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The Time-Varying Systematic Risk of Carry Trade Strategies*

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The Time-Varying Systematic Risk of Carry Trade Strategies

Abstract: We explain the currency carry trade performance using an asset pricing model in which factor loadings are regime-dependent rather than constant. Empirical results show that a typical carry trade strategy has much higher exposure to the stock market and is mean-reverting in regimes of high FX volatility. The findings are robust to various extensions, including more currencies, longer samples, transaction costs, international stock indices, and other proxies for volatility and liquidity. Our regime-dependent pricing model provides significantly smaller pricing errors than a traditional model. Thus, the carry trade performance is better explained by its time-varying systematic risk that magnifies in volatile markets—suggesting a partial explanation for the Uncovered Interest Rate Parity puzzle.

Keywords: carry trade, factor model, FX volatility, liquidity, smooth transition regression, time-varying betas

JEL Classifications: F31, G15, G11

1 Introduction

”(Carry trade) is like picking up nickels in front of steamrollers: you have a long run of small gains but eventually get squashed.” (The Economist, “Carry on speculating”, February 22, 2007).

The common definition of currency carry trade is borrowing a low-yielding asset (for instance, denominated in Japanese yen or Swiss franc) and buying a higher-yielding asset denominated in another currency. Although this strategy has proliferated in practice, it is at odds with economic theory. In particular, the Uncovered Interest Parity (UIP) states that there should be an equality of expected returns on otherwise comparable financial assets denominated in two different currencies. Thus, according to the UIP we expect an appreciation of the low rewarding currency by the same amount as the return differential. However, there is overwhelming empirical evidence against the UIP theory, see e.g. Burnside, Eichenbaum and Rebelo (2007) for a recent study.¹

One of the most plausible explanations for the UIP puzzle and the long-lasting carry trade performance is a time-varying risk premium (Fama (1984)). Relying on this rationale, we analyze whether the systematic risk of a typical carry trade strategy is time-varying and if it varies across regimes. The literature proposes several explanations for the carry trade performance such as the exposure to illiquidity spirals (Plantin and Shin (2008)), crash risk (Brunnermeier, Nagel and Pedersen (2009)) and Peso problems (Farhi and Gabaix (2008))—although the latter argument is not supported by the substantial payoff remaining in hedged carry trade strategies (see Burnside, Eichenbaum, Kleshchelski and Rebelo (2008)). By applying an asset pricing approach with factor mimicking portfolios, some recent studies relate excess return of foreign exchanges to risk factors (e.g. Lustig, Roussanov and Verdelhan (2008)). Here, we propose to account for *FX* time-varying risk premia by adopting a related, but different, approach. We apply a multi-factor model with explicit factors, but where the risk exposures are allowed to change according one or more state variables. This methodology provides a general framework to explain regime-dependent and non-linear risk-return payoffs. The investigation of regime-switching models for exchange rates is not new, see Bekaert and Gray (1998), Sarno, Valente and Leon (2006) and Ichiue and Koyama (2008). Our contribution is to show that the risk exposure to the stock and bond market in the carry trade is regime dependent and that regimes are characterized by the level of foreign exchange

¹Burnside et al. (2007) also find that forward premium strategies yield very high Sharpe ratios, but they argue that the carry trade performance is not correlated with traditional risk factors.

volatility. While there have been other papers that point to the importance of volatility (e.g. Lustig et al. (2008), Menkhoff, Sarno, Schmeling and Schrimpf (2009)), the present paper is the first to demonstrate that volatility affects the exposure to stock market risk.

We use a logistic smooth transition regression methodology to explain the systematic risk of carry trade strategies. In doing so, the state variables have straightforward economic interpretations such as market risk and illiquidity. More specifically, we model the regimes by adopting proxies commonly used to measure market risk (foreign exchange volatility and the *VIX*) and either market or funding illiquidity (the bid-ask spread and the *TED*). The explanatory financial factors include equity and bond returns. The asset pricing analysis shows that the regime-dependent pricing model provides significantly smaller pricing errors.

Our results on the relevance of the regime dependency of the carry trade risk shed light on the gamble of currency speculation. By distinguishing between low and high risk environments, the danger related to carry trade becomes fully visible. In turbulent times, carry trade significantly increases its systematic risk and the exposure to other risky allocations. This finding warns against the apparent attractiveness of carry trade depicted by simple performance measures such as the Sharpe ratio. Overall, our contribution can be seen as a partial reconciliation of the UIP puzzle.

This paper is topical due to the ongoing financial crisis which provides a live experiment for many of the ideas that we explore here.

The structure of the remaining part of the paper is as follows: Section 2 outlines the theoretical motivation and our econometric approach, while Section 3 describes the data. Section 4 contains the empirical results; firstly, we show some preliminary results, secondly, we show the empirical results from estimating the smooth transition regression model, and thirdly we discuss the robustness of the results. Finally, we conclude in Section 5.

2 Theoretical and Empirical Framework

2.1 Theoretical Background

This paper combines three strands of literature to model carry trade returns. First, traditional factor models for exchange rates (McCurdy and Morgan (1991), Dahlquist and Bansal (2000) and Mark (1988)) suggest that currencies are exposed to equity and bond markets. Second, non-linear patterns in exchange rate returns emerge from unwinding carry trade and squeezes in funding liquid-

ity (Plantin and Shin (2008)), Peso problems (Farhi and Gabaix (2008)), limits to speculation hypothesis (Lyons (2001))² and non-linear cost of capital (Dumas (1992))³, the rational inattention mechanism (Bacchetta and van Wincoop (2006)) and the “trigger strategies” and “target zones” possibly implemented by central banks (Krugman (1991)).⁴ These arguments imply that a factor model for exchange rates should allow for different regimes. Third, the recent evidence on market volatility and liquidity risk premia (Acharya and Pedersen (2005), Ang, Hodrick, Xing and Zhang (2006) and Bhansali (2007)) highlights the need to incorporate the effects of high volatility and liquidity squeezes.

To incorporate and assess these different mechanisms, we model the currency return (r) by a factor model where S&P500 futures returns (SP) and Treasury Notes futures returns (TN) are the basic factors

$$r = \beta_{SP}(s)SP + \beta_{TN}(s)TN + \alpha(s) + \varepsilon, \quad (1)$$

but where the slope coefficients (β_{SP} and β_{TN}) as well as the “intercept” (α) are allowed to depend on “regime” variables: measures of market volatility and liquidity (s)—which we discuss in detail below. To account for the autocorrelation that exists in some exchange rates, we also include lags of all variables (see below for details on the econometric specification).

This model has the advantage of being written in terms of traditional risk factors. An alternative is to construct factors from portfolios of exchange rates (Lustig et al. (2008))—which may well give a better fit, but at the cost of making the interpretation of the results more difficult.

We study several proxies for market volatility and liquidity which we use as regime variables. A measure of FX volatility is used to account for market volatility risk premia (Bhansali (2007) and Ang et al. (2006)), the spread between Libor and T-bill rates (TED) is a proxy of funding liquidity (Brunnermeier et al. (2009)), CBOE’s index of equity market volatility (VIX) is often used to represent equity market volatility as well as risk aversion (Lustig et al. (2008)), and the bid-ask spread on the FX market is a natural measure of market liquidity (Roll (1984)), and asymmetric information (Glosten and Milgrom (1985)). See Section 3 for details on the data.

²Limits to speculation refers to the idea that speculators accessing a limited number of capital and investment opportunities would profit from carry trade performance only if its risk adjusted expected return is more attractive in comparative terms.

