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Risk-Premia, Carry-Trade Dynamics, and Speculative Efficiency of Currency Markets

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WORKING PAPER 143

Risk-Premia, Carry-Trade Dynamics, and Speculative Efficiency of Currency Markets

Christian Wagner

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Editorial

Foreign exchange market efficiency is commonly investigated by Fama-regression tests of uncovered interest parity (UIP). In this paper, the author conjectures a speculative UIP relationship which implies that exchange rate changes comprise a time-varying risk component in addition to the forward premium. This suggests that the forward premium anomaly reported in previous research potentially stems from omitting this component in UIP tests and that the popular carry-trade strategy can be rationalized to some extent. Moreover, while related work focuses on the Fama-regression slope coefficient, the author shows that also the intercept is important for judging the economic significance of currency speculation. Empirically, the author finds support for speculative UIP and the existence of a risk-premium. Furthermore, although carry-traders are able to collect some risk-premia, currency speculation does not yield economically significant excess returns, which suggests that foreign exchange markets are speculatively efficient. Disregarding the Fama-regression constant, however, leads to distortions in the assessment of economic significance and induces spurious rejection of speculative efficiency.

May 15, 2008

Risk-Premia, Carry-Trade Dynamics, and Speculative Efficiency of Currency Markets*

Christian Wagner[†]

Abstract

Foreign exchange market efficiency is commonly investigated by Fama-regression tests of uncovered interest parity (UIP). In this paper, we conjecture a speculative UIP relationship which implies that exchange rate changes comprise a time-varying risk component in addition to the forward premium. This suggests that the forward premium anomaly reported in previous research potentially stems from omitting this component in UIP tests and that the popular carry-trade strategy can be rationalized to some extent. Moreover, while related work focuses on the Fama-regression slope coefficient, we show that also the intercept is important for judging the economic significance of currency speculation. Empirically, we find support for speculative UIP and the existence of a risk-premium. Furthermore, although carry-traders are able to collect some risk-premia, currency speculation does not yield economically significant excess returns, which suggests that foreign exchange markets are speculatively efficient. Disregarding the Fama-regression constant, however, leads to distortions in the assessment of economic significance and induces spurious rejection of speculative efficiency.

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1 Introduction

Tests of foreign exchange market efficiency are typically based on an assessment of uncovered interest rate parity (UIP). UIP postulates that the expected change in a bilateral exchange rate is equal to the forward premium, i.e., given that covered interest rate parity holds, it compensates for the interest rate differential. However, empirical research provides evidence that the forward rate is a biased estimate of the future spot rate, finding that the higher interest rate currency tends to not depreciate as much as predicted by UIP or even appreciates. Attempts to explain the forward bias using, among others, risk premia, consumption-based asset pricing theories, and term-structure models have not been able to convincingly solve the puzzle yet. In a recent microstructural approach, Lyons (2001) argues that while the forward bias might be statistically significant, the failure of UIP might not be substantial in economic terms due to limits to speculation. Compared to other investment opportunities, the Sharpe ratios realizable from currency speculation are too small to attract traders' capital, who consequently leave the bias unexploited and persistent. The presumption that traders allocate capital only if Sharpe ratios exceed a certain threshold implies a range of trader inaction for smaller UIP deviations.

In this paper, we aim at testing the *speculative efficiency* of currency markets by assessing the *economic significance* of currency speculation profits. For this purpose, we take a two-step approach. First, we formulate *speculative* pendants to the standard UIP test to examine whether currency speculation yields non-zero profits. Second, we judge the *economic significance* of resulting Sharpe ratios via trader inaction ranges implied by limits to speculation. The trading strategies considered are a static trading approach, i.e. a permanent position in the foreign currency, and the carry-trade. The exchange rate dynamics implied by speculative UIP suggest that exchange rate changes comprise the forward premium and a time-varying risk component which depends on the deviation of the current forward premium from its long-run mean. The forward premium anomaly reported in previous research potentially stems from omitting this risk-premium in standard UIP tests. Furthermore, the carry-trade strategy can be rationalized to some extent in the presence of such a risk-premium. Throughout our analysis, we show

that, although related research focuses on the Fama-regression slope coefficient, the intercept is important for judging the economic significance of currency speculation and consequently the assessment of speculative efficiency.

Empirically, we find support for speculative UIP and the existence of a risk-premium, the omission of which results in the forward premium anomaly. Furthermore, although carry-traders are able to collect risk-premia to some extent, currency speculation does not yield economically significant excess returns as judged by trader inaction ranges. Thus, we conclude that foreign exchange markets are characterized by the preponderance of speculative efficiency. Disregarding the Fama-regression constant, however, leads to distortions in the assessment of economic significance and induces spurious rejection of speculative efficiency.

The remainder of this paper is organized as follows. We briefly review the related literature in section 2 and define our notion of speculative efficiency in section 3. In section 4 we derive the speculative pendants to the standard UIP test and describe the exchange rate dynamics implied by speculative UIP. We derive trader inaction ranges to judge economic significance in section 5. Empirical results are presented in section 6 and section 7 offers a conclusion. Appendix A provides technical details with respect to the derivation of trader inaction ranges, appendix B describes the procedure for testing whether inaction range bounds are over- or undershot.

2 Related Literature on UIP and Currency Speculation

A standard test of uncovered interest rate parity (UIP) is the ‘Fama-regression’,

$$\Delta s_{t+1} = \alpha + \beta p_t^1 + \varepsilon_{t+1} \tag{1}$$

where s_t denotes the logarithm of the spot exchange rate (domestic price of foreign currency) at time t , p_t^1 the one-period forward premium, i.e. $f_t^1 - s_t$ with f_t^1 being the logarithm of the one-period forward rate, and Δ a one-period change. The null hypothesis that UIP holds is represented by α being zero and β equalling unity. The common finding that empirical research over the last decades provided and concentrated on is that β is typically lower than unity and often negative. This indicates that the higher interest rate currency tends to not depreciate

as much as predicted by UIP or even appreciates, apparently allowing for predictable excess returns over UIP. Seminal articles in this area are Bilson (1981) and Fama (1984), surveys of the literature include Hodrick (1987), Froot and Thaler (1990), Taylor (1995), Engel (1996), Sarno and Taylor (2003).

From an economic perspective the statistical rejection of UIP might point at the existence of a risk premium or at market inefficiency. Attempts to explain the forward bias using models of risk premia, however, have met with limited success, especially for plausible degrees of risk aversion, see e.g. Cumby (1988), Hodrick (1989), and Bekaert et al. (1997). Moreover, research based on explanations such as learning, peso problems and bubbles, see e.g. Lewis (1995), consumption-based asset pricing theories, see e.g. Backus et al. (1993), Bekaert (1996), and term-structure models, see e.g. Backus et al. (2001), has not been able to convincingly explain the puzzle.

Based on the finding that order flow drives exchange rates, see e.g. Evans and Lyons (2002), Lyons (2001) suggests a microstructural approach building on institutional realities: Traders only allocate capital to currency speculation if they expect a higher Sharpe ratio than from other investment opportunities, i.e. some threshold in terms of the Sharpe ratio has to be exceeded.¹ Lyons (2001) argues that returns from currency speculation depend on how far β deviates from unity. For minor UIP deviations, Sharpe ratios are too small to attract speculative capital, thereby implying a range of trader inaction in the vicinity of UIP. Lyons (2001) states that β s around -1 or 3 are necessary to achieve a Sharpe ratio of 0.4, the long run performance of a buy-and-hold strategy in US equities. Accordingly, he suggests that a range of β -values between approximately -1 and 3 characterizes a trader inaction band, within which β might be statistically different from unity but without economic relevance; see Figure 1.

[Insert Figure 1 about here.]

While market evidence suggests that carry-trades, a popular trading strategy aimed at exploiting the forward bias, are used in practice, see e.g. Galati and Melvin (2004), recent academic research largely supports the existence of limits to speculation. Inspired by the concept of Lyons (2001), Sarno et al. (2006) and Baillie and Kiliç (2006) investigate the relationship between spot

¹Lyons (2001) stresses that speculative capital is allocated based on Sharpe ratios in practice. This empirical reality is important for his concept rather than a theoretical rationale for why such a behavior arises.

and forward rates in a smooth transition regression framework. Both report evidence for such a non-linear relationship, allowing for a time-varying forward bias. The empirical results indicate that UIP does not hold most of the time but (expected) deviations from UIP are economically insignificant, i.e. too small to attract speculative capital. Furthermore, Burnside et al. (2006) argue that transaction costs and price pressure limit the extent to which traders try to exploit the anomaly.

The aim of our paper is to investigate the speculative efficiency of foreign exchange markets by assessing the long-run dynamics of currency speculation and their economic significance.

3 Defining *Speculative Efficiency* of Currency Markets

Instead of investigating the efficiency of currency markets by standard UIP tests, we assess *speculative efficiency* for which we adopt the following definition:

DEFINITION: *The currency market is speculatively efficient if excess returns from currency speculation are not economically significant.*

We build on Lyons (2001) who argues that deviations of the Fama-regression β from its UIP-theoretic value may not be important in economic terms as long as deviations are too small to attract speculative capital. We extend his logic to the regression constant α and argue that for UIP in a *speculative* sense α and β do not always have to correspond to their standardly hypothesized values but rather that deviations of one or both might occur as long as these do not allow for economically significant profits.

By *economic significance* we mean that finding excess returns to be statistically different from zero, is not sufficient in economic terms. Profits can be strictly positive but still too small to attract capital. Traders compare currency speculation approaches to other investment opportunities, e.g. a buy-and-hold equity investment, and speculative capital would only be allocated to currency strategies offering a higher Sharpe ratio than other investments. Otherwise, no capital would be allocated, thus no order flow produced, and hence the bias be left unexploited and persistent, being visible statistically but without economic relevance.

To assess speculative efficiency, we therefore take a two-step approach. First, we formulate

speculative pendants to the standard UIP test, to examine whether currency speculation yields non-zero profits. If profits are statistically different from zero, we judge the *economic significance* of resulting Sharpe ratios via trader inaction ranges implied by limits to speculation.

