Exchange Rates, Interest Parity, and the Carry Trade*

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The well-documented empirical failure of the *uncovered interest rate parity* (UIP) condition is intimately related to the observed profitability of currency carry trades. In this paper I discuss the theoretical underpinnings of various interest rate parity conditions, and describe the most common approach to testing for UIP. I then discuss a currency trading strategy, referred to as the *carry trade*, in which investors borrow funds in low interest rate currencies in order to fund long positions in high interest rate currencies. This strategy has proven to be profitable, with simple carry trade strategies having Sharpe ratios in excess of those of standard US equity indexes. The failure of the UIP condition and the success of the carry trade are related because both reflect patterns in exchange rate predictability that run contrary to standard textbook theory.

In Section 1, I discuss the theoretical foundations of the UIP condition and the *covered interest rate parity* (CIP) condition. When these conditions are combined they imply that the expected spot exchange rate at some future date is equal to the current forward exchange rate that applies to that date. This has led many researchers to test the UIP condition using regressions of the changes of exchange rates on the corresponding forward premia, with theory predicting that the constant in the regression should be 0 and the slope coefficient should be 1. The typical empirical finding is that this hypothesis can be rejected, with the estimated slope coefficient often being negative. I confirm that this is true for ten industrialized economy exchange rates versus the US dollar in the period 1976–2018.

In Section 2, I describe how a currency carry trade works, and how the returns to various portfolios of carry trades can be measured using historical data. I show that carry trades earned positive profits, on average, in the 1976–2018 period and that three simple carry trade portfolios had higher Sharpe ratios than the value-weighted US stock market over the same period.

In Section 3, I explore the links between the evidence against UIP and the profitability of the carry trade. Most importantly, I show that if the UIP condition held, carry trades could not be profitable on average. So the failure of UIP is a necessary condition for carry trades to be profitable. But the way in which UIP fails is also critical to the profitability of the carry trade. Although there is some evidence that exchange rate changes are predictable, for most of the currencies in my sample it is difficult to reject the null hypothesis that the exchange rate is a random walk. This is a specific violation of UIP condition as it states that the expected exchange rate change equals the interest differential. When, instead, exchange rates are random walks, this means that a carry trader can expect, on average, to pocket the interest differential between the high interest rate currencies (which she lends) and the low
interest rate currencies (which she borrows). Not only does this fact motivate carry trades, it accounts for a large fraction of the profits of carry trades in historical data.

In Section 4, I provide a brief overview of the literature that tries to explain the failure of UIP and the profitability of the carry trade. A vast literature argues that UIP fails because it assumes risk neutrality, and carry trades are profitable because they are risky. I argue that, as yet, there is no fully convincing risk-based explanation of the returns to the carry trade because risk factors that explain the returns to other asset classes do not appear able to explain the returns to currency carry trades.

My updated empirical analysis documents an apparent change in the behavior of exchange rates in the period after the global financial crisis of 2007-08. First, using “UIP regressions” with rolling 60-month long samples, I document that the parameter estimates change sign and become highly unstable after 2007. Second, I show that carry trades became much less profitable after 2007 and that a significant fraction of this change in profitability can be attributed to the compression of interest rate differentials near the zero lower bound that has persisted since 2008.

1 Interest Parity Conditions

The uncovered interest rate parity (UIP) condition is central to standard textbook models of exchange rate determination. These models start from the assumption that there are integrated global money markets in which deposits may be held in a variety of currencies, and in which currencies may be freely traded. The UIP condition arises out of a notion of equilibrium in these markets.

Suppose that an investor can earn the interest rate $i_t$ on a U.S. dollar (USD) denominated deposit held from period $t$ to period $t+1$. Suppose, additionally, that the investor could earn the interest rate $i^*_t$ on a deposit denominated in pounds sterling (GBP). If the investor has one dollar to invest, the gross return to the USD deposit is $1+i_t$. Alternatively, the investor could convert the dollar to $1/S_t$ pounds, where $S_t$ represents the spot exchange rate expressed as USD per GBP. Those pounds could then be invested in a pound-denominated deposit earning $i^*_t$ and could be converted back into dollars at $t+1$. The gross dollar return to this investment is $(1+i^*_t)S_{t+1}/S_t$. If investors view all bank deposits as perfect substitutes, or, if investors are risk neutral, the expected dollar returns on these deposits must be equal.1 Otherwise, investors would sell their low expected return deposits in order to invest exclusively in the

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1See, for example, the discussion in Krugman, Obstfeld, and Melitz (2018).
highest expected return deposits. Stating this condition mathematically, we have

\[
1 + i_t = E_t \left[ \left(1 + i_t^*\right) \frac{S_{t+1}}{S_t} \right],
\]

(1)

where \(E_t\) indicates the mathematical expectations operator, conditional on information available to market participants at time \(t\). Equation (1) is one statement of the UIP condition.