³Dumas (1992) proposes a general-equilibrium two-country model that endogenously produces nonlinearity, heteroskedasticity and mean-reversion in the cost of capital. This setting implies that the real interest rate differential incorporates a risk premium.

⁴Empirical evidence on non-linear patterns is provided in e.g. Bekaert and Gray (1998), Sarno et al. (2006) and Ichiue and Koyama (2008).

Our aims are to study if such a model can explain carry trade returns and to assess which of these different volatility and liquidity proxies are most relevant for the FX market.

2.2 Econometric Approach

Our econometric model is as follows. First, let $G(s_{t-1})$ be a logistic function that depends on the value of some regime variables in the vector s_{t-1}

$$G(s_{t-1}) = \frac{1}{1 + \exp[-\gamma'(s_{t-1} - c)]}, \quad (2)$$

where the parameter c is the central location and the vector γ determines the steepness of the function. Then, our logistic smooth transition regression model (see van Dijk, Tersvirta and Franses (2002)) is

$$r_t = [1 - G(s_{t-1})]\beta_1'x_t + G(s_{t-1})\beta_2'x_t + \varepsilon_t, \quad (3)$$

where the dependent variable r_t (the carry trade or currency excess return) is modeled in terms of the set of explanatory variables x_t (here, stock returns, bond returns, lags, and a constant) and the regime variable s_{t-1} (here, the lagged FX volatility). The parameters (γ, c) are from the logistic function and (β_1, β_2) are from the regression function.

The effective slope coefficients in (3) vary smoothly with the state variables s_{t-1} : from β_1 at low values of $\gamma's_{t-1}$ to β_2 at high values of $\gamma's_{t-1}$. This is illustrated in Figure 1. Clearly, if $\beta_1 = \beta_2$ then we effectively have a linear regression.

Figure 1 also illustrates how the effective slope coefficient depends on the parameters of the $G(s_{t-1})$ function (assuming s_{t-1} is a scalar and $\gamma > 0$). A lower value of the parameter c shifts the curve to the left, which means that it takes a lower value of s_{t-1} to move from the regime where the effective slope coefficient is β_1 to where it is β_2 . In contrast, a higher value of the parameter γ increases the slope of the curve, so the transition from β_1 to β_2 is more sensitive to changes in the regime variable s_{t-1} .

The model is estimated and tested by using GMM, where the moment conditions are set up to replicate non-linear least squares. Diagnostic tests indicate weak first-order (but no second-order) autocorrelation and a fair amount of heteroskedasticity. Therefore, the inference is based on a Newey and West (1987) covariance matrix estimator with a bandwidth of two lags.

The explanatory variables are current and 1-day lagged stock and bond

returns as well as the 1-day lagged currency return and a constant:

$$x_t = \{SP_t, SP_{t-1}, TN_t, TN_{t-1}, r_{t-1}, 1\}. \quad (4)$$

With these regressors, our regression model in equation (3) is just a factor model. The basic factors are the US equity and bond returns—although with extra dynamics due to the lagged factors and also the lagged return (lagged dependent variable). The new feature of our approach is that it allows all coefficients (the betas and the intercept—the alpha) to vary according to a regime variable. The regime-dependent intercept can also be interpreted as the direct effect of the regime on the currency return.⁵

Prompted by preliminary findings (see below), we are initially interested in studying if the systematic risk exposure is greater during volatile periods and therefore we use *FX* volatility as a regime variable—but we later also use other proxies of market volatility and liquidity.

3 Data Description

3.1 Currency Returns

In our base line analysis, we investigate the G10 currencies quoted against the US dollar (USD): Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), euro/German mark (EUR), UK pounds (GBP), Japanese yen (JPY), Norwegian krone (NOK), New Zealand dollar (NZD), and Swedish kronor (SEK). The main sample is based upon daily data and runs from January 1995 through December 2008, thus providing us with 3,652 observations. The starting time is dictated by the availability of data on option-implied *FX* volatility. In a robustness analysis we include 10 more currencies (G20) for a shorter sample covering 2003–2008: Brazil real (BRL), Czech koruna (CZK), Israeli shekel (ILS), Indian rupee (INR), Icelandic krona (ISK), Mexican new peso (MXN), Polish new zloty (PLN), Russian Federation rouble (RUB), new Turkish lira (TRY), and South African rand (ZAR). In another robustness analysis we consider a longer sample period, namely from 1976–2008. In this longer sample, only seven out of the 10 currencies are represented (AUD, CAD, CHF, EUR, GBP, JPY all against the USD)—due to lack of high quality data on short-term interest rates.

⁵We have also used a smooth transition logistic model where the *FX* volatility is both a regime variable (s_{t-1}) as well as an explanatory factor (an element of x_t). The results were similar to those where the *FX* volatility is only used as a regime variable.

The daily WM/Reuters closing spot exchange rates are available through DataStream. Following Brunnermeier et al. (2009), we use the exchange rate return in excess of the prediction by the UIP (i.e. the abnormal return). Thus, we add the currency return (based on mid-quotes) and the one-day lagged interest rate differential between a given country and the US: it is the return (in USD) on a long position in the money market in currency k minus the return on the US money market

$$r_t^k = -(q_t^k - q_{t-1}^k) + i_{t-1}^k - i_{t-1}^{US}, \quad (5)$$

where q_t^k is the log exchange rate (the price, in currency k , of one US dollar), i_t is the log interest rate for currency k and i_t^{US} is the log interest rate for the US dollar. This is thus the return on a foreign currency investment in excess of investing on the US money market.

The interest rate data are taken from DataStream and we use the interest rate with the shortest available maturity, normally the 1-day money market rate (except for Australia and New Zealand where we use 1-week interest rates).

Table 1 (upper rows) contains summary statistics of the returns for the individual G10 currencies. All returns have fat tails, most pronounced for the Australian dollar. The average returns are negative for typical funding/borrowing currencies (-3.7% for JPY and -1.7% for CHF, annualized) and positive for some of the typical investment/lending currencies (1.4% for NZD, annualized).

3.2 Carry Trade Returns

A carry trade strategy consists of selling low interest rate currencies and buying high interest rate currencies. To study typical carry trade strategies, we rely on the explicit strategy followed by Deutsche Bank’s “PowerShares DB G10 Currency Harvest Fund”.⁶ It is based on the G10 currencies listed in the previous subsection. The carry trade portfolio is composed of a long position in the three currencies associated with the highest interest rates and a short position in the three currencies with the lowest interest rates (cf. Gyntelberg and Remolona (2007)). The portfolio is rebalanced every 3 months. We let r_t^{CT} denote the return at time t on the carry trade strategy.

Table 1 (row 10) shows that the average carry trade return is higher than for any individual currency and that the standard deviation is lower than for all except one currency (i.e. CAD). This might explain the popularity of the

⁶More information about this index is available at the Deutsche Bank home page at www.dbfunds.db.com.

strategy. As in Brunnermeier et al. (2009), we find that the distribution of the return of the carry trade strategy is left skewed (i.e. the left tail of the distribution is longer than the right tail), and that it has fat tails.

Figure 2 shows the weights for the carry trade portfolio. The weights seem to be fairly stable. The usual situation is that the carry trade strategy is long in the GBP, NZD, and a third varying currency. Most often the carry trade strategy is short in the CHF, JPY⁷, and a third varying currency.

3.3 Additional Variables

The explanatory variables that we use in the empirical analysis represent the two other main financial markets, namely the stock and bond markets. We use the log-returns on the futures contract on the S&P500 index traded on the Chicago Mercantile Exchange, and the futures contract on the 10-year US Treasury notes traded on the Chicago Board of Trade. Each day, we use the most actively traded nearest-to-maturity or cheapest-to-deliver futures contracts, switching to the next-maturity contract five days before expiration. We denote these returns at time t by SP_t and TN_t , respectively. The futures contracts data are also available from DataStream.

