^j	$\beta_{HML_{FX}}^j$	β_{RX}^j	R^2	$\chi^2(\alpha)$	$p-value$
1	−0.13	−0.26	0.83	65.68			−0.15	−0.18	1.16	80.69		
	[0.08]	[0.03]	[0.05]				[0.06]	[0.03]	[0.05]			
2	−0.00	−0.17	0.73	58.37			−0.03	−0.06	1.03	66.98		
	[0.08]	[0.03]	[0.05]				[0.09]	[0.05]	[0.07]			
3	0.20	−0.15	0.80	64.48			0.00	0.11	1.02	68.10		
	[0.08]	[0.03]	[0.05]				[0.09]	[0.04]	[0.06]			
4	0.28	0.09	0.88	62.41			0.05	0.27	1.12	51.26		
	[0.10]	[0.05]	[0.06]				[0.13]	[0.05]	[0.08]			
All					12.41	1.46					5.53	23.69

Notes: We sort countries alphabetically and consider two groups. The panel on the left uses countries A to M as test assets; the panel on the right uses countries N to Z as test assets. We use two risk factors: the return on high interest rate minus low interest rate countries and the average return on currency markets. On the left panel, risk factors are built from portfolios of countries N to Z. On the right panel, risk factors are built from portfolios of countries A to M. As a result, test assets and risk factors belong to two non-overlapping sets of countries. Panel I reports results from GMM and Fama-McBeth asset pricing procedures. Market prices of risk λ, the adjusted R^2, the square-root of mean-squared errors $RMSE$ and the p-values of χ^2 tests on pricing errors are reported in percentage points. b denotes the vector of factor loadings. Excess returns used as test assets and risk factors take into account bid-ask spreads. All excess returns are multiplied by 12 (annualized). Shanken (1992)-corrected standard errors are reported in parentheses. We do not include a constant in the second step of the FMB procedure. Panel II reports OLS estimates of the factor betas. R^2s and p-values are reported in percentage points. The standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). The χ^2 test statistic $\alpha' V_\alpha^{-1} \alpha$ tests the null that all intercepts are jointly zero. This statistic is constructed from the Newey-West variance-covariance matrix (1 lag) for the system of equations (see Cochrane (2005), p. 234). Data are monthly, from Barclays and Reuters in Datastream. The sample period is 11/1983–12/2009. The alphas are annualized and in percentage points.

Table 4: Asset Pricing - Simulated Data

	Factor Prices and Loadings					
	λ_{RX}	$\lambda_{HML_{FX}}$	b_{RX}	$b_{HML_{FX}}$	R^2	$RMSE$
GMM_1	-0.38	6.04	0.03	0.35	99.31	0.14
GMM_2	-0.38	5.91	0.03	0.34	99.25	0.14
FMB	-0.38	6.04	0.03	0.35	99.31	0.14
$Mean$	-0.38	5.91				
	Factor Betas					
$Portfolio$	α_0^j	β_{RX}^j	$\beta_{HML_{FX}}^j$	R^2		
1	0.08	0.99	-0.52	96.51		
2	-0.28	1.01	-0.17	84.41		
3	-0.06	1.00	-0.04	85.18		
4	0.01	1.00	0.07	85.57		
5	0.17	1.00	0.18	85.73		
6	0.08	0.99	0.48	95.20		

Notes: Panel I reports results from GMM and Fama-McBeth asset pricing procedures. Market prices of risk λ, the adjusted R^2, the square-root of mean-squared errors $RMSE$ are reported in percentage points. b denotes the vector of factor loadings. All excess returns are multiplied by 12 (annualized). We do not include a constant in the second step of the FMB procedure. Panel II reports OLS estimates of the factor betas. R^2s are reported in percentage points.

Table 5: Country-Level Asset Pricing - Model

$\lambda_{HML_{FX}}$	λ_{RX}	$b_{HML_{FX}}$	b_{RX}	R^2	$RMSE$	$MAPE$	χ^2
			Unconditional Betas				
5.66	−0.43	3.83	−0.06	68.39	0.81	0.72	
[1.49]	[0.97]	[1.01]	[1.24]				41.07
			Unconditional and Conditional Betas using Managed Currency Excess Returns				
6.26	−0.47	4.23	−0.06	70.57	0.72	0.59	
[1.42]	[0.97]	[0.97]	[1.24]				40.13
			Conditional Betas using Rolling Windows				
4.75	−0.37	3.21	−0.06	64.61	0.86	0.73	
[1.31]	[0.98]	[0.88]	[1.25]				41.02
			Conditional Betas using Forward Discounts				
4.57	−0.36	3.09	−0.06	62.22	0.89	0.77	
[1.15]	[0.97]	[0.78]	[1.24]				40.92

