Arbitrage Capital and Currency Carry Trade Returns

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Abstract

We develop a model based on risk averse investors and limited arbitrage capital to explain the rationale for the so called carry trades: that is, trades where "the purchase of riskier, higher-yielding assets is funded by selling lower-yielding currencies" (Financial Times, January 28, 2008). Due to differences in risk and limited arbitrage capital, in our model the returns to carry trades are positive, but decrease in the amount of arbitrage capital. In the empirical part of the paper, using 32 years of exchange rate data, we document several new results related to carry trades and provide empirical support for the model's predictions. We empirically document that 1) the interest rate and inflation risk in high interest rate currencies are indeed higher and 2) there is a significant correlation of carry trade returns with the hedge fund indices, which suggests that carry trades are indeed used by arbitrageurs. Other main empirical results are 3) the positive returns to carry trades have been decreasing over time in parallel with an increase in arbitrage capital 4) entry into our "carry trade" long (short) portfolio leads initially to an appreciation (depreciation) of the corresponding currency, inconsistent with the uncovered interest rate parity and 5) the currency impact from entry into our "carry trade" portfolio depends strongly on the amount of arbitrage capital. At the time of the paper, US Dollar has exited and been replaced by Euro in the "carry trade" long portfolio, making the analysis and predictions particularly timely from US and European perspectives.

Key words: Carry Trades, Arbitrage Capital, Risk Arbitrage

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Introduction

In this paper, we develop a model to explain the rationale for the so called currency carry trades: that is, trades where "the purchase of riskier, higher-yielding assets is funded by selling lower-yielding currencies" (Financial Times, January 28, 2008). The model reflects the intuition given by Grossman in his AFA Presidential Address in 1995 that the interest rate differentials across countries do not reflect merely the expected depreciation or appreciation of currencies, but also real rewards to the world for bearing risks related to investments in the respective currencies. In addition to the theoretical model, we provide several new empirical facts regarding the profitability of the carry trades and the effect of carry trade activity on exchange rates.

Our model has two countries, whose risk-averse consumers can only invest in their own country's securities markets, due to prohibitively high transaction costs. In addition, living on an island in between, there are a limited number of arbitrageurs, who can buy and sell short fixed-income securities in all markets. Similar assumption of limited arbitrage capital is present *e.g.,* in Gromb and Vayanos (2002) and Brunnermeier and Pedersen (2007). Due to random shocks, the inflation risk varies across the two countries. This assumption implies that in the absence of arbitrageurs, other things equal, the equilibrium expected real interest rate offered by the nominally fixed income securities is higher in the country with the higher inflation risk. In the presence of some arbitrageurs, who in equilibrium engage in carry trades, this expected real interest rate differential across countries is reduced.

On the theoretical side, we extend the existing literature (reviewed below) by developing a new model that is consistent with the carry trade phenomenon. Our model relies on risk aversion of investors, transaction costs for domestic investors, and the assumption of only a limited number of risk-averse arbitrageurs that exploit the return differentials between countries.[2] The model predicts that the returns to carry trades, while being positive, decrease when the arbitrage capital increases. Additionally, the expected returns to carry trades decrease when the overall level of inflation risk or investors' risk aversion becomes small.

On the empirical side, using 32 years of exchange rate data, we present several new results and provide empirical support for the model's predictions. Our main new empirical findings are that 1) carry trade returns have significant correlation with hedge fund return indices, confirming the idea that arbitrageurs engage in carry trades, 2) the profitability of carry trades has decreased over time, 3) the decrease in carry trade profitability is related to an increase in arbitrage capital, 4) in accordance with our key assumption, the inflation and interest rate risks are higher in high interest rate countries as opposed to low interest rate countries, 5) entry into our "carry trade" long (short) portfolio follows depreciation (appreciation) of the currency and leads to a future appreciation (depreciation) in the corresponding currency, latter result being inconsistent with the uncovered interest rate parity and 6) the currency impact from entry into our "carry trade" portfolio depends strongly on the amount of arbitrage capital.

Our study is tightly connected to the existing literature on the failure of the uncovered interest rate parity (UIP), commonly referred to as the "forward premium puzzle". Regardless of several attempts, the literature has so far failed to agree on an explanation to the failure of the uncovered interest rate parity and the arguably positive returns to carry trades. One paper close in spirit to ours is Brunnermeier *et al.* (2008). Their paper shows that carry trades are subject to currency crash risk, *i.e.*, the exchange rate movements of carry trade portfolios are negatively skewed. This finding

[2] The transaction costs from borrowing and investing in foreign currencies have historically been large especially for individual investors, who in many countries were prior to the 1990's forbidden to do such transactions. In some countries these limitations have continued into the current millennium.

complements our findings regarding the different levels of inflation and interest rate risks in high and low interest rate countries. They argue that the skewness in foreign exchange rates follows from temporary changes in the availability of funding liquidity to arbitrageurs. When the funding liquidity is temporarily reduced, this results in a rapid unwinding of the traders' positions and thus to abrupt changes in the exchange rates, which go against the carry traders. This risk, they argue, is a major factor affecting traders' willingness to enter into these "risk arbitrage" positions and arbitrage away the positive returns to carry trades.

The other existing literature on the subject can be organized into four categories. First, Roll and Yan (2000) question the validity of the statistical inference procedures underlying the early literature regarding the forward premium puzzle. The recent strong empirical results regarding positive carry trade returns reported *e.g.* in Burnside *et al.* (2006), Lyytinen (2007), Lustig *et. al*. (2008), as well as in our paper, do however call for other explanations.

Second, it is argued that the forward premium contains a time-varying risk premium component, which is negatively correlated with the expected change in the exchange rate and this causes the forward premium puzzle, see *e.g.,* Fama (1984), Backus *et al.* (2001), Alvarez *et al.* (2007), Verdelhan (2007), and Farhi and Gabaix (2008). The explanations based purely on risks tend to require high levels of risk aversion or high intertemporal elasticity of substitution. For instance, Lustig and Verdelhan (2007) find that consumption growth risk can explain the cross section of returns on portfolios of currencies sorted by interest rates only if the representative agent has a very high level of risk aversion. Similar to the previous, Bansal and Shaliastovich (2006) show that the puzzle can be explained with long-run risks when consumption volatility is stochastic and agents have high enough intertemporal elasticity of substitution. Mark and Wu (1998), on the other hand, show that intertemporal asset pricing model with habit persistent utility is unable to explain the empirically observed deviations from UIP.

Third category of papers addressing the forward premium puzzle are those based on market microstructure frictions explored *e.g.,* by Burnside *et al.* (2007b). In their model a risk neutral market maker faces an adverse selection problem since she does not know whether she receives orders from informed or uninformed traders. The probability of informed buy and sell orders depends on whether the currency is expected to appreciate or depreciate. To deal with this, the market maker sets the forward ask and bid rates asymmetrically, which in their model results in the forward premium bias. Plantin and Shin (2008) show that under carry costs and financing externalities carry trade profitability can become self-fulfilling: traders buying into a high-yielding currency put upward pressure on the price of the currency and the failure of UIP is thus a consequence of carry trades.

Finally, the fourth category of related papers relies on imperfections in information processing. Albuquerque (2007) models agents that do not perfectly observe shocks driving the monetary policy. Optimal updating of conditional expectations using Kalman filter leads to fixed time effects and conditional heteroscedasticity in the UIP regression. He also shows empirically that this specification significantly weakens the forward premium puzzle. In Gourinchas and Tornell (2004) agents learn about the nature of the interest rate shocks (transitory or persistent), but there is an irrational misperception about the second moments of interest rate forecasts that never disappears, resulting in the forward premium puzzle. Bacchetta and van Wincoop (2006) show that it is optimal for agents to manage their foreign exchange portfolios infrequently if the costs outweigh the gains from active management. Finally, using a model where overconfident agents overreact to their private signals, Han *et al.* (2007) provide a behavioral explanation for the forward premium puzzle.

The rest of the paper is organized as follows: In section 1 we develop the model and in section 2 we show the main theoretical results. Section 3 contains the empirical part of the paper: in section 3A we describe the data and in sections 3B and 3C our main empirical results.