To differentiate between regimes we initially construct a foreign exchange volatility variable (denoted FXV_t and called FX volatility below). We measure the FX volatility by the standardized first principal component extracted from the most liquid 1-month OTC implied volatilities from Reuters (all quoted against the USD): CAD, CHF, EUR, JPY, and GBP. The first principal component is approximately an equally weighted portfolio of the implied volatilities, in particular the weights are $\{0.25, 0.20, 0.17, 0.19, 0.19\}$. This measure of FX volatility is particularly high during spring 1995 to spring 1996 (with somewhat lower values during summer 1995), early 1998, summer 2006 and late 2008.

Table 1 (lower rows) shows that the distribution of the stock returns has fat tails, and to a minor extent this also applies to the bond returns. The standard deviations of the currency returns fall between those of stocks (highest) and bonds (lowest). The distribution of the FX volatility is right skewed and has fat tails.

In further analysis we make use of three additional regime variables representing market volatility and liquidity. Firstly, the so-called TED spread, which is the difference between the 3-month USD LIBOR interbanking market interest rate and the 3-month T-Bill rate. Secondly, we use the CBOE VIX

⁷More about yen carry trade in e.g. Hattori and Shin (2007) and Gagnon and Chaboud (2007).

index, which is the index of implied volatilities on S&P500 stocks. Thirdly, we measure market liquidity with the JPY/USD bid-ask spread computed as the average of the ask price minus the bid price divided by their average at the end of each five-minute interval during the day. We use the 10-day moving average of the daily bid-ask spreads. We cap the spread at its 95% percentile to get rid of the ten-fold increase on (fuzzy) holidays like Christmas.

Finally, we use the order flow for the JPY/USD as an additional explanatory variable which is defined as the number of buys minus the number of sells during the day (divided 10,000). Both the JPY/USD bid-ask spread and the order flow are constructed from firm quotes and trading data obtained by the tick-by-tick data of EBS (Electronic Broking Service). We only have JPY/USD data covering the long sample period from 1997 to 2008. However, the JPY/USD is notoriously considered the exchange rate subjected to most carry trade, so it provides an interesting proxy.

4 Empirical Results

In this section we present the empirical results. First, we provide some preliminary findings that further motivate the econometric framework. Then, we show the empirical results for carry trade strategies as well as for the individual currencies.

4.1 Preliminary Results

The return on the carry trade strategy is positively correlated with the return on the stock market (0.19) and somewhat negatively correlated with the return on the bond market (-0.06). This means that “investment currencies” like NZD (the long positions of the carry trade strategy) tend to appreciate relative to “funding currencies” like JPY and CHF (the short positions) when the stock market booms. Conversely, investment currencies tend to depreciate against funding currencies when bond prices increase (interest rates decrease). That is, when the risk appetite of investors decrease and they move to safe assets (US Treasury bonds are typically considered to be “safe havens”), then investment currencies lose value against funding currencies.

While these patterns are already relatively well understood (see, for instance, Bhansali (2007)), it is less well known that the strength of the correlations depends very much on the level of *FX* market volatility and liquidity. As an illustration, Table 2 (first column) shows how the correlation between the carry trade return and the *SP* varies across the top quantiles of *FX* volatility. The

figure 0.41 is the correlation between the carry trade return and the *SP* return for days when *FX* volatility is in the top 5%. The table shows a very clear pattern, the higher the *FX* volatility, the stronger is the correlation between the stock market and the carry trade strategy. In fact, the correlation coefficients between the stock market and the carry trade strategy for the eight top volatility quantiles are significantly higher than the correlation coefficient for the entire sample (GMM based inference).

Similarly, Table 2 (second column) shows the correlations between the carry trade return and *TN* at various top quantiles for the *FX* volatility. This correlation is negative and numerically stronger for higher *FX* volatility—although only the correlation coefficient at the two top most volatility quantiles are significantly stronger than for the entire sample.

These preliminary results suggest that the risk exposures of the carry trade strategy are much stronger during volatile periods than during calm periods.⁸

Table 2 (third column) reports the average returns of the carry trade strategy for different top quantiles of *FX* volatility. On average, the carry trade strategy yields positive and moderately high returns in normal periods, whereas on average it has dramatic losses during turbulent periods.

4.2 Carry Trade Strategy

The preliminary findings suggest that both the risk exposure of the carry trade return—as well the average carry trade return over short subsamples—are related to volatility of the *FX* markets. We now formalize this idea by using a linear factor model (with stocks and bonds as factors), but where the betas and the alpha (the intercept) depend on the one-day lagged *FX* volatility—according to the logistic smooth transition regression model discussed above.

Table 3 (first column) shows the results from estimating the logistic smooth transition regression model for the carry trade strategy. (The results in the last two columns are discussed later.) The top part of the table shows the parameter estimates applicable for low values of the *FX* volatility, denoted β_1 in (3), and the middle part of the table shows the parameter estimates applicable for high values of *FX* volatility, denoted β_2 . The lower part of the table shows the difference between the parameter estimates for high and low *FX* volatility values, i.e. it shows $\hat{\beta}_2 - \hat{\beta}_1$. Moreover, the table indicates whether these differences are statistically significant.

The explanatory power of the smooth transition regression model is fairly

⁸However, the results should be read with appropriate reservations as Embrechts, McNeil and Straumann (2002) call for caution when using correlations in risk management.

high: The R^2 is 0.18. As a comparison, an OLS regression gives half of that—which suggests that it is empirically important to account for regime changes in order to describe the exchange rate movements. The estimated value of the c parameter (the central location of the logistic function) is 1.25, and the estimated γ parameter (the steepness) is 2.49, so the estimated logistic function is similar to the solid curve in Figure 1 discussed above. In practice, this means that the volatile regime starts to have an impact when the standardized FX volatility variable goes above 1 or so. The resulting time path of $G(FXV)$ is shown in Figure 3. The value is close to zero most of the time (it is less than 0.1 on 80% of the days in the sample) and it only occasionally goes above a half (6% of the days). The calm regime (when β_1 is the effective slope coefficient) is thus the normal market situation, while the volatile regime (when β_2 , or a weighted sum of β_1 and β_2 , is the effective slope) represents periods of extreme stress on the FX market.

The results in Table 3 clearly show that the risk exposure depends on the FX volatility variable. During calm periods, the carry trade strategy is significantly positively exposed to current and lagged stock returns (although the coefficient is numerically small), but not to the bond market (a numerically small, negative, coefficient). During turmoil, the exposure to the current and lagged stock market returns is much larger. The exposure to the bond market also has a more negative coefficient, but the difference between the regimes is not significant. It is also interesting to note that the autoregressive component is small and insignificant during calm periods, but significantly negative during turmoil—which indicates considerable predictability and mean reversion during volatile periods.

These results are robust to various changes in the empirical specification. First, we replace the SP with the $MSCI$ world index denominated in domestic currencies and excluding US stocks. We get similar results. In particular, the exposure to equity in the high volatility regime remains very high.⁹ Thus, the carry trade’s exposure to stock market return appears irrespective of the currency denomination and country of origin of the companies’ returns. Second, taking into account transaction costs affects the average returns of the strategy (decreasing it by 1.12 percentage points per year), but does not change any of the slope coefficients.¹⁰ The main reason is that the trading costs are fairly

⁹Summing the contemporaneous and lagged coefficients gives 0.06 (0.52) for SP in the low (high) regime, -0.01 (-0.16) for TN and 0.03 (-0.16) for the lagged dependent variable.

