Currency portfolios*

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*This note provides an overview of the baggrund and construction of currency portfolios in global foreign exchange (FX) markets. The text draws on treatments in Pennacchi (2008), Burnside, Eichenbaum and Rebelo (2011b), and Lustig, Roussanov and Verdelhan (2011). The note is prepared for use only in the Master's course "Asset Pricing". Please do not cite, circulate, or use for purposes other than this course.

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"Following a carry trade strategy is like picking up nickels in front of a steamroller."

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1. Introduction

When the foreign interest rate is higher than the domestic interest rate, risk-neutral and rational investor should expect the foreign currency to depreciate vís-a-vís the domestic currency by the difference between the two countries' interest rates. That is the central prediction of the uncovered interest parity (UIP): exchange rate changes should exactly offset the interest rate differential between two countries so that investors would be indifferent between holding either of the two currencies. Put differently, exchange rate movements should eliminate any gains or losses arising from differences in interest rates across countries. In practice, however, this relationship is frequently violated and a number of empirical studies show that exchange rate changes fail to compensate for the interest differential (Hansen and Hodrick, 1980, Bilson, 1981, Fama, 1984, Lustig et al., 2011, Menkhoff, Sarno, Schmeling and Schrimpf, 2012, Della Corte, Riddiough and Sarno, 2016). Instead, the opposite observation holds true empirically: currencies with relatively higher interest rates either (i) appreciate or (ii) fail to depreciate sufficiently to offset the interest rate differential (the carry) and vice versa for currencies with relatively lower interest rates. Consequently, investing in currencies with high interest rates (investment currencies) while funding the investment by borrowing (selling) currencies with low interest rates (funding currencies) constitutes a profitable investment strategy. This so-called currency carry trade is explicitly designed to exploit UIP failures and is often blamed for the weakness of the Japanese yen (funding currency) and the unexpected enthusiasm of investors for the New Zealand and Australian dollars (investment currencies). Considering the very liquid foreign exchange (FX) markets, the dismantling of barriers to capital flows between countries, and international currency speculation, it is difficult to understand why carry trades have been profitable for as long as they have. Nevertheless, it is important to emphasize that currency speculation is risky business, and the carry trade is no different in that respect. The excess return earned on a carry trade position depends crucially on the realized spot exchange rate change at termination of the trade, which is unknown at the initiation of the trade. The most natural explanation for the high average payoff to the carry trade is therefore that it compensates agents for bearing risk – as would be suggested by standard finance theory. This is also emphasized in the opening quote, which is often paraphrased as "*the carry trade goes up by the stairs and down by the lift*". The wording here reflects the tendency of the carry trade to do well on average, but occasionally crash and deliver highly negative returns (Brunnermeier, Nagel and Pedersen, 2009, Chernov, Graveline and Zviadadze, 2018). However, the carry trade has proven elusive in the literature and a risk-based explanation using traditional risk factors identified in the literature finds little support. Models such as the Capital Asset Pricing Model (CAPM), the Fama and French (1993) three-factor model, the consumption-based CAPM, and similar asset pricing models all fail to explain the cross-sectional variation in carry trade excess returns (Burnside et al., 2011b, Burnside, Eichenbaum, Kleshchelski and Rebelo, 2011a). Lustig et al. (2011) is an important contribution in this area that makes significant progress on our understanding of currency market dynamics. The main innovation in Lustig et al. (2011) is to propose a risk-based explanation of exchange rate returns by identifying a "*slope*" factor in exchange rates (a factor-mimicking portfolio if you will), build in the spirit of Fama and French (1993), that captures carry risk and explains the cross-section of carry trade portfolios remarkably well. We will review the underlying theory and the construction of currency portfolios in this note, but postpone an actual asset pricing exercise to an upcoming exercise.

