The Returns to Currency Speculation*

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Abstract

Currencies that are at a forward premium tend to depreciate. This 'forward-premium puzzle' represents an egregious deviation from uncovered interest parity. We document the properties of returns to currency speculation strategies that exploit this anomaly. We show that these strategies yield high Sharpe ratios which are not a compensation for risk. In practice bid-ask spreads are an increasing function of order size. In addition, there is price pressure, i.e. exchange rates are an increasing function of net order flow. Together these frictions greatly reduce the profitability of currency speculation strategies. In fact, the marginal Sharpe ratio associated with currency speculation can be zero even though the average Sharpe ratio is positive.
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1 Introduction

Currencies that are at a forward premium tend to depreciate. This 'forward-premium puzzle' represents an egregious deviation from uncovered interest parity (UIP). We document the properties of the payoffs to currency speculation strategies that exploit this anomaly. The first strategy, known as the carry trade, is widely used by practitioners. This strategy involves selling currencies forward that are at a forward premium and buying currencies forward that are at a forward discount. The second strategy relies on a particular regression used by Bilson (1981), Fama (1984), and Backus, Gregory, and Telmer (1993) to forecast the payoff to selling currencies forward. We show that both strategies applied to portfolios of currencies yield high Sharpe ratios. These high Sharpe ratios primarily reflect the low standard deviation of the payoffs as opposed to high average returns.[1] A key property of the payoffs is that they are uncorrelated with traditional risk factors. Consequently, the high Sharpe ratios that we identify cannot be interpreted as compensating agents for bearing risk.[2]

Our empirical findings raise the question: why don't investors massively exploit our trading strategies to the point where either the Sharpe ratios fall to zero or currency-speculation payoffs become correlated with risk factors? We explore two answers to this question. First, we use direct evidence that bid-ask spreads are an increasing function of order size. This pattern of transactions costs substantially reduces the apparent profitability of currency speculation strategies. Second, evidence from the microstructure literature suggests that there is price pressure in spot currency markets: exchange rates change in response to net order flow, i.e. the difference between buyer-initiated and seller-initiated orders. Price pressure drives a wedge between average and marginal Sharpe ratios. By marginal Sharpe ratio we mean the Sharpe ratio associated with the last unit of currency that is bet in a given period. We argue that marginal Sharpe ratios can be zero even though average Sharpe ratios are positive. Consequently, the existence of price pressure can rationalize the view that currency speculators make profits but leave little, if any, money on the table.

Why should macroeconomists care about our results? UIP is a central feature of virtually

[1] Since our currency speculation strategies involve zero net investment, the Sharpe ratio is the ratio of the average payoff to the standard deviation of the payoff.

[2] There is some evidence that for the second strategy the cross-sectional variation in the average excess returns across currencies is correlated with some traditional risk factors. This result does not hold for the first strategy.

all linearized general-equilibrium open-economy models. Model builders tend to respond to the sharp statistical failure of UIP in one of two ways. The first response is to ignore the problem. The second response is to add a shock to the UIP equation. This shock is often referred to as a 'risk premium' shock (see, e.g., McCallum, 1994). Without understanding why UIP fails it is hard to assess the first response. Our evidence strongly suggests that the second response is fraught with danger. In general equilibrium open-economy models "risk premium" shocks affect domestic interest rates which in turn affect aggregate quantities like consumption and output. We find little evidence that currency-speculation payoffs are correlated with variables like consumption or output. While introducing 'risk premium' shocks improves the fit of the UIP equation, these shocks can induce counterfactual correlations between interest rates and aggregate quantities. So allowing for 'risk premium' shocks can introduce an important source of model misspecification that is likely to affect policy analyses.

Our paper is organized as follows. We review the basic parity conditions in Section 2. In Section 3 we briefly describe statistical evidence on UIP. We describe the two speculation strategies that we study in Section 4 and characterize the properties of payoffs to currency speculation in Section 5. In Sections 6 and 7 we study whether the payoffs to currency speculation are correlated with risk and macro factors. In Section 8 we examine the consequences of price pressure. Section 9 concludes.

2 Covered and Uncovered Interest Rate Parity

To fix ideas we derive the standard covered and uncovered interest parity conditions using a simple small-open-economy model with an exogenous endowment of a single good, Y_t. This economy is populated by a representative agent who maximizes his lifetime utility:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t u(C_t, M_t/P_t).$$

Here, C_t represents consumption, M_t denotes beginning-of-period money holdings, and P_t denotes the price level. The momentary utility function $u(.)$ is strictly concave, the discount factor, β, is between zero and one, and E_0 is the expectations operator conditional on the information available at the beginning of time zero. It is convenient to express the agent's time t budget constraint in foreign currency units (FCUs),

$$\begin{aligned} S_t B_{t+1} + B_{t+1}^* &= S_t B_t (1 + R_{t-1}) + B_t^* (1 + R_{t-1}^*) \\ &+ S_t (M_t - M_{t+1}) + x_{t-1}(F_{t-1} - S_t) + S_t P_t (Y_t - C_t). \end{aligned} \tag{1}$$

Here S_t denotes the spot exchange rate defined as FCUs per unit of domestic currency. In our data exchange rates are quoted as FCUs per British pound. So it is natural for us to take the British Pound as the domestic currency. The variable F_t denotes the forward exchange rate, expressed as FCUs per British pound, for forward contracts maturing at time $t + 1$. The variables B_t and B_t^* denote beginning-of-period holdings of domestic and foreign bonds, respectively. Bonds purchased at time t yield interest rates of R_t and R_t^* in domestic and foreign currency, respectively. The variable x_t denotes the number of pounds sold forward at time t. To simplify notation we abstract from state-contingent securities.

The agent's first-order conditions imply two well-known parity conditions,

$$(1 + R_t^*) = \frac{1}{S_t} (1 + R_t) F_t, \tag{2}$$

$$(1 + R_t^*) = (1 + R_t) \left[E_t \left(\frac{S_{t+1}}{S_t} \right) + \frac{\text{cov}_t (S_{t+1}/S_t, \lambda_{t+1})}{E_t \lambda_{t+1}} \right]. \tag{3}$$

Relation (2) is known as covered interest-rate parity (CIP). Relation (3) is a risk-adjusted version of UIP. Here λ_t, the time t marginal utility of a FCU, is the Lagrange multiplier associated with (1).

Together (2) and (3) imply that the forward rate is the expected value of the future spot rate plus a risk premium,

$$F_t = E_t S_{t+1} + \frac{\text{cov}_t (\lambda_{t+1}, S_{t+1})}{E_t \lambda_{t+1}}. \tag{4}$$

We pay particular attention to the case in which $\text{cov}_t (\lambda_{t+1}, S_{t+1}) = 0$ so that the forward rate is an unbiased predictor of the future spot rate:

$$F_t = E_t (S_{t+1}). \tag{5}$$

There is a large literature, surveyed by Hodrick (1987) and Engel (1996), that rejects the implications of (5). There is also a large literature that tests (4) under alternative parameterizations of an agent's utility function that allow for risk aversion. As far as we know there is no utility specification for a representative agent which succeeds in generating a risk premium compatible with (4) (see Backus, Foresi, and Telmer 1998 for a discussion).

3 Evaluating Parity Conditions

In this section we describe our data set and use it to briefly review the nature of the statistical evidence against (5).

Data Our data set, obtained from Datastream, consists of daily observations for bid and ask interbank spot exchange rates, 1-month and 3-month forward exchange rates, and interest rates at 1-month and 3-month maturities. All exchange rates are quoted in FCUs per British pound. The ask (bid) exchange rate is the rate at which a participant in the interdealer market can buy (sell) British pounds from a currency dealer. The ask (bid) interest rate is the rate at which agents can borrow (lend) currency. We convert daily data into non-overlapping monthly observations (see appendix A for details). Our data set covers the period January 1976 to December 2005 for spot and forward exchange rates and January 1981 to December 2005 for interest rates. The countries included in the data set are Belgium, Canada, France, Germany, Italy, Japan, the Netherlands, Switzerland, the UK, and the U.S.[3]

Bid-Ask Spreads Table 1 displays median bid-ask spreads for spot and forward exchange rates. The left-hand panel reports median bid-ask spreads in percentage terms $[100 \times \ln(\text{Ask}/\text{Bid})]$. The right-hand panel reports the difference between ask and bid quotes in units of foreign currency. Three observations emerge from Table 1. First, bid-ask spreads are wider in forward markets than in spot markets. Second, there is substantial heterogeneity across currencies in the magnitude of bid-ask spreads. Third, bid-ask spreads have declined for all currencies in the post-1999 period. This drop partly reflects the advent of screen-based electronic foreign-exchange dealing and brokerage systems, such as Reuters' Dealing 2000-2, launched in 1992, and the Electronic Broking System launched in 1993.[4]

Covered Interest Parity To assess the quality of our data set, and to determine whether we can test UIP using (5), we investigate whether CIP holds taking bid-ask spreads into account. We find that deviations from CIP are small and rare. Details of our analysis are provided in appendix B.

[3] We focus on developed-country currencies with liquid markets where currency speculation strategies are most easily implementable. See Bansal and Dahlquist (2000) and Lustig and Verdelhan (2006) for analyses that include emerging markets.

[4] It took a few years for these electronic trading systems to capture large transactions volumes. We break the sample in 1999, as opposed to in 1992 or 1993, to fully capture the impact of these trading platforms.

Uncovered Interest Parity: Statistical Evidence Tests of (5) generally focus on the regression:

$$(S_{t+1} - S_t)/S_t = \alpha + \beta (F_t - S_t)/S_t + \xi_{t+1}. \tag{6}$$

Under the null hypothesis that (5) holds, $\alpha = 0$, $\beta = 1$, and ξ_{t+1} is orthogonal to time t information. The rejection of this null hypothesis has been extensively documented. Table 2 reports the estimates of α and β that we obtain using non-overlapping data for both 1-month and 3-month horizons. We run these regressions using the average of bid and ask spot and forward exchange rates. Consistent with the literature, we find that β is generally different from 1. We also confirm the existence of the 'forward-premium puzzle,' i.e. point estimates of β are negative. Under the null hypothesis (5), the pound should, on average, appreciate when it is at a forward premium ($F_t > S_t$). The negative point estimates of β imply that the pound actually tends to depreciate when it is at a forward premium. Equivalently, low interest rate currencies tend to depreciate.

There is a large literature aimed at explaining the failure of (5) and the forward premium puzzle. Proposed explanations include the importance of risk premia (Fama, 1984), the interaction of risk premia and monetary policy (McCallum, 1994), statistical considerations such as peso problems (Lewis, 1995) and non-cointegration of forward and spot rates (Roll and Yan, 2000, and Maynard, 2003). Additional explanations include learning (Lewis, 1995) and biases in expectations (Frankel and Rose, 1994). More recently, Alvarez, Atkeson, and Kehoe (2006) stress the importance of time-varying risk premia resulting from endogenous market segmentation, while Bacchetta and Van Wincoop (2006) emphasize the implication of the cost of actively managing foreign exchange portfolios for the failure of UIP.

Our objective in this paper is not to explain the failure of UIP. Instead our goal is to measure the economic significance of this failure. Our metric for significance is the amount of money that can be made by exploiting deviations from UIP.

4 Two Currency-Speculation Strategies

We consider two speculation strategies that exploit the failure of UIP. The first strategy, known to practitioners as the 'carry trade', involves borrowing low-interest-rate currencies and lending high-interest-rate currencies, without hedging the exchange rate risk. The second strategy, suggested by Bilson (1981), Fama (1984), and Backus, Gregory, and Telmer (1993), relies on a particular regression to predict the payoff to selling currency forward. We refer to this strategy as the BGT strategy.

The Carry-Trade Strategy To describe this strategy we abstract, for the moment, from bid-ask spreads. The carry trade consists of borrowing the low-interest-rate currency and lending the high-interest-rate currency,

$$y_t = \begin{cases} > 0 & \text{if } R_t < R_t^*, \\ < 0 & \text{if } R_t^* < R_t, \end{cases} \tag{7}$$

where y_t is the amount of pounds borrowed. The payoff to this strategy, denominated in pounds, is:

$$y_t \left[S_t(1 + R_t^*) \frac{1}{S_{t+1}} - (1 + R_t) \right]. \tag{8}$$

An alternative version of the carry-trade strategy consists of selling the pound forward when it is at a forward premium ($F_t > S_t$) and buying the pound forward when it is at a forward discount ($F_t < S_t$),

$$x_t = \begin{cases} > 0 & \text{if } F_t > S_t, \\ < 0 & \text{if } F_t < S_t. \end{cases} \tag{9}$$

Here x_t is the number of pounds sold forward. The pound-denominated payoff to this strategy is,

$$x_t \left(\frac{F_t}{S_{t+1}} - 1 \right). \tag{10}$$

When (2) holds, strategy (7) yields positive payoffs if and only if strategy (9) has positive payoffs. This result holds because the two payoffs are proportional to each other. In this sense the strategies are equivalent. We focus our analysis on strategy (9) for two reasons. First, strategy (9) is generally more profitable than (7) because it involves lower transactions costs. Second, our sample for forward rates is longer than our interest rate sample.

In general there is no reason to think that the carry trade is an optimal speculation strategy. However, it is widely used by practitioners (see Galati and Melvin, 2004) and can be rationalized under certain assumptions. It is convenient to define the time t marginal utility of a pound, $\lambda_t^* = S_t \lambda_t$. Suppose that an agent increases x_t by one unit, i.e. he sells an additional pound forward. The impact of this action on the agent's utility is given by,

$$E_t \left[\lambda_{t+1}^* (F_t / S_{t+1} - 1) \right]$$

Suppose that $\text{cov}_t \left(\lambda_{t+1}^*, 1/S_{t+1} \right) = 0$ and that the agent believes that $1/S_{t+1}$ is a martingale:

$$E_t \left(1/S_{t+1} \right) = 1/S_t. \tag{11}$$

Then it is optimal for the agent to engage in the carry trade, i.e. he should sell the pound forward ($x_t > 0$) when $F_t > S_t$ and buy the pound forward ($x_t < 0$) when $F_t < S_t$.

We consider two versions of the carry trade distinguished by how bid-ask spreads are treated. In both versions we normalize the size of the bet to 1 pound. In the first version we implement (9) and calculate payoffs assuming that agents can buy and sell currency at the average of the bid and ask rates. From this point forward, we denote the average of the bid (S_t^b) and the ask (S_t^a) spot exchange rates by S_t,

$$S_t = \left(S_t^a + S_t^b\right)/2,$$

and the average of the bid (F_t^b) and the ask (F_t^a) forward exchange rates by F_t,

$$F_t = \left(F_t^a + F_t^b\right)/2.$$

The sign of x_t is given by:

$$x_t = \begin{cases} +1 & \text{if } F_t \geq S_t, \\ -1 & \text{if } F_t < S_t, \end{cases} \tag{12}$$

while the payoff at $t+1$, denoted z_{t+1}, is

$$z_{t+1} = x_t \left(\frac{F_t}{S_{t+1}} - 1\right). \tag{13}$$

We refer to this strategy as 'carry trade without transactions costs'.

In the second version of the carry trade we take bid-ask spreads into account when deciding whether to buy or sell pounds forward and in calculating payoffs. We refer to this strategy as 'carry trade with transactions costs'. While agents know F_t^a and F_t^b at time t, they must forecast $1/S_{t+1}^a$ and $1/S_{t+1}^b$ to decide whether to buy or sell the pound forward. We assume that agents compute these forecasts using $E_t\left(1/S_{t+1}^a\right) = 1/S_t^a$ and $E_t(1/S_{t+1}^b) = 1/S_t^b$. Agents adopt the decision rule,

$$x_t = \begin{cases} +1 & \text{if } F_t^b/S_t^a > 1, \\ -1 & \text{if } F_t^a/S_t^b < 1, \\ 0 & \text{otherwise.} \end{cases} \tag{14}$$

The payoff to this strategy is:

$$z_{t+1} = \begin{cases} x_t\left(F_t^b/S_{t+1}^a - 1\right) & \text{if } x_t > 0, \\ x_t\left(F_t^a/S_{t+1}^b - 1\right) & \text{if } x_t < 0, \\ 0 & \text{if } x_t = 0. \end{cases} \tag{15}$$

The BGT Strategy Backus, Gregory, and Telmer (1993) use the following regression to forecast payoff to selling pounds forward:

$$(F_t - S_{t+1})/S_{t+1} = a + b(F_t - S_t)/S_t + \xi_{t+1}. \tag{16}$$

The BGT strategy involves selling (buying) the pound forward when the payoff predicted by the regression is positive (negative). To avoid 'look-ahead' bias, we use recursive estimates of the coefficients in (16), where the first estimate is obtained using the first 30 data points.[5]

Table 3 displays estimates of a and b computed using data at 1 and 3-month horizons for the 9 bilateral exchange rates in our sample. For many countries the point estimate of b is well above 1 and is not statistically different from 3. To understand the magnitude of the b estimates it is useful to note the close connection between regressions (16) and (6) discussed in Fama (1984). Suppose that $1/S_t$ is a martingale. Then (16) is roughly equivalent to the regression:

$$(F_t - S_{t+1})/S_t = a + b(F_t - S_t)/S_t + \xi_{t+1}.$$

This equation can be re-arranged to show that: $a = -\alpha$ and $b = 1 - \beta$, where α and β are the slope and intercept in (6). Suppose that β, the slope coefficient in (6), is close to -2, as we found for the several currencies in Table 2. This translates into a value of b close to 3.