Stated in this form the UIP condition is often used to discuss the determination of the exchange rate at time \(t\). Suppose, for example, that the U.S. interest rate rises, say because of an action by the Federal Reserve to raise its target for the Federal Funds rate. This increases the left-hand side of equation (1). If \(i_t^*\) and \(E_t S_{t+1}\) are held constant, the equilibrium value of \(S_t\) must fall to maintain equality. That is, the pound depreciates, and the dollar appreciates. If, on the other hand, interest rates rise in the U.K., the right-hand side of equation (1) increases. If \(i_t\) and \(E_t S_{t+1}\) are held constant, the equilibrium value of \(S_t\) must rises to maintain equality. That is, the pound appreciates, and the dollar depreciates. In both cases, of course, the caveat is that the expected value of \(S_{t+1}\) is held fixed.

In the example, above, with the pound deposit, the investor is certain to receive \((1 + i_t^*)/S_t\) pounds at \(t + 1\). Consequently, the investor could sell those pounds forward at the one period forward rate, \(F_t\) USD per GBP, in order to receive a certain payoff of \((1 + i_t^*)F_t/S_t\) dollars at \(t + 1\). A no-arbitrage argument implies, therefore, that

\[
1 + i_t = (1 + i_t^*) \frac{F_t}{S_t}.
\]

(2)

This is the covered interest rate parity (CIP) condition. Both the UIP condition and the CIP condition assume that transactions costs in the foreign exchange and money markets are negligible.\(^2\)

When equations (1) and (2) are combined, they imply that the forward rate is an unbiased predictor of the future spot rate:

\[
E_t(S_{t+1}) = F_t.
\]

(3)

This equation suggests a particularly simple test of the UIP condition: A linear regression of \(S_{t+1}\) on a constant and \(F_t\). If the coefficient vector in this regression differs significantly from \((0 \ 1)\) then UIP is rejected. The problem with using this regression as a test of UIP is that nominal exchange rates often appear to be integrated processes, with \(F_t\) and \(S_t\) being cointegrated, and with \((1 \ -1)\) being the co-integrating vector. When this is true, regressing \(S_{t+1}\) on \(F_t\) is an untrustworthy way of testing UIP.

For this reason, tests of UIP often focus on the following implication of equation (3):

\[ E_t z_{t+1} = f_t, \]  

(4)

where \( z_{t+1} = (S_{t+1} - S_t)/S_t \) and \( f_t = (F_t - S_t)/S_t \). This equation states that if the pound is at a forward premium (i.e. \( F_t > S_t \)) it is expected to appreciate, with the expected rate of appreciation, \( E_t z_{t+1} \), corresponding to the size of the forward premium, \( f_t \). Consequently, the UIP condition is often tested using the regression

\[ z_{t+1} = a + bf_t + \varepsilon_{t+1}, \]  

(5)

where \( \varepsilon_{t+1} \) is an error term. Under the null hypothesis that the UIP condition holds, \( a = 0 \), \( b = 1 \) and \( E_t \varepsilon_{t+1} = 0 \). Table 1 presents results of estimating this regression for a set of ten industrialized country (G10) currencies during the period 1976–2018. For seven of the ten currencies the null hypothesis is rejected at less than the 1% significance level. It is also rejected for the Norwegian krone at the 5% significance level, and for the deutschmark-euro at the 10% significance level. It is not rejected for the Swedish krone. Thus, there is broad evidence against the UIP condition for the G10 currencies. Strictly speaking, the evidence from Table 1 is usually referred to as the forward premium puzzle. However, the UIP and forward premium puzzles are equivalent under CIP.

One notable feature of the estimates in Table 1 is that for nine of the ten currencies \( \hat{b} \) is less than zero. Sometimes this condition is interpreted as implying that currencies at a forward premium tend, on average, to depreciate rather than appreciate. Hassan and Mano (2013) have criticized this interpretation. Clearly, \( b \), alone, does not determine the mapping from the sign of \( f_t \) to the sign of \( E_t z_{t+1} \). The value of \( a \) also matters, and the true values of \( a \) and \( b \) might be time varying. As it turns out, although \( \hat{b} \) is negative for nine of the G10 currencies, the sample averages, \( \bar{z} \) and \( \bar{f} \) have the same sign for seven of the G10 currencies. As Figure 1 illustrates, seven currencies generally had higher interest rates than the US dollar in the 1976–2018 period. Of these, on average, the British pound, Canadian dollar, Swedish krona, Swedish krona, and Canadian dollar, are expected to depreciate, with the expected rate of depreciation, \( \bar{E_t z_{t+1}} \), corresponding to the size of the forward premium, \( \bar{f_t} \).