¹⁰For each daily return we subtract 1/63 of half the bid-ask spread (in DataStream) from the beginning of the investment period (rebalancing every 3 months) and half of the bid-ask spread from the end of the period. Since our return data is based on mid-quotes, this implies that the adjusted return is calculated from buying high and selling low.

stable over time and that there is little rebalancing (see Figure 2) as the interest rate differentials are very persistent. Third, rebalancing the carry trade portfolio more/less often than every three months does not change the qualitative results. The main reason is that interest rates tend to change smoothly across time and so do portfolio weights. The results are also robust to the number of long and short currency positions in the carry trade strategy.¹¹

To assess the economic importance of the systematic risk of the carry trade strategy we consider the fitted values (*CT* returns) in Figures 4–5. Figure 4 shows the fitted carry trade returns split up into two parts: the first part (upper graph) caused by the calm regime $((1 - G)\hat{\beta}_1 x_t)$ and the second part (lower graph) caused by the volatile regime $(G\hat{\beta}_2 x_t)$. The total fitted carry trade return adds up to the sum of the two parts. Almost all the movement in the fitted carry trade returns is caused by the volatile regime. So, it is during volatile *FX* markets that the systematic risk of the carry trade is most important. This is related to the literature that discusses whether financial markets comovement is stronger during financial crises (cf. Forbes and Rigobon (2002) and Corsetti, Pericoli and Sbracia (2005)) and also to the literature on non-linearities and regime-dependence of carry trade returns (cf. Plantin and Shin (2008) and Mark (1988)).

Figure 5 shows the (annualized) fitted returns for different top quantiles of *FX* volatility. The upper left subfigure shows both the actual *CT* returns (cf. Table 2) and the fitted values from the estimated model: the fit is very good.

The other three subfigures in Figure 5 decompose the fitted values into the contribution from (contemporaneous and lagged) *SP* returns, *TN* returns and alpha (together with the lagged dependent variable). All these three subfigures point in the same direction. The contribution from *SP* is negative at high *FX* volatility (around -6%) since the beta of the carry trade strategy is positive—and *SP* has, on average, negative returns when *FX* volatility is high. *TN* also has a negative contribution (-4%) in those states, since the beta is negative and the bond market typically performs well when *FX* volatility is high. Finally, the combined effect of the alpha and the lagged dependent variable is remarkably negative at high *FX* volatility (-18%)—but somewhat positive at low *FX* volatility (5%). To interpret the latter finding, notice that (3) shows that the alpha is

$$\alpha(s_{t-1}) = \alpha_1 + G(s_{t-1})(\alpha_2 - \alpha_1). \quad (6)$$

¹¹Varying the rebalancing frequency between 1 and 6 months (all else equal) and varying the number of long/short positions between 2 and 4 (all else equal) gives very similar (that is small) coefficients in the low state. For the high state the sum of the contemporaneous and lagged coefficients is between 0.38 and 0.51 for *SP* and between -0.16 and -0.35 for *TN*.

Since low volatility is the typical state, we can interpret α_1 (positive) as the typical alpha—and $\alpha_2 - \alpha_1$ (negative) as the direct effect of high volatility on the on the carry trade return. This is similar to Bhansali (2007) and Menkhoff et al. (2009) who discuss how carry trades are negatively affected by market volatility. Notice, however, that the alphas should not be taken as literal performance measures since some of the factors are managed portfolios. (We do a formal asset pricing test below.)

It can also be noticed that both the effect of the lagged dependent variable and the direct FX volatility effect imply a certain amount of predictability (as the state variable is measured in $t - 1$). We leave this aspect to future research.

To sum up, our results show that around one third of the (disastrous) carry trade return in the (extreme) high volatility state is accounted for by the exposure to traditional risk factors (equity and bonds) and two thirds by the market volatility factor. This suggests that it is important to model both regime dependence of traditional risk factors (see, for instance, McCurdy and Morgan (1991), Dahlquist and Bansal (2000)) as well as the direct effect of market volatility on carry trade performance (see, for instance, Bhansali (2007), Lustig et al. (2008) and Menkhoff et al. (2009)).

4.3 Individual Currencies

Table 4 shows the results from estimating the logistic smooth transition regression model for the individual currency returns. In these regressions, we set γ equal to 2.50 to guarantee a unique and consistent number across the panel (the point estimate for the carry trade return is 2.49). The table is structured similarly to Table 3. The results for the individual currencies are broadly in line with those from the carry trade. In both regimes, typical investment currencies like NZD have positive exposure to SP , while typical funding currencies like CHF and JPY have negative SP risk exposure (a safe haven feature). In most cases, this pattern is even stronger in the high volatility regime (the change in the slope coefficient is significant for all currencies). Together this explains why the carry trade is so strongly exposed to SP risk, particularly in the high volatility regime. In addition, the negative autocorrelation in the carry trade strategy in the high volatility regime seems to be driven by the typical investment currencies.

4.4 Larger Set of Currencies

Constructing the carry trade strategy from a larger base of 20 currencies (also called G20) instead of 10 currencies does not alter the conclusion. To show that, Table 3 also reports results for a carry trade strategy based on the G10 currencies for the shorter sample 2003–2008 (instead of the 1995–2008 sample discussed above) and for a strategy based on the G10 and 10 additional currencies (also for 2003–2008). The sample starts in 2003 in order to guarantee high quality data and the existence of an active carry trade market.

The results for the larger set of currencies base are very much in line with those for the G10 currencies—and perhaps even stronger. In particular, the negative exposure to the bond market is stronger (and more significant).

Accounting for the transaction costs decreases the carry trade performance by 1 percentage point per year, but does not affect the slope coefficients—as in the G10 case. Although the trading costs are higher for these additional 10 currencies, there is less rebalancing since some of the interest rate differentials are extremely persistent. Overall this leads to almost the same adjustment of the average performance as in the G10 case.

4.5 Asset Pricing Analysis

These regime-dependent risk exposures have important implications for the cross-sectional fit of the model. To illustrate this, we estimate a simplified model with the following specification: (i) the factors (f_t) are only contemporaneous variables; (ii) SP and TN are expressed as excess returns over a risk-free US interest rate; and (iii) the parameters of the logistic function are fixed (at the values estimated from the carry trade return).

By these simplifications, the model becomes testable (sufficient number of test assets compared to factors) and is a linear factor model with the following factors

$$f_t = [SP_t, TN_t, G_{t-1} \times SP_t, G_{t-1} \times TN_t, G_{t-1}]. \quad (7)$$

Since some of the factors are not excess returns, the asset pricing implications are tested by studying whether the cross-sectional variation in average returns is explained by the betas of the factors

$$\sum_{t=1}^T r_t / T = \beta' \lambda, \quad (8)$$

where λ is a vector of factor risk premia. The model is estimated by GMM where the first set of moment conditions effectively estimate the betas (and an

intercept) by regressing each currency return on the factors (time-series regressions) and the second set of moment conditions estimate the factor risk premia by a cross-sectional regression. We discipline the exercise by using the fact that the SP and TN are excess returns: these factors are included in the vector of test assets (together with the currencies) and formulate the moment conditions so that the factor risk premia for these two factors are just their average returns.

Figure 6 (upper panel) compares the results from using just SP and TN (a 2-factor model) with those from using all 5 factors in (7) for the G10 sample. While the 2-factor model explains virtually nothing of the cross-sectional variation of the currency returns, the 5-factor model is much more successful. For instance, the low return on JPY is well explained—mostly by the negative exposure to equity in the high volatility state. Similarly, the pricing error (the vertical distance to the 45 degree line) for the carry trade strategy (marked by CT) is substantially smaller in the 5-factor model, although it is not zero. Because of the few degrees of freedom, the power of formal tests of the model is low.