Notes: The table reports results from Fama-MacBeth asset pricing procedure using individual currency excess returns. Market prices of risk λ, the adjusted R^2, the square-root of mean-squared errors $RMSE$, the mean absolute pricing error $MAPE$, and the p-values of χ^2 tests on pricing errors are reported in percentage points. b denotes the vector of factor loadings. Excess returns used as test assets do *not* take into account bid-ask spreads. Risk factors HML and RX come from portfolios of currency excess returns that take into account bid-ask spreads. HML correspond to a carry trade strategy, long high interest rate currencies and short low interest rate currencies. RX corresponds to the average currency return across all portfolios. All excess returns are multiplied by 12 (annualized). We do not include a constant in the second step of the FMB procedure. The standard errors in brackets are Newey and West (1987) standard errors computed with the optimal number of lags according to Andrews (1991). Data is simulated from the model at monthly frequency.

Table 6: Volatility Beta-Sorted Currency Portfolios — US Investor

Portfolio	1	2	3	4	5	6	1	2	3	4	5
	Panel I: All Countries						Panel II: Developed Countries				
	Spot change: Δs^j						Δs^j				
Mean	−0.66	−0.57	−0.49	−0.46	−1.52	−0.61	−1.49	0.02	−1.22	−2.40	−2.60
Std	8.37	7.96	7.84	7.71	8.82	7.89	9.45	9.85	10.44	9.56	9.51
	Discount: $f^j - s^j$						$f^j - s^j$				
Mean	0.06	0.50	0.76	1.19	1.79	3.72	−0.59	0.33	0.60	1.11	1.74
Std	0.69	0.83	0.82	0.79	0.79	0.98	0.79	0.83	0.93	0.85	0.61
	Excess Return: rx^j (without b-a)						rx^j (without b-a)				
Mean	0.72	1.07	1.25	1.65	3.31	4.33	0.89	0.31	1.82	3.51	4.34
Std	8.40	7.93	7.81	7.64	8.89	7.98	9.48	9.91	10.46	9.55	9.53
SR	0.09	0.13	0.16	0.22	0.37	0.54	0.09	0.03	0.17	0.37	0.46
	High-minus-Low: $rx^j - rx^1$ (without b-a)						$rx^j - rx^1$ (without b-a)				
Mean		0.35	0.53	0.93	2.59	3.60		−0.58	0.93	2.62	3.45
		[0.33]	[0.39]	[0.37]	[0.45]	[0.51]		[0.40]	[0.39]	[0.43]	[0.54]
Std		5.54	6.39	6.32	7.59	8.40		6.52	6.65	7.26	9.06
SR		0.06	0.08	0.15	0.34	0.43		−0.09	0.14	0.36	0.38
	Pre-formation β						Pre-formation β				
Mean	−1.69	−0.95	−0.59	−0.21	0.24	1.87	−2.06	−1.31	−0.90	−0.43	1.10
Std	1.62	1.26	1.12	1.11	1.12	1.46	1.85	1.80	1.75	1.77	1.41
	Post-formation β						Post-formation β				
Estimate	0.10	0.21	0.00	0.16	0.08	−0.55	0.48	0.22	−0.15	−0.01	−0.54
s.e	[0.20]	[0.13]	[0.21]	[0.10]	[0.13]	[0.30]	[0.30]	[0.10]	[0.09]	[0.13]	[0.24]
	Post-formation HML_{FX} β						Post-formation HML_{FX} β				
Estimate	−0.17	−0.09	−0.05	−0.00	0.03	0.27	−0.22	−0.03	−0.05	0.09	0.29
s.e	[0.05]	[0.05]	[0.04]	[0.04]	[0.04]	[0.04]	[0.07]	[0.04]	[0.04]	[0.04]	[0.04]