1. The Model

There are two countries, A and B, and two periods of time $t = 1$ and $t = 2$. The consumers (also referred to as "investors") in these two countries consume apples and are endowed with plenty of time $t = 1$ apples. They have prohibitively high transaction costs from investing in the other country than their own and thus invest only in their own country of residence.[3] The amount of such investors in both countries is normalized to one.

There are two storage technologies in both countries $i \in \{A,B\}$: 1) a risk free storage technology in unlimited supply, whose return is normalized to zero (the apples do not rot); 2) a risky storage technology, also referred to as the risky asset, whose per capita supply in both countries equals one.[4] Our interpretation is that the risky storage technology (risky asset) corresponds to short term nominally fixed income securities issued by the government at $t = 1$ at a "per unit" price of P_i measured in time t = 1 apples. One unit or "one share" of such risky asset gives a random real payoff equal to

$$V_i = 1 + \varepsilon_i \tag{1}$$

apples in period $t = 2$. Here ε_i, $i \in \{A,B\}$, are two independent normally distributed random variables reflecting the inflation risk in such nominal securities in any given country, with mean zero and standard deviation σ_i. Note that we do not explicitly model the nominal payoff itself, but rather

[3] This assumption is effectively similar to that in the preferred habitat models, see *e.g.*, Vayanos and Vila (2007).

[4] An easy generalization of the model, discussed below, would be to assume that the per capita supply of the risky asset in country i equals $M_i > 0$.

directly the real payoff from the nominal securities. We assume that σ_i, $i \in \{A,B\}$, are drawn from the same continuous distribution, implying that $\sigma_i \neq \sigma_j$ with probability one. We assume that the time $t = 1$ wealth of the investors in both countries i, W_{i1}, exceeds their equilibrium level of investment in the risky asset.

In addition to the countries A and B, there exists an island in between the two countries. On the island there lives K arbitrageurs, who have low transaction costs and can sell short the risky asset in one country, while investing the proceeds in the risky asset of the other country. These islanders have no time $t = 1$ apples, but have plenty of time $t = 2$ apples (and can thus cover the possible losses from their risk arbitrage activities). An additional assumption is that the islanders cannot borrow using the riskless securities, *i.e.*, the baskets of commodities cannot be sold short.

Timing:

$t = 1$: In the beginning of the period σ_i are determined for both countries $i \in \{A,B\}$. Investors and arbitrageurs make their investment decisions.

$t = 2$: The final payoff to the risky assets is determined as $V_i = 1 + \varepsilon_i$ apples.

All investors are risk averse and have a constant absolute risk aversion:

$$U = -exp\ (-aW_2), \tag{2}$$

for their period $t = 2$ wealth, W_2. Here a is the parameter of risk aversion. Equilibrium exists when investors' actions maximize their utility, taking the other players' strategies as given, and markets clear.

Our interpretation is thus that the risky asset corresponds to money, *i.e.*, a short term nominal fixed income security. The risk in this security is the inflation risk, which does not exist in a risk free investment made directly into a basket of goods. We interpret the ratio of the time $t = 1$ prices of the risky assets in countries A and B, P_A/P_B, as the time $t = 1$ currency exchange rate.

2. Equilibrium

2.1 Investments into risky assets in the absence of arbitrageurs

In this subsection we drop the subscripts as the results apply for both countries. In both countries the investors choose their level of investment in the risky asset by selecting the number of shares purchased, λ. The investors maximize:[5]

$$\max_{\lambda} E -\exp(-aW_1 - a\lambda(1 + \varepsilon - P))$$
$$= -\exp(-a(W_1 + \lambda(1 - P) - \tfrac{1}{2} a\lambda^2\sigma^2)). \quad (3)$$

The first order condition to the maximization problem gives:

$$\lambda = (1 - P)/(a\sigma^2). \quad (4)$$

Setting $\lambda = 1$, from market clearing, we obtain:

$$P = 1 - a\sigma^2. \quad (5)$$

[5] Our setting matches that commonly used to study investments in shares of risky assets under uncertainty and CARA utility.

In the absence of arbitrageurs, *i.e.,* when $K = 0,$ the expected return from investing in the risky asset, *i.e.*, the equilibrium interest rate is thus:

$$R \equiv 1 + r \equiv 1/P = 1/(1 - a\sigma^2). \tag{6}$$

Equation (6) implies that in the absence of arbitrageurs, the equilibrium interest rate is higher in the country with the higher inflation risk, σ_i. The higher interest rate in that country is necessary to attract a sufficient amount of investments into the risky asset in order to clear the market, despite the higher risk. Due to the difference in expected returns, there does exist an opportunity for an arbitrageur to borrow from the country with the lower interest rate and invest the proceeds in the country with the higher interest rate and earn a positive expected return. We now turn to this possibility.

2.2. The role of arbitrageurs

Now, assume $K > 0$, so there are some arbitrageurs present in the market. We assume that the arbitrageurs are endowed with a time $t = 2$ wealth of $\underline{W_2}$. As we show below, the presence of arbitrageurs in the market reduces the differential in expected returns between the risky assets in countries *A* and *B*, but, when $K < \infty$, it does not eliminate the return differential.

Denote by *L* the country with the lower level of inflation risk $i \in argmin\{\sigma_A,\sigma_B\},$ and by *H* the country with the higher level of inflation risk, $i \in argmax\{\sigma_A,\sigma_B\}$. In equilibrium, at $t = 1$ (as we show below) the arbitrageurs sell short $X_L(\sigma_A,\sigma_B)$ "shares" of the risky asset in country *L*, *i.e.*, in the country with the lower risk, thus obtaining $P_L X_L$ apples and invest these in country *H*, with the higher risk. This means that the supply of the risky asset in country *L* is $(1+X_L),$ where $X_L > 0,$ and in country *H* it is $(1+X_H)$, where $X_H = -X_L P_L/P_H$.

More formally, the arbitrageurs maximize their utility by selecting the number of "shares" of the risky asset purchased in country H, λ_H, financed by selling short λ_L "shares" of the risky asset in country L:[6]

$$max_{\lambda H, \lambda L}\, E–exp(- a\underline{W}_2 - a(\lambda_H(1+\varepsilon_H–P_H) - \lambda_L(1+\varepsilon_L - P_L))) \qquad (7)$$

$$= -exp(-a\underline{W}_2 - a(\lambda_H(1 – P_H) - \lambda_L(1 - P_L) - ½a\lambda_H{}^2\sigma_H{}^2 - ½a\lambda_L{}^2\sigma_L{}^2)),$$

$$\text{subject to } \lambda_H P_H / P_L = \lambda_L. \qquad (8)$$

This is equivalent to:

$$\max_{\lambda H} -exp(-a\underline{W}_2 - a(\lambda_H(1– P_H) - \lambda_H P_H/P_L(1- P_L) - ½a\lambda_H{}^2\sigma_H{}^2 - ½a(\lambda_H P_H /P_L)^2\sigma_L{}^2)). \qquad (9)$$

The first order condition is:

$$\lambda_H = ((1 – P_H) – P_H/P_L\, (1- P_L)) / (a\sigma_H{}^2 + (P_H /P_L)^2 a\sigma_L{}^2)). \qquad (10)$$

Given that there are K arbitrageurs we have:

$$X_H = -K\lambda_H \qquad (11)$$

and

$$X_L = K\, \lambda_H P_H/P_L. \qquad (12)$$

[6] Note that we do not restrict λ_H to be positive and λ_L to be negative. If the equilibrium λ_H turns out to be negative, this implies that in equilibrium the arbitrageurs sell short the risky asset in country H, while investing the proceeds in country L, in contrast to what we have conjectured.