The lower panel of Figure 6 shows the asset implication for the 20 currencies and the corresponding carry trade strategy (CT). As before, the 2-factor explains almost nothing of the cross-sectional variation of average returns, while the 5-factor works clearly better. In contrast to before, the formal test of the overidentifying restrictions has enough degrees of freedom to discriminate between the models: the 2-factor model is rejected on the 2% significance level, while the 5-factor cannot be rejected even on the 20% significant level. It is also interesting to notice that the pricing error of the carry trade strategy is virtually zero in the 5-factor model (but almost 10% in the 2-factor model).

Overall, this gives considerable support for a model with regime-dependent risk exposures.

4.6 Other Regime Variables

So far, we have related the regime mechanism to a measure of risk on exchange rate markets. Here, we extend our analysis to more general proxies of global risk or risk aversion (the VIX , as used by Lustig et al. (2008) and Menkhoff et al. (2009)), of *funding* liquidity (the TED , as in Brunnermeier et al. (2009)) as well as *market* liquidity. To capture the latter, we use the JPY/USD bid-ask daily spread as a measure of transaction cost due to market illiquidity (Roll (1984)) and asymmetric information (Glosten and Milgrom (1985)). It should be noted that since we use EBS data, this measure accounts only for inter-dealer and brokered FX spot trading and not other trading venues such as OTC markets.

Using these other natural candidates for the regime variable does not change

the results much. Table 5 shows the smooth transition regressions for the carry trade strategy for the sample 1997–2008 for different choices of the regime variable. The sample starts in 1997 (instead of 1995) due to limited data availability for some of the new regime variables. For convenience, the first column of the table uses the same specification as before: the *FX* volatility (*FXV*; now for the shorter sample period).

The second column uses the *TED* spread, the third the *VIX* index, and the fourth the JPY/USD bid-ask spread. The results are similar across these different specifications.

The last column reports results from a regression where we use all four state variables simultaneously. Both the *FXV* and the *TED* are highly significant, while the *VIX* and bid-ask spread are not. (In this regression the state regime variables are rotated to be uncorrelated, but we get a similar result with the original variables.)

The correlations between these different regime variables are reasonably high (0.4–0.75), suggesting a well-expected co-variation between risk and illiquidity (of any nature).¹² Not surprisingly, the different regimes variables generate fairly similar results for the time variation in risk exposure. However, a direct horse race favors the *FX* volatility and the *TED* over *VIX* and the bid-ask spread.

These findings suggest that *FX* market volatility and funding liquidity might be more important than risk measures related to equity markets (*VIX*) and direct measures of *FX* (inter-dealer) market liquidity (bid-ask spread). This is somewhat similar to the findings on the equity market by Bandi, Moise and Russell (2008).

4.7 Further Robustness Analysis

4.7.1 Longer Sample Period

It is of considerable interest to see if the properties of carry trade documented above (on data 1995–2008) also hold for earlier periods—especially during periods of *FX* market turmoil. We therefore study also the sample 1976–2008, but have to reduce the number of currencies under investigation to seven, because we cannot obtain high-quality interest rate data (for the early part of the sample) for Norway, New Zealand, and Sweden.

For the longer sample period we have to define a new *FX* volatility variable, since data on the *FX* options are not available before 1995. Instead we use a

¹²The lowest correlation is between *TED* and the bid-ask spread and the highest is between *FX* volatility and the bid-ask spread.

15-day moving average of the first principal component of the absolute value of the FX daily returns (see Taylor (1986)). This new FX volatility variable is backward looking and does not necessarily represent the beliefs of market participants, but it is still a reasonable approximation. For instance, over the 1995–2008 sample the correlation with the option based measure is 0.85.

For this longer sample most coefficients are numerically small (cf. Burnside et al. (2008) who find no relation between carry trade strategies and an equity factor for the same time period). However, the exposure to equity in the high volatility state is as strong as in the shorter sample (0.18 for the contemporaneous coefficient and 0.21 for the lagged coefficient). The main findings from the long sample and from the shorter sample are highly similar, except that the bond factor is less important.

Overall, it seems as if the time-varying exposure to equity has been an important feature during both earlier periods of FX market turbulence¹³ as well as during more recent episodes¹⁴. This suggests that our findings cannot be solely driven by the current financial crisis.

4.7.2 Effects of Order Flow

In the market microstructure literature, the order flow is often thought of as representing the net demand pressure (Evans and Lyons (2002)). To investigate the importance of this in our model, Table 6 shows logistic smooth transition regressions for the Japanese yen (against the USD) for the sample 1997–2008, with and without controlling for order flow.

The results for the standard specification are very similar to those reported before (but for the sample 1995–2008): the yen appears to be a safe haven asset (the betas have the opposite sign compared to the carry trade strategy). The second column includes one more regressor: the order flow on the JPY/USD exchange rate, measured as the number of buyer-initiated trades minus the number of seller-initiated trades (where a trade means buying JPY and selling USD). The coefficient related to the order flow is significantly positive, so there is a significant price impact meaning that demand pressure is associated with a currency appreciation, as expected. More importantly for our paper, however, is the fact that including the order flow does not materially change the betas on the equity and bond markets.

¹³For instance, the global credit crunch preventing several developing countries from paying their debt in 1982, the bond and equity market crashes in 1987 and the burst of the Japanese bubble together with the junk bond crisis in 1989 and the French Maastricht Treaty that sparked crisis in European Monetary System in 1992.

¹⁴For instance, Asian financial crisis in 1997-8 and the recent financial crisis in 2007-8.

Although limited to the JPY/USD exchange rate, this finding still suggests that our previous conclusions on the time-varying risk exposure are not sensitive to the inclusion/exclusion of order flow.

5 Conclusion

This paper studies the risk exposure of carry trade returns by estimating factor models on daily data from 1995 to 2008. The risk factors are traditional (equity and bond returns), but the risk exposures are allowed to depend on proxies for volatility and (market and funding) liquidity. We also allow for mean-reversion and use the volatility and risk proxies as additional factors.

The results from carry trade strategies based on the G10 currencies show that carry trade returns have highly regime-dependent risk exposures: the beta related to the stock market is positive in normal times—and much more so during turbulent times. In addition, the returns are more predictable (mean-reverting) during turmoil and have a direct exposure to a volatility factor. The results also hold for individual currencies: typical investment currencies have a positive exposure to equities and this exposure is much larger during periods of *FX* market turmoil, while typical funding currencies are the mirror image. The results are robust to applying of a larger set of currencies including emerging market currencies, longer sample periods, other definitions of stock market returns, net of transaction costs, and after controlling for order flow.

The economic importance of the results is significant. For instance, the (abysmal) performance of carry trade strategies during times of high (extreme) market volatility is by one third driven by exposure to traditional risk factors (equity and bond returns) and by two thirds by exposure to the volatility factor itself. Moreover, the regime-dependent factor model assigns a very small pricing error to the carry trade strategy—in stark contrast to a traditional factor model, which suggests a zero risk premium for the strategy.

We tested several variables in order to determine which factors govern the regime-dependency of the systematic risk inherent to the carry trade strategies. We find that *FX* market volatility and funding liquidity (the *TED* spread) are more relevant than measures of equity market volatility and risk aversion (*VIX*) or the *FX* market liquidity (bid-ask spread).