As with the carry trade we report results for two versions of the BGT strategy, with and without transactions costs. Using (16) it is convenient to define

$$E_t(F_t/S_{t+1}) = 1 + \hat{a}_t + \hat{b}_t(F_t - S_t)/S_t, \tag{17}$$

where $\hat{a}_t$ and $\hat{b}_t$ are the time t recursive estimates of a and b. For the BGT strategy without transactions costs we assume that speculators follow the rule:

$$x_t = \begin{cases} +1 & \text{if } E_t(F_t/S_{t+1}) \geq 1, \\ -1 & \text{if } E_t(F_t/S_{t+1}) < 1. \end{cases}$$

The payoff to the strategy is given by (13).

In the version of the BGT strategy with transactions costs speculators compute $E_t\left(F_t^b/S_{t+1}^a\right)$ and $E_t(F_t^a/S_{t+1}^b)$ using the following rules:

$$E_t(F_t^b/S_{t+1}^a) = \left[1 + \hat{a}_t + \hat{b}_t(F_t - S_t)/S_t\right]\frac{F_t^b}{F_t}\frac{S_t}{S_t^a} \tag{18}$$

$$E_t(F_t^a/S_{t+1}^b) = \left[1 + \hat{a}_t + \hat{b}_t(F_t - S_t)/S_t\right]\frac{F_t^a}{F_t}\frac{S_t}{S_t^b}. \tag{19}$$

[5] We investigate variants of the BGT strategy that use separate regressions on bid and ask rates. These refinements make little difference to our results.

Essentially this is a modified version of (17) that assumes that the time t bid-ask spread on the spot is the best predictor of the time $t+1$ spread (see appendix C for details). The speculator's decision rule is given by

$$x_t = \begin{cases} +1 & \text{if } E_t\left(F_t^b/S_{t+1}^a\right) > 1, \\ -1 & \text{if } E_t\left(F_t^a/S_{t+1}^b\right) < 1, \\ 0 & \text{otherwise,} \end{cases} \tag{20}$$

while his payoff is given by (15).

5 The Returns to Currency Speculation

In this section we study the payoff properties of the carry trade and the BGT trading strategies. We consider these strategies for individual currencies as well as for portfolios of currencies.

Table 4 reports the mean, standard deviation, and Sharpe ratio of the monthly non-annualized payoffs to the carry trade, with and without transactions costs. We report payoff statistics for the carry trade implemented for individual currencies against the pound and for an equally-weighted portfolio of the currency strategies. Table 5 is the analogue to Table 4 for the BGT strategy. To put our results into perspective, the monthly non-annualized Sharpe ratio of the Standard & Poors 500 index (S&P 500) is 0.14 for the period 1976 to 2005.

Even though bid-ask spreads are small, they have a sizable impact on the profitability of currency speculation. For example, without transactions costs the Sharpe ratio associated with the equally-weighted portfolio is roughly 0.18 for the carry trade and 0.20 for the BGT strategy. Incorporating bid-ask spreads reduces the Sharpe ratio to 0.15 for the carry trade and to 0.10 for the BGT strategy. Most of the reduction results from a substantial decline in the expected payoff to the strategies.

It is sometimes argued that since bid-ask spreads are small it is reasonable to ignore them. In one sense bid-ask spreads are small. For example, if an agent buys and sells one pound against the U.S. dollar in the spot market he loses on average $S^a - S^b = 0.0013$ dollars. But in the sense relevant to a currency speculator bid-ask spreads are large. They are of the same order of magnitude as the expected payoff associated with our two currency-speculation strategies. For this reason, in the remainder of this paper, we only consider strategies and payoffs that take bid-ask spreads into account.

Even though Sharpe ratios including transactions costs are high, the average payoffs to currency-speculation strategies are low. A speculator who bets one pound on an equally-weighted portfolio of carry-trade strategies receives a monthly (annual) payoff of 0.0029 (0.035) pounds. To generate an average annual payoff of 1 million pounds the speculator must bet of 28.6 million pounds every month. So to generate substantial profits speculators must wager very large sums of money.

Tables 4 and 5 also show that there are large diversification gains from forming portfolios of currency strategies. For the carry-trade strategy the average Sharpe ratio across-currencies is 0.099, while the Sharpe ratio for an equally weighted portfolio of currencies is 0.145. The analogue estimates for the BGT strategy are 0.059 and 0.103, respectively.

Since there are gains to combining currencies into portfolios, it is natural to construct portfolios that maximize the Sharpe ratio. Accordingly, we compute the portfolio frontier and calculate the portfolio weights that maximize the Sharpe ratio. Specifically at each time t we solve the problem:

$$\min_{w_t} \; w_t' V_t w_t \tag{21}$$
$$\text{s.t.} \sum_{i=1}^{9} w_{it} E_t z_{it+1} = z_p, \quad \sum_{i=1}^{9} w_{it} = 1, \quad w_{it} \geq 0, \text{ for all } i.$$

Here w_{it} is the time t portfolio weight of currency i, $E_t z_{it+1}$ is the expected payoff associated with the trading strategy applied to currency i and z_p is the time t expectation of the payoff to the portfolio at $t+1$. The variable w_t represents the vector of portfolio weights. In addition, V_t is the variance-covariance matrix of payoffs to the trading strategy applied to each of the nine currencies. For both strategies V_t is a recursive estimate of the covariance matrix of the one-step ahead forecast errors of the returns. We assume that the true value of this matrix is time-invariant.[6] To compute the recursive estimate for either strategy we take the forecast error to be the difference between the actual payoff and the agent's expected payoff computed using the rules described in appendix C.

Problem (21) is completely standard except for the fact that we impose a non-negativity constraint on the portfolio weights. This constraint is important because negative weights allow agents to trade at negative bid-ask spreads, thus generating spuriously high payoffs. The solution to (21) provides a set of portfolio weights, w_t, for every feasible value z_p. We

[6]In principle we could improve on the Sharpe ratio of our strategies by modeling the conditional variance of the payoffs as time-varying.

choose the weights that maximize the Sharpe ratio of the portfolio.

Table 6 reports Sharpe ratios corresponding to UK pound payoffs for the equally-weighted and optimally-weighted strategies computed over a common sample (1979:10 to 2005:12). These Sharpe ratios are both high and statistically different from zero. The Sharpe ratios of the optimally-weighted portfolio strategies are substantially higher than those of the equally-weighted portfolio strategies.

The top of Figure 1 displays realized payoffs (measured in pounds) for the equally-weighted and optimal portfolio carry-trade strategies. The bottom of Figure 1 presents the analogue results for the BGT strategy. Since realized payoffs are very volatile we display a 12 month moving average of the different series. Interestingly, payoffs to the carry-trade strategy are not concentrated in a small number of periods. In contrast, the BGT strategy does better in the early part of the sample.

We use the realized payoffs to compute the cumulative realized return (measured in U.S. dollars) to committing one dollar in the beginning of the sample (1977 for the carry trade and 1979 for BGT) to various currency-speculation strategies and reinvesting the proceeds at each point in time.[7] The agent starts with one U.S. dollar in his bank account and bets that dollar in the currency strategy. From that point forward the agent bets the balance of his bank account on the currency strategy. Currency strategy payoffs are deposited or withdrawn from the agent's account. Since the currency strategy is a zero-cost investment, the agent's net balances stay in the bank and accumulate interest at the bid Libor rate published by the Federal Reserve. It turns out that the bank account balance never becomes negative in our sample. This result reflects the fact that strategy payoffs are small in absolute value (see Tables 4 and 5).

Figures 2 and 3 display the cumulative returns to various trading strategies. For comparison we also display the cumulative realized return to the S&P 500 index and the 1-month Libor. These figures show that all of the strategies, including the S&P 500, dominate the Libor. More interestingly, the total cumulative return to the optimally-weighted carry-trade strategy is very similar to that of the S&P 500. However, the volatility of the returns to this version of the carry-trade strategy is much smaller than that of the cumulative return associated with the S&P 500.

Figure 4 displays realized Sharpe ratios corresponding to U.S. dollar excess returns com-

[7] Appendix D discusses how we convert the payoffs to our currency speculation strategies to U.S. dollars.

puted using a three-year rolling window. For both strategies Sharpe ratios are high in the early 1980s. The optimally-weighted carry-trade strategy consistently delivers a positive Sharpe ratio except for a brief period around 1995. In contrast the S&P 500 yields negative returns in the early 1980s and in the 2001 to 2005 period.

Robustness Our data set consists of currencies quoted against the British pound, rather than the U.S. dollar. Burnside, Eichenbaum, and Rebelo (2006a) use an alternative data set available over a shorter sample period (1983:11-2005:12) in which currencies are quoted against the U.S. dollar. They show that bid ask spreads are generally smaller against the U.S. dollar than against the British pound and that the Sharpe ratio associated with the carry trade is about 40 percent higher due to the lower bid-ask spreads against the dollar. So the high Sharpe ratios associated with our currency speculation strategies are robust to whether we work with quotes against the British pound or the U.S. dollar.

Our data set only contains forward rates at the 1 and 3-month horizons. The data set used by Burnside, Eichenbaum, and Rebelo (2006a) includes forward rates at 1, 3, 6 and 12-month horizons. They show that long (3, 6 and 12 month) and short (1 month) horizon trading strategies generate similar Sharpe ratios. Long horizon strategies involve less trading but bid-ask spreads rise with the forward horizon. These two effects roughly cancel each other out. So the high Sharpe ratios associated with our currency speculation strategies are robust to whether we work with long or short horizons.

Fat tails So far we have emphasized the mean and variance of the payoffs to currency speculation. Given that these statistics are sufficient to characterize the distributions of the payoffs only if they are normal, we now analyze other properties of the distributions. Figure 5 and 6 show sample distributions of the UK pound payoffs to the carry trade and the BGT strategies implemented for each of our nine currencies. Figure 7 is the analogue to Figures 5 and 6 but pertains to the equally and optimally-weighted BGT and carry-trade strategy payoffs. We exclude from the distribution periods in which the trading strategy dictates no trade. We superimpose on the empirical distribution of payoffs a normal distribution with the same mean and variance as the empirical distribution. It is evident that these distributions are not normal, but are leptokurtic, exhibiting fat tails. This impression is confirmed by Table 7 which reports skewness, excess kurtosis, and the Jarque-Bera normality test. There is mixed evidence regarding the skewness of the payoff distributions but almost all the distributions show evidence of excess kurtosis.

One way to assess the economic significance of these deviations from normality is to confront a hypothetical trader with the possibility of investing in the S&P 500 and wagering bets on the optimally-weighted carry trade. The trader's problem is given by,

$$\begin{aligned} \max_{\{C_t, X^s_{t+1}, X^c_{t+1}\}_{t=0}^{\infty}} U &= E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma} - 1}{1-\sigma} \right) \\ \text{s.t.} \quad C_t &= Y_t + X^s_t(1 + r^s_t) + X^c_t r^c_t - X^s_{t+1}, \\ Y_t &= \gamma^t. \end{aligned}$$

Here C_t denotes consumption, Y_t is an exogenous income endowment assumed to grow at an annual rate of 1.9 percent, X^s_t and X^c_t are the end-of-period $t-1$ investments in, respectively, the S&P 500 and a portfolio of optimally-weighted carry-trade strategies. The variables r^s_t and r^c_t are the time t realized real return to the S&P 500, and the real excess return to the carry trade, respectively.[8] We assume that r^c_t and r^s_t are generated by the joint empirical distribution of returns to the S&P 500 and to the optimally-weighted carry trade.

It is useful to define the ratios $x^s_t = X^s_t/Y_t$ and $x^c_t = X^c_t/Y_t$. We impose that the agent uses a time invariant strategy for these ratios, that is, he sets $x^S_t = x^S$ and $x^C_t = x^C$ for all t. For $\sigma = 5$ we find that the optimal strategy is $x^S = 0.68$, $x^C = 1.89$. These portfolio weights imply that investments in the optimally-weighted carry-trade strategy account for 67 percent of the investor's expected return and 70 percent of the variance of his return. So, even though the distribution of payoffs to the carry trade has fatter tails than those of a comparable normal distribution, agents still want to place very large bets on the optimally-weighted carry-trade strategy.

We can also compare the fat tails associated with currency speculation payoffs with those present in the returns to the S&P 500 for the same time period. S&P 500 returns display higher excess kurtosis (2.2 with a standard error of 1.3) and skewness (-0.5 with a standard error of 0.35) than the optimally-weighted portfolio of carry-trade strategies. We conclude that fat tails are an unlikely explanation of the high Sharpe ratios associated with our currency-speculation strategies.

[8] We define the real excess return to carry trade in appendix D and show how it relates to the nominal payoff, in pounds, defined above.

6 Does Risk Explain the Sharpe Ratio of Currency Strategies?

A natural explanation for the Sharpe ratios of our currency-speculation strategies is that these strategies are risky, in the sense that the payoffs are correlated with risk factors such as consumption growth. We investigate this possibility by regressing the accumulated quarterly real excess returns to these strategies on a variety of risk factors. These factors include U.S. per capita consumption growth, the returns to the S&P 500, the Fama-French (1993) stock-market factors, the slope of the yield curve computed as the yield on 10-year U.S. treasury bills minus the 3-month U.S. treasury-bill rate, the luxury retail sales series constructed by Parker, Ait-Sahalia, and Yogo (2004), U.S. industrial production, the return to the FTSE 100, and per-capita UK consumption growth. We provide detailed definitions of the real excess returns for U.S. and UK investors in appendix D, as well as sources for the risk factor data.

Time-Series Risk-Factor Analysis Tables 8 and 9 report results for time-series regressions of real returns on real risk factors for, respectively, the U.S. and UK. Our key finding is that, with two exceptions, no risk factor is significantly correlated with real returns. The two exceptions are for optimally-weighted carry trade, which is correlated with the Fama-French HML factor and real UK consumption growth. There is no general pattern of correlation of the HML factor with a wider range of our portfolio returns, and while the latter correlation might explain the high Sharpe ratio associated with the optimally-weighted carry trade as compensation for the riskiness of the associated payoffs to UK investors, it cannot be used to explain the high Sharpe ratio from the perspective of U.S. investors. We infer that risk-related explanations for the Sharpe ratios of currency-speculation strategies are empirically implausible. This result is consistent with the literature that shows that allowing for different forms of risk aversion does not render risk-adjusted UIP, (4), consistent with the data.

Panel Risk-Factor Analysis In this subsection we study how much of the cross-sectional variation in average excess returns across currencies is explained by different risk factors.[9] We use r_t to denote an $n \times 1$ vector of time t excess returns to implementing the carry trade

[9] See Cochrane (2005) for a discussion of the relation between the time-series and panel risk factor analyses.

(or BGT) strategies. [10] Also, let m_t denote the time-t stochastic discount factor. Standard asset pricing arguments imply the restriction:

$$E\left(m_t r_t\right) = 0. \tag{22}$$

We use a linear factor pricing model, where m_t takes the form

$$m_t = a - f_t' b,$$

and f_t is a vector of asset-pricing factors. It is convenient to rewrite m_t as

$$m_t = m\left[1 - \left(f_t - \mu\right)' b\right],$$

where m and μ are the unconditional means of m_t and f_t, respectively.