Using also the market clearing conditions, we now have four equations in four unknowns that determine P_H, P_L, X_L and X_H:

$$X_H = -K((1 - P_H) - P_H/P_L\,(1 - P_L)) \;/\; (a\sigma_H^2 + (P_H/P_L)^2 a\sigma_L^2)), \tag{13}$$

$$X_L = -X_H P_H/P_L, \tag{14}$$

$$P_H = 1 - (1+X_H)a\sigma_H^2, \tag{15}$$

$$P_L = 1 - (1+X_L)a\sigma_L^2. \tag{16}$$

Now, from (13) and (14), we see that the arbitrageurs do in equilibrium invest a positive amount in the strategy that we conjectured, *i.e.*, $\lambda_H > 0$ ($X_H < 0$) and $\lambda_L < 0$ ($X_L > 0$) as long as:

$$(1-P_H) > P_H/P_L\,(1 - P_L)$$

$$\Leftrightarrow \quad 1/P_H - 1/P_L > 0 \tag{17}$$

$$\Leftrightarrow \quad r_H - r_L > 0, \tag{18}$$

that is, as long as there is a positive "carry". In the case when there were no arbitrageurs, we showed that the interest rate in country *H* was higher than that in country *L*. In the presence of *K* arbitrageurs the same result holds, as shown in the Appendix, and thus the left hand side of (18) remains strictly positive. As also shown in the Appendix, however, as *K* increases, the left hand side of (18) and thus the returns to carry trades approach zero.

We summarize these findings in the following propositions:

Proposition 1: *In equilibrium, the arbitrageurs engage in carry trades (borrow from the country with the lower interest rate and invest the proceeds in the country with the higher interest rate). The expected returns from carry trades are positive.*

Proposition 2: *When arbitrage capital K increases, returns to carry trades decrease and eventually disappear in the limit.*

Next, recall that the exchange rate in our model is P_A/P_B. From equations (15) and (16) we see that, as X_H is negative, the carry trade activity implies an appreciation in the currency *H* that belongs to our "carry trade" long portfolio, while as X_L is positive, the carry trade activity implies a depreciation of the currency *L* in our "carry trade" short portfolio. That is,

Proposition 3: *Carry trade activity leads to an increase in P_H and a decrease in P_L.*

Finally, an additional result is that:

Proposition 4: When $\sigma_H \rightarrow 0$ *or* $a \rightarrow 0$ *the returns to carry trades approach zero.*

Proofs of Propositions 1-4 are given in the Appendix. The result in Proposition 4 is consistent with the finding in Lustig *et al*. (2008) that an increase in the VIX volatility index leads to an increase in the expected returns to carry trades. Their finding is also consistent with the finding in Brunnermeier *et al.* (2008) that increases in VIX index lead to contemporaneous losses to carry traders. Finally, when the parameter of risk aversion approaches zero, this also leads to the disappearance of the expected returns from carry trades.

2.3 Extensions of the model and discussion

Our model can be extended in several ways to account for other phenomena that affect the real or only the nominal interest rates. First, as already discussed in footnote 4, one possibility to extend the model is to assume that the per capita supply of the risky asset is more generally M_i, as opposed to being the same in both countries, as it is in our model. It is easy to show that in such a model the market interest rate would become

$$R_i \equiv 1 + r_i \equiv 1/P_i = 1/(1 - aM_i \sigma_i^2), \tag{19}$$

in the absence of arbitrageurs. In such a model, a high interest rate in any given country could thus be a result of either high inflation risk, as it is in our model, or be due to a large per capita supply of the risky asset. An example of the latter possibility is described in Grossman (1995). He discusses how the high financing needs in Germany after the unification led to a high market interest rate for the German mark.

A second possibility why interest rates across countries may differ, that we also chose to exclude from our model, is that one country's investors' risk aversion would be higher than that of the other country's investors'.

In the empirical part we show that on average an entry into our "carry trade" long portfolio is preceded by a depreciation of the currency and an entry into our "carry trade" short portfolio is preceded by an appreciation of the currency. These results are in fact is consistent with our model, where $P_H/P_L < 1$, given (17). While being consistent with the empirical facts, this particular theoretical result depends heavily on the model specification. In an alternative specification we could have a structure where the expected payoff to the risky asset varies across securities and risk depends on the expected payoff. An example of such specification would be a setting where $V_i = v_i\varepsilon$, where ε is a normally distributed random variable with mean one and v_i another random variable drawn separately for $i \in \{A,B\}$. In this specification a higher expected payoff v_i would be associated with higher risk, as in Cochrane *et al.* (2007). While being able to derive all propositions 1-4, depending on parameters we could now have the result that $P_H/P_L > 1$. Hence, theoretically we cannot predict the exchange rate movements prior to entry into "carry trade" portfolios.

Empirical Part

3a. The Data

To test our model empirically, we use a data set that is obtained from Datastream and consists of month-end observations of interbank spot and 1-month forward exchange rates for Belgian franc, Canadian dollar, euro, French franc, German mark, Italian lira, Japanese yen, Netherlands guilder, Swiss franc, and U.S. dollar against British pound. The data covers a 384 month period from January 1976 to December 2007. All currencies are not available in the data set throughout this period, but enter as data becomes available. Data for Japanese yen begins in June 1978 and for euro in January 1999, and data for euro legacy currencies (Belgian franc, French franc, German mark, Italian lira, and Netherlands guilder) ends in December 1998. Altogether, we have 3949 currency-month observations. The data set contains mid, ask and bid quotes. The ask exchange rate is the price at which a participant of the interbank market can buy British pounds and the bid rate is the price at which one can sell British pounds. Mid rate is the average of the bid and the ask rates. To supplement the data, we also collect data of the 1-month euro interest rate for the British pound. This data is also from Datastream and covers the period from January 1976 to December 2007. Although Datastream gives us only an incomplete data set of the currencies, we cannot think of any systematic bias arising from the fact that not all currencies at all times have been included in the data set. Our dataset contains the currencies used *e.g.* in Burnside *et al.* (2006).

In order to analyze carry trades, we trace the returns to a very simple carry trade strategy. At the end of every month, we rank the currencies according to their forward premiums. We sell pounds forward in the currencies that rank in the top third and buy pound forward in the bottom third currencies. At the end of the next month, the forwards are settled, a new ranking is composed and new forward contacts are entered into. This approach differs somewhat from that used by Burnside *et al*. (2006 and 2007a) who sell pound forward in all the currencies that have a positive forward premium and buy pound forward in all the currencies that have a negative forward premium. Our approach of leaving out middle ranked currencies matches that commonly used in the asset pricing literature and is similar to that used for currencies *e.g.,* by Lustig and Verdelhan (2007) and Lustig *et al.* (2008).

We calculate carry trade returns both using the mid rates and using the bid and the ask quotes. Returns calculated based on the mid rates we call gross returns, and returns calculated based on bid and ask quotes we refer to as net returns, as they take into account the transaction costs faced by a carry trader.

3b. Main Empirical Results

Key assumption of the model: inflation risk is higher in high interest rate countries

One of the key assumptions underlying our theoretical model is that the return differential between two countries is due to differences in inflation risk. We examine the validity of this assumption by analyzing the standard deviations of monthly changes in the consumer price indices in countries belonging to the short and long portfolios, presented in Table 1.[7] Our assumption would be consistent with a finding that the standard deviation of inflation in the “carry trade” long portfolio countries is higher than that in the “carry trade” short portfolio countries.

[Insert Table 1 here]

In accordance with our assumption, the inflation risk is indeed higher in the “carry trade” long portfolio countries than in the short portfolio countries, and this inequality of standard deviations is also statistically highly significant. Similarly, the standard deviation of the interest returns, as also reported in Table 1, is higher in the “carry trade” long portfolio countries.

Our theoretical model produced three main empirically testable hypotheses, which will be analyzed one-by-one below.

Prediction 1: Carry trades are profitable and used by arbitrageurs

The first conclusion of the theoretical model is that under limited arbitrage capital the carry trades are profitable. Table 2 presents the descriptive statistics for monthly gross returns on the carry trade strategy and Figure 1 shows the cumulative return, in pounds, to a constant 100 pound size investment in three portfolios: short carry trade, long carry trade and a long-short carry trade portfolios.

[Insert Table 2 and Figure 1 here]

[7] Consumer price index data are from European Central Bank (for euro area) and from OECD (for individual countries).