The rest of the note progresses as follows. Section 2 outlines the covered interest parity (CIP) and the uncovered interest parity (UIP), and details their predictions about the behavior of exchange rates. Section 3 discusses the construction of currency portfolios and the risk factors from Lustig et al. (2011). Last, Section 4 briefly outlines the forward premium puzzle (Fama, 1984) that is often cited as having paved the way for the carry trade literature.

2. Interest rate parities

This sections outlines two important interest rate parities in international finance: the covered and the uncovered interest parities. Both play important roles in our understanding of the determination of exchange rates, but whereas the covered interest parity often holds tightly, the uncovered interest parity appears to be frequently and systematically violated — leading to a highly profitable, albeit risky, trading system in international markets.

2.1. Covered interest parity (CIP)

If there are no barriers to arbitrage across international financial markets, then no arbitrage should ensure that the interest rate differential between two bonds, identical in every aspect except currency of denomination, is equal to zero when the rates are appropriately adjusted and covered against fluctuations in exchange rates at the maturity of the contract in the forward market. This condition is implied by the covered interest parity (CIP). If this condition is in disequilibrium, speculative traders have an opportunity to earn pure arbitrage profits. Consequently, CIP provides a no arbitrage relation between spot and forward exchange rates through nominal interest rates denominated in the two currencies that similarly implies a pricing equation for the no-arbitrage forward exchange rate involving today-available spot prices and interest rates. That all quantities are observable at the time of contract initiation is central to the no arbitrage argument for the forward exchange rate.

Notation and exchange rate definitions We begin by outlining notation and defining the exchange rates. Let S_t denote the spot exchange rate at time t, where we define S_t as the units of foreign currency per U.S. dollar (USD) so that an increase in the exchange rate indicates an appreciation of the home currency.[1] We will take the USD to be the domestic currency to align with the literature, but any currency can in principle function as the home currency. However, for the construction of currency portfolios, a common home currency is often needed. Similarly, we let F_t denote the time t available forward exchange rate for delivery in one-period's time at time $t+1$. Finally, i_t and $i_t^\star$ will denote the US and foreign per-period risk-free rates of return for one-period borrowing and lending, respectively. These are known at time t as well.

Deriving covered interest parity Consider a U.S. investor with current wealth $Y_t = 1$ dollar. This investor faces the decision between investing at home or abroad. The investor's first alternative, investing at home, will provide a return of $(1 + i_t)$ such that the investor's wealth after one period becomes

$$Y_{t+1} = (1 + i_t)\,. \tag{1}$$

The investor's second alternative, investing abroad, involves selling $\$1$ at the current spot price to obtain S_t units of foreign currency to invest in the foreign money market at a rate of interest of $i_t^\star$ and hedging away currency risk by selling the proceed $S_t\,(1 + i_t^\star)$ forward at the forward exchange rate

$$Y_{t+1}^\star = S_t\,(1 + i_t^\star)\,\frac{1}{F_t}. \tag{2}$$

The two alternatives both involve investing one USD and because both provide a certain USD-denominated return at the end of the investment period, the USD-dominated return from either investment must be identical by no arbitrage. A key prerequisite, as mentioned above, is that the two investments are identical in terms of maturity, default risk, liquidity risk, etc. That is, we must have that $Y_{t+1} = Y_{t+1}^\star$ at the end of the period, which gives rise to the covered interest parity (CIP)

$$(1 + i_t) = \frac{S_t}{F_t}\,(1 + i_t^\star)\,. \tag{3}$$

If the CIP condition is violated, investors have the opportunity to make a for sure arbitrage profit at maturity since all quantities are fully determined today at time t. That is, we we can setup the full trade today and earn the risk-free profits at a future known date — if the condition

[1] One could alternative define S_t as the U.S. dollar (USD) price per unit of foreign currency so that an increase in the exchange rate indicates an appreciation of the foreign currency. Whichever definition is adopted is inconsequential for the results, but will require slight alterations to some of the formulas. In this set of notes, we adopt the definition used in Lustig et al. (2011) for consistency.