We estimate b by generalized method of moments using (22). It is evident from (22) that m is not identified. Fortunately, the point estimate of b and inference about the model's over-identifying restrictions are invariant to the value of m so we set m to 1 for convenience. Given an estimate of b we calculate the mean excess returns predicted by the model using:

$$E\left(r_t\right) = -\frac{\operatorname{cov}(m_t, r_t)}{E\left(m_t\right)} = E\left[r_t\left(f_t - \mu\right)' b\right]. \tag{23}$$

We compute the R^2 between the predicted and actual mean excess returns. The predicted mean excess return is the sample analogue of the right-hand side of (23), which we denote by $\hat{r}$. The actual mean excess return is the sample analogue of the left-hand side of (23), which we denote by $\bar{r}$. Let the average across the elements of $\bar{r}$ be $\tilde{r}$. The R^2 measure is

$$R^2 = 1 - \frac{(\bar{r} - \hat{r})'(\bar{r} - \hat{r})}{(\bar{r} - \tilde{r})'(\bar{r} - \tilde{r})}.$$

This R^2 measure is also invariant to the value of m.

In practice we consider several alternative candidates for f_t. These are specified in the far left column of Table 10. For each factor, or vector of factors, we report the estimated value of b, the R^2, and the value of Hansen's (1982) J statistic used to test the over-identifying restrictions implied by (22).

[10] For our panel analysis we examine quarterly returns over a balanced sample. This is 78Q3–98Q3 in the case of the carry trade, and 81Q1–98Q3 in the case of the BGT strategy. In the vector r_t we include payoffs corresponding to Belgium, Canada, France, Germany, Italy, Japan, the Netherlands, Switzerland, the U.S., and the optimally-weighted portfolio. Our results are qualitatively robust to excluding the portfolio return.

For both strategies, the J statistic reveals mixed evidence against the model. For example, for the returns to carry trade, the model is soundly rejected when f_t is given by the S&P500 return or the CAPM excess return. However, there is very little evidence against the model when f_t is given by the Fama-French (1993) factors. For the BGT strategy, the model is only rejected when f_t is given by luxury retail sales growth or the growth rate of industrial production.

In sharp contrast, the R^2s almost always paint a dismal picture of the ability of risk factors to explain the cross-sectional variation in expected returns. Most of the R^2s are *negative*.[11] The only exceptions to the negative R^2 problem are for the BGT strategy, when f_t is given by the Fama-French factors, consumption growth, or the factors suggested by Yogo (2006).[12] These factors, however, perform dismally in explaining the payoffs to carry trade.

In sum, we find very little evidence in either time-series data or panel data that the payoffs to our trading strategies are compensation for bearing risk.

7 Are Currency Strategy Payoffs Correlated with Monetary Variables?

There is a large literature that emphasizes the role of monetary policy in generating deviations from UIP (e.g. Grilli and Roubini 1992, McCallum 1994, Schlagenhauf and Wrase 1995, and Alvarez, Atkeson, and Kehoe 2006). A common theme in this literature is that monetary policy can generate time-varying risk premia. The precise transmission mechanism varies across papers. Motivated by this literature we investigate whether real excess returns to the currency-speculation strategies are correlated with various monetary variables. We regress real dollar returns on the Federal Funds rate, the rate of inflation (of the deflator for nondurables plus services), and the growth rates of four different measures of money (M1, M2, M3, and MZM). We also regress real pound returns on the UK rate of inflation and the UK 3-month treasury-bill rate. Our results are reported in Table 11.

[11] This result reflects the fact that the mean-square of $\bar{r} - \hat{r}$ (the difference between the predicted and actual expected returns) is larger than the cross-sectional variance of $\bar{r}$ (the actual expected returns). This can occur because the GMM procedure does not center $\hat{r}$ around the average of the elements of $\bar{r}$, which we denoted $\tilde{r}$.

[12] The factors used by Yogo (2006) are the growth rate of per capita consumption of nondurables and services, the growth rate of the per capita service flow from the stock of consumer durables and one of the Fama-French factors: the market premium.

Inflation and the Fed funds rate enter significantly and positively in regressions for three currency-speculation strategies, the equally-weighted carry trade, the equally-weighted BGT, and the optimally-weighted BGT. This statistical significance of inflation and the Fed funds rate in these regressions reflects in part the fact that these variables and the payoffs to the three currency-speculation strategies trend downwards over the sample. The correlation between currency-speculation payoffs and monetary variables offers some support for theories that emphasize the link between monetary policy and the failure of UIP. Still, it is troubling that none of the monetary variables enter the regression significantly.

8 Transactions Costs and Price Pressure

Taken at face value, our results pose an enormous challenge for asset pricing theory. In Section 5 we argue that there are currency-speculation strategies that yield much higher Sharpe ratios than the S&P 500. Moreover, the payoffs to these strategies are uncorrelated with standard risk factors. So, investors can significantly increase their expected return, for a given level of the variance of returns, by combining currency speculation with a passive strategy of holding the S&P 500. A crucial question is: How can such a situation persist in equilibrium?

In this section we explore two answers to this question. First, direct evidence suggests that bid-ask spreads are an increasing function of order size. Second, evidence from the microstructure literature suggests that there is price pressure: exchange rates change in response to net order flow, i.e. the difference between buyer-initiated and seller-initiated orders.

Transactions Costs Unlike simple textbook Walrasian markets, the foreign exchange market is a decentralized, over-the-counter market. There are no disclosure requirements, so trades are not observable. The market is sufficiently fragmented that transactions can occur at the same time at different prices (see Lyons 2001 and Sarno and Taylor 2001). The bid and ask exchange rates quoted by dealers are indicative in nature. These quotes only apply to relatively small trades with transaction costs increasing in order size. To illustrate the nature of these costs, Table 12 displays a "currency pricing matrix" that a major dealer issues to its large customers.[13] This table summarizes the bid-ask spread as a function of

[13] We thank Ryan Owen of Belvedere Trading for providing us with this information.

the time of day, the size of the order, and the currencies involved. The time of the day is relevant because it governs which exchange rate markets are open. The business day starts in Asia between 10:00 pm and 3:00 am, New York time. Markets open in London at 3:00 am New York time, while the New York market is open between 8:00 am and 3:00 pm. Table 12 shows that bid-ask spreads are highest when only Asian markets are open and lowest when both European and American markets are open.

The key feature of Table 12 is that the bid-ask spread is an increasing function of order size. The relation between order size and bid-ask spreads is approximately linear. For example, when we fit a linear regression to bid-ask spreads as a function of order size for the U.S. dollar rate/British Pound we obtain a constant and slope coefficient of 2.482 and 0.09. The R^2 for this regression is 0.9945.[14] These regression estimates imply that the bid-ask spread goes up by 9 pips when the order size increases by 100 million dollars. For example, suppose that indicative bid and ask quotes for the U.S. dollar/British pound rate are 2.0000 and 2.0003. These quotes are operative for order sizes smaller than 10 million. For an order of 100 million the bid and ask prices are 1.9997 and 2.0006.

Suppose, for institutional reasons, that it is not feasible to break up trades into very small amounts.[15] Then the dependence of bid-ask spreads on order size substantially reduces currency speculation payoffs. Since our spot and forward rate quotes are against the British pound, we can only investigate the impact of this dependence for speculation involving the U.S. dollar and the British pound. Comparing tables 4 and 12 we see that the average payoff to the carry trade (0.0030) is the same as the bid-ask spread associated with orders of 300 million U.S. dollars worth of British pounds between 3am and noon, New York time. Clearly, the dependence of bid-ask spreads on order size severely limits the total potential profits from the carry trade.

To illustrate the previous point we conducted the following exercise. Consider two traders, A and B, who pursue the carry-trade strategy between the pound and the dollar. For simplicity we assume that both traders have a bet limit of one billion pounds. Suppose that trader A can trade at the indicative bid-ask spread, regardless of order size. Trader B faces a linear bid-ask spread schedule with slope coefficient of 9 pips per 100 million dollar order

[14] This regression is based on order size and bid-ask spreads in New York between 8:00 am and 3:00 pm.

[15] We do not understand why it is not possible to break large trades into very small amounts. But banks issue currency pricing matrices like the one in Table 12 to large customers to attract their business. Presumably, the banks would not issue matrices in which bid-ask spreads are increasing in order size if it was straighforward for banks' customers to break up trades.

size. We assume that this schedule applies to both spot and forward market transactions.

Using our data set we find that trader A either trades zero (when the expected payoff is smaller than the bid-ask spread) or places the maximum bet of one billion pounds. The average bet over the sample is equal to 786 million pounds, the average payoff is 3.0 million pounds, and the average payoff per pound bet is 0.0030 pounds. Trader B places an average bet of 177 million pounds, generates an average payoff of 0.79 million. The payoff per pound bet is 0.0021 pounds. So the dependence of bid-ask spreads on order size reduces the average payoff per pound by 70 percent and total expected payoff by 73 percent.

Price Pressure An important feature of the foreign exchange market is that trade is bilateral in nature. Customers trade with dealers and brokers. Dealers trade amongst themselves to reduce the risk associated with holding large currency inventories.[16] The bilateral nature of trades leads naturally to asymmetric information problems between customers and dealers and between dealers. Various authors in the microstructure literature argue that asymmetric information problems generate a phenomenon known as 'price pressure'. In the presence of price pressure the price at which investors can buy or sell an asset depends on the quantity they wish to transact. For example, Kyle (1985) and Easley and O'Hara (1987) stress the importance of adverse selection between customers and dealers in generating price pressure. Garman (1976), Stoll (1978), and, most recently, Cao, Evans, and Lyons (2006) stress the importance of inventory motives in generating price pressure. For our purposes the precise source of price pressure is not important.

The empirical literature on price pressure in foreign exchange markets is small because it is difficult to obtain data on trading volume. In an important paper Evans and Lyons (2002) estimate price pressure for the Deutsche Mark/U.S. dollar and Yen/U.S. dollar markets using daily order flow data collected between May and August 1996. In their empirical model the exchange rate depends on the order flow, x_t, defined as the difference between buyer-initiated and seller-initiated orders over a one-day period. Evans and Lyons (2002) model price pressure as taking the form,

$$S_{t+1} = S_t \exp(bx_t + u_{t+1}). \tag{24}$$

Here u_{t+1} is an i.i.d. random variable with zero mean realized at the beginning of day $t+1$.

[16] These inter-dealer trades, often referred to as "hot-potato" trades, account for roughly 53 percent of daily volume in 2004 (Bank for International Settlements, 2005).

The variable S_t denotes the exchange rate quote at the beginning of day t, before trade starts. During the day the order flow x_t accumulates. The exchange rate at the close of day t is $S_t \exp(bx_t)$, reflecting both the order flow and the random shock.

Evans and Lyons (2002) estimate $b = 0.0054$, so that a buy order of 1 billion dollars increases the execution spot exchange rate by 0.54 percent.[17] The R^2 of regression (24) is 0.63 for the Deutsche Mark/U.S. dollar and 0.40 for the Yen/U.S. dollar.[18]

In a recent study Berger, Chaboud, Chernenko, Howorka, and Wright (2006) estimate (24) using high-frequency order flow data from the Electronic Broking System for Euro-Dollar and Dollar-Yen exchange rates. Their data covers the period from January 1999 to December 2004. Berger et al. (2006) provide estimates of b under different assumptions about the length of the time period, ranging from one minute to three months. Their estimates of b for daily frequencies are roughly equal to 0.0040, with a corresponding R^2 of about 0.50. Using monthly data Berger et al. (2006) estimate b to be roughly 0.0020. The corresponding R^2 is 0.20 for the Euro/U.S. dollar and 0.30 for the U.S. Dollar/Yen. Their quarterly data results are similar to the monthly data results. Overall, Berger et al. (2006)'s results establish that price pressure exists, even in the era of electronic trading and for horizons as long as three months.

We use Evans and Lyons' and Berger et al.'s estimates of b to study the implications of price pressure for the profitability of the carry-trade strategy. We assume that their estimate of b applies to both bid and ask spot exchange rates. To simplify we abstract from price pressure in the forward market. We define the average payoff as the payoff per pound bet and the average Sharpe ratio as the payoff per pound bet divided by the standard deviation of the payoff per pound bet. In general the average payoff depends on the timing of agents' actions and whether or not they internalize the impact of their actions on price pressure.

To illustrate the key implications of price pressure we consider a sequence of monopolist traders indexed by t. Trader t buys pounds forward at time t and settles these contracts at time $t+1$. We assume that $\text{cov}_t\left(\lambda^*_{t+1}, 1/S^a_{t+1}\right) = \text{cov}_t\left(\lambda^*_{t+1}, 1/S^b_{t+1}\right) = 0$, where λ^*_{t+1} is the time $t+1$ marginal utility of a pound. While this market structure is stark it allows us to

[17] Our definition of x_t is the *dollar* value of buy orders minus the *dollar* value of sell orders. Evans and Lyons (2002) measure of order flow as the *number* of buy orders minus the *number* of sell orders. They translate their estimate of price pressure into the estimate of b that we report.

[18] See Evans and Lyons (2002) for a discussion of the identifying assumptions underlying their estimate of b based on equation (24).

demonstrate the key implications of price pressure in a very transparent way.[19]

Equation (24) implies that there is an incentive to break up a large trade into small orders. A trader who places an order for z pounds at the beginning of t pays $zS_t \exp(bz)$. In contrast, if the trader divides this order into infinitesimal orders and the net order flow is zero while execution occurs, he pays $\int_0^z S_t \exp(bw)dw = S_t \left[\exp(bz) - 1\right]/b$, which is lower than $zS_t \exp(bz)$. To be conservative we allow the trader to break his orders up, even though in practice there are limits to how finely orders can be broken up.

Let each period be an interval of unit length and let i denote the time within that interval. The subscript it denotes the value of a variable in period t at time i. For example, x_{it} denotes the amount of pounds sold forward in period t at time i.[20] When a trader sells x_{it} pounds forward he must buy x_{it} pounds spot at time i in period $t+1$ to settle the forward contract. This purchase exerts price pressure on period $t+1$ spot exchange rates.

We assume that covered interest parity holds throughout the day and that interest rates in money markets are not affected by price pressure in spot exchange rate markets. It follows that the forward premium is constant throughout period t, so that:

$$\frac{F_{it}^a}{S_{it}^b} = \frac{F_{0t}^a}{S_{0t}^b}, \tag{25}$$

$$\frac{F_{it}^b}{S_{it}^a} = \frac{F_{0t}^b}{S_{0t}^a}. \tag{26}$$

The spot exchange rates S_{it}^a and S_{it}^b are affected by price pressure as traders settle their time $t-1$ forward contracts:

$$S_{it}^a = S_{0t}^a \int_0^i \exp(bx_{jt-1})dj, \tag{27}$$

$$S_{it}^b = S_{0t}^b \int_0^i \exp(bx_{jt-1})dj. \tag{28}$$

Equations (25)–(28) imply that forward rates at time i in period t satisfy:

$$F_{it}^a = F_{0t}^a \int_0^i \exp(bx_{jt-1})dj,$$

$$F_{it}^b = F_{0t}^b \int_0^i \exp(bx_{jt-1})dj.$$

[19] For example, these properties hold if there are N large traders who internalize price pressure and trade before a competitive fringe.

[20] A negative value of x_{it} means that the trader buys pounds forward.