Our findings provide further evidence on the recent research showing that financial markets are regime-dependent with stronger comovements during financial crises (Plantin and Shin (2008), Forbes and Rigobon (2002) and Corsetti et al. (2005)), and that volatility and liquidity have important direct effects on

asset returns (Acharya and Pedersen (2005), Ang et al. (2006) and Bhansali (2007)). Our results also indicate that carry trade looks less attractive once correctly priced by means of regime-dependent models—suggesting a partial resolution of the UIP puzzle.

References

- Acharya, V. V. and Pedersen, L. H.: 2005, Asset pricing with liquidity risk, *Journal of Financial Economics* **77**(2), 375–410.
- Ang, A., Hodrick, R. J., Xing, Y. and Zhang, X.: 2006, The cross-section of volatility and expected returns, *Journal of Finance* **61**(1), 259–299.
- Bacchetta, P. and van Wincoop, E.: 2006, Can information heterogeneity explain the exchange rate determination puzzle?, *American Economic Review* **96**, 552–576.
- Bandi, F. M., Moise, C. E. and Russell, J. R.: 2008, The joint pricing of volatility and liquidity. mimeo, University of Chicago.
- Bekaert, G. and Gray, S. F.: 1998, Target zones and exchange rates: an empirical investigation, *Journal of International Economics* **45**, 1–35.
- Bhansali, V.: 2007, Volatility and the carry trade, *Journal of Fixed Income* **17**(3), 72–84.
- Brunnermeier, M., Nagel, S. and Pedersen, L.: 2009, Carry trades and currency crashes, *NBER Macroeconomics Annual 2008* **23**, 313–347.
- Burnside, C., Eichenbaum, M., Kleshchelski, I. and Rebelo, S.: 2008, Can peso problems explain the returns to the carry trade?, *Working Paper 14054*, NBER.
- Burnside, C., Eichenbaum, M. and Rebelo, S.: 2007, The returns to currency speculation in emerging markets, *American Economic Review* **97**(2), 333–338.
- Corsetti, G., Pericoli, M. and Sbracia, M.: 2005, Some contagion, some interdependence: more pitfalls in tests of financial contagion, *Journal of International Money and Finance* **24**(8), 1177–1199.
- Dahlquist, M. and Bansal, R.: 2000, The forward premium puzzle: different tales from developed and emerging economies, *Journal of International Economics* **51**, 115–144.
- Dumas, B.: 1992, Dynamic equilibrium and the real exchange rate in a spatially separated world, *Review of Financial Studies* **5**(2), 153–180.
- Embrechts, P., McNeil, A. and Straumann, D.: 2002, Correlation and dependence in risk management: properties and pitfalls, in M. Dempster (ed.),

- Risk Management: Value at Risk and Beyond*, Cambridge University Press, Cambridge, pp. 176–223.
- Evans, M. D. and Lyons, R. K.: 2002, Order flow and exchange rate dynamics, *Journal of Political Economy* **110**(1), 170–180.
- Fama, E. F.: 1984, Forward and spot exchange rates, *Journal of Monetary Economics* **14**(3), 319–338.
- Farhi, E. and Gabaix, X.: 2008, Rare disasters and exchange rates, *Working paper*, Harvard University and NYU Stern.
- Forbes, K. J. and Rigobon, R.: 2002, No contagion, only interdependence: measuring stock market comovements, *Journal of Finance* **57**(5), 2223–2261.
- Gagnon, J. E. and Chaboud, A.: 2007, What can the data tell us about carry trades in japanese yen?, *International Finance Discussion Paper 899*, Federal Reserve Bank.
- Glosten, L. R. and Milgrom, P. R.: 1985, Bid, ask and transaction prices in a specialist market with heterogeneously informed traders, *Journal of Financial Economics* **14**(1), 71–100.
- Gyntelberg, J. and Remolona, E. M.: 2007, Risk in carry trade: A look at target currencies in asia and the pacific, *BIS Quarterly Review* (December), 73–82.
- Hattori, M. and Shin, H. S.: 2007, The broad yen carry trade, *Working paper*, Bank of Japan.
- Ichiue, H. and Koyama, K.: 2008, Regime switches in exchange rate volatility and uncovered interest parity, *Working paper*, Bank of Japan.
- Krugman, P.: 1991, Target zones and exchange rate dynamics, *Quarterly Journal of Economics* **106**, 669–682.
- Lustig, H., Roussanov, N. and Verdelhan, A.: 2008, Common risk factors in currency markets, *Working Paper 14082*, NBER.
- Lyons, R. K.: 2001, *The microstructure approach to exchange rates*, MIT Press, Cambridge, Massachusetts.
- Mark, N. C.: 1988, Time-varying betas and risk premia in the pricing of forward exchange contracts, *Journal of Financial Economics* **22**, 335–354.

- McCurdy, T. H. and Morgan, I. G.: 1991, Tests for a systematic risk component in deviations from uncovered interest rate parity, *Review of Economic Studies* **58**(3), 587–602.
- Menkhoff, L., Sarno, L., Schmeling, M. and Schrimpf, A.: 2009, Carry trades and global foreign exchange volatility. mimeo, Leibniz Universitaet Hannover.
- Newey, W. K. and West, K. D.: 1987, A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix, *Econometrica* **55**(3), 703–708.
- Plantin, G. and Shin, H. S.: 2008, Carry trades and speculative dynamics, *Working paper*, London Business School and Princeton University.
- Roll, R.: 1984, A simple implicit measure of the effective bid-ask spread in an efficient market, *Journal of Finance* **39**(4), 1127–1139.
- Sarno, L., Valente, G. and Leon, H.: 2006, Nonlinearity in deviations from uncovered interest parity: an explanation of the forward bias puzzle, *Review of Finance* **10**(3), 443–482.
- Taylor, S.: 1986, *Modeling Financial Time Series*, Wiley.
- van Dijk, D., Tersvirta, T. and Franses, P. H.: 2002, Smooth transition autoregressive models - a survey of recent developments, *Econometric Reviews* **21**(1), 1–47.