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3Equivalently, using equation (2), if the pound has a higher interest rate (\( i^*_t > i_t \)) it is expected to depreciate by the amount of the interest differential.

4A common alternative is to regress \( \Delta \ln S_{t+1} \) on \( \ln S_t - \ln F_t \), which should have similar properties up to a log approximation. Hansen and Hodrick (1980), Bilson (1981), Fama (1984) are early examples from the literature that present these or related estimates. More recently, Engel (1996) and Burnside (2014) provide similar regression estimates.

Norwegian krone, and Swedish krone depreciated. On the other hand, the New Zealand dollar, Australian dollar, and Danish krone appreciated. None of the currencies depreciated as much, on average, as would be predicted by the UIP condition. At the same time, on average, the three currencies with generally lower interest rates than the US dollar (the Japanese yen, the euro, and the Swiss franc) appreciated.

[INSERT FIGURE 1 HERE]

If we focus on time series variation, on the other hand, for these ten currencies there is a tendency for \( z_{t+1} \) and \( f_t \) to have opposite signs: Across all observations this is true 54 percent of the time, and it is also true more than 50 percent of the time for every individual currency except the Swiss franc, as indicated in Table 2. So high (low) interest rate currencies do have a slight tendency to appreciate (depreciate).

[INSERT TABLE 2 HERE]

When equation (5) is estimated using rolling samples, it displays parameter instability. This is illustrated in Figure 2, which shows the median (across currencies) of \( \hat{b} \) when running the regression using a rolling window of 60 months of data ending at each date on the x-axis. The grey area illustrates the 30th and 70th quantiles of the cross-section of estimates at each date. Until 2008 the cross-sectional distribution of \( \hat{b} \) was narrow and was centered around a value between \(-7\) and 1 that was usually negative. Since the end of 2008 the cross-sectional distribution of \( \hat{b} \) has been wide, highly unstable, and has typically been centered around a large positive value.

[INSERT FIGURE 2 HERE]

Another notable feature of the estimates in Table 1 is that the \( R^2 \)'s are very small. This suggests that the forward premium is not a very reliable predictor of the change in the spot rate. It also suggests that the spot rate might be well approximated by a random walk. Table 1 also presents tests of the random walk hypothesis, which can be summarized as \( a = b = 0 \). For seven of the ten currencies the hypothesis cannot be rejected at conventional significance levels. This mirrors classic findings on exchange rate predictability documented by Meese and Rogoff (1983). In particular, forecasts based on the full sample estimates of equation (5) offer only tiny improvements in terms of root mean squared error (RMSE) compared to assuming that \( E_t z_{t+1} = 0 \) for all \( t \), and they are subject to look-ahead bias. Forecasts based on rolling estimates of equation (5) that are not subject to look ahead bias do worse (see Table 3).
Recently, Engel (2016) and Valchev (2017) have shown that the pattern of exchange rate predictability changes with the forecasting horizon. In particular, Valchev (2017) considers the forecasting regression $z_{t+k} = a_k + b_k f_t + \varepsilon_{k,t+k}$. Using panel regressions he shows $\hat{b}_1$, the coefficient at the one-step-ahead horizon, is approximately 0, but $\hat{b}_k$ becomes negative thereafter and bottoms out at roughly the two-year horizon, then turns positive between three and eight years ahead. His findings suggest that when a currency’s interest rate rises, the currency appreciates in the short run, but in the longer run it depreciates.

2 Currency Carry Trades

An investor in a currency carry trade borrows funds in a low interest rate currency in order to invest in a high interest rate currency. Consider, for an example, an investor who creates a zero cost long position in British pounds by borrowing US dollars. The investor borrows a one dollar deposit, translates this deposit into pounds, invests in a pound-denominated deposit, and earns the net return:

$$x_{t+1}^L = (1 + \hat{i}_t^*) \frac{S_{t+1}}{S_t} - (1 + \hat{i}_t).$$  \hspace{1cm} (6)

Using historical data, Burnside et al. (2011a), Burnside, Eichenbaum, and Rebelo (2011), and Burnside (2012) implement this strategy on a currency-by-currency basis against the US dollar, and form an equally weighted carry-trade (EWC) portfolio from these currency bets. For an individual currency, $j$, the carry trade payoff is:

$$x_{jt+1}^C = \text{sign}(i_{jt}^* - \hat{i}_t)x_{jt+1}^L.$$  \hspace{1cm} (7)

The payoff of the EWC portfolio is

$$x_{t+1}^{EWC} = \frac{1}{N_t} \sum_{j=1}^{N_t} x_{jt+1}^C,$$  \hspace{1cm} (8)

where $N_t$ is the number of currencies available in the sample at time $t$.