4 Speculative UIP, Risk-Premia, and Dynamics of Speculation

Starting from a static trading approach, i.e. a permanent long (or short) position in the foreign currency, which can be viewed as a lower benchmark for speculative efficiency, we motivate a *speculative* UIP test on the Fama-regression. Subsequently, we present arguments suggesting that the traditional UIP regression suffers an omitted variable bias that stems from ignoring a time-varying risk premium. We propose a test for this risk-premium and outline the dynamics of excess returns from the static trading approach as well as the carry-trade.

4.1 Static Trading Approach: Risk-Premia and Excess Return Dynamics

Building on the argument of Lyons (2001) that traders use Sharpe ratios to evaluate the performance of their trading strategies, it is instructive to reparametrize the regression in equation (1) in terms of excess returns. Defining the excess return by the difference between the exchange rate return and the lagged premium, see e.g. Bilson (1981), Fama (1984), and Backus et al. (1993), Sarno et al. (2006), $ER_{t+1} \equiv \Delta s_{t+1} - p_t^1 \equiv s_{t+1} - f_t^1$, yields

$$ER_{t+1} = \alpha + (\beta - 1)p_t^1 + \varepsilon_{t+1}, \quad (2)$$

where ER_{t+1} corresponds to the payoff of a long forward position in the foreign currency entered at time t and maturing at $t+1$. Analogously, $-ER_{t+1}$ corresponds to a short position.² Market efficiency arguments suggest that in the long-run excess returns should be zero on average. Given that the domestic and the foreign interest rates are stationary, the forward premium reverts to a long-run mean which we denote by μ_p .³ The long-run average of excess returns,

²Equivalently, one could enter corresponding spot market and money market transactions.

³We consciously leave the issue of interest rate modeling outside the scope of this paper. For the purpose of motivating the subsequent arguments it is sufficient to build on the theoretical as well as empirical results of previous work that interest rates are mean reverting.

\overline{ER} , can then be written as

$$\overline{ER} = \alpha + (\beta - 1) \mu_p. \quad (3)$$

Note that, since the Fama-regression is usually estimated by OLS, by the least squares principle the average residual is zero because the regression includes a constant. The standard procedure to assess whether UIP holds is to test the restrictions $\alpha = 0$ and $\beta = 1$. Taking a speculative efficiency perspective, one notes that an average excess return of zero does not only result if α and β exactly correspond to these theoretical values but for any values that satisfy the less restrictive relationship $\alpha = -(\beta - 1)\mu_p$. Hence, both parameters might deviate from their hypothesized values but still not allow for a non-zero average excess return. In fact, this illustrates that if one of the parameters deviates from its theoretical value, the other one should do so as well such that the average excess return growing with the deviation of the one parameter is reduced by an opposing deviation of the other one. In our empirical analysis we formally test for the existence of such offsetting effects which is equivalent to testing whether average profits from static trading positions are zero. Since previous research usually reports tests on whether $\beta = 1$, we formulate our test in terms of β as well, proposing

TEST 1 (SPECULATIVE UIP TEST): *For the parameters of the Fama-regression (1), we test the hypothesis $\beta = 1 - \alpha/\mu_p$. If this restriction holds, offsetting effects between α and β exist and average excess returns from the static trading approach are zero.*

For the subsequent derivation we conjecture that the relationship $\beta = 1 - \alpha/\mu_p$ holds, i.e. we conjecture a minimum level of speculative efficiency. If the restriction would not hold, non-zero excess returns could be generated in the long-run just by taking a permanent long or short position in the foreign currency.⁴ Imposing the restriction on the Fama-regression (1) yields

$$\Delta s_{t+1} = \alpha - \alpha \frac{p_t^1}{\mu_p} + p_t^1 + \varepsilon_{t+1} \quad (4)$$

and rewriting the excess return equation (2) gives

$$ER_{t+1} = \alpha - \alpha \frac{p_t^1}{\mu_p} + \varepsilon_{t+1}. \quad (5)$$

⁴This would imply an even more severe violation of market efficiency as documented so far and is also not in line with market evidence, thus, we feel safe that our conjecture is reasonable.

The spot rate dynamics as given in (4) can be described as follows: the core movement in the change of the exchange rate corresponds just to the forward premium, p_t^1 , as postulated by UIP. Additionally, Δs_{t+1} is driven by a constant term, α , and a component, $-\alpha \frac{p_t^1}{\mu_p}$, that is governed by the extent to which the forward premium at t deviates from its long-run mean. Hence, our dynamics suggest that temporary deviations from UIP are possible, but in the long-run reversion towards the parity condition occurs. Such a specification is consistent with other modeling approaches that capture the stylized facts of exchange rates well; for instance vector error correction models, see e.g. Brenner and Kroner (1995) and Zivot (2000), and smooth transition regression frameworks recently applied by Baillie and Kiliç (2006) and Sarno et al. (2006). In this context, α plays a role in determining the reversion to long-run UIP. Defining $\bar{\alpha} = \alpha/\mu_p$ we can rewrite equations (4) and (5) as

$$\begin{aligned}\Delta s_{t+1} &= \bar{\alpha} (\mu_p - p_t^1) + p_t^1 + \varepsilon_{t+1}, \\ ER_{t+1} &= \bar{\alpha} (\mu_p - p_t^1) + \varepsilon_{t+1}\end{aligned}\tag{6}$$

where $\bar{\alpha}$ should be positive, i.e. α should have the same sign as μ_p , to ensure convergence to long-run UIP. This, however, suggests that over shorter horizons deviations from UIP occur and that excess returns represent a time-varying risk-premium.

Given that the exchange rate process is indeed governed as represented in (4), estimating the Fama-regression (1) leads to a biased estimate of β due to the omission of $-\alpha \frac{p_t^1}{\mu_p}$:

$$\begin{aligned}E[\beta] &= \beta^{UIP} - \alpha \left\{ \frac{\text{cov}[p_t^1; p_t^1/\mu_p]}{\sigma_p^2} \right\} \\ &= 1 - \alpha \left\{ \frac{1}{\mu_p} \right\}.\end{aligned}\tag{7}$$

As argued above for equation (6), α and μ_p should have the same sign to ensure a proper reversion towards long-run UIP. This suggests that the slope coefficient in the Fama-regression will be biased downwards from its theoretical UIP value, $\beta^{UIP} = 1$, which is consistent with empirical research documenting the forward premium anomaly. Hence, our results contribute to the literature attempting to explain the puzzle by recourse to risk-premium arguments, for a survey see e.g. Engel (1996), and are in line with research suggesting that standard UIP tests may be non-informative in the presence of an omitted risk-premium, see e.g. Barnhart

et al. (1999). Our empirical analysis is based on equation (5) for which we present unrestricted estimates as given by

$$ER_{t+1} = \alpha_1 + \alpha_2 \frac{p_t^1}{\mu_p} + \varepsilon_{t+1}. \quad (8)$$

The attempt to explain the forward premium puzzle by recourse to risk-premium arguments is supported if α_2 is significantly different from zero and if one cannot reject that $\alpha_1 = -\alpha_2$; note that the later is already ensured if one finds evidence for offsetting effects between α and β . Accordingly, we formulate

TEST 2 (RISK-PREMIUM TEST): *For the parameters of regression (8), we test the hypotheses $\alpha_2 = 0$ and $\alpha_1 = -\alpha_2$. If the former restriction is rejected and the latter holds, a non-zero risk-premium exists.*

If a non-zero-risk premium exists and the relationship between α and β conjectured above holds, i.e. equivalently $\alpha_1 = \alpha_2$, the long-run dynamics of excess returns from the static trading approach can be described by enumerating all possible scenarios. Although we provided a rationale above that we expect $\beta < 1$ in the long-run, we also present scenarios where $\beta > 1$ since we refer to these scenarios in the next subsection. Overall, the excess return process can then be summarized in 12 scenarios which depend on the sign of μ_p , the relation between p_t^1 and μ_p and the combination of β and α values:

$\mu_p > 0$			
	$\beta < 1, \alpha > 0$	$\beta > 1, \alpha < 0$	
$0 < \mu_p < p_t^1$	$ER_{t+1} < 0$	$ER_{t+1} > 0$	[1a, 1b]
$0 < p_t^1 < \mu_p$	$ER_{t+1} > 0$	$ER_{t+1} < 0$	[2a, 2b]
$p_t^1 < 0 < \mu_p$	$ER_{t+1} > 0$	$ER_{t+1} < 0$	[3a, 3b]
$\mu_p < 0$			
	$\beta < 1, \alpha < 0$	$\beta > 1, \alpha > 0$	
$\mu_p < 0 < p_t^1$	$ER_{t+1} < 0$	$ER_{t+1} > 0$	[4a, 4b]
$\mu_p < p_t^1 < 0$	$ER_{t+1} < 0$	$ER_{t+1} > 0$	[5a, 5b]
$p_t^1 < \mu_p < 0$	$ER_{t+1} > 0$	$ER_{t+1} < 0$	[6a, 6b]

An optimal speculation strategy would take long and short positions such as to always realize positive excess returns. However, such a strategy would require to have perfect knowledge or

foresight of μ_p and the combination of α and β ; for the latter we already motivated above that scenarios 1a to 6a are relevant.⁵ In practice, market participants often use rules like the carry-trade described in the next subsection.

4.2 Exploiting the Forward Bias: Carry-Trade

Empirical evidence reports that the Fama- β is typically less than unity and often negative. ‘Carry-trade’ strategies attempting to exploit this forward bias, take a long position in the higher interest rate currency, financed by a short position in the low interest rate currency and are popular among market participants; see e.g. Galati and Melvin (2004).