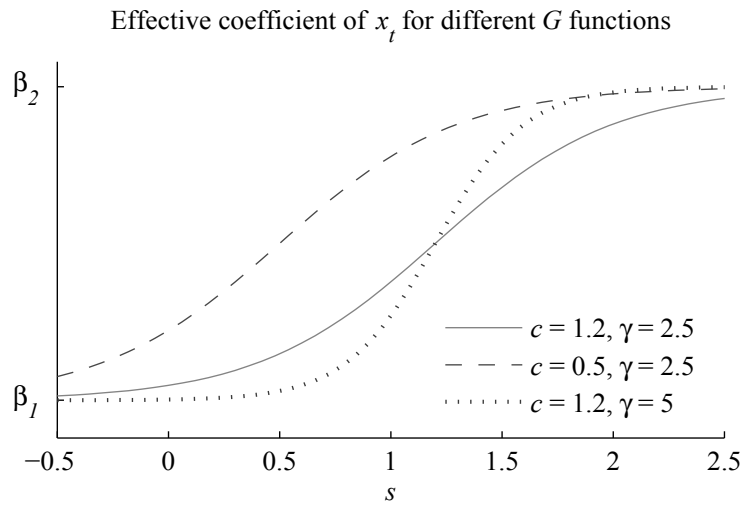


Figure 1: **Example of Smooth Transition Regression Model**

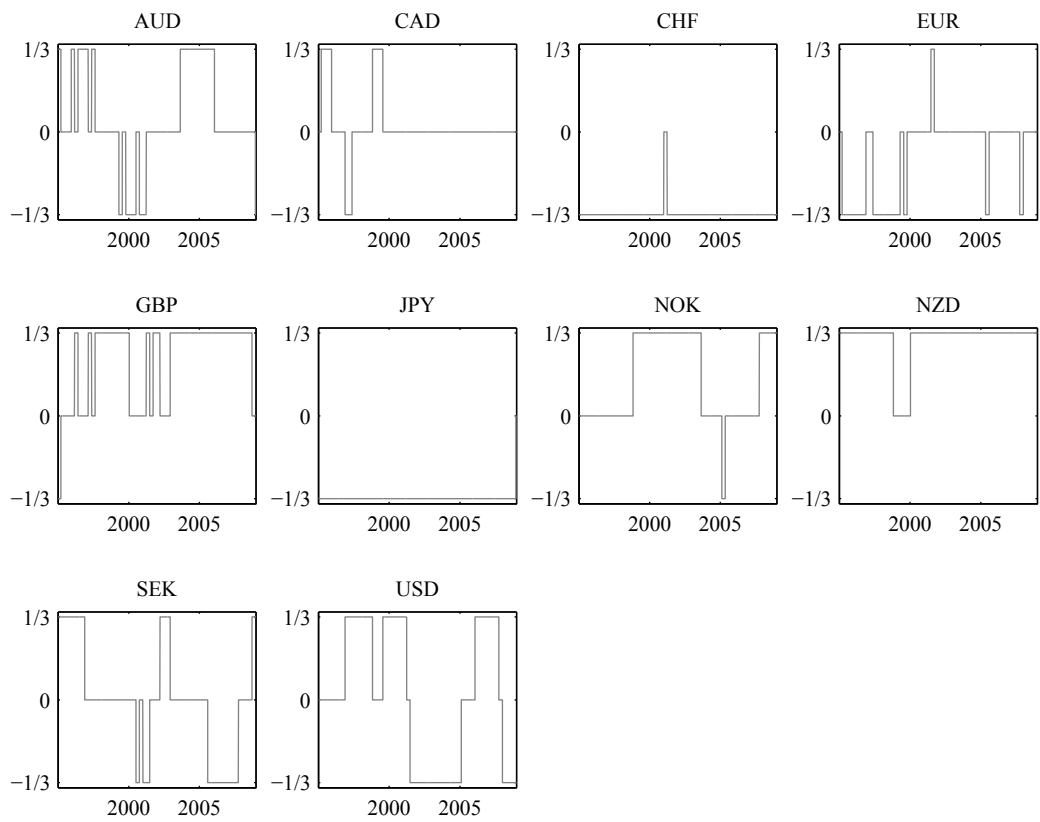


Figure 2: Carry Trade Strategy Weights

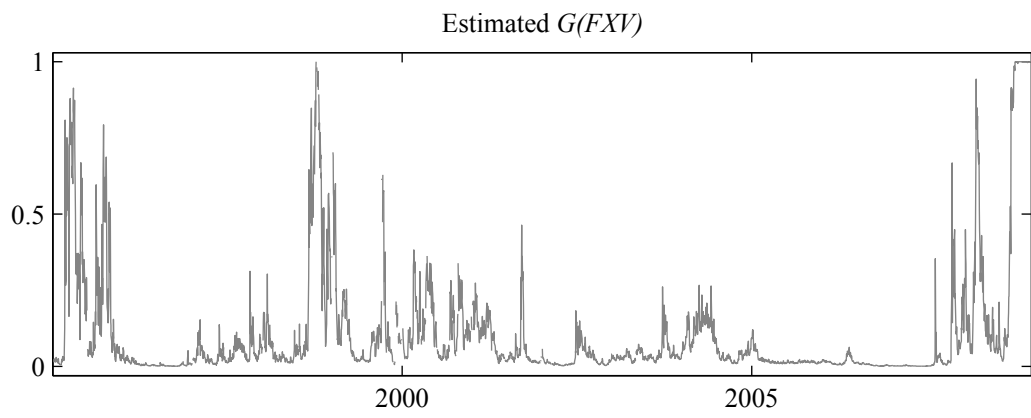


Figure 3: **Estimated $G(FXV)$ Time Series**

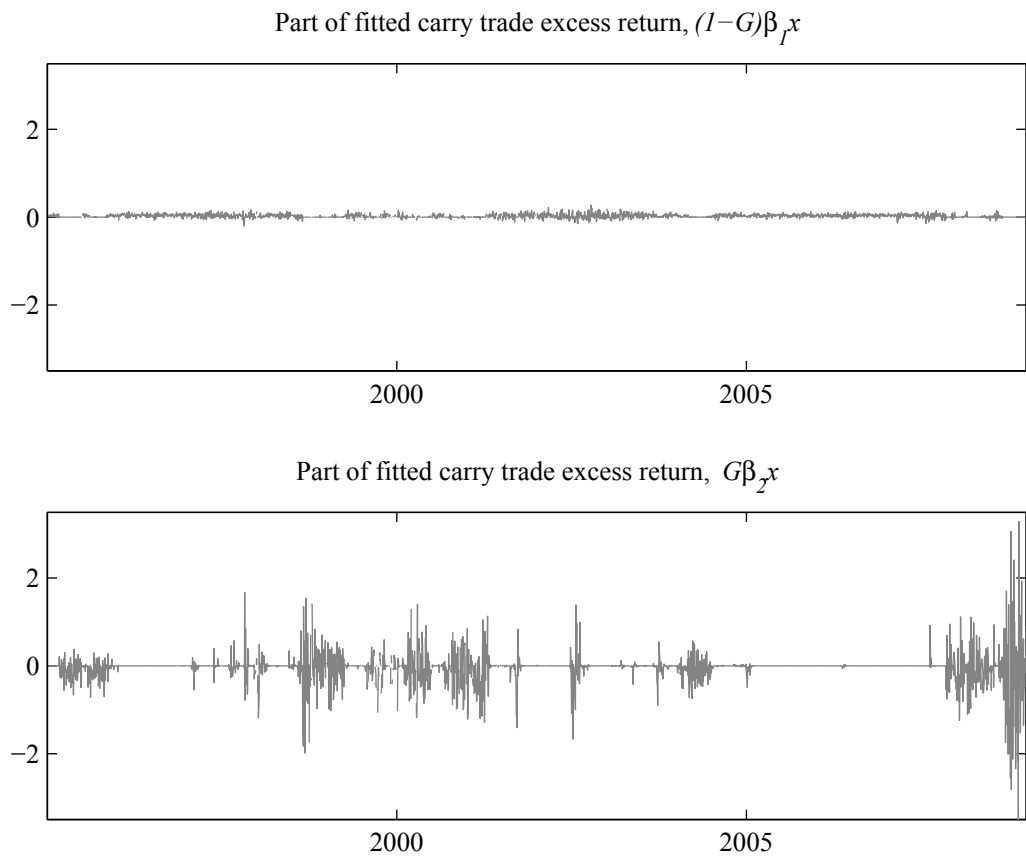


Figure 4: **Time Series of Fitted Carry Trade Excess Return**

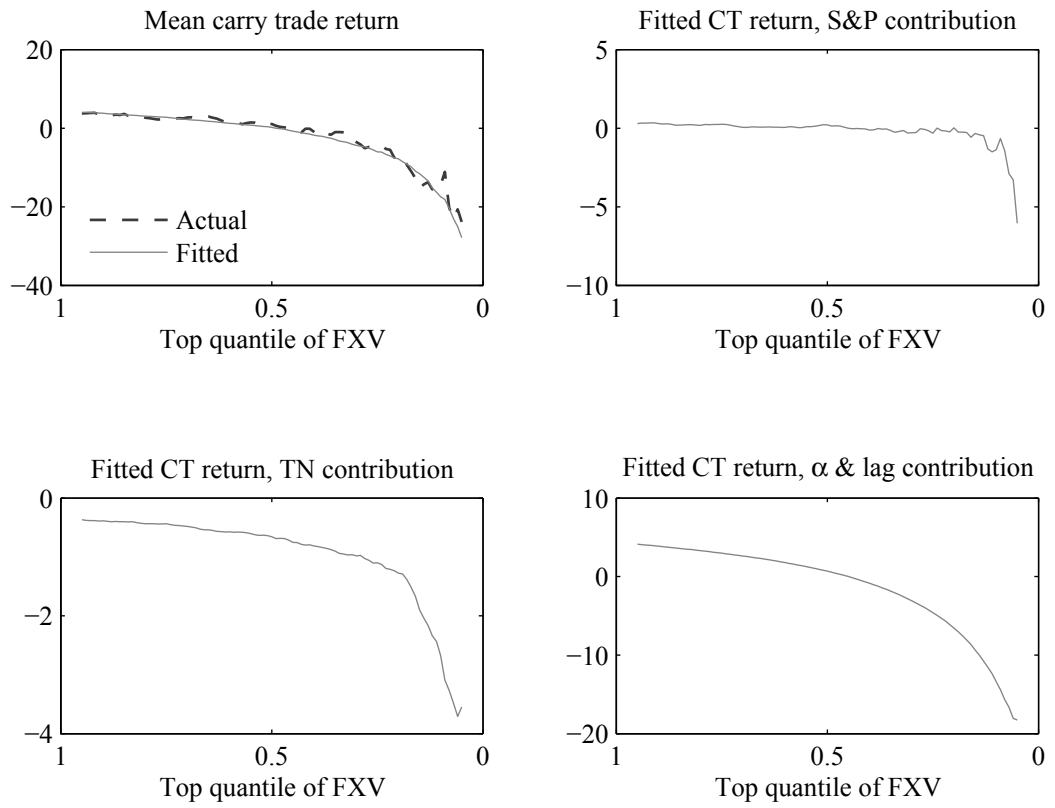


Figure 5: **Fitted (Annualized) *CT* Returns for Different Top Quantiles of *FX* Volatility**

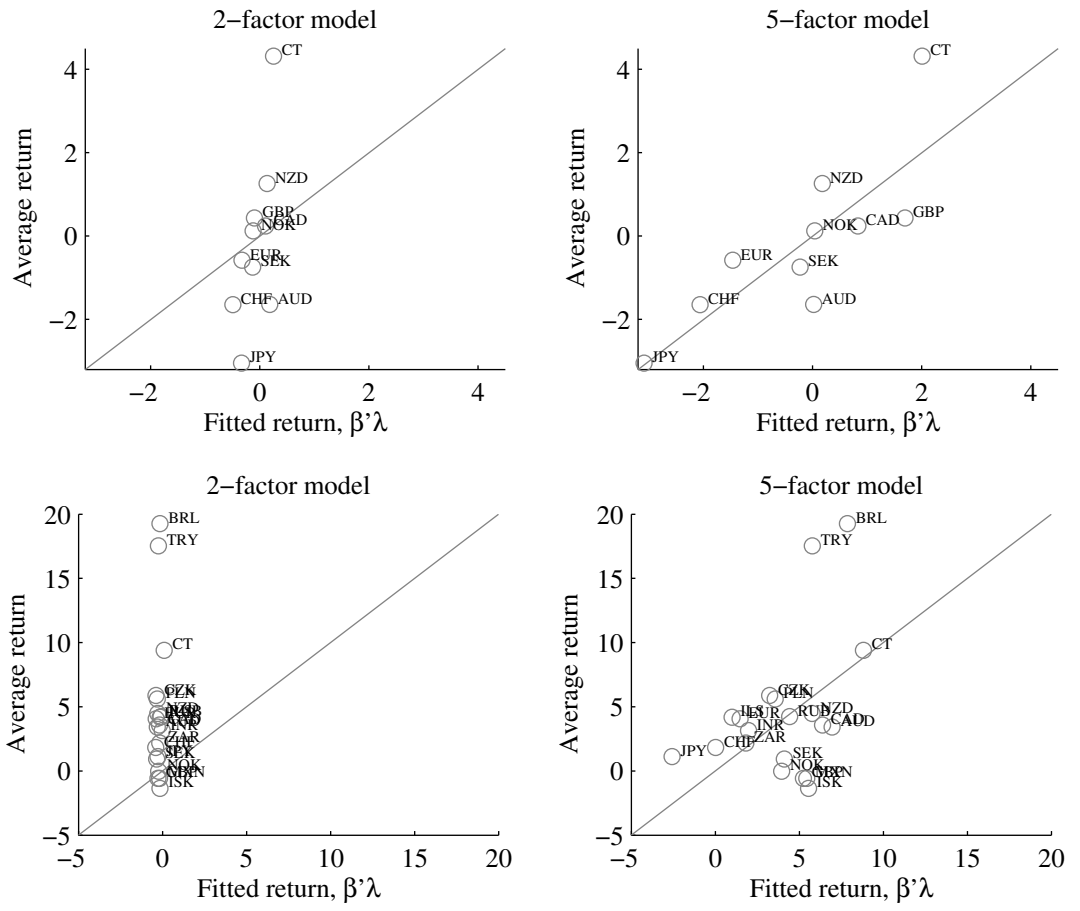


Figure 6: Cross-Sectional Fit of Asset Pricing Model (G10 Top, G20 Bottom)

	mean	mean/year	std	skewness	exkurtosis	min	max	nObs
AUD	-0.01	-1.33	0.78	-1.28	19.47	-9.22	6.50	3652.00
CAD	0.00	0.52	0.49	0.07	10.67	-4.43	4.93	3652.00
CHF	-0.01	-1.71	0.67	0.27	3.06	-4.55	5.30	3652.00
EUR	-0.00	-0.56	0.61	0.12	2.46	-3.91	3.96	3652.00
GBP	0.00	0.22	0.53	-0.13	4.23	-3.79	4.39	3652.00
JPY	-0.01	-3.72	0.70	0.61	5.05	-3.65	6.35	3652.00