As is typical in the literature, the strategy is implemented at a one-month horizon using end-of-month observations on exchange rates. The exercise is repeated here using only the G10 currencies to form the portfolio with results presented in Table 4. For the purposes of comparison the table also includes performance benchmarks for the value-weighted US stock market. In the 1976–2018 period, the EWC portfolio earned an average annual return of
4.1%, a little more than half that of the US stock market (7.6%) in the same period. However, the payoffs to the carry trade portfolio are much less volatile than the stock market (by a factor of three), so the Sharpe ratio of the EWC portfolio is much larger at 0.82 versus 0.51.

[CINSERT TABLE 4 HERE]

Casual discussions of the risks associated with carry trades often make reference to the higher moments of carry trade returns, most specifically their skewness. For example, Brunnermeier, Nagel, and Pedersen (2008) state that a common phrase used by traders is that “exchange rates go up by the stairs and down by the elevator.” The idea is that carry traders collect small profits, as they work their way up the stairs, but then take large losses when high interest rate currencies suddenly depreciate. Indeed, as can be seen in Table 4, the EWC portfolio has negatively skewed returns. So do the other currency portfolios that we discuss below. Additionally the returns are leptokurtotic. One might believe that the skewness of carry trade returns would be sufficient reason for traders to shy away from this type of investment. However, when the evidence is compared to that for stock returns, it becomes clear that if there is an equity premium puzzle, there is certainly a carry trade premium puzzle. As Table 4 indicates, US stock returns are more left skewed than the returns to the EWC portfolio, and are equally leptokurtotic. They are also considerably more volatile, meaning that the worst outcomes from holding a value-weighted index of stocks are much worse than the worst outcomes for the EWC portfolio. Over the 1976–2018 sample, the worst payoff for the EWC portfolio was −6.4%, in March 1991. The portfolio lost more than 5% of its value in only one other month (October 1992) out of 506 months in the sample. In contrast, the worst month for US stocks was an excess return of −23% (October 1987), and there were ten months with returns less than −10%, and 45 months with returns less than −5%.

A number of other carry trade portfolios are discussed in the literature, and I discuss two of them here. These alternatives are dollar-neutral, in the sense that the US interest rate plays no special role, as it does in the EWC portfolio, in determining the sign of the position in each of the foreign currencies. The first portfolio mimics the Deutsche Bank G10 Currency Future Harvest (DBCFH) index. This index, which dates back to 1993, takes positions in up to six currencies from a list of ten. It is formed by taking equally-weighted long (short) positions in the three currencies with the highest (lowest) interest rates. Its currency composition is rebalanced quarterly. To mimic this index, I follow procedures similar to those used by Lustig, Roussanov, and Verdelhan (2011) and Menkhoff et al. (2012). In each month, the available currencies are sorted into three bins according to their interest
rates (the 0–30 percentile, the 30–70 percentile and the 70–100 percentile). The USD is also included in the sort. Equally-weighted portfolios of the currencies within these bins are labeled C1, C2, and C3. I then form a carry trade portfolio, referred to as the DBM portfolio, which takes a long position in C3 and takes a short position in C1. This strategy is different than the EWC strategy in three ways. First, it does not take positions in all of the currencies. Second, it is approximately long in as many currencies as it is short, and the composition of the portfolio does not depend on a basis currency. By contrast, the EWC portfolio is long all the foreign currencies if the dollar interest rate is lower than the others, and is short all the foreign currencies if the dollar interest rate is highest. Additionally, if we thought of the pound or the euro as the base currency, the composition of the EWC portfolio would change. Lastly, it is arguable that the DBM portfolio is more highly leveraged than the EWC portfolio as the sum of the absolute values of its constituent currency positions is two rather than one.

A second alternative strategy works just like the DBM portfolio, but sorts the currencies into just two bins, those with interest rates below the median, and those with interest rates higher than the median. The carry portfolio is long the high interest rate currencies and short the low interest rate currencies, and is equally weighted. I refer to this strategy as HML.

As Table 4 indicates, both of the alternative carry trade strategies are also profitable, have large Sharpe ratios, and have downwardly-skewed and leptokurtotic returns.

3 UIP and the Carry Trade

If the UIP condition holds, and financial markets are frictionless, it is not possible to implement a simple currency trading strategy that earns a positive average excess return. To see this, notice that the UIP condition tells us that $E_t z_{t+1}^L = 0$. In our example, above, this means that whatever information is available to investors at time $t$, this information cannot be used to generate profits from signed bets on the British pound versus the US dollar. If we define a signal variable, $\phi_t$, that, based on time $t$ information, takes on the value 1 if the investor chooses to be long the pound, and $-1$ if the investor chooses to be short the pound, then, on average, the payoff to the agent’s strategy is $E(\phi_t x_{t+1}^L) = E[E_t(\phi_t x_{t+1}^L)] = E(\phi_t E_t x_{t+1}^L) = 0$.