The excess return from a bilateral carry-trade can be written in terms of ER_{t+1} introduced in (2): one would sell forward the foreign currency at time t if $p_t^1 > 0$ and realize a payoff of $-ER_{t+1}$ at $t + 1$; a long position is entered if $p_t^1 < 0$, yielding a payoff of ER_{t+1} :

$$CT_{t+1} = \begin{cases} ER_{t+1} = \alpha + (\beta - 1)p_t^1 + \varepsilon_{t+1} & \text{if } p_t^1 < 0, \\ -ER_{t+1} = -\alpha - (\beta - 1)p_t^1 - \varepsilon_{t+1} & \text{if } p_t^1 > 0. \end{cases} \quad (10)$$

It is instructive to reconcile this representation of carry-trade profits with the excess return dynamics of the static trading approach outlined in the previous section. Given that the conjectured relationship of offsetting effects between α and β exist, the long-run dynamics of carry-trade profits can be summarized as follows:

$\mu_p > 0$					
	$\beta < 1, \alpha > 0$		$\beta > 1, \alpha < 0$		
$0 < \mu_p < p_t^1$	$ER_{t+1} < 0$	$CT_{t+1} > 0$	$ER_{t+1} > 0$	$CT_{t+1} < 0$	[1a, 1b]
$0 < p_t^1 < \mu_p$	$ER_{t+1} > 0$	$CT_{t+1} < 0$	$ER_{t+1} < 0$	$CT_{t+1} > 0$	[2a, 2b]
$p_t^1 < 0 < \mu_p$	$ER_{t+1} > 0$	$CT_{t+1} > 0$	$ER_{t+1} < 0$	$CT_{t+1} < 0$	[3a, 3b]
$\mu_p < 0$					
	$\beta < 1, \alpha < 0$		$\beta > 1, \alpha > 0$		
$\mu_p < 0 < p_t^1$	$ER_{t+1} < 0$	$CT_{t+1} > 0$	$ER_{t+1} > 0$	$CT_{t+1} < 0$	[4a, 4b]
$\mu_p < p_t^1 < 0$	$ER_{t+1} < 0$	$CT_{t+1} < 0$	$ER_{t+1} > 0$	$CT_{t+1} > 0$	[5a, 5b]
$p_t^1 < \mu_p < 0$	$ER_{t+1} > 0$	$CT_{t+1} > 0$	$ER_{t+1} < 0$	$CT_{t+1} < 0$	[6a, 6b]

(11)

⁵A better performance based on information of (long-run / future) forward premia is consistent with evidence that exchange rate forecasting can be improved with approaches that incorporate the term structure of forward premia, see e.g. Clarida et al. (2003).

Although carry-trades are designed to profit from β less than unity, positive excess returns only emerge in four out of six scenarios where $\beta < 1$. While in scenarios 2a and 5a a loss is incurred although $\beta < 1$, carry-trades result in profits in situations when $\beta > 1$ in scenarios 2b and 5b. We discuss the pitfalls of exclusively focusing on β and neglecting offsetting effects of α in the next subsection. Since we motivated in the previous subsection that β should be less than unity, the carry-trade can be viewed as a proxy of the perfect foresight strategy based on the assumption that $\mu_p = 0$. Under this assumption the scenarios 2a and 5a do not exist and the carry-trade could be rationalized.

In order to formulate a test of zero-profitability of carry-trades we rewrite equation (10). Since the sign of the position taken in the foreign currency is opposite to the sign of the forward premium, i.e. long if $p_t^1 < 0$ respectively short if $p_t^1 > 0$, we adjust the parameters and residuals of the Fama-regression. To indicate that a component i of the regression is adjusted for the position taken, we use superscript $'$, with $i' = -\text{sgn}[p_t^1] i$. Hence, the excess return from the carry-trade can be written as

$$\begin{aligned} CT_{t+1} &= ER'_{t+1} = \alpha' + (\beta - 1) (p_t^1)' + \varepsilon'_{t+1}, \\ \overline{CT} &= \overline{\alpha'} + (\beta - 1) \overline{p'} + \overline{\varepsilon'}. \end{aligned} \tag{12}$$

Note that, if over the investigated period the sign of the premium changes at least once, α' is not a constant and the mean of ε'_{t+1} is non-zero. Therefore, the means of α' , $(p_t^1)'$, and ε'_{t+1} are components of the average carry-trade excess return, \overline{CT} . Excess returns from the carry-trade are not significantly different from zero if the restriction $\beta = 1 - (\overline{\alpha'} + \overline{\varepsilon'})/\overline{p'}$ holds on the parameters in regression (1).

TEST 3 (CARRY-TRADE ZERO PROFIT TEST): *For the parameters of the Fama-regression (1), we test the hypothesis $\beta = 1 - (\overline{\alpha'} + \overline{\varepsilon'})/\overline{p'}$. If this restriction holds, average excess returns from the carry-trade are zero.*

4.3 The Pitfalls of Exclusively Focusing on β

The Fama-regression (1) assesses market efficiency as a joint test of rational expectations and risk-neutrality. While rational expectations imply that $\beta = 1$ and that the forecast error (ε_{t+1})

is uncorrelated with information at t , risk-neutrality suggests that $\alpha = 0$. A non-zero α would represent a constant risk-premium. Hundreds of studies have estimated the Fama-regression for different exchange rates and sample periods with the focus of discussion always directed towards β . Although the results in the literature exhibit mixed evidence of whether α is significantly different from zero or not, we are not aware of a paper that investigates the role of the constant in more detail or provides an interpretation for the estimates of α .

Our motivation for speculative UIP in section 4.1 suggests that one should look beyond the question of whether the slope coefficient equals unity and also consider the intercept. By relying on speculative efficiency arguments we suggest that offsetting effects between α and β exist and to test whether $\beta = 1 - \alpha/\mu_p$ which corresponds to zero-profits from static trading positions in the foreign currency. Given that the hypothesized offsetting effects exist, exclusively focusing on β leads to misestimation of profits generable from static foreign currency positions: excess returns, ER , will be overestimated (in absolute terms) due to neglecting the offsetting effect by α .

Analogously, the assessment of carry-trade profitability might be spurious if the null of the speculative UIP test holds. If - as expected by carry-traders - $\beta < 1$, the following can be said for \overline{CT} : since $\mu'_p < 0$ it follows from $\beta < 1$ that $(\beta - 1)\mu'_p > 0$ but also that $\overline{\alpha'} < 0$, again highlighting the offsetting effects. Thus, one generates profits from β being lower than unity, but profits are eroded by the constant, sometimes even leading to a loss despite $\beta < 1$ (scenarios 2a and 5a). If $\beta > 1$ the reverse is true, but it is not necessarily the case that one makes a loss even though the strategy is motivated by trading on a $\beta < 1$ (scenarios 2b and 5b). Considering β only, may lead to a spurious appraisal of carry-trade profitability and in particular to an overestimation of profits if $\beta < 1$.

In general, disregarding α distorts the assessment of zero-profitability of currency speculation. Consequently, as shown in the next section, also the judgment of economic significance based on trader inaction ranges will be distorted which may lead to wrong conclusions about speculative efficiency.

5 Assessment of Economic Significance: Derivation of Trader Inaction Ranges

To assess the economic significance of excess returns we derive trader inaction ranges implied by limits to speculation. First we directly follow Lyons (2001), subsequently we derive the inaction range bounds for the static trading approach and the carry-trade. We show for both speculation strategies that disregarding α may lead to a spurious assessment of speculative efficiency.

5.1 Inaction Range as Motivated by Lyons (2001)

In this subsection we derive the trader inaction range following the verbal description of Lyons (2001), suggesting that excess returns and hence Sharpe ratios realizable from UIP deviations solely depend on β ; he does neither consider the effect of α on excess returns nor the impact of β on the standard deviation of profits. For a given forward premium, Sharpe ratios increase as β deviates from unity. Traders only allocate speculative capital to currency strategies if Sharpe ratios exceed a certain threshold (as e.g. given by the long run performance of a buy-and-hold equity investment), implying that β needs to deviate correspondingly far from unity to generate order flow. This logic suggests a range of trader inaction for β s close to unity while capital could only be attracted if β over- respectively undershoots the bounds of this range. In the following, we derive the inaction range bounds; some technical details are provided in appendix A.1.

Based on the excess return defined in equation (2), we present the Sharpe ratio and the corresponding trader inaction range only considering β but disregarding α , i.e. presuming $\alpha = 0$. However, we account for β when calculating the standard deviation of ER_{t+1} . The variance of excess returns is given by

$$\sigma_{ER}^2 = (\beta - 1)^2 \sigma_p^2 + \sigma_\varepsilon^2 + 2(\beta - 1) \text{cov}_{p,\varepsilon} \quad (13)$$

with σ denoting the standard deviations and $\text{cov}_{p,\varepsilon}$ the covariance of p and ε . If the Fama-regression parameters are estimated by OLS, the residuals are orthogonal to the premium by assumption, i.e. $\text{cov}_{p,\varepsilon} = 0$. Setting $\alpha = 0$ and combining equations (2) and (13), the Sharpe

ratio can be written as

$$SR^{ER,\alpha=0} = \frac{(\beta - 1)\mu_p}{\sqrt{(\beta - 1)^2\sigma_p^2 + \sigma_\varepsilon^2}}. \quad (14)$$

The numerator changes in proportion to μ_p as β deviates from unity. However, β also enters the denominator and the standard deviation increases as β deviates from unity. Thus, for increasing deviations of β , the Sharpe ratio changes monotonically but only at a decreasing rate, and therefore, from a pure mathematical point of view, one could say that speculation is limited since the Sharpe ratio is bounded. It is an empirical matter whether the limiting Sharpe ratios as well as the associated β s are economically reasonable.

From equation (14) one can derive the trader inaction range in terms of β , i.e. the β s necessary to achieve a certain Sharpe ratio threshold, SR_{th} , by rearranging and solving the resulting quadratic equation,

$$\beta [SR_{th}, \alpha = 0] = \frac{\pm SR_{th}\sigma_\varepsilon}{\sqrt{(\mu_p^2 - SR_{th}^2\sigma_p^2)}} + 1. \quad (15)$$

The β for which the Sharpe ratio is zero, the center of the inaction range, $\beta^c[0, \alpha = 0]$, is unity and therefore corresponds to the standardly hypothesized UIP value. Around this center, the upper and lower bound are symmetric, as suggested by Lyons (2001), with the width of the range increasing overproportionally with the Sharpe ratio threshold. Note that for very small $|\mu_p|$ extremely large Sharpe ratio thresholds may be necessary to define the bounds, or put differently, a given SR_{th} might be unreachable high.