The mean monthly return to carry trades is 0.53%, which corresponds to a 6.36% annual return and is statistically very significant. The standard deviation of the monthly returns is 1.99% resulting in a monthly Sharpe ratio of 0.266 (0.920 annualized).[8] To allow for some comparison, over the same time period, S&P 500 had an average monthly return of 0.79%, monthly standard deviation of 4.17% and monthly Sharpe ratio of 0.142. These results are in line with those by Burnside *et al*. (2006), allowing for the fact that their method of constructing portfolios slightly differs from ours. The returns to the total carry trade portfolio are rather evenly attributable to short positions (0.31%) and long positions (0.22%). All the portfolios exhibit fat tails and the Jarque-Bera test clearly rejects the hypothesis of normality. Both short and long positions exhibit some positive autocorrelation, but for the total portfolio autocorrelation is insignificant. The profitability of carry trades is evident in Figure 1.

In Table 3, we break down the average monthly returns from carry trades to components due to interest rate differential, exchange rate movements and transaction costs, *i.e.* the bid-ask spreads.

[Insert Table 3 here]

The average level of interest rates is 3.53% in the short portfolio and 10.08% in the long portfolio, resulting in an interest return of 6.56% on annual basis or 0.55% on monthly basis. On average, exchange rate movements have only reduced the returns by 0.02% per month. If uncovered interest parity held, the average currency return should be close to the negative of the interest return, but it only is 3% of that value. Trading forwards and settling them monthly induces significant transaction costs, although bid-ask spreads are small for our sample of currencies. Over the sample period the

[8] Since the carry trade is a zero investment strategy, Sharpe ratio is simply the ratio of average of returns to standard deviation of returns.

average monthly trading costs are 0.32% of the portfolio value.[9] After transaction costs, the average monthly net return from carry trades is thus 0.21%, which corresponds to an annual net return of 2.56%.

Carry trades are often referred to as yen carry trades. This name is due to the fact that the low yielding and depreciating yen has been widely used as funding currency by carry traders. It is, thus, interesting to further analyze the contribution of each currency, especially the yen, to the total return on carry trades and study whether the positive returns are heavily dependent on the yen. Table 4 shows the contribution of each individual currency to the average monthly return on the carry trade strategy as well as the short and long portfolios.

[Insert Table 4 here]

Japanese yen stands out as a major factor of carry trade returns, 46.7% of short portfolio returns and 27.0% of the total carry trade returns are due to positions in the yen. Other major contributors are Swiss franc, in which only short positions are taken, and Canadian dollar, in which mainly long positions are taken. One obvious reason for the high return contribution by Japanese yen is that it is almost throughout the sample period one of the lowest yielding currencies and hence the simulated carry trade portfolio holds a short position in the yen for almost the entire sample period. Table 5 shows the total number of months each currency is in each of the portfolios and Figure 2 shows the development of the positions in each currency over time.

[Insert Table 5 and Figure 2 here]

[9] Note that these transaction costs are only available for professional investors corresponding to arbitrageurs in our model. Individual investors, presumably, have much higher transaction costs. On the other hand, professional investors may be able to trade at better prices than by merely buying at the end-of-month ask and selling at the end-of-month bid.

The yen is in the short portfolio for a total of 319 months which is equal to almost 90% of the sample period from which we have data for the yen. Figure 2 shows that in the 80's the carry trade strategy has periods of no position in Japanese yen, but from 1988 through 2007 a short position is maintained in the yen. The most active currency in terms of long carry trades is Italian lira, in which a long position is kept for 268 out of 276 months. The least active carry trade currencies are Belgian franc and euro. It is also worth noting that a long position is never taken in Japanese yen or Swiss franc, and a short position is never taken in Italian lira.

Table 6 presents the monthly average returns from positions in each currency. Whereas Table 4 presents the average returns over the whole sample period, including zero returns from months when there are no position in the currency, Table 6 presents the average from those months when there is a position open in the currency.

[Insert Table 6 here]

Table 6 gives a much more even picture of the sources of carry trade returns than Table 4 does. According to Table 6, positions in euro are the most profitable ones, followed by Belgian franc, Japanese yen and Netherlands guilder. All position except short positions in Belgian franc and French franc yield positive returns.

It remains a valid concern whether the positive returns to carry trades are heavily dependent on Japanese yen. To test this, we exclude the yen from the sample of currencies, re-run the trading simulation and report the key performance metrics in Table 7.

[Insert Table 7 here]

Excluding the yen slightly decreases the average return as well as the standard deviation of the returns, resulting in a small increase in the Sharpe ratio. Statistically, none of the differences is significant which provides for the conclusion that carry trade returns are robust and not sensitive to the exclusion of a single currency.

Finally, as shown also in Lyytinen (2007), Table 8 presents the correlation between carry trade portfolio and equities, bonds and hedge funds. We use the Standard & Poor's 500 as equity index, Lehman US Aggregate as bond index and Credit Suisse/Tremont Hedge Fund index family as hedge fund indices.

[Insert Table 8 here]

Carry trade returns have a low correlation with both equity and bond returns. The correlation with hedge fund returns is positive and statistically significant, which indicates that arbitrageurs do, indeed, engage in currency carry trades. Of the hedge fund sub-indices, carry trade returns are most highly correlated with fixed income arbitrage, global macro, convertible arbitrage and emerging market strategies. The strong correlation with global macro and fixed income arbitrage strategies suggests that these funds are most commonly engaging in carry trades.

Prediction 2: Increase in arbitrage capital will extinguish the profitability of carry trades

The second conclusion of the theoretical model is that although carry trades provide positive return, this return will diminish as more arbitrageurs enter the market. To summarize the change in the profitability of carry trades, we divide our sample period in three sub periods (1976-1987, 1988-

1997 and 1998-2007) and present returns and Sharpe ratios in each of the time periods in Table 9 and Figure 3.

[Insert Table 9 and Figure 3 here]

Average return and Sharpe ratio have both declined from period to period; both have almost halved from the first period to the last. According to the hedge fund advisory Hennessee Group LLC, the total hedge fund assets (AUM) were 20 billion USD in 1987, 130 billion in 1997 and 1.5 trillion in 2007.[10] These results provide empirical support for the second proposition of the theoretical model that the increase in arbitrage capital decreases carry trade returns. Second, it is likely that the transaction costs for the non-professional investors to exploit this strategy have significantly been reduced over time.

To study the relationship of arbitrage capital and carry trade returns, we use two alternative proxies for the amount of arbitrage capital. Our first measure of arbitrage capital is the beginning of year hedge fund AUM reported by Hennessee Group LLC. Since this data is only available on a yearly basis and is not a perfect measure of arbitrage capital involved in currency carry trades, we follow Greenwood and Vayanos (2008) and use the monthly cumulative return to currency carry trades (measured from the beginning of the sample period) as our second proxy of arbitrage capital. The results of regressing carry trade returns on the logarithm of arbitrage capital are reported in Table 10.

[Insert Table 10 here]

[10] Hennessee Group LLC: 13th Annual Hedge Fund Manager Survey, 2007. http://www.hennesseegroup.com/.

As predicted, the amount of arbitrage capital has a negative effect on carry trade returns. The coefficient of logarithmic hedge fund AUM is not statistically significant, most likely due to the low number of observations available, but the coefficient of cumulative carry trade return is statistically significant at a 10% level.

<u>Prediction 3: Carry trade activity will lead to appreciation (depreciation) of the currencies in the "carry trade" long (short) portfolio.</u>

If we conjecture that the traders follow the simple carry trade strategy that we have shown to be profitable, then in accordance with Proposition 3, the carry trade activity will lead to an appreciation (depreciation) of the currencies in our "carry trade" long (short) portfolio.

Figure 4 presents an event time analysis of the development of the spot exchange rate of a currency 121 months around the currency's entry into the long or the short portfolio. The spot rate development is calculated against an equally weighted basket of all the other currencies. Date zero denotes the month when the currency enters a portfolio. As Figure 4 depicts, in accordance with our conjecture it seems that especially entry into our "carry trade" long portfolio results in appreciation of the currency. However, the appreciation after entry to the long portfolio happens only gradually, partly explaining the positive returns to carry trades.

[Insert Figure 4 here]

Also in accordance with our conjecture there is depreciation following entry into our "carry trade" short portfolio. This depreciation followed by entry into the short portfolio is not statistically significant, however, though the appreciation trend preceding the entry clearly slows down for about 24 months. The sharp one month appreciation following entry into the long portfolio is statistically significant at 5% level and is followed by further appreciation for about 18 months.