The trader takes the bid and ask spot exchange rates at the end of period t as given:

$$\begin{aligned} S^a_{1t} &= S^a_{0t}\int_0^1 \exp(bx_{jt-1})dj, \\ S^b_{1t} &= S^b_{0t}\int_0^1 \exp(bx_{jt-1})dj. \end{aligned}$$

In forming expectations about $1/S_{it+1}$ the trader takes into account the price pressure impact of his actions on period $t+1$ spot rates:

$$\begin{aligned} E_t\left(S^a_{it+1}\right)^{-1} &= [S^a_{1t}\int_0^i \exp(bx_{jt})dj]^{-1}, \\ E_t\left(S^b_{it+1}\right)^{-1} &= [S^b_{1t}\int_0^i \exp(bx_{jt})dj]^{-1}. \end{aligned}$$

The trader's expected time $t+1$ payoff is given by:

$$\pi = \int_0^1 x_{it}\left(\frac{F^b_{it}}{S^a_{1t}\int_0^i \exp(bx_{jt})dj} - 1\right)di,$$

if the trader sells pounds forward, or

$$\pi = \int_0^1 x_{it}\left(\frac{F^a_{it}}{S^b_{1t}\int_0^i \exp(bx_{jt})dj} - 1\right)di.$$

if he buys pounds forward. The solution to this problem has three key properties. First, the optimal trade size is finite, $\int_0^1 x_{it}di < \infty$. Second, the expected payoff associated with the last pound bet by the trader is zero. Third, the expected payoff to the inframarginal pounds is positive. So the average Sharpe ratio is positive, even though the marginal Sharpe ratio is zero.[21]

We now provide a quantitative example to illustrate these points. Suppose that the trader implements the carry trade for each of the nine currencies.[22] To simplify our computations we assume that the trader chooses the total amount of trade at time t, x_t and executes the trades uniformly throughout the day: $x_{it} = ix_t$. Also, we assume that the data corresponds to end-of-day quotes ($i = 1$). Our assumptions imply that our quotes reflect the day's net order flow. Appendix E contains the details of our calculations.

Table 13 reports our results. Using Evans and Lyon's estimates of b (0.0054) we find that the trader places an average monthly bet of 1.3 billion pounds. The amounts invested are

[21] These results do not rely on price pressure taking the functional form given by (24).

[22] The portfolio constructed in this way does not correspond to either the equally-weighted carry trade or the optimally-weighted carry trade discussed above.

very volatile with a standard deviation of 1.1 billion pounds. This high standard deviation is consistent with the notion that speculative currency flows are very volatile. The expected average payoff per pound and average Sharpe ratio are 0.013 pounds per month and 0.138, respectively.

The average payoff per pound and the average Sharpe ratio are independent of b as long as b is strictly positive. However, b affects the total bet size on the carry trade. When b is equal to 0.0020, which corresponds to Berger et al.'s (2006) monthly estimates, the amount bet rises to 3.6 billion pounds per month. Finally, when b is equal to 0.0010 we obtain a mean monthly bet size of 7.2 billion pounds.

We conclude with the following observation about price pressure and its implications. Suppose that an econometrician uses end-of-day quotes from an economy in which there is price pressure. Suppose he ignores price pressure and calculates the Sharpe ratio associated with a one-pound bet in the carry trade. The econometrician would obtain the Sharpe ratios that we report in Section 5. Taken at face value those Sharpe ratios imply that the trader could make potentially infinite expected profits. But, as we just saw, in the presence of transactions costs and price pressure those Sharpe ratios greatly overstate the profitability of currency speculation.

9 Conclusion

In this paper we document that implementable currency-speculation strategies generate very large Sharpe ratios and that their payoffs are uncorrelated with standard risk factors. We argue that the presence of transactions costs and price pressure limits the size of the bets that agents choose to place on these strategies. Moreover, the average payoff to currency speculation is much smaller than suggested by calculations based on indicative quotes. So, while the statistical failure of UIP is very sharp, the amount of money that can be made from this failure, at least with our currency-speculation strategies, seems relatively small.

While we provide an explanation for why deviations from UIP persist, our analysis does not address the obvious question of why the 'forward-premium puzzle' arises in the first place. There is a very large literature on this problem, which remains a central issue in open economy macroeconomics. Burnside, Eichenbaum, and Rebelo (2006b) stress the potential of microstructure frictions for explaining the 'forward premium puzzle.' The central feature of their model is that market makers face an adverse selection problem that is less severe when a currency is expected to appreciate.

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Appendix A: Data

Our data set is obtained from Datastream. Mnemonics are indicated in Table A1. The original data are daily and represent end of day quotes from the London market. The foreign exchange rate data are originally sourced by Datastream from the WM Company/Reuters, with the exception of the euro, which is sourced from Barclay's Bank International. The interbank eurocurrency interest rate data are originally sourced by Datastream from the Financial Times. With the exception of the euro each exchange rate is quoted as currency units per British pound. The euro exchange rates are quoted as euro per U.S. dollar. These quotes were converted to quotes against the British pound by assuming that trades of the pound against the euro go through the U.S. dollar.

The original data set includes observations on all weekdays regardless of whether they are national holidays or not. There are obvious problems with data on the 1st of January, as these usually appear to be repeats of the observations from the previous business day. To avoid this problem, rather than sampling on the first of every month, to obtain our monthly data set we sampled the monthly data on the 2nd of each month. If the 2nd was a Sunday, we used the data from the 3rd. If the 2nd was a Saturday we used the data from the 4th.

Upon examining the resulting monthly data set, of approximately 360 observations, we observed a few dates on which the data appeared to be measured with error due to gross violations of covered interest parity. As a result, we made the following departures from the rule described above.

- For 11/2/78 we noticed that the forward rate and spot rate for the Dutch guilder moved in opposite directions. The forward rate data appeared suspect, so we sampled the Dutch data on 11/3/78.

- For 9/2/93, we noticed that the forward rate and spot rate for the Japanese yen moved in opposite directions. There appeared to be a data entry error, so we sampled the Japanese data on 9/3/93.

- For 4/4/94, 5/4/98 and 8/2/02, the forward rate data for all countries (except the euro) appear to have been repeated from the previous day and do not represent genuine observations. Therefore we sampled the data for all countries from 4/1/94, 5/1/98 and 8/1/02 instead.

Appendix B: Assessing Covered Interest Parity

To assess whether CIP holds it is critical to take bid-ask spreads into account. The variables R_t^a and R_t^b denote the ask and bid interest rate in British pounds. The variables R_t^{*a} and R_t^{*b} denote the ask and bid interest rate in foreign currency.

In the presence of bid-ask spreads equation (2) is replaced with the following two inequalities,

$$\pi_{CIP} = S_t^b \left(1 + R_t^{*b}\right) \frac{1}{F_t^a} - \left(1 + R_t^a\right) \leq 0, \tag{29}$$

$$\pi_{CIP}^* = \frac{1}{S_t^a} \left(1 + R_t^b\right) F_t^b - \left(1 + R_t^{*a}\right) \leq 0. \tag{30}$$

Equation (29) implies that there is a non-positive payoff (π_{CIP}) to the "borrowing pounds covered strategy." This strategy consists of borrowing one pound, exchanging the pound into foreign currency at the spot rate, investing the proceeds at the foreign interest rate, and converting the payoff into pounds at the forward rate. Equation (30) implies that there is a non-positive payoff (π_{CIP}^*) to the "borrowing foreign currency covered strategy." This strategy consists of borrowing one unit of foreign currency, exchanging the foreign currency into pounds at the spot rate, investing the proceeds at the domestic interest rate, and converting the payoff into foreign currency at the forward rate. Table A2 reports statistics for π_{CIP} and π_{CIP}^* for nine currencies. We compute statistics pertaining to the Euro-legacy currencies over the period January 1981 to December 1998. For all other currencies the sample period is January 1981 to December 2005.

Table A2 indicates that for all nine currencies, the median value for π_{CIP} and π_{CIP}^* is negative. Also the fraction of periods in which π_{CIP} and π_{CIP}^* are positive is small. Even in periods where the payoff is positive, the median payoff is very small. Similar results hold for 3-month horizon investments and the post-1994 time period.

Our finding that deviations from CIP are small and rare is consistent with the results in Taylor (1987) who uses data collected at 10-minute intervals for a three-day period, Taylor (1989) who uses daily data for selected historical periods of market turbulence, and Clinton (1988) who uses daily data from November 1985 to May 1986.

Appendix C: Defining the Carry Trade and BGT Strategies with Transactions Costs

We let x_t denote the number of pounds the speculator sells forward, and, as in the main text, assume that x_t is either 1, 0 or -1. When we ignore transactions costs the speculator's payoff is $x_t(F_t/S_{t+1}-1)$.

Suppose that $E_tS_{t+1}^{-1} = S_t^{-1}$. If this is true, the expected payoff to the speculator is $x_t(F_t/S_t-1)$. This provides the motivation for carry trade, which, by setting x_t according to (12), ensures that the expected payoff is always non-negative.

The BGT regression directly forecasts the payoff to selling domestic currency forward and implies that $E_t(F_t/S_{t+1}-1) = a + b(F_t - S_t)/S_t$. In this case the speculator ensures that his expected payoff is nonnegative by setting

$$x_t = \begin{cases} +1 & \text{if } a + b(F_t - S_t)/S_t \geq 0, \\ -1 & \text{if } a + b(F_t - S_t)/S_t < 0. \end{cases}$$

When transactions costs are taken into account the speculator's payoff is $x_t(F_t^b/S_{t+1}^a - 1)$ if $x_t = 1$ and $x_t(F_t^a/S_{t+1}^b - 1)$ when $x_t = -1$. When we ignored transactions costs we assumed that $E_tS_{t+1}^{-1} = S_t^{-1}$ so it is natural to assume that $E_t(S_{t+1}^a)^{-1} = (S_t^a)^{-1}$ and $E_t(S_{t+1}^b)^{-1} = (S_t^b)^{-1}$ when taking into account transactions costs. We think this is a reasonable assumption given that bid-ask spreads are quite stable over time in our data set. Given these assumptions, the speculator ensures that his expected payoff is non-negative if he sets x_t according to

$$x_t = \begin{cases} +1 & \text{if } F_t^b > S_t^a, \\ -1 & \text{if } F_t^a < S_t^b \\ 0 & \text{otherwise.} \end{cases}$$

This is the carry trade strategy modified for transactions costs.

Notice that implicit in the BGT regression is an estimate

$$E_tS_{t+1}^{-1} = \left[1 + a + b(F_t - S_t)/S_t\right] F_t^{-1}.$$

Hence it is natural to assume that

$$\begin{aligned} E_t(F_t^b/S_{t+1}^a) &= \left[1 + a + b(F_t - S_t)/S_t\right] \frac{F_t^b}{F_t}\frac{S_t}{S_t^a} \\ E_t(F_t^a/S_{t+1}^b) &= \left[1 + a + b(F_t - S_t)/S_t\right] \frac{F_t^a}{F_t}\frac{S_t}{S_t^b}, \end{aligned}$$

when taking into account transactions costs. Implicit in these expression is the speculator's belief that the percentage bid-ask spread tomorrow will be the same as today's. With these assumptions, the speculator ensures that his expected payoff is non-negative if he sets x_t according to (14). This is the BGT strategy modified for transactions costs.

Appendix D: Details of Risk-Factor Analysis

Defining UK Pound Quarterly Real Returns The monthly payoffs to currency speculation, denoted generically here as z_t, we studied in section 5, were defined for trades where one pound is either bought or sold forward. It is useful, instead, to normalize the number of pounds bought or sold to $1+R_{t-1}$, where R_{t-1} is the nominal interest rate at the time when the currency bet is made. That is, we define

$$r_t = (1 + R_{t-1})z_t.$$

To see that r_t can be interpreted as an excess return, consider the case where one pound is being sold forward, in which case $z_t = F_{t-1}/S_t - 1$. This means $r_t = (1+R_{t-1})\,(F_{t-1}/S_t - 1)$. Assuming CIP, (2), holds $r_t = (1 + R^*_{t-1})S_{t-1}/S_t - (1 + R_{t-1})$. So when one pound is being sold forward r_t is the excess return, in pounds, from taking a long position in foreign T-bills relative to the UK T-bill rate.

Let t index months, and let $s = t/3$ be the equivalent index for quarters. To convert the monthly excess return to a quarterly excess return we define:

$$r^q_s = \Pi^2_{j=0}(1 + R_{t-1-j} + r_{t-j}) - \Pi^2_{j=0}(1 + R_{t-1-j}).$$

This expression corresponds to the appropriate excess return because it implies that the agent continuously re-invests in the currency strategy by betting (in month t) his accumulated funds from currency speculation times $1 + R_t$. To define the quarterly real excess return, notice that this is simply:

$$r^{q,\text{real}}_s = \frac{r^q_s}{1 + \pi_s}$$

where π_s is the inflation rate between quarter $s - 1$ and quarter s.

To generate the returns we use the 1 month Sterling interbank lending rate (mean LIBID/LIBOR), published by the Bank of England (mnemonic IUDVNEA), as a measure of R. Because this series only begins in January 3, 1978 we use the series IUDAMIH, which is the daily average of 4 UK banks' base rates, for the period prior to this date. We use point-in-time data that are aligned with our exchange rate data.

To convert nominal returns to real returns we use the inflation rate corresponding to the deflator for consumption of nondurables and services found in the British national accounts.

To deal with the fact that our exchange rate data are point in time, while inflation data re time-averaged, we proceed as follows. Recall, from appendix A, that our exchange rate data is sampled near the beginning of each month. To take an example, we might measure the exchange rates on February 2nd, and March 2nd. We record the return generated between these two dates as one generated during the month of February. Analogously, the quarterly return for the 1st quarter is generated, say, between January 2nd and April 2nd. We use the inflation rate between the 4th quarter and the 1st quarter to deflate this return.

Defining U.S. Dollar Nominal and Quarterly Real Returns To define monthly nominal U.S. dollar returns, we first define the U.S. dollar payoffs to currency speculation. When we defined the payoffs in pounds, each bet was normalized to 1 pound. The natural analog is to consider bets whose size is normalized to 1 dollar. To do this we assume that at time $t-1$ the speculator bets a number of pounds equal to $1/S_{t-1}^{US}$ where S_{t-1}^{US} is the spot exchange rate as U.S. dollars per pound. This would give the speculator a payoff (in pounds) of z_t/S_{t-1}^{US}. The value of this payoff in dollars would be $z_t^{US} = z_t S_t^{US}/S_{t-1}^{US}$. In converting the pound payoffs to dollar payoffs in this way, we use the average of bid and ask prices for S_t^{US} and S_{t-1}^{US} so that the U.S. investor does not pay more bid-ask spreads than the British investor.

The monthly U.S. dollar excess returns is $r_t^{US} = (1 + R_{t-1}^{US})z_t^{US}$ where R_t^{US} is the U.S. nominal interest rate. The quarterly excess return and the real quarterly excess return are defined as

$$r_s^{q,US} = \Pi_{j=0}^{2}(1 + R_{t-1-j}^{US} + r_{t-j}^{US}) - \Pi_{j=0}^{2}(1 + R_{t-1-j}^{US}).$$

and

$$r_s^{q,\mathrm{real},US} = \frac{r_s^{q,US}}{1 + \pi_s^{US}},$$

where π_s^{US} is the U.S. inflation rate.

To generate the U.S. returns we use 1-month Eurodollar deposit rates in London with a 1-month maturity as our measure of R^{US}. Daily quotes are published in the Federal Reserve Board's Statistical Release H.15, and correspond to bid rates. We use point-in-time data that are aligned with our exchange rate data.

We convert nominal returns to real returns using the inflation rate corresponding to the deflator for consumption of nondurables and services found in the U.S. National Income and Product Accounts.

Data Sources for Risk Factors and Monetary Variables The S&P500 (inclusive of the dividend) return is measured monthly and is taken from Ibbotson and Associates (2006). Recent observations can be found on the Standard and Poors website: http://www2.standardandpoors.com/spf/xls/index/MONTHLY.xls. Monthly returns are converted to quarterly returns by accumulating them geometrically within each quarter. Nominal returns are converted to real returns as described above for our currency strategies, except that the inflation rate is also subtracted from the return because it is not an excess return.

The three Fama-French factors are from Kenneth French's data library: http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html. The three factors are Mkt-RF (the market premium, which we also use to define the CAPM factor), SMB (the size premium) and HML (the book to market premium). Each of these objects is an excess return. Monthly returns are converted to quarterly returns by accumulating them geometrically within each quarter. Nominal returns are converted to real returns as described above for our currency strategies.

Real per-capita consumption growth is from the U.S. National Income and Product Accounts which can be found at the website of the Bureau of Economic Analysis: www.bea.gov. We define real consumption as the sum of nondurables and services. We convert these to per capita terms using the quarterly average of the Bureau of Labor Statistics (www.bls.gov) series for the civilian noninstitutional population 16 years and over. We then compute the quarterly growth rate of the series. The inflation series for all our U.S.-based calculations is the deflator corresponding to this consumption measure.

Real luxury retail sales growth is available from 1987Q1–2001Q4 and is obtained from Parker, Aït-Sahalia and Yogo (2004).