5.2 Inaction Range for the Static Trading Approach

We now take the impact of α on excess returns explicitly into account as given in equation (2). Some technical details are provided in appendix A.2. The standard deviation can be taken from equation (13) since α as a constant has no impact on the variance. The Sharpe ratio therefore is

$$SR^{ER} = \frac{\alpha + (\beta - 1)\bar{p}}{\sqrt{(\beta - 1)^2\sigma_p^2 + \sigma_\varepsilon^2}}. \quad (16)$$

Compared to presuming $\alpha = 0$, a non-zero α affects the Sharpe ratio by a change proportional to the standard deviation. Given that offsetting effects between α and $(\beta - 1)\mu_p$ exist, the

Sharpe ratios implied by equation (16) will be lower than those from equation (14) where α was set to zero. Furthermore, the Sharpe ratio is not a monotonic function of β anymore; while the Sharpe ratio is still bounded (with the same limits), the Sharpe ratio does not converge to its extremes with β approaching plus or minus infinity, rather the global optimum occurs when $\beta = (\mu_p \sigma_\varepsilon) / (\alpha \sigma_p) + 1$.

For a given Sharpe ratio threshold, SR_{th} , the respective β -bounds of the inaction range can be calculated from rearranging equation (16) and solving the resulting quadratic equation. The bounds are given by

$$\beta [SR_{th}, \alpha] = \frac{-\alpha \mu_p \pm SR_{th} \sqrt{\alpha^2 \sigma_p^2 + \sigma_\varepsilon^2 (\mu_p^2 - SR_{th}^2 \sigma_p^2)}}{\mu_p^2 - SR_{th}^2 \sigma_p^2} + 1. \quad (17)$$

The center of the inaction range, i.e. the β resulting in a Sharpe ratio of zero, corresponds to the β -value hypothesized in the speculative UIP test (Test 1) assessing the profitability of static foreign currency positions: $\beta^c[0, \alpha] = 1 - \alpha / \mu_p$. Hence, for non-zero values of α , the inaction range is not centered around unity and, furthermore, the bounds are not symmetric around $\beta^c[0, \alpha]$. There might also be situations in which the Sharpe ratio threshold is unreachable high, resulting in the inaction range to be undefined.

Comparing the bounds derived with $\alpha = 0$ to those derived using the Fama- α , a misinterpretation of economic significance might arise due to the fact that the former differ from the latter in terms of the level of the inaction range (different centers) as well with respect to its shape (symmetric vs. asymmetric). Accordingly, we formulate the following prediction.

PREDICTION 1: *Disregarding α leads to an overestimation of excess returns and consequently to inaccurate trader inaction ranges for the static trading approach. If offsetting effects between α and β exist (Test 1), speculative efficiency might be spuriously rejected.*

5.3 Inaction Range for the Carry-Trade

The excess return from the carry-trade was presented in equation (12), the corresponding variance is given by

$$\sigma_{CT}^2 = \sigma_{\alpha'}^2 + (\beta - 1)^2 \sigma_{p'}^2 + \sigma_{\varepsilon'}^2 + 2(\beta - 1)\text{cov}_{\alpha',p'} + 2\text{cov}_{\alpha',\varepsilon'} + 2(\beta - 1)\text{cov}_{p',\varepsilon'}. \quad (18)$$

Note that if the sign of the premium changes at least once, α' is not a constant and therefore also affects the standard deviation of carry-trade returns. Furthermore, the covariances can be different from, although will typically be close to, zero. The Sharpe ratio of the carry-trade is given by $SR^{CT} = \overline{CT}/\sigma_{CT}$.

The bounds of the carry-trade inaction range for a given Sharpe ratio threshold can be calculated from rearranging SR^{CT} and solving the following quadratic equation:

$$\begin{aligned} & (\beta - 1)^2 \left\{ \overline{p'}^2 - SR_{th}^2 \sigma_{p'}^2 \right\} + (\beta - 1) \left\{ 2 \left(\overline{\alpha'p'} + \overline{p'\varepsilon'} - SR_{th}^2 (\text{cov}_{\alpha',p'} + \text{cov}_{p',\varepsilon'}) \right) \right\} \\ & + \left\{ \overline{\alpha'}^2 + \overline{\varepsilon'}^2 + 2\overline{\alpha'\varepsilon'} - SR_{th}^2 (\sigma_{\alpha'}^2 + \sigma_{\varepsilon'}^2 + 2\text{cov}_{\alpha',\varepsilon'}) \right\}. \end{aligned} \quad (19)$$

The center of the inaction range is given by $\beta^c [0, \alpha] = 1 - (\overline{\alpha'} + \overline{\varepsilon'})/\overline{p'}$, corresponding to the value hypothesized in Test 3 for assessing whether the carry-trade yields non-zero profits. Note that the center of the range can be different from unity even if $\alpha = 0$. Analogously to the inaction range derived for the static approach, the bounds can be asymmetric.

Disregarding α by presuming the constant, and thereby also the corresponding covariances, to be zero, again affects the judgement of economic significance and hence the assessment of speculative efficiency. The centers of the respective inaction ranges differ by $\beta^c[0, \alpha] - \beta^c[0, \alpha = 0] = -\overline{\alpha'}/\overline{p'}$. If offsetting effects between α and $(\beta - 1)\mu_p$ exist, one finds that $\beta^c[0, \alpha] < \beta^c[0, \alpha = 0]$ if $\beta < 1$ and $\beta^c[0, \alpha] > \beta^c[0, \alpha = 0]$ if $\beta > 1$. Given previous empirical evidence that β is typically less than unity, neglecting α potentially results in an inaction range on a too high level and spurious indication of economic significance. Based on these arguments we state the following prediction.

PREDICTION 2: *If $\beta < 1$, disregarding α leads to an overestimation of carry-trade profits and consequently to inaccurate trader inaction ranges. If offsetting effects between α and β exist (Test 1), speculative efficiency might be spuriously rejected.*

6 Empirical Analysis

For our empirical analysis we use monthly spot exchange rates and one-month forward premia provided by the Bank for International Settlements. The exchange rates considered are the US Dollar versus the Canadian Dollar (CAD), Swiss Franc (CHF), British Pound (GBP), Japanese Yen (JPY), Danish Krone (DKK), and German Mark (DEM). For the DEM the time series covers the period from December 1978 to December 1998, for all other currencies September 1977 to December 2005.

6.1 Results

The first rows of Table 1 display the results of the Fama-regression (1) as commonly reported in previous literature; α and β are the parameter estimates with corresponding standard errors in parentheses. Consistent with previous research, all estimates of β are negative. Standard tests do not support UIP as they reject (at least at the 5 percent level) the hypotheses $\alpha = 0$ for three out of five currencies, $\beta = 1$ for all currencies, and the joint hypothesis also for all currencies. In contrast, Test 1, $\beta = 1 - \alpha/\mu_p$, to assess whether UIP holds in a speculative sense, does not reject UIP in a single case. This indicates that the hypothesized offsetting relationship between α and β exists.

The existence of these offsetting effects forms the basis for our spot rate process as given in equation (4). The underlying exchange rate dynamics allow for time-varying deviations from UIP and are consistent with modeling approaches that capture the stylized facts of exchange rates such as vector error correction models or smooth transition regression models; for the former see e.g. Brenner and Kroner (1995) and Zivot (2000), for the latter see e.g. Baillie and Kiliç (2006) and Sarno et al. (2006). Our results suggest the existence of a premium (Test 2) for deviations of the current forward premium from its long-run mean which supports the standard - yet, however, rather unsuccessful - argument that forward premium anomaly stems from the omission of a risk-premium in the Fama-regression.

Assessing the profitability of carry-trade excess returns as proposed in Test 3, reveals mixed evidence: excess returns are significantly different from zero for CAD and GBP while not so for the CHF, JPY, and DEM.

[Insert Table 1 about here.]

The existence of offsetting effects between α and β , as supported by the results of Test 1, allows to illustrate the dynamics of excess returns from the static trading approach (*ER*) and the carry-trade (*CT*) by enumerating all possible scenarios which depend on the sign of μ_p , the relation between p_t^1 and μ_p and the combination of β and α values; see sections 4.1 4.2. Since the Fama- β estimates are below unity for all currencies, only scenarios 1a to 6a are relevant. For the static trading approach, Panel A of Table 2 lists the predicted signs of excess returns for each scenario in the first column and reports the corresponding realizations in the remaining columns. The results show that the excess returns are signed as predicted. Furthermore, Panel A reports the performance of a static long position in the foreign currency as well as corresponding results for the perfect foresight strategy i.e. the performance if one had knowledge about μ_p and the combination of α and β and could therefore perfectly predict the next period scenario. Interestingly, the performance of the perfect foresight strategy is very similar across all currencies: the Sharpe ratios range from 0.54 to 0.75.

In Panel B, analogous results are reported for the carry-trade, which can be viewed as a simple proxy of the perfect foresight strategy . First, we find that the realized excess returns are signed as predicted. Second, the performance of carry-trades is mixed: Sharpe ratios vary between 0.1726 to 0.6109.

[Insert Table 2 about here.]