These results, especially for the long positions, supplement the results of Eichenbaum and Evans (1995) who find that the contractionary shocks to U.S. monetary policy (*i.e.* tightening of the monetary policy) are followed by appreciation of the dollar and persistent deviations from UIP. Our results show that similar appreciation in a currency occurs after a large enough relative rise in interest rate also in a wider sample of currencies.

If our conjecture is correct, the appreciation (depreciation) following the entry into the long (short) portfolio should become stronger as the amount of arbitrageurs' capital increases. The event time analysis is reproduced for two sub-periods (1976-1991 and 1992-2007) in Figure 5. We use two sub-periods instead of three as earlier because there are very few entries into the portfolios over the last ten years of the sample period.

[Insert Figure 5 here]

The gradual strengthening of the price effect of portfolio entry is evident in Figure 5. There is no price effect from entry into the short portfolio during the first sub-period (1976-1991) and a clear negative price effect during the second sub-period (1992-2007). For the long portfolio, the positive price effect is small in the first sub-period and much stronger in the second sub-period.

To further study the effect of arbitrage capital on the price effect of portfolio entry we regress the 24-month price effect on the logarithm of the two arbitrage capital proxies used earlier: the hedge fund AUM in the beginning of the year during which the entry into a portfolio happens, and the cumulative return to currency carry trades in the beginning of the month during which the entry into a portfolio happens. The results are reported in Table 11.

[Insert Table 11 here]

The amount of arbitrage capital clearly affects the magnitude of the price effect. The coefficients of both arbitrage capital proxies are significantly negative for entries into the short portfolio and significantly positive for entries into the long portfolio. These results, that the amount of arbitrage capital strengthens the price effect, provide further empirical support for the idea that in practice traders use similar trading rules to the one we have analyzed. Note also that a similar prediction to ours that carry trades affect exchange rates is present in Plantin and Shin (2008) and Brunnermeier *et al.* (2008).

3c. On the research of the forward premium puzzle

The results related to the third prediction, *i.e.* that entry into the long (short) portfolio is followed by an appreciation (depreciation) of the currency, are useful for understanding the forward premium puzzle. On average, this currency impact caused by an entry into a carry trade portfolio seems to last between 18 and 24 months, after which the exchange rate continues to behave as predicted by the UIP, at least as far as the direction of change is concerned. Since the disruptions caused by the entry into a carry trade portfolio are in contrast with the UIP and are associated with the most extreme values of the forward premium, they may significantly affect the empirical analysis of the UIP. To test this effect, we augment the traditional UIP regression introduced by Fama (1984) by including dummy variables that indicate, whether the currency has entered one of the portfolios during the past 24 months:

$$s_{t+1}-s_t=\alpha+\beta(f_t-s_t)+\gamma_1 I^S_t+\gamma_2 I^L_t+\gamma_3 I^S_t(f_t-s_t)+\gamma_4 I^L_t(f_t-s_t)+\varepsilon_{t+1}, \qquad (20)$$

where s_t and f_t are the logarithmic spot and forward rates at time t, I^S_t is one if the currency has entered the short portfolio in the previous 24 months, and I^L_t is one if the currency has entered the long portfolio in the previous 24 months. The results of estimating equation (20) on all currencies pooled, against an equally weighted basket of the other currencies, with and without the dummy variables are presented in Table 12.

[Insert Table 12 here]

Without the dummies, the coefficient of the forward premium is 0.12 and not significantly different from zero, whereas with the dummies in place, the coefficient is 0.48. The coefficient with the dummies is significantly different from zero, and is also significantly different from unity which is the coefficient predicted by the UIP. Including the dummies thus significantly weakens the forward premium puzzle, but does not remove it. These results help to explain why numerous authors have found close to zero or even significantly negative estimates of β when testing the UIP empirically. The finding, that beta is positive but less than one, also supports our proposition that there is a real reward for carrying the risk of the high interest rate currencies.

These findings suggest that the problem with the UIP regressions is twofold. First, as high interest rate investments are riskier, with limited arbitrage capital UIP should not hold even theoretically. Second, as arbitrage capital has increased over time, the risk return relations in currency investments have changed over time. With larger arbitrage capital the rewards for carrying risks have become smaller over time and thus in future the expected currency returns should be closer to those forecasted by the UIP.

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Appendix

Proof of Propositions 1: Assume that $1/P_H - 1/P_L \leq 0$. In this case $X_H \geq 0$ and $X_L \leq 0$ by (13) and (14). But then $P_H \leq P_H|_{X_H = 0}$, and $P_L \geq P_L|_{X_L = 0}$, by (15) and (16), which implies that $1/P_H - 1/P_L > 1/(P_H|_{X_H = 0}) - 1/(P_L|_{X_L = 0}) > 0$, or $P_H < 0$, which is a contradiction. □

Proof of Proposition 2: Assume now that $\lim_{K \to \infty} [1/P_H - 1/P_L] > 0$. It must be that $P_L > 0$, as otherwise the carry trade strategy cannot be financed, as (8) cannot hold, and $\lim_{K \to \infty} P_L > 0$, as otherwise (17) becomes negative, implying that $\lim_{K \to \infty} X_H = -\infty$. Using (13) $\lim_{K \to \infty} X_L = \infty$, implying (from 16) that $\lim_{K \to \infty} P_L = -\infty$. Contradiction. Assuming that $\lim_{K \to \infty} [1/P_H - 1/P_L] < 0$ leads similarly to a contradiction. Hence $\lim_{K \to \infty} [1/P_H - 1/P_L] = 0$.□

Proof of Proposition 3: From the proof of Proposition 1 we know that $1/P_H - 1/P_L > 0$, implying that $X_H < 0$ and $X_L > 0$, given (13) and (14). The result now follows from equations (15) and (16).□

Proof of Proposition 4: Assume now that $\lim_{\sigma \to 0} [1/P_H - 1/P_L] > 0$. It must be that $P_L > 0$, as otherwise the strategy cannot be financed, as (8) cannot hold, and $\lim_{\sigma \to 0} P_L > 0$, as otherwise (17) becomes negative, implying that $\lim_{\sigma \to 0} X_H = -\infty$. Using (14) $\lim_{\sigma \to 0} X_L = \infty$, implying (from 16) that $\lim_{\sigma \to 0} P_L = -\infty$. Contradiction. Assuming that $\lim_{\sigma \to 0} [1/P_H - 1/P_L] < 0$ leads similarly to a contradiction. Hence $\lim_{\sigma \to 0} [1/P_H - 1/P_L] = 0$.

The result that $\lim_{a \to 0} [1/P_H - 1/P_L] = 0$ follows as given Proposition 1, $[1/P_H - 1/P_L] > 0$, and thus using (15) and (16), $P_H > P_H|_{X_H = 0}$, and $P_L < P_L|_{X_L = 0}$, as $X_H < 0$ and $X_L > 0$, by (13) and (14). Given this, $0 \leq \lim_{a \to 0} [1/P_H - 1/P_L] \leq \lim_{a \to 0} 1/(P_H|_{X_H = 0}) - 1/(P_L|_{X_L = 0}) = 0$, by (6)□

Table 1. Inflation and interest return risk in carry trade portfolios.

This table presents the standard deviations of changes in consumer price indices of countries belonging to short and long portfolios (*Inflation risk*), and the standard deviations of interest returns from the short and long currency carry trade portfolios (*Interest return risk*). *Short* refers to portfolio of short positions in low interest rate currencies, *Long* refers to portfolio of long positions in high interest rate currencies, and *Long/Short* refers to the ratio of the two standard deviations with *p*-value given in parenthesis for the test of equality of the standard deviations.

	Inflation risk	Interest return risk
Short	0.27%	0.19%
Long	0.41%	0.25%
Long/Short	1.527	1.325
	(0.000)	(0.000)

Table 2. Descriptive statistics of carry trade returns.

This table presents the basic descriptive statistics of monthly gross returns to carry trade strategy. *Short* refers to portfolio of short positions in low interest rate currencies, *Long* refers to portfolio of long positions in high interest rate currencies, and *Short+Long* refers to portfolio of short positions in low interest rate currencies and long positions in high interest rate currencies. *p*-values are given in parenthesis for selected statistics.