The growth rate of the per capita service flow from the stock of consumer durables was estimated as follows. Annual end-of-year real stocks of consumer durables are available from the U.S. National Income and Product Accounts, as are quarterly data on purchases of durables by consumers. Within each year we determine the depreciation rate that makes the quarterly purchases consistent with the annual stocks, and use this rate to interpolate quarterly stocks using the identity: $K_{t+1}^D = C_t^D + (1-\delta^D)K_t^D$. Here K_t^D is the beginning of period t stock of consumer durables, C_t^D is purchases of durables, and δ^D is the depreciation rate. We assume that the service flow from durables (per capita) is proportional to the stock of durables (per capita).

The risk factors proposed by Yogo (2006) are the market premium (the CAPM risk factor above), the growth rate of per-capita consumption of nondurables and services, and the growth rate of the per-capita service flow from the stock of consumer durables, each of which was described above.

The quarterly index of industrial production is from the Federal Reserve Board of Governors (www.federalreserve.gov), Statistical Release Table G.17. We use the growth rate of this series as a risk factor.

For the UK we define per-capita real consumption growth using data published by the UK Office for National Statistics (www.statistics.gov.uk). Consumption is defined in terms of semi-durable goods, non-durable goods, and miscellaneous goods and services plus net tourism. The real growth rate is computed as the weighted average of the real growth rates of the individual components, where the weights are the shares in nominal consumption. The inflation rate is computed as the same weighted average of the inflation rates of the deflators for the individual components. As with our U.S. data, we convert the UK data to per-capita terms using the population 16 years and older. This series is only available every five years beginning in 1976, and annually since 1998, so we log-linearly interpolate it on a quarterly basis between 1976 and 2005.

The FTSE 100 price index is from Datastream (mnemonic FTSE100). We compute its monthly ex-dividend return. Monthly returns are converted to quarterly returns by accumulating them geometrically within each quarter. Nominal returns are converted to real returns as described above for our currency strategies using the UK inflation rate.

The average monthly value of the Fed funds rate is from the Federal Reserve Board of Governors (www.federalreserve.gov), Statistical Release Table H.15 (Selected Interest Rates), Effective Federal Funds Rate (mnemonic FEDFUNDS). We convert this to the quarterly frequency using the average of the three monthly values within each quarter.

Seasonally-adjusted monthly data on the stocks of M1, M2, M3 and MZM are from the Federal Reserve Board of Governors (www.federalreserve.gov), Statistical Release Table H.6 (Money Stock Measures), (mnemonics M1SL, M2SL, M3SL and MZMSL). We compute quarterly growth rates by taking the growth rate from the 3rd month of the previous quarter to the 3rd month of the current quarter.

The term premium is defined as the difference between the 10-year T-bond rate and the 3-month T-bill rate. Data are from the Federal Reserve Board of Governors (www.federal reserve.gov), Statistical Release Table H.15 (Selected Interest Rates) for the 3-Month Treasury Bill Secondary Market Rate (mnemonic TB3MS) and the 10-Year Treasury Constant Maturity Rate (mnemonic GS10). We convert this to the quarterly frequency using the average of the three monthly values within each quarter.

The UK 3 Month T-bill rate is from the UK Office for National Statistics (www.statistics. gov.uk) and has mnemonic AJRP. We convert this to the quarterly frequency using the average of the three monthly values within each quarter.

Appendix E: Details of Price Pressure Calculations

Let each period be an interval of unit length and let i denote the time within that interval. Let F_{it} be the forward price at time i in period t, and let S_{it} the spot price at the same point in time. Given the assumption of uniform trading, the rest of ours assumptions in the main text imply that

$$\begin{aligned} F_{it} &= F_{0t}\exp(ibx_{t-1}) \\ S_{it} &= S_{0t}\exp(ibx_{t-1}) \end{aligned}$$

where x_{t-1} is the total order flow from forward sales in period $t-1$. If there were forward purchases then x_{t-1} is negative. In what follows we assume that bid ask spreads are constant so that $F^a_{it} = F_{it}(1+b_f/2)$, $F^b_{it} = F_{it}(1-b_f/2)$, $S^a_{it} = S_{it}(1+b_s/2)$ and $S^b_{it} = S_{it}(1-b_s/2)$. The speculative monopolist observing F_{it} and S_{it} believes that $E_t\left(S_{it+1}\right)^{-1} = [S_{0t}\exp(bx_{t-1}+ ibx_t)]^{-1}$ where x_t is the size of his order flow in period t.

Suppose the agent considers selling the pound forward. His expected payoff of breaking up a total volume of x_t into infinitesimal trades is

$$\begin{aligned} \pi_e^{\text{sell}}(x_t) &= \int_0^1 x_t\left[\frac{F_{0t}(1-b_f/2)\exp(ibx_{t-1})}{S_{0t}(1+b_s/2)\exp(bx_{t-1}+ibx_t)} - 1\right]di \\ &= \int_0^1 x_t\left\{\frac{F^b_{0t}}{S^a_{0t}}\exp\left[(i-1)bx_{t-1} - ibx_t\right] - 1\right\}di. \end{aligned}$$

Evaluating this integral:

$$\pi_e^{\text{sell}}(x_t) = \begin{cases} x_t\frac{F^b_{0t}}{S^a_{0t}}\frac{\exp(-bx_t)-\exp(-bx_{t-1})}{b(x_{t-1}-x_t)} - x_t & \text{if } x_t \neq x_{t-1} \\ x_t\frac{F^b_{0t}}{S^a_{0t}}\exp(-bx_{t-1}) - x_t & \text{if } x_t = x_{t-1}. \end{cases}$$

Now suppose the agent considers selling the pound forward. His expected payoff of breaking up a total volume of x_t (keep in mind that $x_t < 0$ in this case) into infinitesimal trades is

$$\begin{aligned} \pi_e^{\text{buy}}(x_t) &= \int_0^1 x_t \left[\frac{F_{0t}(1+b_f/2)\exp(ibx_{t-1})}{S_{0t}(1-b_s/2)\exp(bx_{t-1}+ibx_t)} - 1 \right] di \\ &= \int_0^1 x_t \left\{ \frac{F_{0t}^a}{S_{0t}^b} \exp\left[(i-1)bx_{t-1} - ibx_t\right] - 1 \right\} di. \end{aligned}$$

Evaluating this integral:

$$\pi_e^{\text{buy}}(x_t) = \begin{cases} x_t \frac{F_{0t}^a}{S_{0t}^b} \frac{\exp(-bx_t)-\exp(-bx_{t-1})}{b(x_{t-1}-x_t)} - x_t & \text{if } x_t \neq x_{t-1} \\ x_t \frac{F_{0t}^a}{S_{0t}^b} \exp(-bx_{t-1}) - x_t & \text{if } x_t = x_{t-1} \end{cases}.$$

In practice we would the optimal value of x_t by checking whether $d\pi_e^{\text{sell}}(0)/dx_t > 0$ or $\pi_e^{\text{buy}}(0)/dx_t < 0$. From the concavity of the profit functions, if neither of these conditions is satisfied, the agent will chose $x_t = 0$. If $d\pi_e^{\text{sell}}(0)/dx_t > 0$, the agent sells pounds forward, and we numerically maximize $\pi_e^{\text{sell}}(x_t)$ to find the optimal x_t. If $\pi_e^{\text{buy}}(0)/dx_t < 0$, the agent buys pounds forward, and we numerically maximize $\pi_e^{\text{buy}}(x_t)$ to find the optimal x_t. The events that $d\pi_e^{\text{sell}}(0)/dx_t > 0$ and $\pi_e^{\text{buy}}(0)/dx_t < 0$ are mutually exclusive.

If the agent sells pounds forward the actual payoff is

$$\pi^{\text{sell}}(x_t) = \int_0^1 x_t \left[\frac{F_{0t}^b \exp(ibx_{t-1})}{S_{0t+1}^a \exp(ibx_t)} - 1 \right] di$$

Evaluating the integral we have

$$\pi^{\text{sell}}(x_t) = \begin{cases} x_t \frac{F_{0t}^b}{S_{0t+1}^a} \frac{\exp[b(x_{t-1}-x_t)]-1}{b(x_{t-1}-x_t)} - x_t & \text{if } x_t \neq x_{t-1} \\ x_t \frac{F_{0t}^b}{S_{0t+1}^a} - x_t & \text{if } x_t = x_{t-1} \end{cases}$$

If the agent buys pounds forward the actual payoff is

$$\pi = \int_0^1 x_t \left[\frac{F_{0t}^a \exp(ibx_{t-1})}{S_{0t+1}^b \exp(ibx_t)} - 1 \right] di$$

Evaluating the integral we have

$$\pi^{\text{buy}}(x_t) = \begin{cases} x_t \frac{F_{0t}^a}{S_{0t+1}^b} \frac{\exp[b(x_{t-1}-x_t)]-1}{b(x_{t-1}-x_t)} - x_t & \text{if } x_t \neq x_{t-1} \\ x_t \frac{F_{0t}^a}{S_{0t+1}^b} - x_t & \text{if } x_t = x_{t-1} \end{cases}$$

We treat the end-of-period quotes as observed. Since $F_{1t} = \exp(bx_{t-1})F_{0t}$ and $S_{1t+1} = \exp(bx_t)S_{0t+1}$ this means that profits expressed in terms of observable quotes are

$$\pi^{\text{sell}}(x_t) = \begin{cases} x_t \frac{F_{1t}^b}{S_{1t+1}^a} \frac{1-\exp[b(x_t-x_{t-1})]}{b(x_{t-1}-x_t)} - x_t & \text{if } x_t \neq x_{t-1} \\ x_t \frac{F_{0t}^b}{S_{0t+1}^a} - x_t & \text{if } x_t = x_{t-1} \end{cases}$$

and

$$\pi^{\text{buy}}(x_t) = \begin{cases} x_t \frac{F^a_{0t}}{S^b_{0t+1}} \frac{1-\exp[b(x_t - x_{t-1})]}{b(x_{t-1} - x_t)} - x_t & \text{if } x_t \neq x_{t-1} \\ x_t \frac{F^a_{0t}}{S^b_{0t+1}} - x_t & \text{if } x_t = x_{t-1}. \end{cases}$$

TABLE 1

Median Bid-Ask Spreads

	Spot	1 month Forward	3 month Forward	Spot	1 month Forward	3 month Forward	Units	
	100 x ln(Ask/Bid)			foreign currency units				
	Full Sample Period							Dates
Belgium	0.159	0.253	0.291	10.00	15.93	20.00	Centimes	76:01-98:12
Canada	0.053	0.096	0.111	0.10	0.20	0.23	Cents	76:01-05:12
France	0.100	0.151	0.176	1.00	1.50	1.88	Centimes	76:01-98:12
Germany	0.213	0.311	0.319	1.00	1.12	1.13	Pfennig	76:01-98:12
Italy	0.063	0.171	0.208	1.00	4.00	5.00	Lire	76:01-98:12
Japan	0.216	0.272	0.280	1.00	1.08	1.13	Yen	78:06-05:12
Netherlands	0.234	0.344	0.359	1.00	1.25	1.25	Cents	76:01-98:12
Switzerland	0.255	0.412	0.456	1.00	1.13	1.13	Centimes	76:01-05:12
USA	0.055	0.074	0.082	0.10	0.12	0.13	Cents	76:01-05:12
Euro*	0.043	0.060	0.070	0.04	0.06	0.07	Cents	99:01-05:12
	1999-2005							
Canada	0.066	0.071	0.076	0.15	0.16	0.17	Cents	
Japan	0.061	0.066	0.070	0.11	0.12	0.13	Yen	
Switzerland	0.087	0.094	0.103	0.21	0.22	0.24	Centimes	
USA	0.023	0.027	0.027	0.04	0.04	0.05	Cents	
Euro*	0.043	0.060	0.070	0.04	0.06	0.07	Cents	

*Euro quotes are Euro/USD, whereas other quotes are originally in FCU/British pound

Note : Results are based on daily data

TABLE 2

UIP Regressions, 1976-2005

	1 Month Regression			3 Month Regression		
	α	β	R^2	α	β	R^2
Belgium†	-0.002	-1.531	0.028	-0.005	-0.625	0.008
	(0.002)	(0.714)		(0.006)	(0.669)	
Canada	-0.003	-3.487	0.045	-0.007	-2.936	0.072
	(0.002)	(0.803)		(0.005)	(0.858)	
France†	0.000	-0.468	0.004	0.001	-0.061	0.000
	(0.002)	(0.589)		(0.005)	(0.504)	
Germany†	-0.005	-0.732	0.005	-0.012	-0.593	0.007
	(0.003)	(0.704)		(0.008)	(0.650)	
Italy†	0.005	-0.660	0.010	0.008	-0.012	0.000
	(0.002)	(0.415)		(0.006)	(0.392)	
Japan*	-0.019	-3.822	0.030	-0.063	-4.482	0.100
	(0.005)	(0.924)		(0.014)	(1.017)	
Netherlands†	-0.009	-2.187	0.029	-0.018	-1.381	0.026
	(0.004)	(1.040)		(0.009)	(0.816)	
Switzerland	-0.008	-1.211	0.012	-0.020	-1.050	0.022
	(0.003)	(0.533)		(0.008)	(0.536)	
USA	-0.003	-1.681	0.017	-0.008	-1.618	0.037
	(0.002)	(0.880)		(0.006)	(0.865)	

* Data for Japan begin 7/78
† Data for Euro legacy currencies ends 12/98
Notes : Regression of [S(t+1)/S(t)-1] on [F(t)/S(t)-1]. Standard errors in parentheses.

TABLE 3

BGT Regressions, 1976-2005

	1 Month Regression			3 Month Regression		
	a	*b*	R^2	*a*	*b*	R^2
Belgium†	0.003	2.617	0.076	0.007	1.676	0.051
	(0.002)	(0.746)		(0.006)	(0.677)	
Canada	0.004	4.392	0.068	0.010	3.914	0.119
	(0.002)	(0.815)		(0.005)	(0.923)	
France†	0.001	1.534	0.040	0.001	1.122	0.047
	(0.002)	(0.590)		(0.005)	(0.508)	
Germany†	0.005	1.689	0.024	0.014	1.542	0.045
	(0.003)	(0.722)		(0.009)	(0.682)	
Italy†	-0.004	1.707	0.060	-0.006	1.041	0.058
	(0.002)	(0.424)		(0.006)	(0.403)	
Japan*	0.020	4.753	0.043	0.065	5.333	0.125
	(0.005)	(0.957)		(0.015)	(1.060)	
Netherlands†	0.009	3.232	0.060	0.020	2.377	0.067
	(0.004)	(1.090)		(0.010)	(0.849)	
Switzerland	0.008	2.130	0.035	0.021	1.954	0.067
	(0.003)	(0.550)		(0.008)	(0.556)	
USA	0.004	2.584	0.038	0.011	2.503	0.079
	(0.002)	(0.920)		(0.006)	(0.940)	

* Data for Japan begin 7/78

† Data for Euro legacy currencies ends 12/98

Notes : Regression of [F(t)/S(t+1)-1] on [F(t)/S(t)-1]. Standard errors in parentheses.

TABLE 4

Payoffs to the Carry Trade Strategies 76:01-05:12

	No Transactions Costs			With Transactions Costs		
	Mean	Standard Deviation	Sharpe Ratio	Mean	Standard Deviation	Sharpe Ratio
Belgium*	0.0044	0.028	0.157	0.0029	0.021	0.140
	(0.0019)	(0.002)	(0.068)	(0.0015)	(0.002)	(0.072)
Canada	0.0053	0.032	0.169	0.0042	0.026	0.161
	(0.0018)	(0.002)	(0.059)	(0.0014)	(0.002)	(0.055)
France*	0.0054	0.027	0.201	0.0031	0.023	0.134
	(0.0016)	(0.002)	(0.060)	(0.0015)	(0.002)	(0.066)
Germany*	0.0011	0.028	0.038	0.0014	0.024	0.060
	(0.0018)	(0.002)	(0.066)	(0.0016)	(0.002)	(0.068)
Italy*	0.0029	0.028	0.105	0.0024	0.024	0.102
	(0.0017)	(0.002)	(0.058)	(0.0014)	(0.002)	(0.056)
Japan†	0.0022	0.036	0.061	0.0017	0.034	0.049
	(0.0022)	(0.003)	(0.063)	(0.0020)	(0.003)	(0.060)
Netherlands*	0.0024	0.028	0.087	0.0014	0.023	0.062
	(0.0018)	(0.002)	(0.068)	(0.0015)	(0.002)	(0.067)
Switzerland	0.0019	0.030	0.063	0.0008	0.027	0.028
	(0.0017)	(0.002)	(0.060)	(0.0015)	(0.002)	(0.057)
USA	0.0039	0.031	0.124	0.0030	0.029	0.103
	(0.0017)	(0.002)	(0.058)	(0.0016)	(0.002)	(0.059)
Euro‡	0.0014	0.021	0.066	0.0024	0.016	0.153
	(0.0017)	(0.002)	(0.083)	(0.0013)	(0.002)	(0.090)
Average	0.0031	0.029	0.107	0.0023	0.025	0.099
Equally-weighted portfolio	0.0031	0.017	0.183	0.0029	0.020	0.145
	(0.0009)	(0.001)	(0.061)	(0.0011)	(0.001)	(0.057)

* Euro legacy currencies available 76:1-98:12
† Japanese yen available 78:7-05:12
‡ Euro available 99:1-05:12
Notes : Other currencies and the equally-weighted portfolio are available for 76:1-05:12. Standard errors in parentheses.