To assess the economic significance of UIP deviations, we report trader inaction ranges for the static trading approach in Table 3. The derivation of inaction ranges is based on a Sharpe ratio threshold of 0.5, which Lyons (2001) argues to be reasonable since the long-run performance of a simple buy-and-hold strategy in US equity is around 0.4.⁶ The first rows repeat the Fama regression estimates with corresponding standard errors in parentheses. Next, we report the bounds of the trader inaction range when disregarding α , i.e. presuming $\alpha = 0$. β^u denotes the upper bound, β^c the center, and β^l the lower bound of the inaction range. The values in parentheses are the p-values for testing whether β is below the upper bound, whether the

⁶Lyons (2001), p. 215, states “[...] I feel safe in asserting that there is limited interest at these major institutions in allocating capital to strategies with Sharpe ratios below 0.5.”

estimate is equal to the center of the range, and whether β is above the lower bound. Details of the testing procedure can be found in appendix Appendix B. The inaction ranges taking α into account are presented in the same way in the subsequent rows.

The lower and the upper bound derived when presuming $\alpha = 0$ are symmetrically centered around $\beta^c = 1$ while the bounds derived when using the Fama- α are centered asymmetrically around $\beta^c = 1 - \alpha/\mu_p$, i.e. the hypothesized value of zero-profits from the static trading approach (Test 1). Note that these bounds do not even necessarily contain the theoretical UIP value of unity. In particular the results based on the bounds calculated with $\alpha = 0$ suggest that zero Sharpe ratios are always rejected and even indicate a significant violation of the lower bound for the GBP and JPY, pointing at an economically significant Sharpe ratio. Incorporating the Fama- α into the assessment reveals that this finding is spurious, since for no currency the β is found to be different from the center of the range and, accordingly, β s are always within the inaction range bounds. The finding of whether β is within the inaction range calculated with $\alpha = 0$ /Fama- α is summarized in the last three rows by indicating whether $\beta = \beta^c$ is rejected (R.) or not rejected (N.) and whether β is inside (I.) or outside (O.) the lower bound and the upper bound. Overall, we find support for Prediction 1: focusing exclusively on β leads to an overestimation of excess returns and hence Sharpe ratios. As a consequence, trader inaction ranges are not adequate and a wrong judgement of economic significance can occur leading to spurious conclusions with respect to speculative efficiency.

[Insert Table 3 about here.]

A similar picture evolves when looking at the carry-trade results in Table 4. Consistent with Prediction 2, disregarding α leads to overestimation of Sharpe ratios when $\beta < 1$. The inaction range bounds for $\alpha = 0$ and the Fama- α respectively differ in level and shape resulting in an inaccurate assessment of economic significance if α is disregarded. When setting $\alpha = 0$, zero Sharpe ratios, i.e. $\beta = \beta^c$, are rejected for all currencies, while this is only the case for CAD and GBP when taking α into account. With respect to the lower bound, the results with $\alpha = 0$ indicate violations of the lower bound for four out of five currencies thereby suggesting economically significant Sharpe ratios for these currencies. Taking account of the Fama- α reveals that for none of the currencies β violates the inaction range bounds, again highlighting the importance of considering the regression constant when evaluating economic significance.

[Insert Table 4 about here.]

While our results suggest that foreign exchange markets are speculatively efficient, carry-trades are used in practice; see e.g. Galati and Melvin (2004). Whereas Villanueva (2007) finds that exploiting the forward bias allows for statistically significant profits, our results are based on economic significance and are in line with the concept of limits to speculation, see Lyons (2001), and recent work by Baillie and Kiliç (2006) and Sarno et al. (2006). The latter suggest that a reason why practitioners may view the carry-trade as profitable is that they use multi-currency approaches and that also hedging or diversification considerations play a role. This view is supported by Hochradl and Wagner (2007) who compare the performance of optimal carry-trade portfolios to buy-and-hold equity and bond investments, finding that carry-trade portfolios have the potential to attract speculative capital and to serve as diversification devices. Yet, the findings in the present paper suggest that the puzzle is less indicative for (speculative) inefficiencies in foreign exchange markets as often believed.

Independent of whether carry-trades are viewed as attractive investment opportunities, we showed that motivating trading rules solely by referring to a β less than unity - as is common in practice, see e.g. Deutsche Bank (2004) - may be misleading. Ignoring the offsetting effects between α and β leads to an overestimation of carry-trade excess returns. Furthermore, we have shown that the carry-trade is just a proxy of the perfect foresight strategy. Although perfect information on μ_p may not be available in practice, trading rules can potentially be improved.

6.2 Robustness of Results

With respect to the robustness of our results we examine whether our conclusions remain the same when investigating other currencies, other forward-maturities, or other sample periods. These results support the findings presented above, therefore we prefer for most to just summarize them instead of providing full tables. Detailed results are available upon request.

Apart from the currencies reported in the paper, we have also analyzed a variety of others such as the Australian Dollar, New Zealand Dollar, Euro (all have been excluded because of short data availability), other European non-Euro currencies (e.g. Norwegian Krone, Swedish Krone),

and further European pre-Euro currencies (e.g. French Franc, Italian Lira). The conclusions that can be drawn for these currencies are qualitatively equivalent to those reached in the paper.

Second, our conclusion of speculative efficiency is not dependent on the choice of forward rate maturity. The Bank for International Settlements also provides data for three, six, and twelve month horizons.⁷ Repeating the analysis for this data, results are qualitatively the same.

Finally, our findings are robust over time. We did the whole empirical analysis on various subsamples as well. For instance, if one splits the sample in two periods of approximately same length (to retain for both periods a reasonable number of observations for the test statistics), i.e. 1977-1991 and 1992-2005, one finds support for speculative UIP in all cases (Test 1). Risk-premia are always signed as predicted and significant in all but two cases (Test 2), and evidence for the profitability of carry-trades is mixed again (Test 3). With regards to the judgement of economic significance one finds again, that inaction ranges based on $\alpha = 0$ might suggest that the lower bounds for the static trading approach and the carry trade are undershot while this does not hold when taking account of α . Based on the correct inaction ranges, the lower bounds are only violated once: in the earlier subsample, the carry-trade involving the GBP is significant at the 10 percent level.

To provide a visual indication for the relevance of considering α , we graph the Fama- β as well as the inaction ranges based on $\alpha = 0$ and the Fama- α for the static trading approach in Figure 2 and for the carry-trade in Figure 3. The plots are based on 60-month rolling estimates.

[Insert Figure 2 and Figure 3 about here.]

The findings related to the static trading approach are that the shape of the inaction ranges for $\alpha = 0$ are solely driven by the lagged forward premium resulting in bounds symmetric around unity. In contrast, the inaction ranges calculated with the Fama- α exhibit substantial variability in terms of level and shape. While the rolling β is frequently outside the inaction range bounds calculated with $\alpha = 0$, this is hardly the case when bounds are calculated with the Fama- α . This indicates that disregarding α potentially distorts the judgement of economic significance

⁷In the context of analyzing different maturities, it is worth mentioning that carry-trades are typically based on (rolling over) short-term contracts since liquidity is higher than for longer maturities.

and hence the assessment of speculative efficiency. Note that considering the bounds with $\alpha = 0$ there are a few periods in which the bounds are (close to) plus / minus infinity because the forward premium is (very close to) zero. In such cases the bounds calculated with α can revert i.e. the lower bound has a higher value than the upper and vice versa, and the “center” of the range is not between the two which leads to high Sharpe ratios for β s within the range and low ones for β s outside.

A similar picture evolves for the carry-trade. Our results indicate that disregarding α distorts the evaluation of the economic significance of carry-trade profits. While the rolling Fama- β s often seem to undershoot the lower bound when calculating the inaction range with $\alpha = 0$, this is merely true when accurately taking account of the Fama- α . These findings provide further support for our conclusions that foreign exchange markets are characterized by speculative efficiency and that disregarding the Fama-regression α may lead to spuriously concluding the opposite.

7 Conclusion

Foreign exchange market efficiency is commonly investigated by Fama-regression tests of uncovered interest parity (UIP). In this paper, we aim at testing the *speculative efficiency* of currency markets by assessing the *economic significance* of currency speculation profits. For this purpose, we take a two-step approach. First, we formulate *speculative* pendants to the standard UIP test to examine whether currency speculation yields non-zero profits. Second, we judge the *economic significance* of speculative profits via trader inaction ranges implied by limits to speculation.

The speculative UIP relationship conjectured in this paper implies that exchange rate changes comprise a time-varying risk component in addition to the forward premium. This suggests that the forward premium anomaly reported in previous research potentially stems from omitting this risk-premium in standard UIP tests. At the same time, the popular carry-trade strategy can be rationalized to some extent. Throughout our analysis, we show that, although related research focuses on the Fama-regression slope coefficient, the intercept is also important for judging the economic significance of currency speculation and consequently the assessment of

speculative efficiency.

Empirically, we find support for speculative UIP and the existence of a risk-premium, the omission of which may cause the forward premium anomaly. Furthermore, although carry-traders are able to collect risk-premia to some extent, currency speculation does not yield economically significant excess returns as judged by trader inaction ranges. We therefore conclude that foreign exchange markets are characterized by speculative efficiency. Disregarding the Fama-regression intercept, however, leads to distortions in the assessment of economic significance and induces spurious rejection of speculative efficiency. Thus, our findings suggest that the forward premium puzzle is not necessarily indicative for (speculative) inefficiencies in foreign exchange markets as often thought. For market participants, our results imply that trading rules solely should not be motivated solely by referring to a Fama-regression slope coefficient less than unity since disregarding the intercept leads to an overestimation of carry-trade excess returns.

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Appendix

Appendix A. Sharpe Ratios and Trader Inaction Ranges

This appendix summarizes the properties of Sharpe ratios and trader inaction ranges for the static trading approach. Section A.1. reports technical details when α is disregarded, i.e. presumed to zero, section A.2. for calculations based on the Fama- α . We abstain from presenting analogous derivations for the carry-trade approach, since the details are lengthy but straightforward along the arguments for the static trading approach.