is at an imbalance. Re-arranging the CIP conditions allows us to obtain an expression for the no-arbitrage forward exchange rate

$$F_t = S_t \frac{(1+i_t^\star)}{(1+i_t)}. \tag{4}$$

One can view this as a classic example of no-arbitrage pricing in finance. It further allows us to connect the difference between the spot and forward exchange and the difference in interest rates as follows by re-arranging the CIP condition and subtracting 1 from both sides

$$\frac{F_t - S_t}{S_t} = \frac{(1+i_t^\star)-(1+i_t)}{(1+i_t)} \approx i_t^\star - i_t, \tag{5}$$

where the approximation will be close if the domestic interest rate i_t is small. That is, under CIP, the percentage forward discount $\frac{F_t - S_t}{S_t}$ approximately equals the interest rate differential $i_t^\star - i_t$ between the foreign and domestic interest rate, respectively.

2.2. Uncovered interest parity (UIP)

Covered interest rate parity predicts that a domestic money market investment and a foreign money market investment have the same domestic currency return as long as exchange rate risk is covered using a forward contract. But what if investors choose not to cover currency risk in the forward market? The story is similar, but is now stated in terms of the expected future spot rate instead (because we no longer cover risk in the forward market and so the actual outcome is uncertain). The uncovered interest parity (UIP) can then be expressed as

$$(1+i_t) = \frac{S_t}{\mathbb{E}_t\left[S_{t+1}\right]}\left(1+i_t^\star\right), \tag{6}$$

where $\mathbb{E}_t\left[\cdot\right]$ is the expectations operator conditional on information at time t. Without coverage from the forward market, investors accept exchange rate risk by exposing themselves to fluctuations in the actual realization of the spot rate S_{t+1} at time $t+1$. Assuming rational expectations, then the CIP and UIP conditions jointly imply that the forward rate should be an unbiased predictor of the future spot rate, i.e.,

$$F_t = \mathbb{E}_t\left[S_{t+1}\right]. \tag{7}$$

This statement, however, finds little empirical support in the data. Hansen and Hodrick (1980), Bilson (1981), and Fama (1984) provide compelling evidence that forward rates are not unbiased predictors of the future spot rate, but that spot rates tend to move either too little or in the wrong direction. A brief discussion of this finding is presented in Section 4 using the approach of Fama (1984). For now, we settle for an intuitive understanding of the implications that can be secured by re-arranging the UIP condition in (6) to obtain the International Fisher Hypothesis.[2] It relates the expected spot exchange rate change to the current interest rate differential

$$\frac{\mathbb{E}_t\left[S_{t+1}\right]-S_t}{S_t}=\frac{(1+i_t^{\star})-(1+i_t)}{(1+i_t)}\approx i_t^{\star}-i_t. \tag{8}$$

Under unbiasedness, and according to the International Fisher Hypothesis, the currency of the country with the highest interest rate is expected to depreciate, yet the results in Fama (1984) indicates that (i) their depreciation is smaller than implied by the interest rate differential or (ii) that they appreciate in value instead. Said differently, the International Fisher Hypothesis in (8) does not fare well when confronted with real world data and interest rate differentials are not correctly offset by spot exchange rate changes. This lays the foundation for the currency carry trade strategy that we detail in the next section.

3. Carry trade portfolios

This section introduces the currency carry trade in a portfolio setting and details the construction of currency portfolios sorted on interest rate differentials, or equivalently, forward discounts. We first discuss the construction of currency excess returns and, second, outline how to build currency portfolios and risk factors as well as discuss their properties. The section ends with a discussion of principal components and potential explanations for the carry risk factor.