	Short+Long	Short	Long
Mean	0.53%	0.31%	0.22%
	(0.000)	(0.020)	(0.016)
Standard deviation	1.99%	2.57%	1.82%
Sharpe ratio	0.266	0.119	0.123
Skewness	-0.640	-0.661	0.898
Excess kurtosis	2.441	1.674	3.631
Jarque-Bera	123.670	74.135	266.371
	(0.000)	(0.000)	(0.000)
AR(1)	0.045	0.107	0.127
	(0.376)	(0.035)	(0.013)

Table 3. Breakdown of carry trade returns.

This table provides the breakdown of average monthly returns. *Short* refers to portfolio of short positions in low interest rate currencies, *Long* refers to portfolio of long positions in high interest rate currencies, and *Short+Long* refers to portfolio of short positions in low interest rate currencies and long positions in high interest rate currencies. *Interest return* is the return earned from the difference in interest rates between funding and investment currencies, *Currency return* is the return due to the changes in exchange rates, *Gross return* is the total return excluding transaction costs, *Transaction costs* are due to the bid-ask spread, and *Net return* is the total return including transaction costs. Figures are calculated against British pound.

	Short+Long	Short	Long
Interest return	0.55%	0.45%	0.10%
Currency return	-0.02%	-0.14%	0.12%
Gross return	0.53%	0.31%	0.22%
Expenses	-0.32%	-0.23%	-0.09%
Net return	0.21%	0.08%	0.14%

Table 4. Return contribution of individual currencies.

This table shows how different currencies have contributed to the average return of the portfolios. Figures in parenthesis show the contribution as proportional to the total average return of the portfolio. *Short* refers to portfolio of short positions in low interest rate currencies, *Long* refers to portfolio of long positions in high interest rate currencies, and *Short+Long* refers to portfolio of short positions in low interest rate currencies and long positions in high interest rate currencies. Returns are calculated against the British pound and hence positions in the pound will have a zero return and are not reported.

	Short+Long		Short		Long	
BEF	0.03%	(6.2%)	0.00%	-(1.1%)	0.04%	(16.2%)
CAD	0.06%	(11.6%)	0.02%	(7.7%)	0.04%	(16.9%)
CHF	0.09%	(16.8%)	0.09%	(29.1%)	0.00%	(0.0%)
DEM	0.02%	(4.3%)	0.02%	(5.8%)	0.00%	(2.2%)
EUR	0.01%	(2.4%)	0.00%	(0.8%)	0.01%	(4.7%)
FRF	0.05%	(9.3%)	-0.01%	-(1.9%)	0.06%	(24.7%)
ITL	0.03%	(5.0%)	0.00%	(0.0%)	0.03%	(11.8%)
JPY	0.14%	(27.0%)	0.14%	(46.7%)	0.00%	(0.0%)
NLG	0.05%	(8.9%)	0.03%	(8.5%)	0.02%	(9.4%)
USD	0.04%	(8.4%)	0.01%	(4.4%)	0.03%	(13.9%)
Total	0.53%		0.31%		0.22%	

Table 5. Carry trade positions.

This table presents the number of total months a position is in individual currencies over the sample period. Figures in parenthesis show the number of months divided by the length of the sample for the particular currency. *Short* refers to portfolio of short positions in low interest rate currencies, *Long* refers to portfolio of long positions in high interest rate currencies, and *Short+Long* refers to portfolio of short positions in low interest rate currencies and long positions in high interest rate currencies.

	Short+Long		Short		Long	
BEF	73	(26.4%)	8	(2.9%)	65	(23.6%)
CAD	165	(43.0%)	28	(7.3%)	137	(35.7%)
CHF	348	(90.6%)	348	(90.6%)	0	(0.0%)
DEM	175	(63.4%)	168	(60.9%)	7	(2.5%)
EUR	25	(22.9%)	1	(0.9%)	24	(22.0%)
FRF	135	(48.9%)	4	(1.4%)	131	(47.5%)
GBP	293	(76.3%)	1	(0.3%)	292	(76.0%)
ITL	268	(97.1%)	0	(0.0%)	268	(97.1%)
JPY	319	(89.9%)	319	(89.9%)	0	(0.0%)
NLG	108	(39.1%)	99	(35.9%)	9	(3.3%)
USD	177	(46.1%)	67	(17.4%)	110	(28.6%)

Table 6. Average performance of positions.

This table gives the average monthly return from positions held in individual currencies. *Short* refers a short position in a low interest rate currency, *Long* refers to a long position in a high interest rate currency, and *Short+Long* refers to portfolio of short positions in low interest rate currencies and long positions in high interest rate currencies. Returns are calculated against the British pound and hence positions in the pound have a zero return and are not reported.

	Short+Long	Short	Long
BEF	0.17%	-0.16%	0.21%
CAD	0.14%	0.32%	0.11%
CHF	0.10%	0.10%	-
DEM	0.05%	0.04%	0.27%
EUR	0.20%	0.93%	0.17%
FRF	0.14%	-0.56%	0.16%
ITL	0.04%	-	0.04%
JPY	0.17%	0.17%	-
NLG	0.17%	0.10%	0.90%
USD	0.10%	0.08%	0.11%

Table 7. Effect of excluding Japanese yen.

This table presents the performance of carry trade strategy with and without the Japanese yen. *Difference* column tells how much the figure changes with the exclusion of the yen with *p*-values given in parenthesis for the test of the difference being zero. Test of the equality of the Sharpe ratios is done according to Jobson and Korkie (1981).

	With JPY	Without JPY	Difference
Mean	0.53%	0.50%	-0.02%
			(0.654)
Standard deviation	1.99%	1.89%	-0.11%
			(0.272)
Sharpe ratio	0.266	0.268	0.002
			(0.939)

Table 8. Correlations with other asset classes.

This table presents the correlation between returns to carry trade and other asset classes. Data for S&P 500 and Lehman US Aggregate are from January 1976 through December 2007. Data for Credit Suisse/Tremont Hedge Fund indices are from December 1993 through December 2007, except for Multi-Strategy for which data begin in April 1994. *p*-values are given for the test that the correlation is equal to zero.

	Correlation	p-value
S&P 500	0.053	0.297
Lehman US Aggregate	-0.098	0.056
Credit Suisse/Tremont Hedge Fund	0.244	0.001
Convertible Arbitrage	0.232	0.002
Dedicated Short Bias	0.001	0.987
Emerging Markets	0.172	0.026
Equity Market Neutral	-0.112	0.149
Event Driven	0.147	0.058
Fixed Income Arbitrage	0.299	0.000
Global Macro	0.288	0.000
Long/Short Equity	0.056	0.471
Managed Futures	-0.006	0.943
Multi-Strategy	0.058	0.456

Table 9. Carry trade performance by period.

This table presents monthly mean return, standard deviation and Sharpe ratio in different sub-periods: 1976-1987, 1988-1997 and 1998-2007.

Period	Mean	Standard deviation	Sharpe ratio
1976-1987	0.63%	1.82%	0.344
1988-1997	0.58%	2.33%	0.251
1998-2007	0.36%	1.82%	0.197

Table 10. Arbitrage capital and carry trade returns.

This table gives the results of regressing returns to carry trade strategy on the logarithm of arbitrage capital. We use two alternative measures for arbitrage capital: beginning-of-year total hedge fund assets under management (AUM), and beginning-of-month cumulative return to the carry trade strategy. The hedge fund AUM data is from Hennessee Group LLC. The AUM data is not available for years 1976-1986 and 1988-1991. We fill in the missing data assuming that the growth rate of hedge fund AUM between 1974 and 1987 as well as between 1987 and 1992 has been constant. The dependent variable in the hedge fund AUM regression is yearly return to carry trade (32 observations), and monthly return to carry trade (382 observations) in the cumulative return regression. *p*-values are given in parenthesis for the test that the coefficients are equal to zero.

	Return	
Intercept	0.0790	0.0229
	(0.001)	(0.030)
log(Hedge fund AUM)	-0.0063	
	(0.221)	
log(Cumulative return)		-0.0031
		(0.095)
R^2	0.0495	0.0073
	(0.221)	(0.095)

Table 11. Arbitrage capital and price effect of carry trade entry.