A.1. Sharpe Ratio and Inaction Range Bounds when $\alpha = 0$

A.1.a. Sharpe Ratio with $\alpha = 0$

Based on equation (16) we investigate the Sharpe ratio when setting $\alpha = 0$,

$$SR^{DEV} = \frac{(\beta - 1)\bar{p}}{\sqrt{(\beta - 1)^2\sigma_p^2 + \sigma_\varepsilon^2}}.$$

The first derivative of the Sharpe ratio with respect to β is given by

$$\frac{\partial SR}{\partial \beta} = \frac{\mu_p \sigma_\varepsilon^2}{\left[\sigma_\varepsilon^2 + (\beta - 1)^2 \sigma_p^2\right]^{3/2}},$$

i.e. depending on the sign of μ_p , the Sharpe ratio increases ($\mu_p > 0$) or decreases ($\mu_p < 0$) monotonically.

The second derivative,

$$\frac{\partial^2 SR}{\partial \beta^2} = -\frac{3(\beta - 1)\mu_p \sigma_\varepsilon^2 \sigma_p^2}{\left[\sigma_\varepsilon^2 + (\beta - 1)^2 \sigma_p^2\right]^{5/2}},$$

shows that, if $\mu_p > 0$, the Sharpe ratio function is concave ($\frac{\partial^2 SR}{\partial \beta^2} < 0$) for $\beta > 1$, while it is convex ($\frac{\partial^2 SR}{\partial \beta^2} > 0$) for $\beta < 1$. The reverse is true if $\mu_p < 0$.

Calculating the limits of the Sharpe ratio function with β going to plus and minus infinity,

$$\lim_{\beta \rightarrow \infty} SR = \frac{\mu_p \sqrt{\sigma_p^2}}{\sigma_p^2} \quad \text{and} \quad \lim_{\beta \rightarrow -\infty} SR = -\frac{\mu_p \sqrt{\sigma_p^2}}{\sigma_p^2},$$

reveals that the Sharpe ratio is bounded.

A.1.b. Inaction Range Bounds with $\alpha = 0$

Based on equation (15) we investigate the inaction range for UIP deviations when setting $\alpha = 0$,

$$\beta [SR_{th}, \alpha = 0] = \frac{\pm SR_{th} \sigma_\varepsilon}{\sqrt{(\mu_p^2 - SR_{th}^2 \sigma_p^2)}} + 1.$$

To investigate the shape of the inaction range bounded by a upper β , β^u and a lower β , β^l , we look at the derivatives with respect to the Sharpe ratio threshold, SR_{th} ,

$$\begin{aligned} \text{upper bound:} \quad \frac{\partial \beta^u}{\partial SR_{th}} &= \frac{\mu_p^2 \sigma_\varepsilon}{[\mu_p^2 - \sigma_p^2 SR_{th}^2]^{3/2}} > 0 \quad \text{and} \quad \frac{\partial^2 \beta^u}{\partial SR_{th}^2} = \frac{3\mu_p^2 \sigma_\varepsilon \sigma_p^2 SR_{th}}{[\mu_p^2 - \sigma_p^2 SR_{th}^2]^{5/2}} > 0, \\ \text{lower bound:} \quad \frac{\partial \beta^l}{\partial SR_{th}} &= -\frac{\mu_p^2 \sigma_\varepsilon}{[\mu_p^2 - \sigma_p^2 SR_{th}^2]^{3/2}} < 0 \quad \text{and} \quad \frac{\partial^2 \beta^l}{\partial SR_{th}^2} = -\frac{3\mu_p^2 \sigma_\varepsilon \sigma_p^2 SR_{th}}{[\mu_p^2 - \sigma_p^2 SR_{th}^2]^{5/2}} < 0. \end{aligned}$$

Thus, the upper bound is an increasing convex function of the Sharpe ratio threshold, while the lower bound is decreasing and concave.

A.2. Sharpe Ratio and Inaction Range Bounds when using the Fama- α

A.2.a. Sharpe Ratio with Fama- α

In order to investigate the change in the Sharpe ratio when incorporating the Fama- α instead of setting $\alpha = 0$, we look at the partial derivatives:

$$\begin{aligned} \frac{\partial SR}{\partial \alpha} &= \frac{1}{\sqrt{\sigma_\varepsilon^2 + (\beta - 1)^2 \sigma_p^2}}, \\ \frac{\partial^2 SR}{\partial \alpha^2} &= 0. \end{aligned}$$

Hence, depending on the sign of α , the Sharpe ratio changes inversely proportional to the standard deviation.

Looking at the partial derivatives of the Sharpe ratio with respect to β ,

$$\frac{\partial SR}{\partial \beta} = \frac{\mu_p \sigma_\varepsilon^2 - \alpha(\beta - 1)\sigma_p^2}{\left[\sigma_\varepsilon^2 + (\beta - 1)^2 \sigma_p^2\right]^{3/2}},$$

$$\frac{\partial^2 SR}{\partial \beta^2} = -\frac{3(\beta - 1)\mu_p \sigma_\varepsilon^2 \sigma_p^2 + \alpha \sigma_p^2 [\sigma_\varepsilon^2 - 2(\beta - 1)^2 \sigma_p^2]}{\left[\sigma_\varepsilon^2 + (\beta - 1)^2 \sigma_p^2\right]^{5/2}},$$

reveals that the function is non-monotonic. While the Sharpe ratio is still bounded with the same limits as given above (see appendix A.2.a.), the global optimum, i.e. $\partial SR/\partial \beta = 0$, is not reached with β going to plus or minus infinity but when $\beta = (\mu_p \sigma_\varepsilon)/(\alpha \sigma_p) + 1$.

A.2.b. Inaction Range Bounds with Fama- α

To investigate the impact of including α in the assessment of economic significance, we consider the partial derivatives of the inaction range bounds with respect to α :

upper bound:

$$\frac{\partial \beta^u}{\partial \alpha} = \frac{-\mu_p + \frac{\alpha \sigma_p^2 SR_{th}}{\sqrt{\alpha^2 \sigma_p^2 + \sigma_\varepsilon^2 (\mu_p^2 - \sigma_p^2 SR_{th}^2)}}}{\mu_p^2 - \sigma_p^2 SR_{th}^2} \quad \text{and} \quad \frac{\partial^2 \beta^u}{\partial \alpha^2} = \frac{\sigma_\varepsilon^2 \sigma_p^2 SR_{th}}{\left[\sigma_\varepsilon^2 (\mu_p^2 - \sigma_p^2 SR_{th}^2) + \alpha^2 \sigma_p^2\right]^{3/2}} > 0,$$

lower bound:

$$\frac{\partial \beta^l}{\partial \alpha} = \frac{-\mu_p - \frac{\alpha \sigma_p^2 SR_{th}}{\sqrt{\alpha^2 \sigma_p^2 + \sigma_\varepsilon^2 (\mu_p^2 - \sigma_p^2 SR_{th}^2)}}}{\mu_p^2 - \sigma_p^2 SR_{th}^2} \quad \text{and} \quad \frac{\partial^2 \beta^l}{\partial \alpha^2} = -\frac{\sigma_\varepsilon^2 \sigma_p^2 SR_{th}}{\left[\sigma_\varepsilon^2 (\mu_p^2 - \sigma_p^2 SR_{th}^2) + \alpha^2 \sigma_p^2\right]^{3/2}} < 0,$$

indicating that a non-zero α affects the level as well as the shape of the inaction range.

Appendix B. Testing Inaction Range Bounds

To test whether β significantly overshoots the upper bound or undershoots the lower bound, we use the nonlinear analog to the F statistic; see e.g. Greene (2003) p.175ff. The general specification is given by

$$F[J, n - K] = \frac{[S(\mathbf{b}_*) - S(\mathbf{b})]/J}{S(\mathbf{b})/(n - K)} \quad (20)$$

where \mathbf{b}_* denotes the estimates obtained when the hypothesis is imposed and \mathbf{b} denotes the unrestricted estimates. J is the number of restrictions, n the number of observations, K the number of parameters. $S(\cdot)$ denotes sum of squared residuals of the estimation with \mathbf{b}_* and \mathbf{b} respectively. The test statistic is (approximately) F -distributed with $[J, n - K]$ degrees of freedom.

One could also use a Wald test which might be simpler to compute. However, as also for the linear case, the Wald statistic is not invariant to how hypotheses are formulated, potentially leading to different answers depending on the specification of the hypothesis. Furthermore, Greene (2003) p. 176 states that “the small-sample behavior of W can be erratic, and the more conservative F statistic may be preferable if the sample is not large”.

To judge whether β overshoots the upper bound β^u , we want to obtain the probability that β is within the inaction range, i.e. whether $\beta < \beta^u$. Since our F -Test has one numerator degree of freedom, the square-root of the F -statistic corresponds to the absolute value of the t -statistic for the one-sided test. Taking the sign of the estimate into account, the probability that β is below β^u is therefore given by the reverse cumulative t -distribution for $\text{sgn}[\beta - \beta^u] \sqrt{F_{[J, n-k]}}$ with $(n - k)$ degrees of freedom. If this probability is below our confidence level threshold, we reject the hypothesis and say that β overshoots the upper bound. For the lower bound we proceed analogously.