3.1. Data sources

The data used throughout this section include spot and one-month forward exchange rates quoted against the U.S. dollar (USD) from October 1983 to December 2018 from Barclay's Bank International (BBI) and WM/Reuters (via Eikon). Monthly observations are constructed by sampling end-of-month (last trading day) rates. The set of 48 currencies is composed of Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Egypt, Euro area, Finland, France, Germany, Greece, Hong Kong, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Japan, Kuwait, Malaysia, Mexico, Netherlands, New Zealand, Norway, Philippines, Poland, Portugal, Russia, Saudi Arabia, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Ukraine, and the United Kingdom. Individual Eurozone countries are removed following their adoption of the Euro. As in Lustig et al. (2011), we remove data when observing large covered interest parity (CIP) deviations.[3] Last, we consider a smaller sample of 15 developed countries: Australia, Bel-

[2]Named after the great economist Irving Fisher, it is a generalization of the Fisher hypothesis stating that nominal rates are given by the sum of the real rate and the expected rate of inflation. That is, the Fisher hypothesis postulates that $i_t \approx r_t + \mathbb{E}_t\left[\pi_{t+1}\right]$, where i_t is the nominal interest rate, r_t the real interest rates, and $\mathbb{E}_t\left[\pi_{t+1}\right]$ the expected rate of inflation.

[3]The following observations are removed: South Africa from July 1985 to August 1985 and again from January 2002 to May 2005, Malaysia from August 1998 to June 2005, Indonesia from December 2000 to May 2007, Egypt

gium, Canada, Denmark, Euro area, France, Germany, Italy, Japan, Netherlands, New Zealand, Norway, Sweden, Switzerland, and the United Kingdom to verify that the results are not driven by extreme returns on developing currencies.

3.2. Currency excess returns

The empirical support for the uncovered interest parity (UIP) is limited, implying that investors, on average, can make a profit by betting against the UIP and the International Fisher Hypothesis by investing in high interest rate countries and borrowing in low interest rate countries. Abstracting from transaction costs, we can compute the realized currency excess return (RX_{t+1}) to a long position in the foreign currency as

$$RX_{t+1} = \frac{F_t - S_{t+1}}{S_t}, \tag{9}$$

which can be interpreted as a simple trading strategy in which investors purchase foreign currency forward at time t and sell it in the spot market at time $t+1$. Note that this is equivalent to the forward discount minus the spot exchange rate change

$$RX_{t+1} = \frac{F_t - S_t}{S_t} - \frac{S_{t+1} - S_t}{S_t}, \tag{10}$$

where $RX_{t+1} = 0$ if UIP holds true so that spot exchange rate changes offset interest rate differentials. Moreover, if the future spot exchange rate remains around its current value, then investors pocket the interest rate differential. However, should the foreign currency depreciate by more than implied by the UIP, then investors incur a loss. In normal conditions, forward rates satisfy the CIP (Akram, Rime and Sarno, 2008) so that (5) holds.[4] Hence, the definition in (9) approximately corresponds to

$$RX_{t+1} \approx \frac{(1 + i_t^\star)}{(1 + i_t)} - \frac{S_{t+1}}{S_t}, \tag{11}$$

which is indeed what one would find by re-arranging (6). Note that these equations are equivalent to those presented in Lustig et al. (2011), except that ours here are stated in terms of level exchange rates and theirs are stated in terms of log exchange rates. We can note that using log for building portfolios is fine, but that one should always use level (or simple) returns for asset pricing exercises (which Lustig et al. (2011) also do).

from November 2011 to August 2013, and Ukraine from the end of June 2014 onwards.

[4] Du, Tepper and Verdelhan (2018), in contrast, document widespread CIP violations in the FX market during and following the most recent financial crisis. This, obviously, challenges the maintained assumption. Rime, Schrimpf and Syrstad (2020), on the other hand, provide evidence that the CIP may hold for most market participants once the marginal funding cost faced by the arbitrageur is accounted for.