Thus, the fact that currency carry trades have non-zero average returns is inextricably linked to the failure of UIP. Additionally, the nature of the failure of the UIP condition plays

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6Under CIP this is equivalent to sorting the currencies according to their forward discount against the USD, or any other currency.
an an important role in the fact that the average returns are positive. Above, we saw that several of the G10 exchange rates appear to be well approximated by random walks with no drift. If, in fact, it were exactly true that $S_t = E_t S_{t+1}$ it would follow that $E_t x_{t+1}^t = i_t^* - i_t$. That is, if an investor held a long position in British pounds, the expected payoff would be the difference between the UK interest rate and the US interest rate. The EWC portfolio would have an expected payoff equal to the average absolute interest differential of its constituent currencies versus the US dollar:

$$E_t(x_{t+1}^{EWC}) = \frac{1}{N_t} \sum_{j=1}^{N_t} |i_{jt}^* - i_{jt}|. \quad (9)$$

Similar expressions hold for the DBM and HML carry trade portfolios under the random walk assumption. In each case, the investor expects to earn the interest differentials between the constituent currencies of the portfolios.

As it turns out, the predictions of the random walk assumption are not fully borne out in the data. Over the 1976–2018 period, the average interest differentials of the EWC, DBM and HML portfolios were 2.8%, 6.4% and 4.3%. Thus the EWC portfolio outperformed expectations under the random walk assumption, while the DBM portfolio underperformed.

Of course, the empirical behavior of the currencies in our sample does not perfectly match that of a random walk. For example, if all of the currencies were random walks, the points in Figure 1 would all lie on the $x$-axis where $\bar{z} = 0$. Assuming a symmetric distribution, we would also not observe the modest tendency of higher interest rate currencies to depreciate rather than appreciate (see Table 2). So the random walk assumption is just an approximation. More generally, however, the reason carry trades are profitable is that more often than not higher interest rate currencies do not depreciate by as much as the UIP condition would predict.

Hassan and Mano (2013) have de-emphasized the link between the profitability of the carry trade and the forward premium puzzle. It should be noted, however, that they specifically refer to the forward premium puzzle as the fact that $\hat{b}$ is often found to be negative when estimating equation (5). They argue that the predictability of the exchange rate implied by these estimates is not an important aspect of understanding carry trades. But this does not mean that violations of UIP are not critical to understanding carry trades. When exchange rate changes are unpredictable, as we have seen, UIP is violated, and carry traders pocket, on average, the interest rate differentials between currencies.

Since the 2007-08 financial crisis, there has been an apparent decline in the profitability of the carry trade. The average annual returns of the EWC, DBM and HML portfolios
were 5.2%, 7.0%, and 5.2% in the 1976–2007 period, but were just 0.6%, 0.9% and 0.8% in the 2008–2018 period. The change in profitability, which is also illustrated in Figure 3, is partly attributable to the decline and compression of interest rates near the zero lower bound during this period. The average absolute interest differentials implicit in the EWC, DBM and HML portfolios were 3.3%, 7.5%, and 5.0% in the 1976–2007 period, and were just 1.3%, 3.2% and 2.2% in the 2008–2018 period. Therefore, the change in the behavior of interest rates accounts for, respectively, 43%, 70% and 64% of the changed profitability of the EWC, DBM and HML portfolios. The remainder, by construction, must be attributable to the changed pattern in exchange rate predictability illustrated in Figure 2.

[INSERT FIGURE 3 HERE]

4 Explaining UIP’s Failure and Carry Trade Profits

A vast literature has explored possible explanations of the empirical failure of UIP. As we have seen, any theory that can rationalize observed estimates of equation (5) can, by extension, explain the profitability of carry trades.

Some research has focused on differences between agents subjective beliefs and econometrically based exchange rate forecasts. For example, Froot and Frankel (1989) study direct measures of market participants expectations of exchange rates and conclude that departures of these expectations from rational expectations explain the forward premium puzzle because although regression analysis suggests that $E_t S_{t+1} \neq F_t$, market participants’ time $t$ forecasts of $S_{t+1}$ closely correspond to $F_t$. Gourinchas and Tornell (2004) explore a theoretical explanation. In their model, interest rates are driven by persistent and transitory shocks. Agents systematically misperceive information they receive about these shocks, and overemphasize the importance of transitory shocks. Burnside et al. (2011b) explore a related theory in which agents have overconfidence in the signals they receive about future monetary policy shocks or technology shocks. In these setups, UIP holds subjectively, but not objectively. That is, agents in the model think UIP holds, even though an econometrician with sufficient data would find regression based evidence against it. In a different strand of research with similar implications, Ilut (2012) argues that ambiguity averse agents rationally place greater than objective probabilistic weight on negative outcomes. As in the other theories, UIP holds under the agents’ beliefs, the difference being that the pessimism inherent in these beliefs arises endogenously from the agent’s preferences. Learning models provide related explanations. In these model agents are not endowed with the correct model in real time, so
they can rationally hold beliefs that seem biased ex-post.\textsuperscript{7}