This table gives the results of regressing the 24-month price effect of an entry into the short or long carry trade portfolio on the logarithm arbitrage capital. We use two alternative measures for arbitrage capital: beginning-of-year total hedge fund assets under management (AUM), and beginning-of-month cumulative return to the carry trade strategy. The hedge fund AUM data is from Hennessee Group LLC. The AUM data is not available for years 1976-1986 and 1988-1991. We fill in the missing data assuming that the growth rate of hedge fund AUM between 1974 and 1987 as well as between 1987 and 1992 has been constant. *p*-values are given in parenthesis for the test that the coefficients are equal to zero.

24-*month price effect*	Short		Long	
Intercept	0.1095	0.5706	-0.1058	-0.6804
	(0.015)	(0.028)	(0.004)	(0.001)
log(Hedge fund AUM)	-0.0286		0.0367	
	(0.022)		(0.000)	
log(Cumulative return)		-0.0988		0.1242
		(0.031)		(0.001)
R^2	0.0920	0.0819	0.1363	0.1212
	(0.022)	(0.031)	(0.000)	(0.001)

Table 12. Uncovered interest rate parity regression.

This table presents the results of UIP pooled regression. The dependent variable is the change in the logarithm of spot exchange rate, calculated against an equally weighted basket of the other currencies. Forward premium (f_t-s_t) is also calculated against an equally weighted basket of the other currencies. The first column gives the coefficients without the dummy variables indicating a recent addition into a carry trade portfolio, and the second column gives the coefficients with the dummy variables *p*-values are given in parenthesis for the test that the coefficients are equal to zero.

	$s_{t+1}-s_t$	
Intercept	0.0003	0.0006
	(0.456)	(0.307)
f_t-s_t	0.1236	0.4831
	(0.262)	(0.001)
I^S_t		-0.0024
		(0.007)
I^L_t		0.0005
		(0.538)
$I^S_t\times(f_t-s_t)$		-1.5363
		(0.000)
$I^L_t\times (f_t-s_t)$		-0.7063
		(0.010)
R^2	0.0004	0.0084
	(0.262)	(0.000)

Figure 1. Cumulative performance of carry trade strategy.

This figure shows the cumulative return, in pounds, to a constant 100 pound size investment in carry trade strategy from 1976 through 2007. *Short* refers to portfolio of short positions in low interest rate currencies, *Long* refers to portfolio of long positions in high interest rate currencies, and Short+*Long* refers to portfolio of short positions in low interest rate currencies and long positions in high interest rate currencies.

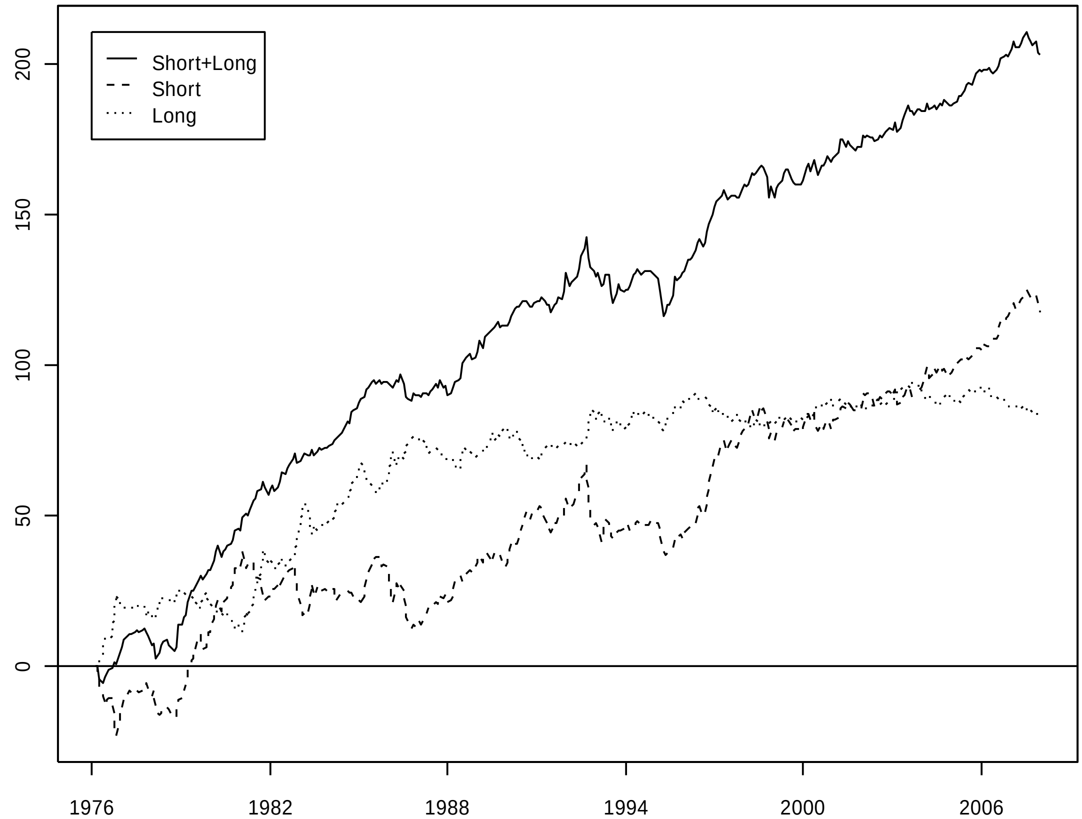

Figure 2. Carry trade positions.

The lines show the time periods when a short or a long position is held in individual currencies. *Short* refers a short position in a low interest rate currency, and *Long* refers to a long position in a high interest rate currency.