Table 1: Standard vs. Speculative UIP, Risk-Premia, and Carry-Trade Profitability

	CAD	CHF	GBP	JPY	DEM
<u>Fama-regression</u>					
α	-0.0013 (0.0009)	0.0052 (0.0026)	-0.0048 (0.0021)	0.0090 (0.0029)	0.0017 (0.0024)
β	-1.3714 (0.5619)	-1.2554 (0.6356)	-2.8704 (0.8045)	-2.2899 (0.7831)	-0.8337 (0.7493)
<u>Standard UIP Tests</u>					
$p[\alpha = 0]$	0.1695	0.0499	0.0249	0.0022	0.4909
$p[\beta = 1]$	0.0000	0.0004	0.0000	0.0000	0.0151
$p[\alpha = 0, \beta = 1]$	0.0001	0.0018	0.0000	0.0002	0.0443
<u>Test 1 (Speculative UIP)</u>					
$p[\beta = 1 - \frac{\alpha}{\bar{p}}]$	0.5253	0.5880	0.3306	0.7849	0.5678
<u>Test 2 (Risk-Premia)</u>					
α_1	-0.0013 (0.0009)	0.0052 (0.0026)	-0.0048 (0.0021)	0.0090 (0.0029)	0.0017 (0.0024)
α_2	-0.0018 (0.0004)	0.0062 (0.0018)	-0.0064 (0.0013)	0.0095 (0.0023)	0.0029 (0.0012)
$p[\alpha_1 = \alpha_2]$	0.5253	0.5880	0.3306	0.7849	0.5678
$p[\alpha_2 = 0]$	0.0000	0.0004	0.0000	0.0000	0.0151
<u>Test 3 (CT Zero Profits)</u>					
$p[\beta = 1 - \frac{\alpha' + \varepsilon'}{\bar{p}'}]$	0.0003	0.3661	0.0006	0.2655	0.2214

Notes: Results are for 09/1977-12/2005 for CAD, CHF, GBP, JPY, and 12/1978-12/1998 for DEM. α and β are the estimates of the Fama-regression with standard errors in parentheses, μ_p denotes the long run average of the forward premium. $p[\cdot]$ denotes the p-value for testing the hypothesis formulated in $[\cdot]$. The first three p-values are for standard hypotheses applied when testing UIP. Test 1 corresponds to the test of speculative efficiency that we proposed in section 4.1. Results related to Test 2 are estimates of regression (8) with standard errors in parantheses and p-values of relevant tests. Test 3 is applied to the Fama-regression (1) and investigates whether excess returns from carry-trades are significantly different from zero. Superscript ' indicates that a variable is adjusted for the position taken in the strategy; see (12) in section 4.2. ε denotes the Fama-regression residual.

Table 2: Dynamics of Currency Speculation

Panel A: Static Trading Approach (<i>ER</i>) and Perfect Foresight Strategy						
		CAD	CHF	GBP	JPY	DEM
<u>Predicted sign vs. realized:</u>						
scenario 1a	–		–0.0067		–0.0080	–0.0048
scenario 2a	+		0.0073		0.0058	0.0078
scenario 3a	+		0.0032		0.0108	0.0034
scenario 4a	–	–0.0034		–0.0114		
scenario 5a	–	–0.0003		–0.0013		
scenario 6a	+	0.0035		0.0087		
<u>Static long FC position:</u>						
mean		0.0005	–0.0011	0.0016	–0.0005	–0.0012
sd		0.0155	0.0365	0.0314	0.0349	0.0334
SR (p.a.)		0.1167	–0.1003	0.1776	–0.0502	–0.1266
<u>Perfect foresight strategy:</u>						
mean		0.0028	0.0065	0.0066	0.0065	0.0050
sd		0.0151	0.0357	0.0307	0.0340	0.0317
SR (p.a.)		0.6421	0.6284	0.7461	0.6617	0.5433

Panel B: Carry-Trade (<i>CT</i>)						
		CAD	CHF	GBP	JPY	DEM
<u>Predicted sign vs. realized:</u>						
scenario 1a	+		0.0067		0.0080	0.0048
scenario 2a	–		–0.0073		–0.0058	–0.0078
scenario 3a	+		0.0032		0.0108	0.0034
scenario 4a	+	0.0034		0.0114		
scenario 5a	–	–0.0003		–0.0013		
scenario 6a	+	0.0035		0.0087		
<u>Carry-Trade strategy:</u>						
mean		0.0027	0.0018	0.0054	0.0020	0.0021
sd		0.0152	0.0362	0.0309	0.0346	0.0323
SR (p.a.)		0.6091	0.1726	0.6109	0.2046	0.2273

Notes: Results are for 09/1977-12/2005 for CAD, CHF, GBP, JPY, and 12/1978-12/1998 for DEM.

Panel A compares realized excess returns from the static trading approach (*ER*) to the signs predicted for scenarios 1a to 6a; see section 4.1. Monthly mean and standard deviations as well as annualized Sharpe ratios are reported for a permanent long position in the foreign currency as well as for the perfect foresight strategy.

Panel B compares realized carry-trade excess returns (*CT*) to the signs predicted for scenarios 1a to 6a; see section 4.2. Furthermore, monthly mean and standard deviations as well as annualized Sharpe ratios of carry-trades are reported.

Table 3: Trader Inaction Ranges and Sharpe Ratios for the Static Trading Approach

	CAD	CHF	GBP	JPY	DEM
<u>Fama-regression</u>					
α	-0.0013 (0.0009)	0.0052 (0.0026)	-0.0048 (0.0021)	0.0090 (0.0029)	0.0017 (0.0024)
β	-1.3714 (0.5619)	-1.2554 (0.6356)	-2.8704 (0.8045)	-2.2899 (0.7831)	-0.8337 (0.7493)
<u>Bounds with $\alpha = 0$</u>					
β^u	3.9976 (1.0000)	2.9023 (1.0000)	3.7028 (1.0000)	2.7046 (1.0000)	4.1122 (1.0000)
β^c	1.0000 (0.0000)	1.0000 (0.0004)	1.0000 (0.0000)	1.0000 (0.0000)	1.0000 (0.0151)
β^l	-1.9976 (0.8671)	-0.9023 (0.2894)	-1.7028 (0.0738)	-0.7046 (0.0219)	-2.1122 (0.9554)
<u>Bounds with Fama-α</u>					
β^u	2.2168 (0.9992)	1.0057 (0.9992)	0.7647 (0.9998)	-0.4147 (0.9984)	2.986 (0.9964)
β^c	-0.6817 (0.4747)	-0.8717 (0.412)	-1.8942 (0.6694)	-2.1157 (0.2151)	-0.0633 (0.4322)
β^l	-3.8643 (0.9779)	-2.8487 (0.9833)	-4.7471 (0.9594)	-3.9042 (0.9922)	-3.2666 (0.9490)
<u>Inference $\alpha = 0$/Fama-α</u>					
β^u	I./I.	I./I.	I./I.	I./I.	I./I.
β^c	R./N.	R./N.	R./N.	R./N.	R./N.
β^l	I./I.	I./I.	O./I.	O./I.	I./I.

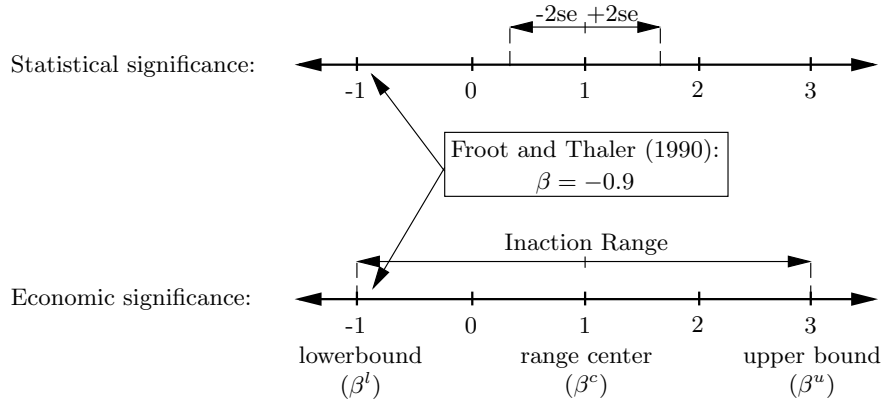
Notes: Results are for 09/1977-12/2005 for CAD, CHF, GBP, JPY, and 12/1978-12/1998 for DEM. α and β are the estimates of the Fama-regression with standard errors in parentheses. Based on equation (17) and a Sharpe ratio threshold of 0.5, the upper (β^u) and lower (β^l) bound as well as the center (β^c) of the inaction range for the static trading approach are calculated, first setting $\alpha = 0$, second using α from the Fama regression. The values in parentheses are the p-values for testing whether β is below β^u , β equals β^c , and β is above β^l . The last three rows summarize these findings by indicating whether the hypothesis of $\beta = \beta^c$ is rejected (R.) or not rejected (N.) and whether β is inside (I.) or outside (O.) the lower bound and the upper bound when comparing the bounds calculated with $\alpha = 0$ or the Fama- α respectively.

Table 4: Trader Inaction Ranges and Sharpe Ratios for Carry-Trades

	CAD	CHF	GBP	JPY	DEM
<u>Fama-regression</u>					
α	-0.0013 (0.0009)	0.0052 (0.0026)	-0.0048 (0.0021)	0.0090 (0.0029)	0.0017 (0.0024)
β	-1.3714 (0.5619)	-1.2554 (0.6356)	-2.8704 (0.8045)	-2.2899 (0.7831)	-0.8337 (0.7493)
<u>Bounds with $\alpha = 0$</u>					
β^u	2.7766 (1.0000)	1.9127 (1.0000)	3.5028 (1.0000)	2.4047 (1.0000)	2.1078 (0.9999)
β^c	1.0891 (0.0000)	0.3749 (0.0107)	1.4218 (0.0000)	0.8572 (0.0001)	0.4309 (0.0928)
β^l	-0.5920 (0.0832)	-1.2032 (0.4673)	-0.6306 (0.0028)	-0.6990 (0.0215)	-1.2779 (0.7231)
<u>Bounds with Fama-α</u>					
β^u	2.3803 (1.0000)	0.8639 (0.9995)	1.9976 (1.0000)	0.1446 (0.9990)	1.762 (0.9997)
β^c	0.6902 (0.0003)	-0.6802 (0.3661)	-0.0822 (0.0006)	-1.4164 (0.2655)	0.085 (0.2214)
β^l	-0.9967 (0.2526)	-2.2787 (0.9458)	-2.1586 (0.1884)	-3.0099 (0.8207)	-1.6292 (0.8553)
<u>Inference $\alpha = 0$/Fama-α</u>					
β^u	I./I.	I./I.	I./I.	I./I.	I./I.
β^c	R./R.	R./N.	R./R.	R./N.	R./N.
β^l	O./I.	I./I.	O./I.	O./I.	I./I.