Some explanations revolve around small sample issues such as peso problems or other econometric subtleties related to the persistence of exchange rates. According to these explanations, ex-post econometric assessments of equation (5) might not provide reliable measures of agents beliefs about future exchange rates.\textsuperscript{8}


Perhaps the most obvious potential explanation for the failure of UIP is that agents are risk averse. If this is the case, and markets are frictionless, the UIP condition will not hold, and the observed positive returns to the carry trade should reflect their covariance with some measure of aggregate risk. That is, if there is a carry trade portfolio whose time $t$ payoff is $x_t$, there should be some variable $m_t$ such that $E_t(m_{t+1}x_{t+1}) = 0$ (as opposed to $E_t x_{t+1} = 0$, which follows from risk neutrality). A vast literature, both structural and empirical, has considered this possibility.\textsuperscript{9} In structural models, $m$ is typically the intertemporal marginal rate of substitution of a representative agent. In the more empirical approach, $m$ is a reduced-form stochastic discount factor (SDF) that can correctly price the currency portfolios. While there are structural models that internally replicate the UIP puzzle, empirical evidence in favor of any particular model remains elusive. It is possible to build reduced-form SDFs that are reasonably successful in pricing portfolios of currencies. However, these SDFs are generally constructed from risk factors that are derived from currency-specific data.\textsuperscript{10} Risk factors used to price equities are not sufficiently correlated with carry trade portfolios to price them correctly.\textsuperscript{11}

\textsuperscript{7}See, for example, Lewis (1989) and Chakraborty and Evans (2008).

\textsuperscript{8}See, for example, Baillie and Bollerslev (2000), Maynard (2006), Rossi (2007), and Burnside et al. (2011a).


\textsuperscript{10}See, for example, Lustig and Verdelhan (2007) and Menkhoff et al. (2012).

\textsuperscript{11}See Burnside, Eichenbaum, and Rebelo (2011), Burnside et al. (2011a), and Burnside (2012).
To illustrate the latter point, Figure 4 provides the result of estimating a linear factor model in an attempt to simultaneously price portfolios of equities and the carry trade portfolios. The pricing model is from Fama and French (1993) and uses three factors: The market excess return, the SMB portfolio (the return differential between small and big firms), and the HML portfolio (the return differential between high value and low value firms). The test assets are Fama and French’s set of 25 equity portfolios sorted on the basis of size and value, along with the three carry trade portfolios, EWC, HML and DBM. The y-axis in the graph is the sample mean return for each of the 28 portfolios. The x-axis is the predicted mean return from the estimated three factor model. The equity portfolios are marked in blue, while the currency portfolios are marked in red. The graph illustrates that the currency portfolios are only modestly exposed to the model-implied measure of risk, as the model-predicted expected returns are much smaller than the actual expected returns. The difference is also highly statistically significant for each of the currency portfolios. The previously cited literature shows that this pattern is observed for a long list of standard factor models.

[INSERT FIGURE 4 HERE]

5 Conclusion

The empirical failure of the UIP condition is one of the longest standing puzzles in international finance. In the 1976–2018 period, exchange rates have come close to approximating random walks, a finding which is at odds with the UIP condition, which suggests that the interest rate differential between two currencies should be the expected rate of change of their exchange rate. In this same period of time, a variety of trading strategies known as currency carry trades, in which investors lend low interest rate currencies and borrow high interest rate currencies, have been profitable. As we have seen, the failure of UIP and the profitability of carry trades are intimately linked as carry trades could not be profitable, on average, if the UIP condition held. A large literature considers a variety of theoretical explanations for the failure of UIP. Empirically successful risk-based explanations remain elusive. A change in the behavior of exchange rates emerged during and has persisted after the financial crisis. It appears to be linked to the compression of interest rates near the zero lower bound in most of the industrialized economies.
References