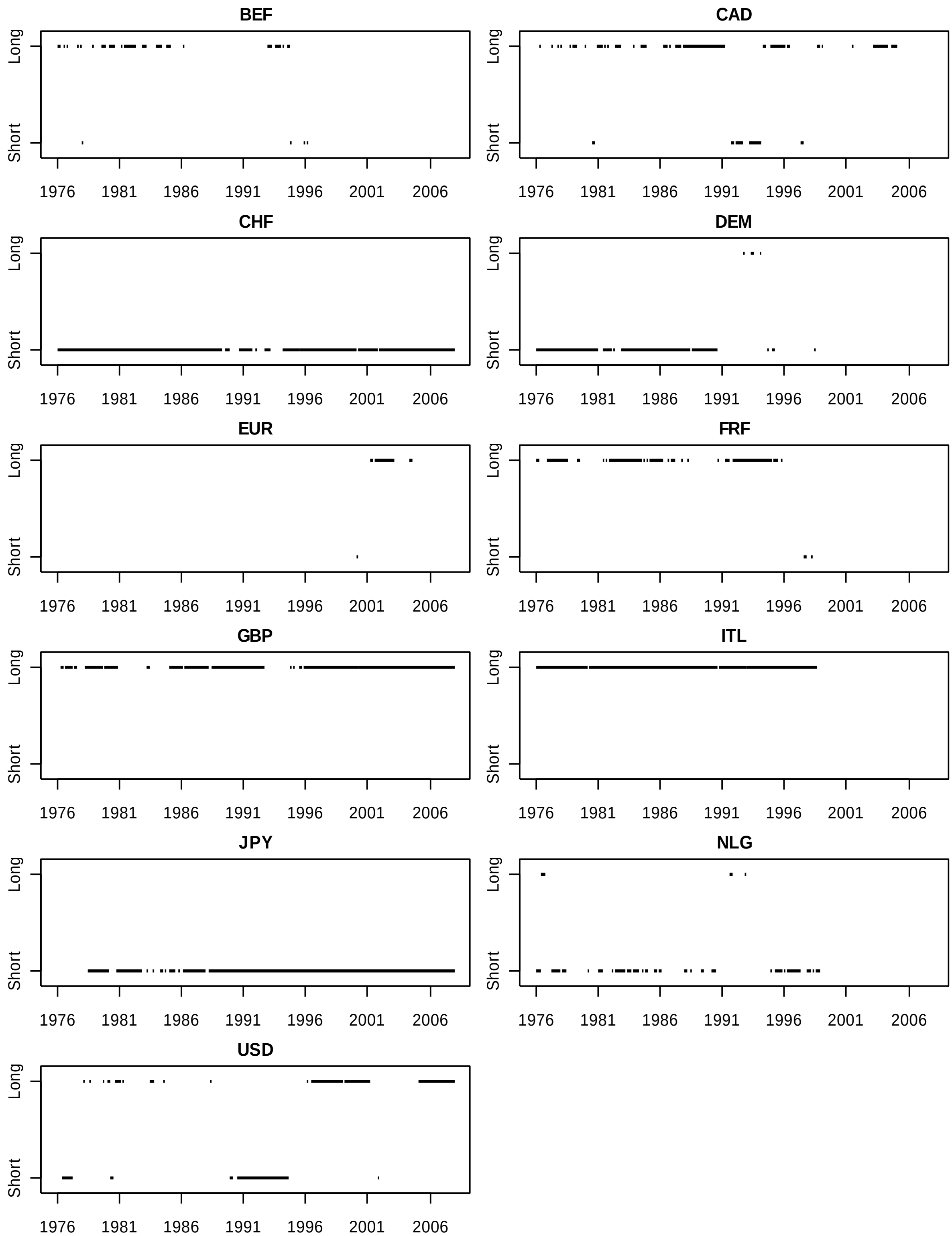

Figure 3. Carry trade performance in three sub-periods.

This figure shows the monthly mean return (black bar, left scale) and Sharpe ratio (gray bar, right scale) in three different sub-periods: 1976-1987, 1988-1997, 1998-2007.

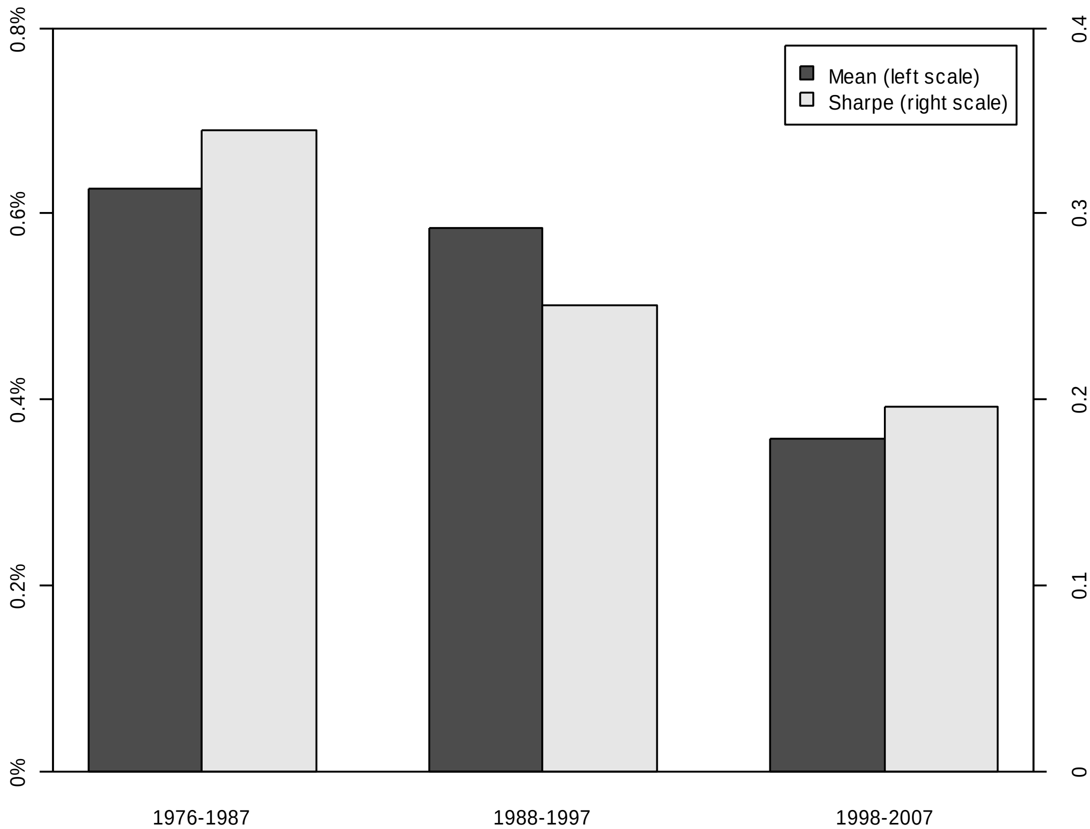

Figure 4. Spot exchange rate development around entry into carry portfolio.

This figure shows the development of spot exchange rate 60 months before and 60 months after the currency entering a portfolio. *Short* refers to portfolio of short positions in low interest rate currencies, *Long* refers to portfolio of long positions in high interest rate currencies. Gray lines represent the 5% confidence intervals. t=0 represents the month of entry into the portfolio.

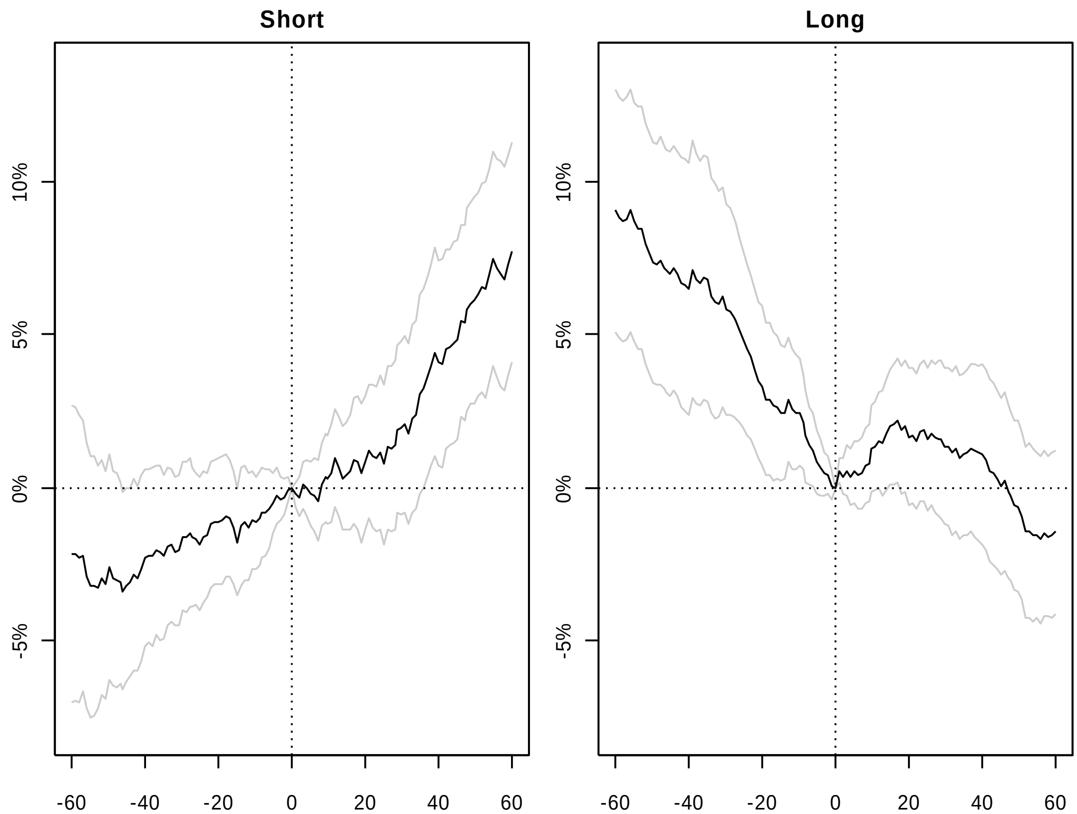

Figure 5. Spot exchange rate development around entry into carry portfolio, two sub-periods.

This figure shows the development of spot exchange rate 60 months before and 60 months after the currency entering a portfolio in two different sub-periods: 1976-1991 (light gray line) and 1992-2007 (dark gray line). *Short* refers to portfolio of short positions in low interest rate currencies, *Long* refers to portfolio of long positions in high interest rate currencies. The dash line represents the period 1976-1991, and the solid line represents the period 1992-2007. *t*=0 represents the month of entry into the portfolio.