3.3. Currency carry portfolios

We now turn to a discussion of the construction of currency portfolios sorted on forward discounts and their properties. We will follow the tradition of Lustig and Verdelhan (2007) and Lustig et al. (2011) and sort currencies into five portfolios (in the spirit of the Fama and French (1992, 1993)) that are rebalanced monthly. Specifically, at the end of each month, we allocate currencies to five portfolios on the basis of their forward discounts. The 20% of currencies with the lowest forward discounts (or lowest interest rate differential relative to the U.S.) are assigned to portfolio 1 (S1, funding currencies) and currencies with the 20% highest forward discounts are assigned to portfolio 5 (S5, investment currencies). Currency excess returns are equal-weighted within each portfolio. We equal-weight portfolio returns as no well-defined measure exist for value-weighting currency returns.

Table 1 reports standard descriptive statistics for the five currency carry trade portfolios. Excess returns are monotonically increasing from S1 to S5, indicating a clear relation between future returns and interest rate differentials. Currencies with relatively lower interest rates earn negative returns, whereas currencies with relatively higher interest rates earn positive and sizable excess returns. The table further presents descriptive statistics for the currency factors of Lustig et al. (2011), namely the dollar risk factor (DOL) and the carry risk factor (HML$_{FX}$).[5] DOL is constructed as the mean excess return across the five carry trade portfolios, and therefore resembles a portfolio that is long all foreign currencies and short the dollar. The high-minus-low FX factor, HML$_{FX}$, is constructed as a zero-cost long-short strategy in which investors purchase a basket of investment currencies (S5) and sell a basket of funding currencies (S1). That is, it mimicks a carry trade strategy in FX markets.

3.4. Principal components of currency portfolios

Lustig et al. (2011) conduct a principal component analysis to better understand the common factors in the cross-section of carry trade returns. This is standard practice when one is interested in determining the common factors associated with a panel of correlated variables (and is useful in the eyes of the APT). First, collect all excess currency portfolio returns at time $t + 1$ in the vector $\mathbf{RX}_{t+1}$. We can write the covariance matrix of this set of currency portfolio excess returns as

$$\mathrm{Cov}\left[\mathbf{RX}_{t+1}\right] = \Omega\Lambda\Omega^{\intercal} \tag{12}$$

where Λ is a diagonal matrix of eigenvalues of the matrix $\mathrm{Var}\left[\mathbf{RX}_{t+1}\right]$ and Ω is an orthogonal matrix (meaning that it satisfies $\Omega^{\intercal} = \Omega^{-1}$) whose columns are standardized eigenvectors.[6] Suppose that the eigenvalues are ordered from largest to smallest ($\Lambda_{1,1}$ is the largest), then $\Omega^{\intercal}_{(:,n)}\mathbf{RX}_{t+1}$ is

[5] I use the notation DOL here for the dollar risk factor as it is more common than RX as used by Lustig et al. (2011) nowadays, but it is purely terminology.

[6] This particular way of factorizing a matrix is known as an eigendecomposition and is implemented in most statistical software packages.

Table 1: Descriptive statistics

This table reports annualized net mean excess returns, standard deviations (annualized), Sharpe ratios (annualized), skewness, and kurtosis of currency carry portfolios sorted on time $t-1$ forward discounts, Portfolios are rebalanced monthly. Portfolio 1 contains the 20% of currencies with the lowest forward discounts, whereas portfolio 5 contains currencies with highest forward discounts. Excess returns are in U.S. dollars. DOL denotes the average return across the five currency strategy portfolios and HML_{FX} denotes a long-short portfolio that is long in portfolio 5 and short in portfolio 1. The sample period is November 1983 to December 2018.