Table 1: Tests of UIP for the G10 Currencies

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<thead>
<tr>
<th>Currency</th>
<th>$a \times 100$</th>
<th>$b$</th>
<th>$R^2 \times 100$</th>
<th>Test of UIP</th>
<th>Test of RW</th>
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<td>EUR/DEM</td>
<td>0.22</td>
<td>-0.69</td>
<td>0.25</td>
<td>0.093</td>
<td>0.357</td>
</tr>
<tr>
<td></td>
<td>(0.16)</td>
<td>(0.80)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JPY</td>
<td>0.54</td>
<td>-1.43</td>
<td>0.96</td>
<td>0.003</td>
<td>0.030</td>
</tr>
<tr>
<td></td>
<td>(0.20)</td>
<td>(0.71)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOK</td>
<td>-0.09</td>
<td>-0.42</td>
<td>0.15</td>
<td>0.047</td>
<td>0.768</td>
</tr>
<tr>
<td></td>
<td>(0.16)</td>
<td>(0.61)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NZD</td>
<td>-0.16</td>
<td>-0.97</td>
<td>0.95</td>
<td>0.000</td>
<td>0.142</td>
</tr>
<tr>
<td></td>
<td>(0.23)</td>
<td>(0.52)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEK</td>
<td>0.03</td>
<td>0.83</td>
<td>0.79</td>
<td>0.904</td>
<td>0.369</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.61)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHF</td>
<td>0.52</td>
<td>-1.14</td>
<td>0.78</td>
<td>0.014</td>
<td>0.050</td>
</tr>
<tr>
<td></td>
<td>(0.21)</td>
<td>(0.75)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GBP</td>
<td>-0.23</td>
<td>-1.45</td>
<td>1.17</td>
<td>0.002</td>
<td>0.100</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.71)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: The table presents estimates of equation (5). Estimates of $a$ and the $R^2$s of the regression are scaled by 100 for readability. The table also presents results of two hypothesis tests. Under “Test of UIP” the p-value associated with a test of $H_0: a = 0, b = 1$ is presented. Under “Test of RW” the p-value associated with a test of $H_0: a = 0, b = 0$ is presented. The latter can be viewed as a test of whether the spot exchange rate is a random walk with no drift. Using end-of-month observations sourced from Datastream, the sample period is 1976M1–2018M3, with different start dates for JPY (1978M6), AUD and NZD (both 1984M12). The DEM series is spliced to the EUR series on December 31 1998.
Table 2: Time Series Variation of Appreciation and Forward Premia

<table>
<thead>
<tr>
<th>Currency</th>
<th>(f_t &gt; 0)</th>
<th>(f_t \leq 0)</th>
<th>Opposite Sign</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(z_{t+1} &lt; 0)</td>
<td>(z_{t+1} \geq 0)</td>
<td>(z_{t+1} &lt; 0)</td>
</tr>
<tr>
<td>AUD</td>
<td>33</td>
<td>14</td>
<td>162</td>
</tr>
<tr>
<td>CAD</td>
<td>89</td>
<td>68</td>
<td>168</td>
</tr>
<tr>
<td>DKK</td>
<td>126</td>
<td>104</td>
<td>120</td>
</tr>
<tr>
<td>EUR/DEM</td>
<td>179</td>
<td>185</td>
<td>61</td>
</tr>
<tr>
<td>JPY</td>
<td>233</td>
<td>210</td>
<td>11</td>
</tr>
<tr>
<td>NOK</td>
<td>71</td>
<td>72</td>
<td>177</td>
</tr>
<tr>
<td>NZD</td>
<td>14</td>
<td>12</td>
<td>167</td>
</tr>
<tr>
<td>SEK</td>
<td>99</td>
<td>76</td>
<td>155</td>
</tr>
<tr>
<td>CHF</td>
<td>222</td>
<td>233</td>
<td>21</td>
</tr>
<tr>
<td>GBP</td>
<td>64</td>
<td>38</td>
<td>198</td>
</tr>
</tbody>
</table>

Notes: The table presents the number of monthly observations in which \(f_t\) and \(z_{t+1}\) have the indicated properties during the 1976–2018 period. “Opposite Sign” provides the frequency with which the variables indicated have the opposite sign.
Table 3: Root Mean Squared Errors of Exchange Rate Forecasts (%)

<table>
<thead>
<tr>
<th>Currency</th>
<th>$E_t z_{t+1} = 0$</th>
<th>$E_t z_{t+1} = f_t$</th>
<th>$E_t z_{t+1} = a + b f_t$</th>
<th>Full Sample Regression</th>
<th>Rolling Regression</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUD</td>
<td>3.25</td>
<td>3.27</td>
<td>3.24</td>
<td>3.31</td>
<td></td>
</tr>
<tr>
<td>CAD</td>
<td>2.07</td>
<td>2.08</td>
<td>2.07</td>
<td>2.11</td>
<td></td>
</tr>
<tr>
<td>DKK</td>
<td>3.08</td>
<td>3.11</td>
<td>3.06</td>
<td>3.11</td>
<td></td>
</tr>
<tr>
<td>EUR/DEM</td>
<td>3.12</td>
<td>3.14</td>
<td>3.11</td>
<td>3.16</td>
<td></td>
</tr>
<tr>
<td>JPY</td>
<td>3.22</td>
<td>3.23</td>
<td>3.21</td>
<td>3.29</td>
<td></td>
</tr>
<tr>
<td>NOK</td>
<td>3.12</td>
<td>3.14</td>
<td>3.12</td>
<td>3.20</td>
<td></td>
</tr>
<tr>
<td>NZD</td>
<td>3.36</td>
<td>3.38</td>
<td>3.36</td>
<td>3.37</td>
<td></td>
</tr>
<tr>
<td>SEK</td>
<td>3.20</td>
<td>3.20</td>
<td>3.19</td>
<td>3.25</td>
<td></td>
</tr>
<tr>
<td>CHF</td>
<td>3.34</td>
<td>3.37</td>
<td>3.32</td>
<td>3.39</td>
<td></td>
</tr>
<tr>
<td>GBP</td>
<td>2.93</td>
<td>2.97</td>
<td>2.91</td>
<td>2.99</td>
<td></td>
</tr>
</tbody>
</table>