TABLE 5

Payoffs to the BGT Strategies 76:01-05:12

	No Transactions Costs			With Transactions Costs		
	Mean	Standard Deviation	Sharpe Ratio	Mean	Standard Deviation	Sharpe Ratio
Belgium*	0.0051	0.027	0.188	0.0029	0.026	0.114
	(0.0017)	(0.002)	(0.066)	(0.0017)	(0.002)	(0.065)
Canada	0.0060	0.031	0.194	0.0038	0.029	0.130
	(0.0017)	(0.002)	(0.055)	(0.0017)	(0.002)	(0.058)
France*	0.0047	0.027	0.173	0.0032	0.023	0.137
	(0.0018)	(0.002)	(0.065)	(0.0016)	(0.002)	(0.073)
Germany*	0.0012	0.028	0.043	0.0005	0.022	0.021
	(0.0019)	(0.002)	(0.070)	(0.0015)	(0.002)	(0.067)
Italy*	0.0043	0.026	0.163	0.0026	0.024	0.108
	(0.0017)	(0.002)	(0.069)	(0.0016)	(0.002)	(0.069)
Japan†	0.0017	0.036	0.049	0.0008	0.029	0.028
	(0.0020)	(0.003)	(0.058)	(0.0017)	(0.003)	(0.058)
Netherlands*	0.0030	0.027	0.115	0.0000	0.023	0.000
	(0.0018)	(0.002)	(0.065)	(0.0015)	(0.002)	(0.067)
Switzerland	0.0018	0.029	0.064	-0.0008	0.026	-0.031
	(0.0017)	(0.002)	(0.056)	(0.0015)	(0.002)	(0.059)
USA	0.0057	0.031	0.185	0.0049	0.029	0.166
	(0.0018)	(0.002)	(0.064)	(0.0017)	(0.003)	(0.064)
Euro‡	-0.0011	0.021	-0.052	-0.0012	0.016	-0.078
	(0.0017)	(0.002)	(0.083)	(0.0015)	(0.002)	(0.100)
Average	0.0032	0.028	0.112	0.0017	0.025	0.059
Equally-weighted portfolio	0.0027	0.013	0.202	0.0017	0.017	0.103
	(0.0008)	(0.001)	(0.057)	(0.0010)	(0.001)	(0.061)

* Euro legacy currencies available 76:1-98:12
† Japanese yen available 78:7-05:12
‡ Euro available 99:1-05:12

Notes: Other currencies available 76:1-05:12. To run the first BGT regression 30 observations are used, so equally-weighted portfolio returns are generated over the period 78:07-05:12. Standard errors in parentheses.

TABLE 6

Sharpe Ratios of the Portfolio Strategies with Transactions Costs
Over a Common Sample (79:10-05:12)

	Equally Weighted	Optimally Weighted	Difference
Carry trade	0.154	0.197	0.043
	(0.060)	(0.057)	(0.037)
BGT	0.096	0.137	0.041
	(0.062)	(0.063)	(0.032)
Difference	0.058	0.060	
	(0.069)	(0.065)	

Notes : Standard errors in parentheses. The equally-weighted carry trade portfolio is available over the period 76:1-05:12. For the optimally-weighted carry trade 16 observations are used to compute the first covariance matrix for the optimal portfolios, so optimally-weighted returns are generated over the period 77:04-05:12. For the equally-weightd BGT strategy 30 observations are used to run the first BGT regression, so returns are generated over the period 78:07-05:12. For the optimally-weighted BGT strategy 16 observations are used to compute the first covariance matrix for the optimal portfolio, so optimally-weighted returns are generated over the period 79:10-05:12. For comparability this shorter common sample is used to generate the statistics in the table for all portfolios.

TABLE 7

Skewness, Kurtosis and Tests for Normality

	Payoffs to Carry Trade With Transactions Costs			Payoffs to BGT Strategy With Transactions Costs		
	Skewness	Excess Kurtosis	Jarque-Bera Test	Skewness	Excess Kurtosis	Jarque-Bera Test
Belgium*	0.078	1.27	10.7	0.287	2.66	61.5
	(0.312)	(0.44)	(0.005)	(0.472)	(1.58)	(0.000)
Canada	-0.247	0.50	5.0	-0.114	0.34	2.1
	(0.179)	(0.35)	(0.082)	(0.160)	(0.30)	(0.351)
France*	-0.140	0.70	4.5	-0.122	1.19	12.4
	(0.233)	(0.35)	(0.105)	(0.303)	(0.47)	(0.002)
Germany*	-0.402	1.44	22.3	1.159	4.43	165.7
	(0.227)	(0.52)	(0.000)	(0.527)	(2.42)	(0.000)
Italy*	0.445	1.60	25.8	-0.310	1.26	16.6
	(0.291)	(0.86)	(0.000)	(0.251)	(0.72)	(0.000)
Japan†	-1.253	5.60	411.2	-0.399	5.20	259.2
	(0.458)	(1.62)	(0.000)	(0.792)	(2.69)	(0.000)
Netherlands*	-0.094	1.13	9.8	1.262	4.68	222.9
	(0.236)	(0.48)	(0.007)	(0.512)	(2.60)	(0.000)
Switzerland	-0.759	1.84	69.5	1.179	3.85	217.5
	(0.200)	(0.62)	(0.000)	(0.379)	(1.62)	(0.000)
USA	-0.546	2.33	77.8	-0.585	2.97	124.7
	(0.454)	(1.40)	(0.000)	(0.519)	(1.72)	(0.000)
Euro‡	-0.289	-0.54	1.7	0.156	-0.62	1.0
	(0.156)	(0.31)	(0.424)	(0.210)	(0.28)	(0.593)
Average	-0.321	1.59	63.8	0.251	2.60	108.4
Equally-weighted portfolio	-0.824	4.03	283.6	0.620	2.20	87.6
	(0.428)	(1.93)	(0.000)	(0.275)	(0.74)	(0.000)
Optimally-weighted portfolio	-0.220	1.02	17.6	-0.001	1.81	42.7
	(0.202)	(0.36)	(0.000)	(0.355)	(1.10)	(0.000)

* Euro legacy currencies available 76:1-98:12
† Japanese yen available 78:7-05:12
‡ Euro available 99:1-05:12

Notes: Other currencies available 76:1-05:12. Payoffs in periods of zero trade are excluded. Standard errors in parentheses for skewness and kurtosis statistics. P-values in parentheses for Jarque-Bera statistics. See the footnotes to Tables 4, 5 and 6 for the sample periods used for the equally and optimally weighted portfolios.

TABLE 8

Quarterly Real Excess Returns to Currency Speculation and U.S. Risk Factors

	Carry Trade Equally-Weighted Portfolio					Carry Trade Optimally-Weighted Portfolio				
	Intercept	Slope Coefficient(s)			R^2	Intercept	Slope Coefficient(s)			R^2
S&P500	0.010	-0.007			0.000	0.013	-0.017			0.001
	(0.003)	(0.039)				(0.004)	(0.049)			
CAPM	0.010	-0.006			0.000	0.013	-0.019			0.002
	(0.003)	(0.038)				(0.004)	(0.046)			
Fama-French factors	0.010	-0.008	-0.019	-0.019	0.002	0.010	0.047	-0.024	0.150	0.045
	(0.003)	(0.051)	(0.075)	(0.069)		(0.004)	(0.057)	(0.093)	(0.071)	
Per-capita consumption growth	0.012	-0.548			0.005	0.015	-0.545			0.004
	(0.004)	(0.673)				(0.005)	(0.746)			
Luxury retail sales growth	0.008	0.009			0.001	0.012	-0.010			0.001
	(0.007)	(0.045)				(0.008)	(0.052)			
Per-capita durables services growth	0.014	-0.463			0.004	0.014	-0.096			0.000
	(0.007)	(0.664)				(0.009)	(0.772)			
Yogo factors	0.015	-0.004	-0.412	-0.341	0.007	0.015	-0.016	-0.533	0.061	0.005
	(0.007)	(0.036)	(0.747)	(0.732)		(0.009)	(0.048)	(0.847)	(0.847)	
Industrial production	0.009	0.150			0.003	0.013	-0.062			0.000
	(0.003)	(0.203)				(0.004)	(0.234)			
	BGT Strategy Equally-Weighted Portfolio					**BGT Strategy Optimally-Weighted Portfolio**				
	Intercept	Slope Coefficient(s)			R^2	Intercept	Slope Coefficient(s)			R^2
S&P500	0.005	0.021			0.003	0.010	-0.036			0.005
	(0.003)	(0.044)				(0.004)	(0.056)			
CAPM	0.006	0.010			0.001	0.010	-0.047			0.010
	(0.003)	(0.042)				(0.004)	(0.052)			
Fama-French	0.005	0.024	0.004	0.037	0.005	0.009	-0.021	-0.028	0.044	0.014
	(0.003)	(0.044)	(0.069)	(0.050)		(0.004)	(0.062)	(0.094)	(0.064)	
Per-capita consumption growth	0.005	0.071			0.000	0.006	0.828			0.008
	(0.004)	(0.777)				(0.006)	(0.966)			
Luxury retail sales growth	0.003	-0.005			0.000	0.007	-0.020			0.003
	(0.005)	(0.038)				(0.006)	(0.048)			
Per-capita durables services growth	0.016	-1.030			0.025	0.017	-0.743			0.008
	(0.007)	(0.679)				(0.010)	(0.834)			
Yogo factors	0.015	0.005	0.538	-1.194	0.030	0.016	-0.058	1.462	-1.229	0.041
	(0.007)	(0.038)	(0.857)	(0.782)		(0.010)	(0.049)	(1.045)	(0.940)	
Industrial production	0.006	-0.029			0.000	0.008	0.165			0.003
	(0.003)	(0.235)				(0.004)	(0.314)			

Notes : See the appendix for definitions of real excess returns in US dollars. Standard errors in parentheses. Fama-French factors are Rm-Rf, SMB and HML, respectively (see Fama and French 1992 for details). Yogo factors are the CAPM factor, the growth rate of per capita consumption of nondurables and services, and the growth rate of the per capita consumption (service flow) of durables. See appendix D for the definition of the service flow of durables.

TABLE 9

Quarterly Real Excess Returns to Currency Speculation and U.K. Risk Factors

	Carry Trade Equally-Weighted Portfolio			Carry Trade Optimally-Weighted Portfolio		
	Intercept	Slope Coefficient(s)	R^2	Intercept	Slope Coefficient(s)	R^2
Per-capita consumption growth	0.006	0.581	0.018	0.006	1.242	0.064
	(0.004)	(0.400)		(0.004)	(0.415)	
FTSE return	0.010	-0.011	0.001	0.013	-0.003	0.000
	(0.003)	(0.036)		(0.004)	(0.046)	
	BGT Strategy Equally-Weighted Portfolio			**BGT Strategy Optimally-Weighted Portfolio**		
	Intercept	Slope Coefficient(s)	R^2	Intercept	Slope Coefficient(s)	R^2
Per-capita consumption growth	0.003	0.409	0.010	0.006	0.568	0.011
	(0.004)	(0.341)		(0.005)	(0.489)	
FTSE return	0.006	-0.028	0.005	0.011	-0.101	0.041
	(0.003)	(0.034)		(0.004)	(0.047)	

Notes : See the appendix for definitions of real excess returns in UK pounds. Standard errors in parentheses.

TABLE 10

Quarterly Real Excess Returns to Currency Speculation and Risk Factors
Panel Analysis using GMM

	Carry-Trade Strategy				
	b			R^2	J-test
S&P500	3.9			-3.46	23.3
	(4.5)				(0.006)
CAPM	4.0			-3.53	23.0
	(3.8)				(0.006)
Fama-French factors	7.7	8.4	-8.6	-5.42	4.1
	(29.3)	(43.0)	(25.2)		(0.763)
Consumption growth	-419.3			-3.09	10.8
	(142.5)				(0.287)
Luxury retail sales	5.4			-2.64	17.2
	(4.2)				(0.045)
Durables services growth	-64.3			-3.59	23.8
	(61.2)				(0.005)
Yogo factors	-5.0	-439.6	-240.1	-2.88	2.8
	(17.9)	(280.5)	(304.7)		(0.899)
Industrial production	-11.9			-3.99	18.5
	(25.3)				(0.030)
	BGT Strategy				
	b			R^2	J-test
S&P500	12.8			-0.36	13.4
	(6.4)				(0.143)
CAPM	10.1			-0.66	15.4
	(6.2)				(0.081)
Fama-French factors	25.6	-18.9	19.0	0.40	4.8
	(8.8)	(18.9)	(15.3)		(0.681)
Consumption growth	412.4			0.49	3.6
	(138.9)				(0.937)
Luxury retail sales	1.4			-0.37	17.2
	(3.3)				(0.045)
Durables services growth	49.7			-1.02	16.2
	(58.8)				(0.062)
Yogo factors	7.2	355.1	1.4	0.58	2.2
	(10.2)	(277.4)	(184.6)		(0.947)
Industrial production	39.1			-1.21	18.6
	(27.0)				(0.029)

Notes : Panel analysis uses 9 country returns and the return on the optimally weighted portfolio. Optimal weighting matrix takes into account the estimation of the means of the risk factors. The R^2 is a measure of cross-sectional fit of the model's predicted mean excess returns to the actual mean excess returns. For *b* numbers in parentheses are standard errors. For the J-test of overidentifying restrictions, the numbers in parentheses are p-values.

TABLE 11

Real Excess Returns to Currency Speculation and Monetary Variables

	Carry-Trade Equally-Weighted Portfolio			Carry-Trade Optimally-Weighted		
	Intercept	Slope Coefficient	R^2	Intercept	Slope Coefficient	R^2
U.S. Variables						
Fed funds rate	0.000	0.147	0.025	0.005	0.111	0.012
	(0.006)	(0.071)		(0.007)	(0.085)	
Inflation	0.000	0.997	0.032	0.008	0.505	0.007
	(0.006)	(0.415)		(0.007)	(0.531)	
M1 Growth	0.012	-0.178	0.006	0.015	-0.165	0.004
	(0.004)	(0.221)		(0.004)	(0.210)	
M2 Growth	0.010	0.004	0.000	0.009	0.281	0.004
	(0.007)	(0.397)		(0.008)	(0.453)	
M3 Growth	0.005	0.242	0.005	0.011	0.135	0.001
	(0.007)	(0.352)		(0.009)	(0.466)	
MZM Growth	0.012	-0.118	0.007	0.011	0.080	0.002
	(0.003)	(0.105)		(0.004)	(0.116)	
Term Premium	0.016	-0.326	0.015	0.016	-0.195	0.004
	(0.005)	(0.249)		(0.007)	(0.306)	
UK Variables						
Inflation	0.007	0.117	0.002	0.015	-0.177	0.002
	(0.005)	(0.296)		(0.005)	(0.313)	
UK 3 Mo. T-bill rate	0.002	0.080	0.007	0.006	0.077	0.006
	(0.007)	(0.073)		(0.008)	(0.086)	

	BGT Strategy Equally-Weighted Portfolio			BGT Strategy Optimally-Weighted		
	Intercept	Slope Coefficient	R^2	Intercept	Slope Coefficient	R^2
U.S. Variables						
Fed funds rate	-0.011	0.247	0.088	-0.016	0.387	0.134
	(0.006)	(0.078)		(0.007)	(0.101)	
Inflation	-0.006	1.202	0.054	-0.012	2.378	0.098
	(0.005)	(0.462)		(0.007)	(0.607)	
M1 Growth	0.004	0.141	0.005	0.005	0.332	0.018
	(0.003)	(0.205)		(0.004)	(0.228)	
M2 Growth	0.001	0.324	0.008	0.000	0.644	0.021
	(0.005)	(0.330)		(0.006)	(0.423)	
M3 Growth	0.005	0.047	0.000	0.003	0.364	0.008
	(0.005)	(0.290)		(0.007)	(0.403)	
MZM Growth	0.004	0.063	0.002	0.007	0.110	0.005
	(0.003)	(0.128)		(0.005)	(0.164)	
Term Premium	0.006	-0.037	0.000	0.018	-0.471	0.021
	(0.005)	(0.260)		(0.008)	(0.348)	
UK Variables						
Inflation	-0.001	0.471	0.025	-0.005	1.226	0.067
	(0.005)	(0.350)		(0.007)	(0.549)	
UK 3 Mo. T-bill rate	-0.013	0.211	0.064	-0.016	0.311	0.083
	(0.007)	(0.079)		(0.009)	(0.103)	

Notes : See appendix D for definitions of real excess returns in U.S. dollars and UK pounds. Standard errors in parentheses.