	S1	S2	S3	S4	S5	DOL	HML_{FX}
Panel A: All countries							
Mean	-1.07	0.14	2.74	3.14	4.80	1.95	5.87
	[-0.75]	[0.11]	[1.86]	[2.07]	[2.67]	[1.46]	[3.91]
Std	7.88	7.15	7.85	8.22	9.36	7.13	8.14
SR	-0.14	0.02	0.35	0.38	0.51	0.27	0.72
Skew	0.20	-0.05	0.03	-0.51	-0.48	-0.28	-0.63
Kurt	4.00	4.09	4.00	4.95	5.08	3.80	4.25
Panel B: Developed countries							
Mean	-0.60	0.44	2.20	1.63	4.96	1.73	5.56
	[-0.35]	[0.25]	[1.34]	[0.95]	[2.44]	[1.09]	[3.05]
Std	9.75	9.42	9.05	9.58	11.00	8.54	10.09
SR	-0.06	0.05	0.24	0.17	0.45	0.20	0.55
Skew	0.34	0.09	0.03	-0.37	-0.11	-0.06	-0.69
Kurt	3.76	3.47	3.91	4.75	4.29	3.48	4.58

the nth factor and the fraction of variance explained is $\Lambda_n/(\iota^\intercal \Lambda \iota)$. More generally, the principal components, call them $\mathcal{P}_t$, are then defined by

$$\mathcal{P}_t = \Omega^\intercal \mathbf{RX}_{t+1}. \tag{13}$$

Table 2 replicates the findings of Lustig et al. (2011) for the set of 48 currencies considered here. The first principal component ($\mathcal{P}1$) explains more than 75% of the common variation in portfolio returns (for both all and developed countries), and can be interpreted as a level factor as all portfolios load more or less equally on it. The second principal component ($\mathcal{P}2$) explain an additional 11% of the common variation in currency portfolio excess returns and can be interpreted as a slope factor. This interpretation comes out naturally as portfolio loadings are decreasing monotonically from S1 to S5. Moreover, the loadings are positive for S1-S3 and negative for S4-S5, which implies that the second principal component can act as a plausible risk factor for explaining the cross-sectional heterogeneity in expected currency carry returns. The remaining components are harder to interpret and contribute less to explaining overall variation. As such, Lustig et al. (2011) keep focus on the first two components and use DOL and HML_{FX} as observable proxies for these components.

Table 2: Principal components

This table reports the principal component loadings of the currencies portfolios presented in Table 1. Portfolio 1 contains the 20% of currencies with the lowest forward discounts, whereas portfolio 5 contains currencies with highest forward discounts. In each panel, the last reports the share of the total variance explained by each principal component. The sample period is November 1983 to December 2018.

	$\mathcal{P}1$	$\mathcal{P}2$	$\mathcal{P}3$	$\mathcal{P}4$	$\mathcal{P}5$
Panel A: All countries					
S1	0.42	0.51	-0.40	0.54	0.34
S2	0.39	0.33	-0.34	-0.77	-0.16
S3	0.45	0.18	0.45	0.25	-0.71
S4	0.47	-0.10	0.61	-0.20	0.59
S5	0.49	-0.77	-0.39	0.10	-0.08
% Var	77.57	11.40	5.34	3.34	2.36
Panel B: Developed countries					
S1	0.42	0.65	-0.58	0.21	0.16
S2	0.44	0.27	0.46	-0.66	0.30
S3	0.43	0.10	0.22	0.09	-0.86
S4	0.45	-0.23	0.41	0.66	0.38
S5	0.50	-0.66	-0.49	-0.28	0.01
% Var	76.44	11.44	4.81	4.01	3.30