Notes: The table presents root mean squared errors of forecasts of $z_{t+1}$ based on three assumptions: (1) that $E_t z_{t+1} = 0$, (2) that $E_t z_{t+1} = f_t$, and (3) that $E_t z_{t+1} = a + b f_t$ where $a$ and $b$ are estimated using either (a) the full sample or (b) regressions using rolling windows of 60 months of data. The sample period for the regressions is the same as in Table 1 but the forecasts are evaluated over comparable sample periods beginning in 1981M2 except for JPY (1983M7), AUD and NZD (both 1990M1).
## Table 4: Returns of Carry Trade Portfolios and US Equities (%)

<table>
<thead>
<tr>
<th>Portfolio</th>
<th>Mean</th>
<th>SD</th>
<th>SR</th>
<th>Skew</th>
<th>Kurt</th>
</tr>
</thead>
<tbody>
<tr>
<td>EWC</td>
<td>4.1</td>
<td>4.9</td>
<td>0.82</td>
<td>-0.48</td>
<td>2.28</td>
</tr>
<tr>
<td></td>
<td>(0.8)</td>
<td>(0.3)</td>
<td>(0.18)</td>
<td>(0.22)</td>
<td>(0.63)</td>
</tr>
<tr>
<td>DBM</td>
<td>5.5</td>
<td>8.8</td>
<td>0.62</td>
<td>-0.74</td>
<td>1.82</td>
</tr>
<tr>
<td></td>
<td>(1.4)</td>
<td>(0.5)</td>
<td>(0.18)</td>
<td>(0.16)</td>
<td>(0.52)</td>
</tr>
<tr>
<td>HML</td>
<td>4.2</td>
<td>6.0</td>
<td>0.69</td>
<td>-0.32</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>(1.0)</td>
<td>(0.3)</td>
<td>(0.18)</td>
<td>(0.17)</td>
<td>(0.42)</td>
</tr>
<tr>
<td>US stocks</td>
<td>7.6</td>
<td>15.0</td>
<td>0.51</td>
<td>-0.74</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td>(2.4)</td>
<td>(0.8)</td>
<td>(0.17)</td>
<td>(0.27)</td>
<td>(1.20)</td>
</tr>
</tbody>
</table>

Notes: The table presents statistics on the annualized excess returns to carry trade strategies described in the text, including the mean, the standard deviation (SD), the Sharpe Ratio (SR), skewness (Skew), and excess kurtosis (Kurt). Standard errors are presented in parentheses. The strategies are implemented over the period 1976M1–2018M2. EWC indicates the equally-weighted carry trade strategy of Burnside et al. (2011a). DBM mimics the construction of the Deutsche Bank G10 Currency Future Harvest (DBCFH) index. HML is a strategy which is long the high interest rate currencies, and short the low interest rate currencies. For US equities I use the excess return of the value-weighted stock market provided in Kenneth French’s database. See the main text for details.
Figure 1: Average Rates of Appreciation and Forward Premia

Notes: The sample average of the rate of appreciation, \( \bar{z} \), is plotted against the sample average of the forward premium, \( \bar{f} \). See Table 1 for details of the data. The UIP condition predicts that the points in this graph should lie on the red 45 degree line.
Figure 2: Rolling Estimates of the UIP Regression

Notes: The black line illustrates the median, across currencies, of the estimate of $\hat{b}$ corresponding to a 60-month rolling window sample ending on the date indicated on the x-axis. The grey area illustrates the 30th–70th quantile range of the estimates of $b$ for each sample.
Notes: For each portfolio, the black line illustrates the 60-month moving average of the excess return, with each date corresponding to the end of the 60-month period. The blue line, in each case, represents the 60-month moving average of the absolute interest differentials implicit in the construction of the portfolio.
Notes: The y-axis in the graph is the sample mean return for each of Fama and French’s 25 portfolios sorted on the basis of size and value (the blue dots) and the three carry trade portfolios (EWC, HML and DBM, the red dots). The x-axis is the predicted mean return from the estimated three factor model.