Table 12

Bid-ask Spread Matrix

ASIA : 10:00 pm to 3:00 am, New York time

Amounts (USD million)	EURUSD	USDJPY	GBPUSD	AUDUSD	NZDUSD	USDCHF	USDCAD	EURJPY	EURGBP	EURCHF	EURSEK	EURNOK
10	1	1	3	1	3	3	3	2	2	3	100	100
30	3	3	10	3	7	7	10	4	4	10	200	200
50	4	5	20	5	12	10	15	7	5	18	300	300
100	7	9	35	9	25	20	30	18	10	30	500	500
150	12	15		15	37	30		25	15			
200	18	20		20	50	40		35	20			
300	25	30		30				50	30			

EUROPE: from 3:00 am to 8:00 am, New York time

Amounts (USD million)	EURUSD	USDJPY	GBPUSD	AUDUSD	NZDUSD	USDCHF	USDCAD	EURJPY	EURGBP	EURCHF	EURSEK	EURNOK
10	1	2	3	2	5 to 7	3	3	3	1	2	25	25
30	2	3	5	4	12 to 15	5	7 to 8	4	2	3	40	50
50	3	4	8	5	25 to 30	7	12	5	3	4	75	100
100	4	8	12	10		12	20 to 25	10	6	7	100	200
150	7	10	15	15		20		15	8	10	200	300
200	10	15	20	25		30		20	10	12	250	
300	15	25	30	35		40		25	12	17	400	

NORTH AMERICA: from 8:00 am to 12 pm, New York Time

Amounts (USD million)	EURUSD	USDJPY	GBPUSD	AUDUSD	NZDUSD	USDCHF	USDCAD	EURJPY	EURGBP	EURCHF	EURSEK	EURNOK
10	1	2	3	2	7	3	3	3	1	2	25	25
30	2	3	5	4	15	7	5	4	2	3	40	50
50	3	4	8	5	30	10	12	5	3	4	75	100
100	4	8	12	12		15	20	10	6	7	100	200
150	7	10	15	15		20	25	15	8	10	200	300
200	10	15	20	25		30	40	20	10	12	250	
300	15	20	30	35		40	50	25	12	17	400	
400	20	30				50	70	35				
500	25	40				60	80	45				

NORTH AMERICA: from 12:00 pm to 2:00 pm, New York Time

Amounts (USD million)	EURUSD	USDJPY	GBPUSD	AUDUSD	NZDUSD	USDCHF	USDCAD	EURJPY	EURGBP	EURCHF	EURSEK	EURNOK
10		2	3	4	7	3	3	3	3	3	75	50
30		5	5	10	15	10	5	5	5	6	100	75
50		8	10	20	35	12	10	8	7	10	125	100
100		12	20	30		20	20	15	10	15	175	150
150		15	25	60		30	30	30	15	20		
200		20	30			40	45	40				
300		30	60			50	60	50				
400		45				60	70	55				
500		55				80	80	60				

TABLE 13

Effects of Price Pressure on Payoffs to Carry Trade Strategy

	Bet Size (millions pounds)		Profit per Pound Bet		
Individual country results	Mean	Standard Deviation	Mean	Standard Deviation	Sharpe Ratio
Belgium*	121	239	0.0031	0.0207	0.152
Canada	128	178	0.0041	0.0253	0.163
France*	218	339	0.0040	0.0231	0.172
Germany*	208	228	0.0014	0.0234	0.062
Italy*	283	442	0.0028	0.0228	0.124
Japan†	283	217	0.0031	0.0304	0.102
Netherlands*	141	156	0.0014	0.0224	0.062
Switzerland	263	272	0.0010	0.0261	0.040
USA	226	240	0.0032	0.0289	0.112
Euro‡	130	152	0.0024	0.0167	0.142
Portfolio with all currencies					
using b =0.0054	1340	1103	0.0127	0.0921	0.138
	(110)	(93)	(0.0059)	(0.0147)	(0.060)
using b =0.002	3618	2979	0.0127	0.0921	0.138
	(297)	(251)	(0.0059)	(0.0147)	(0.060)
using b =0.001	7236	5958	0.0127	0.0921	0.138
	(593)	(502)	(0.0059)	(0.0147)	(0.060)

* Euro legacy currencies available 76:1-98:12

† Japanese yen available 78:7-05:12

‡ Euro available 99:1-05:12

Notes : Individual country results use b =0.0054. Standard errors in parentheses.

TABLE A1

Mnemonics for Data Obtained from Datastream

Currency	Spot Exchange Rate	Forward Exchange Rate	Interest Rate
Belgian franc	BELGLUX	BELXF*n* F	ECBFR*n* M
Canadian dollar	CNDOLLR	CNDOL*n* F	ECCAD*n* M
French franc	FRENFRA	FRENF*n* F	ECFFR*n* M
German mark	DMARKER	DMARK*n* F	ECWGM*n* M
Italian lira	ITALIRE	ITALY*n* F	ECITL*n* M
Japanese yen	JAPAYEN	JAPYN*n* F	ECJAP*n* M
Netherlands guilder	GUILDER	GUILD*n* F	ECNLG*n* M
Swiss franc	SWISSFR	SWISF*n* F	ECSWF*n* M
UK pound	...	...	ECUKP*n* M
U.S. dollar	USDOLLR	USDOL*n* F	ECUSD*n* M
euro	BBEURSP	BBEUR*n* F	ECEUR*n* M

Notes : Here *n* indicates the number of months (either 1 or 3) forward in the case of the forward rate, and the term of the contract in the case of the eurocurrency interest rates. To obtain bid and ask (offer) quotes for the exchange rates the suffixes (EB) and (EO) are added to the mnemonic indicated. To obtain the average of bid and ask quotes the suffix (ER) is used. For the interest rates the equivalent suffixes are (IB), (IO) and (IR).

TABLE A2

Covered Interest Arbitrage at the 1-Month Horizon

Currency	Median return to borrowing covered in: Pounds (percent)	Median return to borrowing covered in: FX (percent)	Fraction of periods with positive returns to borrowing covered in: Pounds (percent)	Fraction of periods with positive returns to borrowing covered in: FX (percent)	Median of positive returns to borrowing covered in: Pounds (percent)	Median of positive returns to borrowing covered in: FX (percent)
			Full Sample			
Belgium	-0.21	-0.22	1.92	2.19	0.12	0.14
Canada	-0.11	-0.08	0.37	1.38	0.06	0.02
France	-0.14	-0.12	1.00	1.00	0.26	0.07
Germany	-0.23	-0.22	0.15	0.04	0.09	0.37
Italy	-0.16	-0.13	0.81	0.66	0.10	0.04
Japan	-0.26	-0.27	0.43	0.11	0.09	0.31
Netherlands	-0.30	-0.29	0.06	0.15	0.11	0.10
Switzerland	-0.32	-0.32	0.30	0.18	0.20	0.46
USA	-0.07	-0.07	0.72	0.67	0.01	0.11
Average	-0.20	-0.19	0.64	0.71	0.11	0.18
			1994:1-2005:1			
Belgium	-0.18	-0.19	2.07	2.76	0.05	0.05
Canada	-0.11	-0.09	0.48	1.00	0.12	0.01
France	-0.10	-0.10	0.92	0.61	0.22	0.05
Germany	-0.11	-0.11	0.31	0.08	0.14	0.28
Italy	-0.16	-0.13	0.31	0.23	0.07	0.21
Japan	-0.10	-0.12	0.83	0.24	0.19	0.31
Notes : Individua	-0.11	-0.11	0.23	0.08	0.11	0.20
Switzerland	-0.12	-0.12	0.42	0.31	0.17	0.17
USA	-0.05	-0.05	1.25	0.62	0.01	0.13
Average	-0.12	-0.12	0.76	0.66	0.12	0.16

FIGURE 1

Realized Nominal (GBP) Payoffs to Currency Speculation (12-month Moving Average), 1976–2005

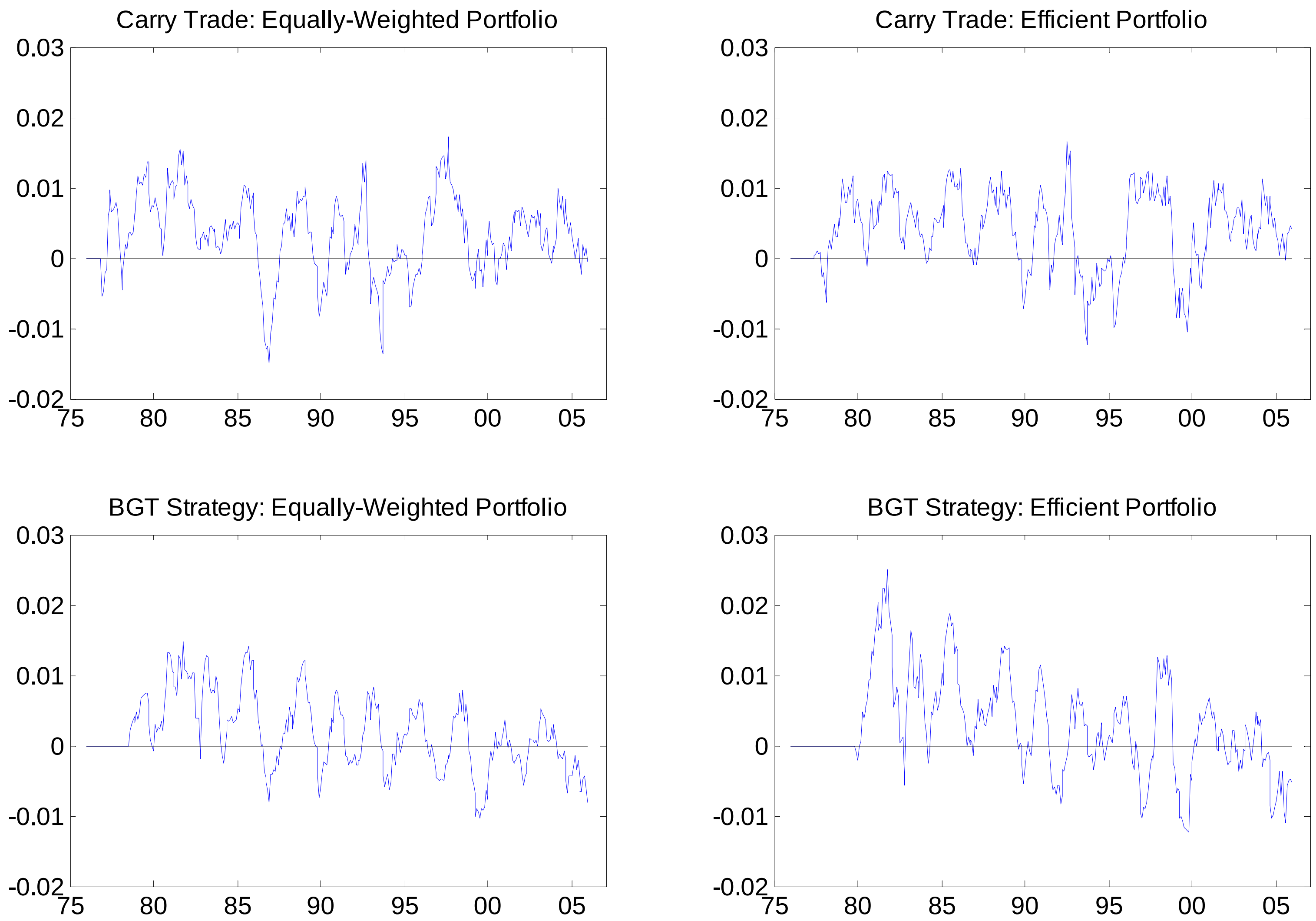


FIGURE 2

Cumulative Realized Nominal (USD) Returns to Currency Speculation (May 1977=1)

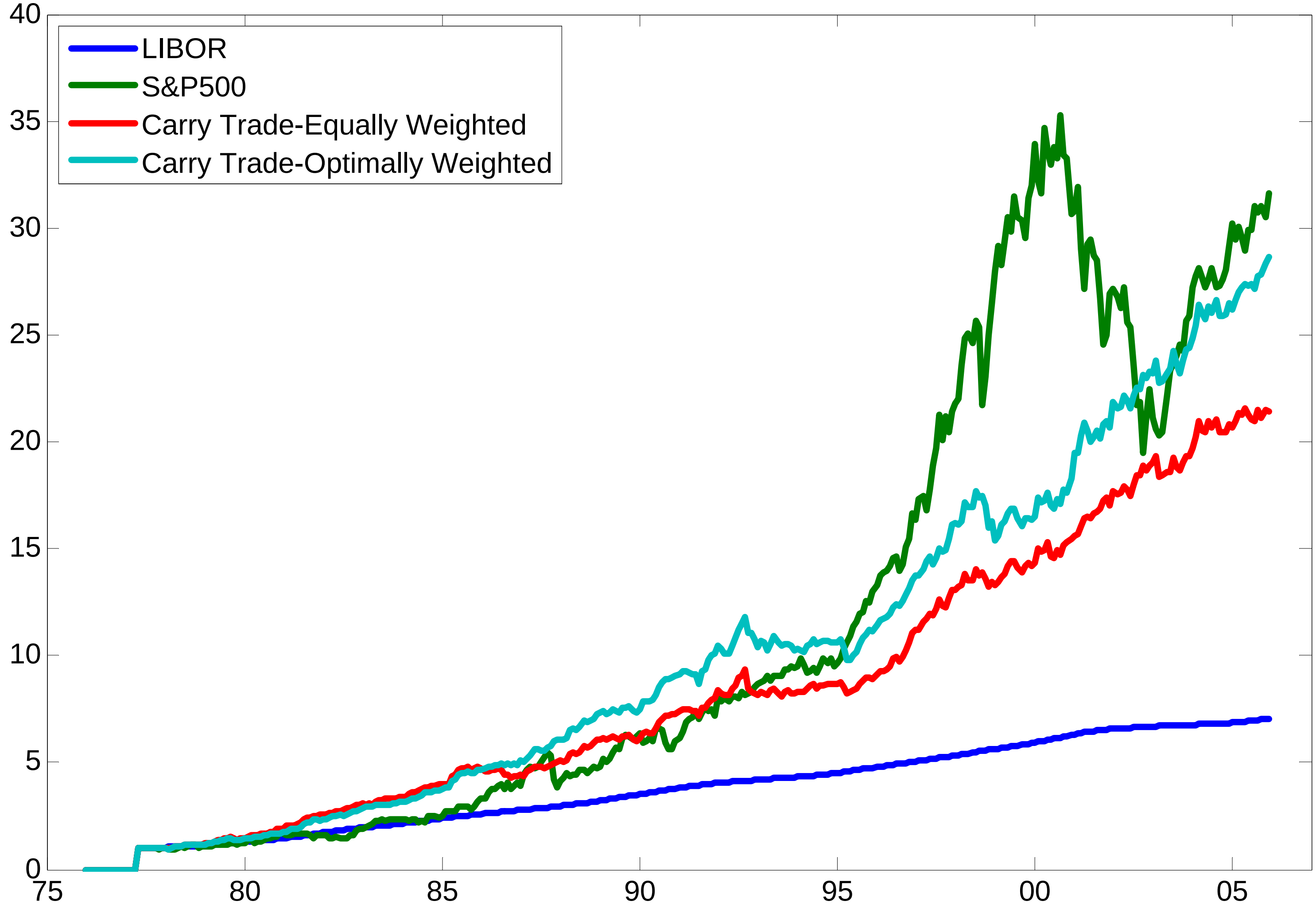


FIGURE 3

Cumulative Realized Nominal (USD) Returns to Currency Speculation (Nov. 1979=1)