Notes: This table reports, for each portfolio j, the average change in the log spot exchange rate Δs^j, the average log forward discount $f^j - s^j$, the average log excess return rx^j without bid-ask spreads and the average returns on the long short strategy $rx^j - rx^1$. The left panel uses our sample of developed and emerging countries. The right panel uses our sample of developed countries. Log currency excess returns are computed as $rx^j_{t+1} = -\Delta s^j_{t+1} + f^j_t - s^j_t$. All moments are annualized and reported in percentage points. For excess returns, the table also reports Sharpe ratios, computed as ratios of annualized means to annualized standard deviations. Portfolios are constructed by sorting currencies into five or six groups at time t based on slope coefficients β^i_t. Each β^i_t is obtained by regressing currency i log change in exchange rate Δs^i on Vol_{Equity} on a 36-period moving window that ends in period $t-1$. The first portfolio contains currencies with the lowest βs. The last portfolio contains currencies with the highest βs. We report the average pre-formation beta for each portfolio. The last two panels report the post-formation betas obtained by regressing realized log excess returns on portfolio j on either HML_{FX} and RX_{FX}, or Vol_{Equity} and RX_{FX}. We only report the Vol_{Equity} and HML_{FX} betas. The standard errors are reported in brackets. Data are monthly, from Barclays and Reuters (Datastream). The sample period is 11/1983–12/2009.

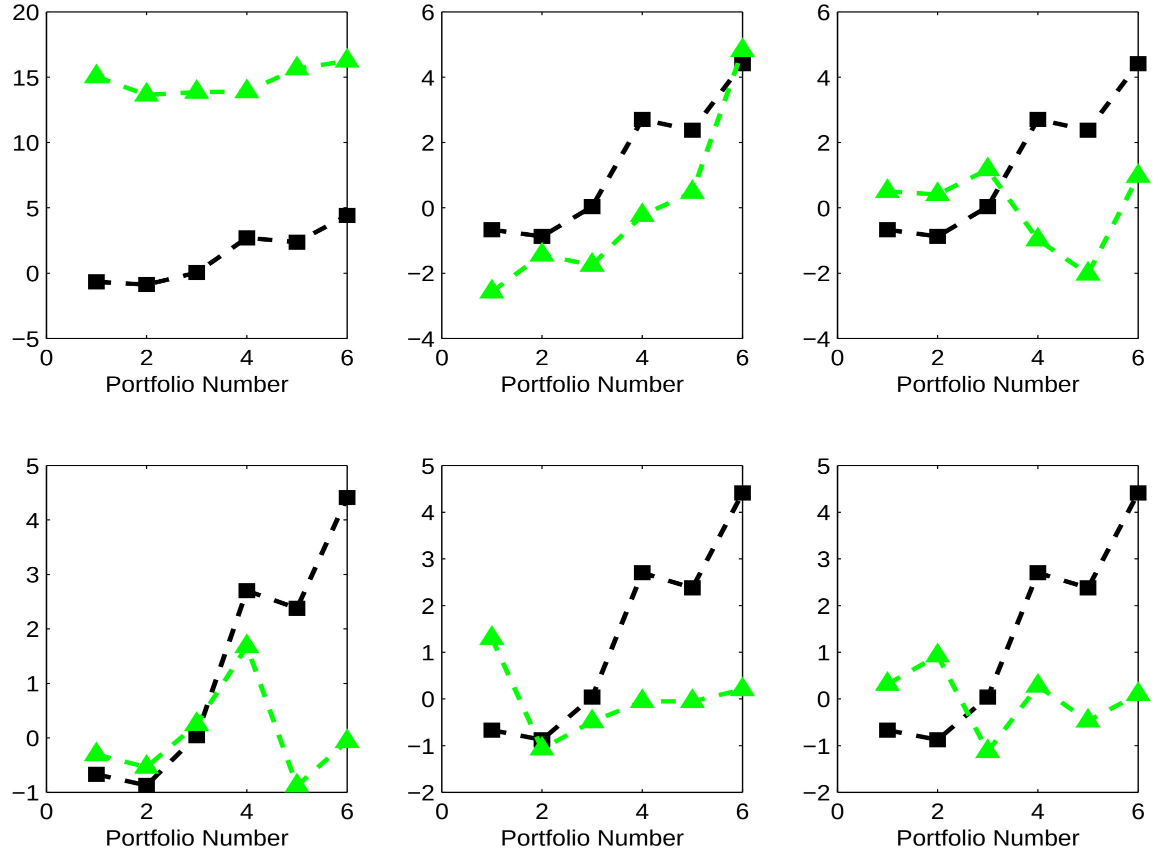

Figure 1: Mean Excess Returns and Covariances between Excess Returns and Principal Components - Developed and Emerging Countries

Each panel corresponds to a principal component. The upper left panel uses the first principal component. The black squares represent the average currency excess returns for the six portfolios. Each green triangle represents a covariance between a given principal component and a given currency portfolio. The covariances are rescaled (multiplied by 15,000). The average excess returns are annualized (multiplied by 12) and reported in percentage points. The sample is 11/1983–12/2009.