3.5. Potential stories for the carry risk factor

The high excess returns to the zero-cost long-short carry risk factor is detrimental to the uncovered interest parity and can be viewed as complementing the results in, among others, Hansen and Hodrick (1980), Bilson (1981), and Fama (1984). In fact, the failure of the UIP and the International Fisher Hypothesis to find support in the data, something often referred to as the "*forward premium puzzle*", is often cited as a source of profits for this type of carry trades. While the carry risk factor, HML_{FX}, of Lustig et al. (2011) is able to explain the cross-sectional variation in the mean excess returns to the five carry trade portfolios (you will verify this in an upcoming exercise), it, like the Fama-French factors, leaves the underlying economic story blank. However, there is a large and rapidly growing literature trying to rationalize the returns to carry trade portfolios and link them to underlying economic fundamentals. Menkhoff et al. (2012), building on the idea of Ang, Hodrick, Xing and Zhang (2006), construct a measure of global FX volatility (VOL_{FX}) and show that it can explain the carry trade portfolios about as well as HML_{FX}. Moreover, HML_{FX} and VOL_{FX} are highly correlated, suggesting that HML_{FX} picks up risk related to currency market volatility. Empirically, investment currencies load negatively on innovations in global FX volatility and deliver low returns in times of unexpectedly high volatility, when low interest rate currencies provide a hedge by yielding positive returns. In other words, carry trades perform especially poorly during times of market turmoil, and thus their high returns can be rationalized from the perspective of standard asset pricing. Other explanations include crash risk (Brunnermeier et al., 2009, Chernov et al., 2018), market and funding liquidity (Brunnermeier and Pedersen, 2009), exposure to global imbalances in current accounts (Della Corte et al., 2016), business cycle risk as measured by the output gap (Colacito, Riddiough and Sarno, 2020), sovereign risk measured by credit default swap spreads (Della Corte, Sarno, Schmeling and Wagner, 2021b), and the credit-implied risk premium (Della Corte, Jeanneret and Patelli, 2021a).

4. Briefly on the forward premium puzzle

The forward premium puzzle and the carry trade anomaly are two major stylized facts in international economics reflecting failures of uncovered interest parity. The forward premium puzzle is a fact about a regression coefficient, whereas the carry trade anomaly describes a profitable trading strategy (Hassan and Mano, 2019). A classic study of forward rates being unbiased predictors of future spot rates is Fama (1984). To consider his famous regression, we first need to develop some notation. In particular, let $s_t = \ln S_t$ and $f_t = \ln F_t$ denote the log spot and one-month forward rate, respectively. In this case the CIP becomes $f_t - s_t = i_t^\star - i_t$ and the UIP becomes $\mathbb{E}_t [s_{t+1}] - s_t = i_t^\star - i_t$. The fundamental insight of Fama (1984) is that this implies a simple testable relation $\mathbb{E}_t [s_{t+1}] - s_t = f_t - s_t$ that can be expressed as a linear regression (the "Fama regression") assuming rational expectations

$$s_{t+1} - s_t = \alpha + \beta (f_t - s_t) + \varepsilon_{t+1} \tag{14}$$

where we should expect to find $\alpha = 0$ and $\beta = 1$ under UIP. However, one often find that $\beta < 1$ and sometimes even that β is negative, implying that currencies with relatively higher interest rates either appreciate, or do not depreciate sufficiently to offset the interest rate differential. The regression in (14) can equivalently be stated as

$$f_t - s_{t+1} = \delta + \theta (f_t - s_t) + \nu_{t+1} \tag{15}$$

where $rx_{t+1} = f_t - s_{t+1}$ is the log currency excess return. A key observation here is — since $s_{t+1} - s_t$ and $f_t - s_{t+1}$ sum to $f_t - s_t$ — that we have the following restrictions on the parameters: (i) the sum of the intercepts must be zero, i.e., $\alpha + \delta = 0$, (ii) the sum of the slopes must be one, i.e., $\beta + \theta = 1$, implying that $\theta = 1 - \beta$, and (iii) the error terms ε_{t+1} and ν_{t+1} must sum to zero period-by-period. Thus, if we observe a $\beta < 1$ in (14), then we would obtain a $\theta > 0$ in (15). This would imply that currency excess returns are predictable by the forward discount. It is important to emphasize that this is also a clear violation of the UIP because it assumes risk neutral investors. Indeed, β <1 is typically what one finds for most currencies.

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