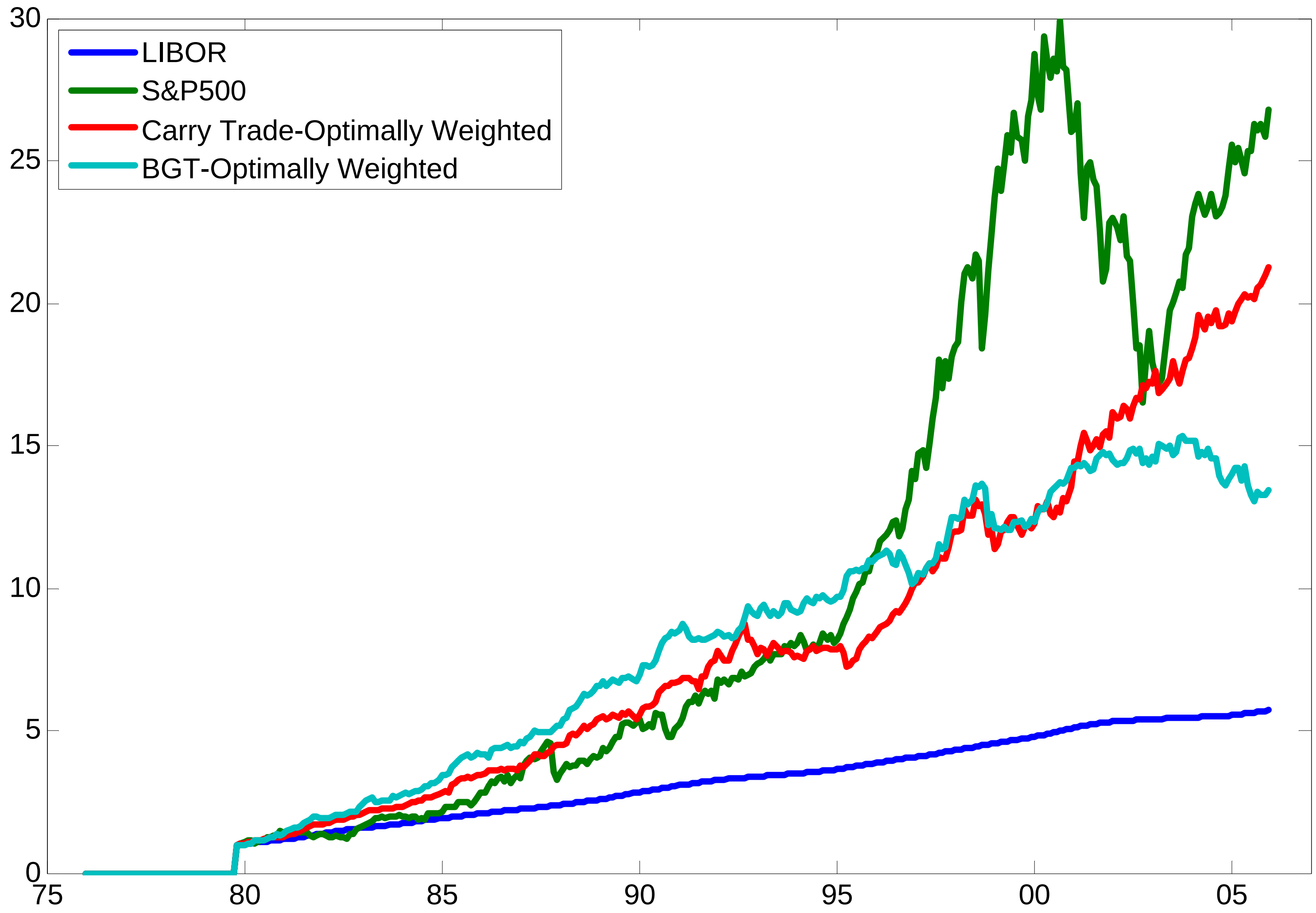


FIGURE 4

Realized Sharpe Ratio for Nominal (USD) Excess Returns (Three-Year Rolling Window)

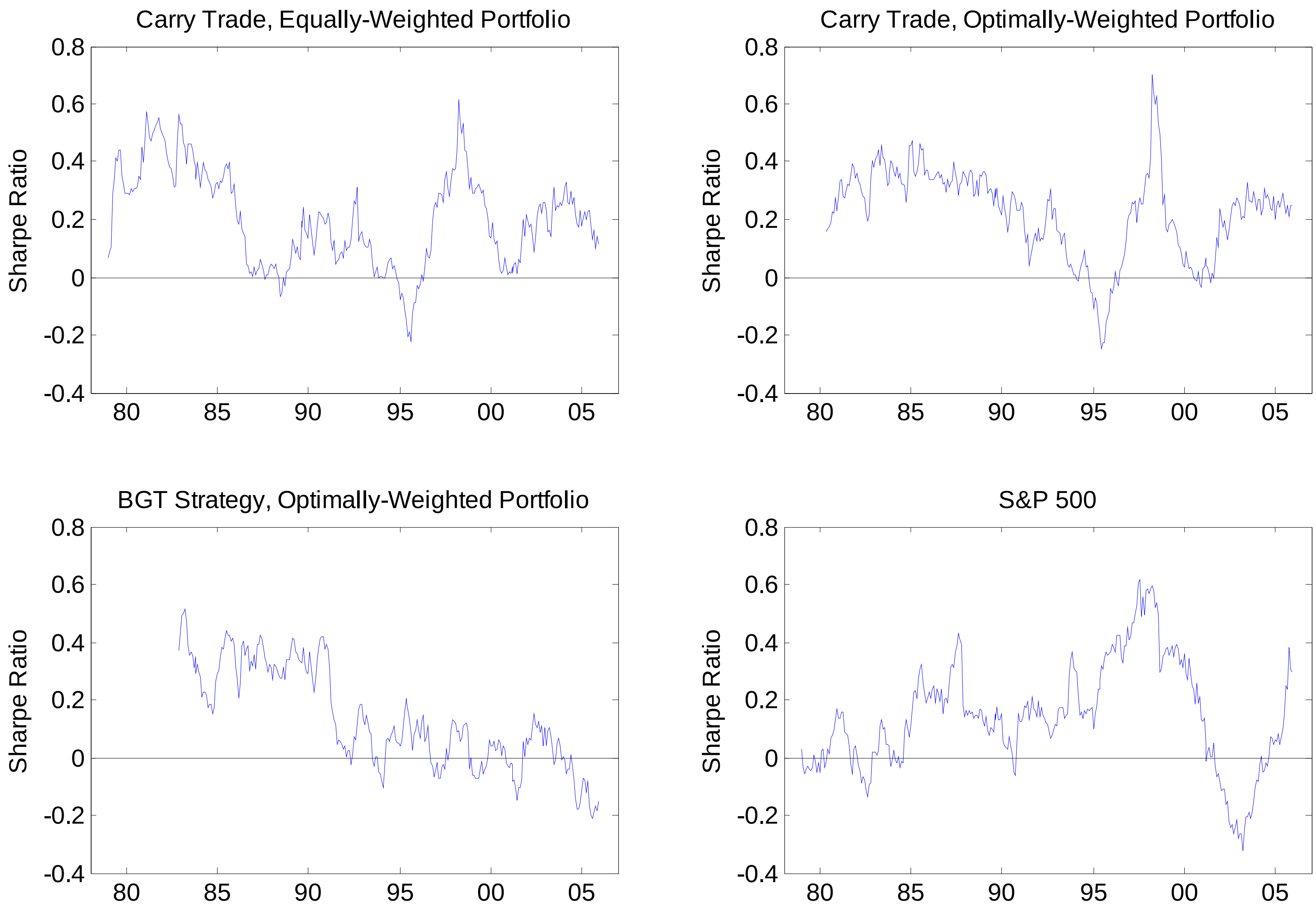
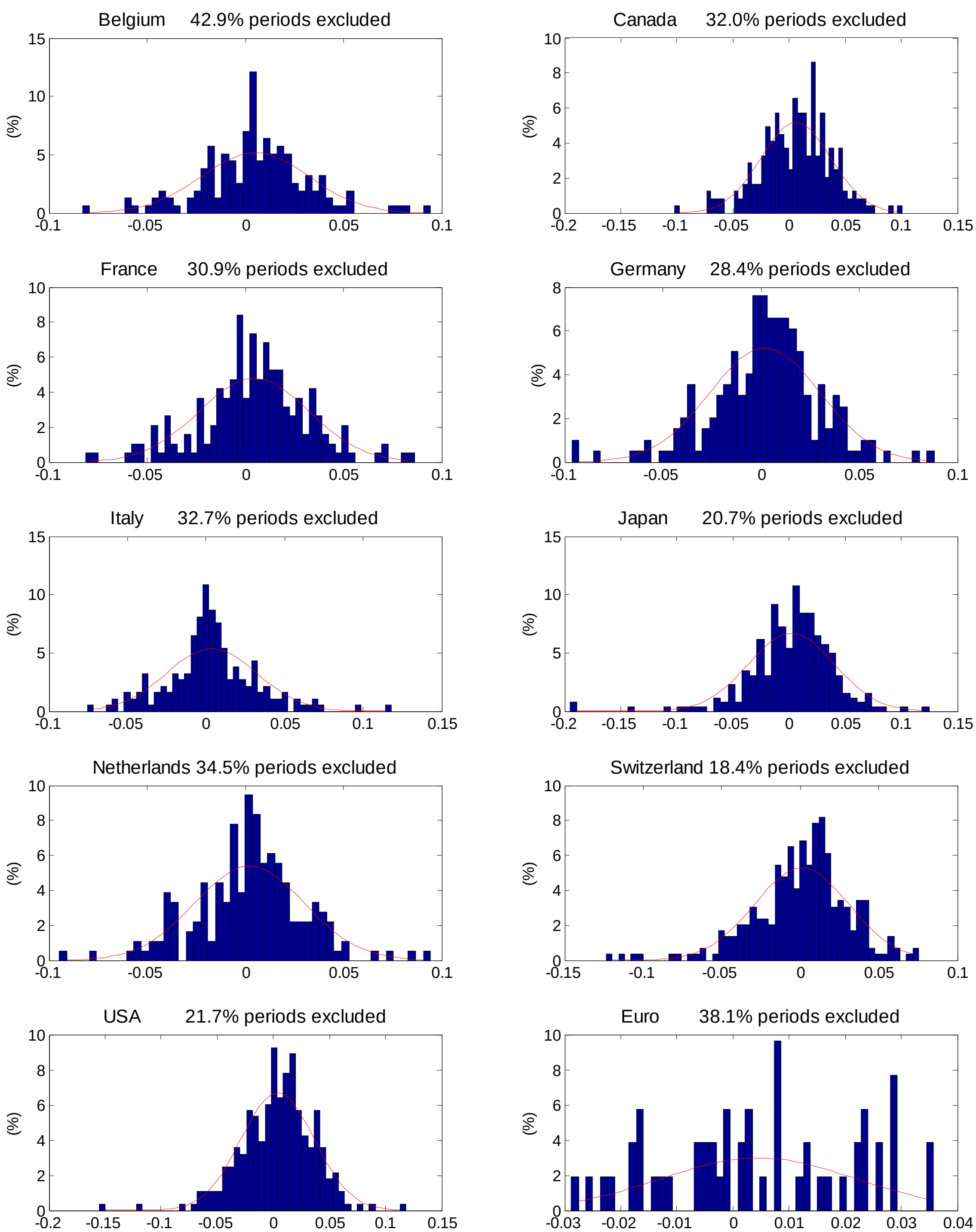


FIGURE 5

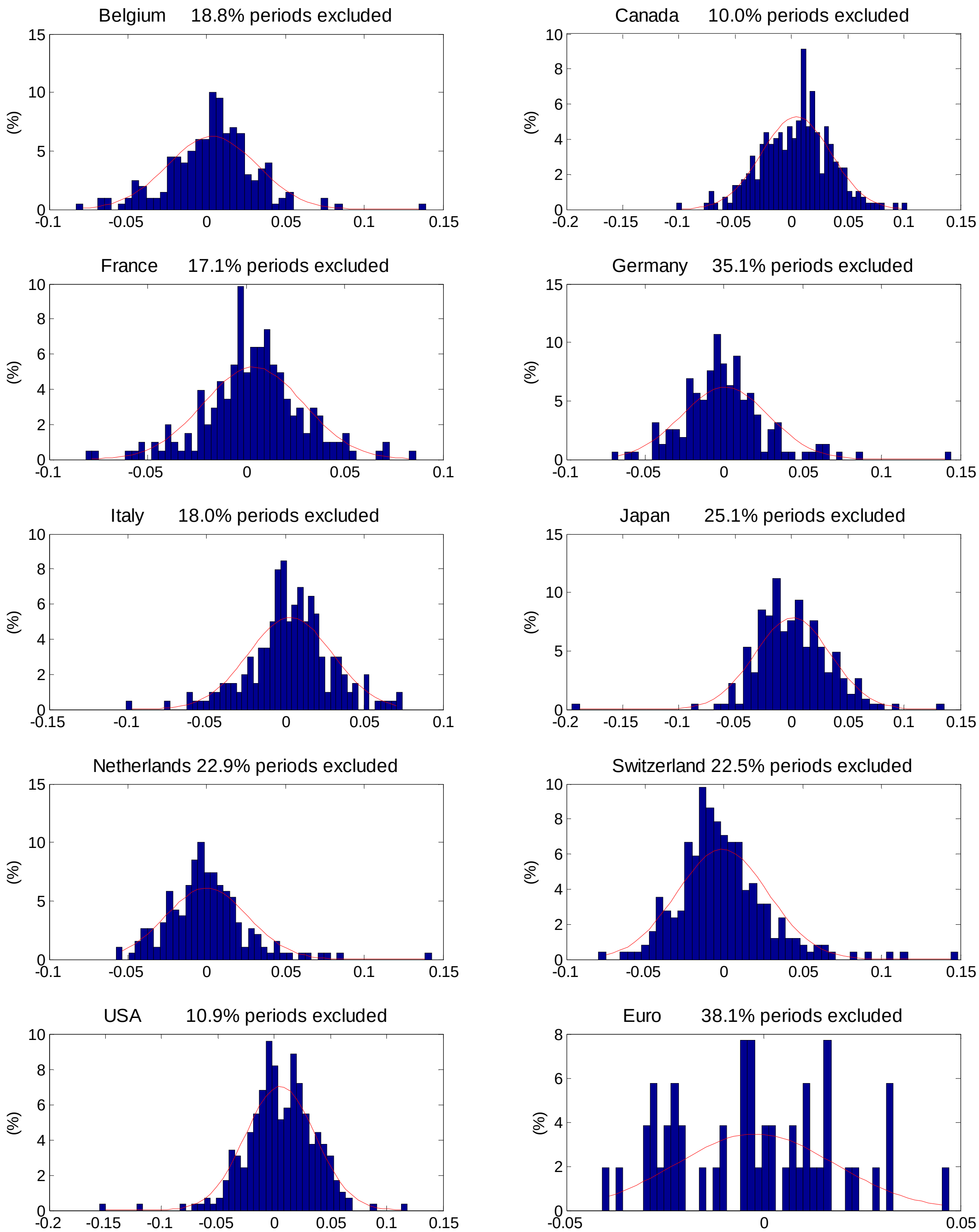
Sampling Distributions of the Payoffs to Carry Trade



Note: Periods of no trade excluded. The percentage of such periods is indicated in figure titles.

FIGURE 6

Sampling Distributions of the Payoffs to the BGT Strategy



Note: Periods of no trade excluded. The percentage of such periods is indicated in figure titles

FIGURE 7

Sampling Distributions of the Payoffs to Portfolios of Currency Speculation Strategies