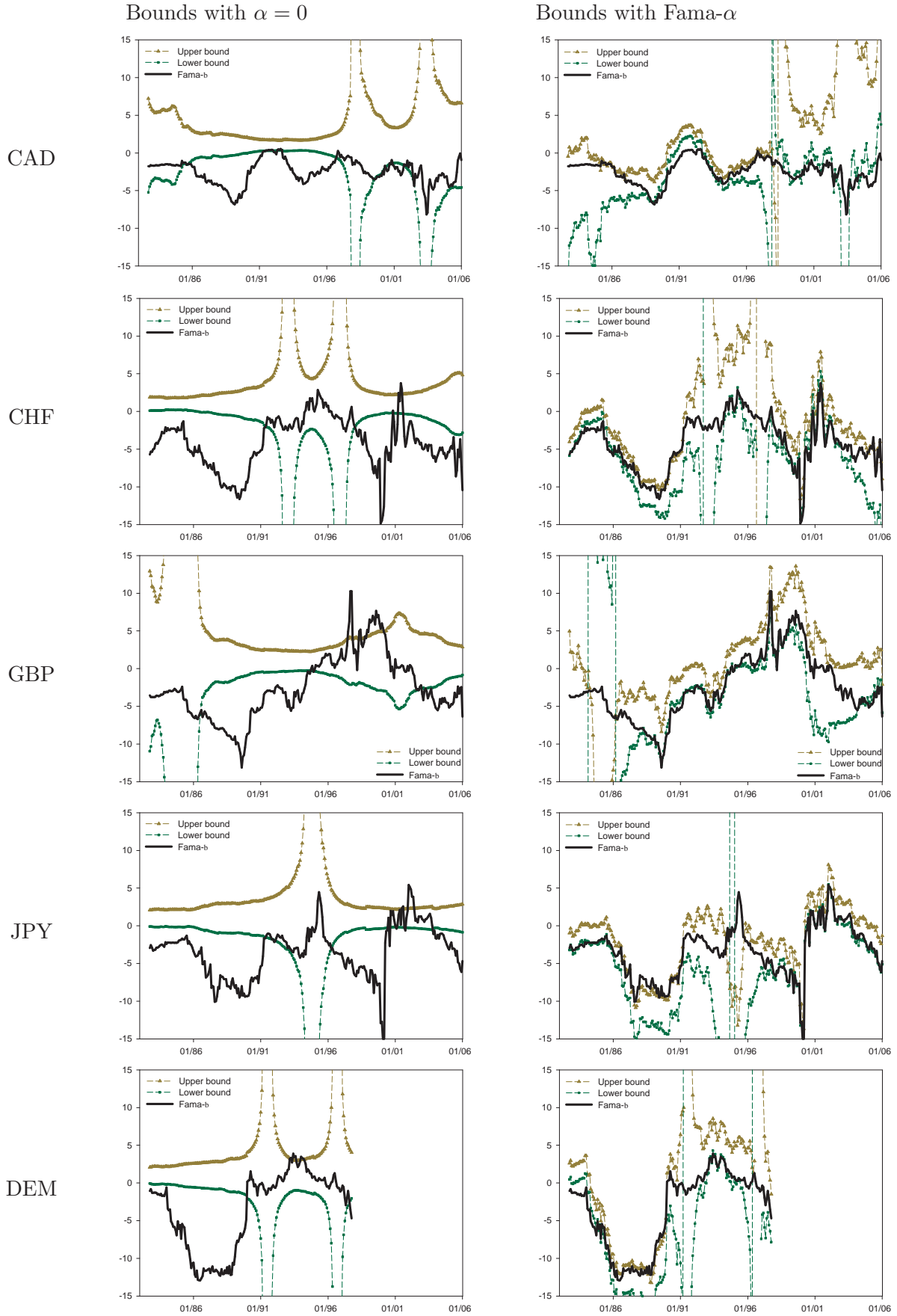
Notes: Results are for 09/1977-12/2005 for CAD, CHF, GBP, JPY, and 12/1978-12/1998 for DEM. α and β are the estimates of the Fama-regression with standard errors in parentheses. Based on equation (19) and a Sharpe ratio threshold of 0.5, the upper (β^u) and lower (β^l) bound as well as the center (β^c) of the inaction range for the carry-trade are calculated, first setting $\alpha = 0$, second using α from the Fama regression. The values in parentheses are the p-values for testing whether β is below β^u , β equals β^c , and β is above β^l . The last three rows summarize these findings by indicating whether the hypothesis of $\beta = \beta^c$ is rejected (R.) or not rejected (N.) and whether β is inside (I.) or outside (O.) the lower bound and the upper bound when comparing the bounds calculated with $\alpha = 0$ or the Fama- α respectively.

Figure 1: Statistical vs. Economic Significance of UIP Deviations



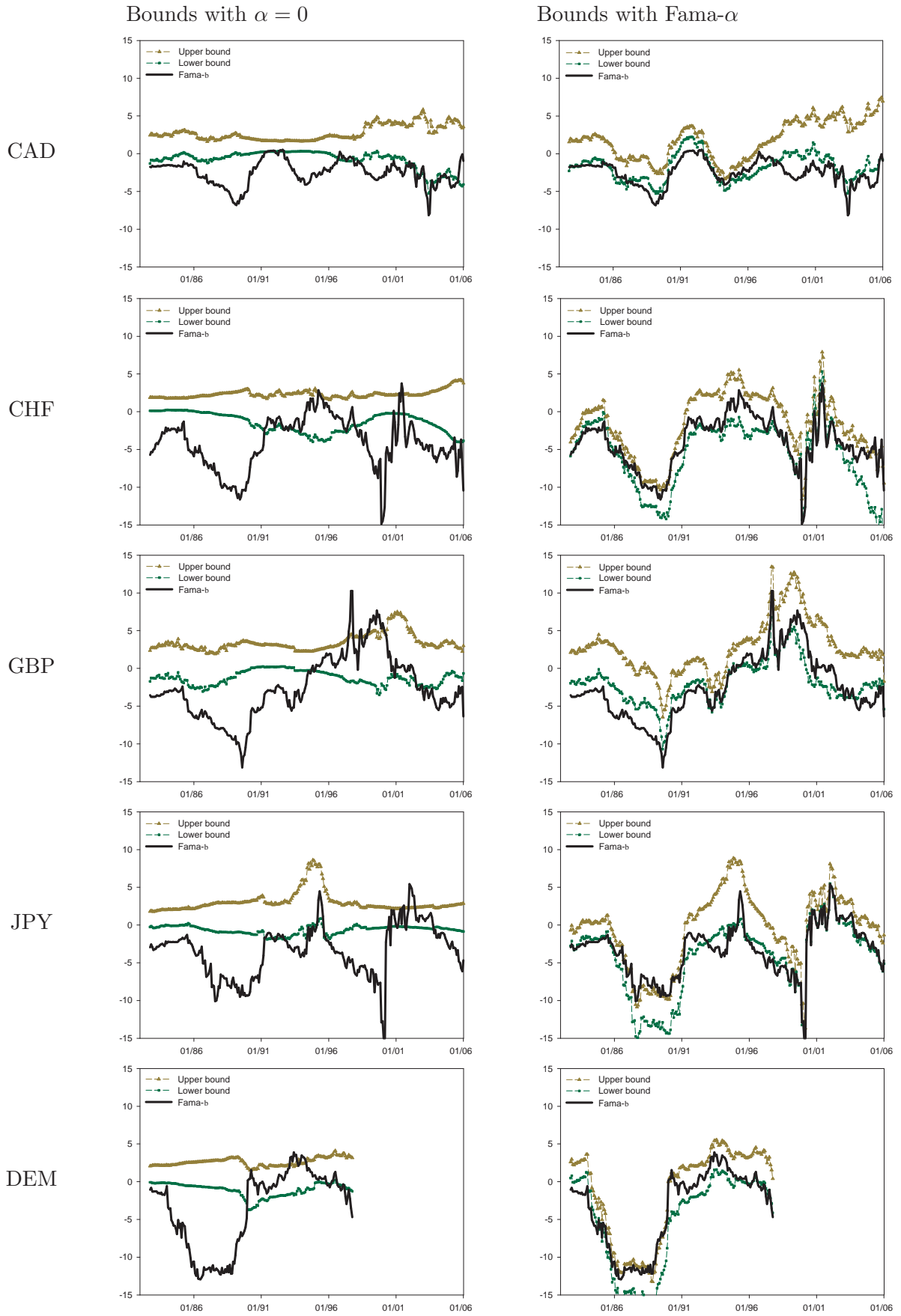
Notes: This figure visualizes the difference between statistical and economic significance of UIP deviations as proposed by Lyons (2001). While from a statistical perspective one would judge whether the estimate of the Fama- β falls within a (two-)standard error (se) band around the hypothesized value of unity, the judgement of economic significance is based on Sharpe ratios realizable from UIP deviations. Lyons (2001) argues that β values below -1 or above +3 are necessary to generate Sharpe ratios around 0.4, thereby corresponding to the long run performance of a US equity buy-and-hold strategy. Froot and Thaler (1990) surveyed 75 studies on the forward bias and found an average β across these papers of -0.88. Typically, this value is clearly outside the standard error band but within the trader inaction range, thus indicating that UIP deviations might be found to be statistically significant but not relevant in economic terms, because the deviation is too small to attract speculative capital.

Figure 2: Trader Inaction Ranges for the Static Trading Approach



Notes: The graphs show the 60-month rolling Fama- β estimates for the exchange rates USD against the indicated foreign currency and the corresponding trader inaction ranges for the static trading approach. The inaction range bounds are calculated with $\alpha = 0$ (left), see equation (15), and the Fama- α (right), see equation (17), respectively. The underlying Sharpe ratio threshold is 0.5.

Figure 3: Trader Inaction Ranges for the Carry-Trade



Notes: The graphs show the 60-month rolling Fama- β estimates for the exchange rates USD against the indicated foreign currency and the corresponding trader inaction ranges for the carry-trade. The inaction range bounds are calculated with $\alpha = 0$ (left) and the Fama- α (right) respectively, see equation (19). The underlying Sharpe ratio threshold is 0.5.

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