NOK	0.00	0.21	0.67	-0.13	5.63	-4.90	5.34	3652.00
NZD	0.01	1.38	0.77	-0.61	7.37	-6.85	5.69	3652.00
SEK	-0.00	-0.99	0.65	0.23	4.37	-3.50	5.40	3652.00
CT	0.02	4.64	0.52	-0.90	11.12	-5.35	4.29	3652.00
SP	0.03	6.64	1.27	0.20	12.32	-9.88	14.11	3652.00
TN	0.01	2.57	0.39	-0.47	3.28	-2.82	1.76	3652.00
FXV	0.00	0.00	1.00	2.87	14.85	-1.80	8.16	3566.00

Table 1: **Descriptive Statistics, 1995–2008.** This table shows descriptive statistics for the excess returns on 9 individual currencies (relative to the USD), the carry trade strategy (CT), the SP500 (SP), the 10-year Treasury bonds (TN), as well as for the FX volatility (FXV). All returns are in percent.

FXV top quantile	Corr(z ,SP)	Corr(z ,TN)	Mean CT return	nObs
0.05	0.41**	-0.19*	-25.35	178.00
0.15	0.33**	-0.13*	-14.54	535.00
0.25	0.30**	-0.10	-3.96	892.00
0.35	0.27**	-0.09	-1.36	1248.00
0.45	0.24**	-0.08	0.21	1605.00
0.55	0.23**	-0.06	1.37	1961.00
0.65	0.21**	-0.06	3.01	2318.00
0.75	0.21**	-0.05	2.47	2674.00
0.85	0.20	-0.05	3.65	3031.00
0.95	0.19	-0.06	3.71	3388.00
1.00	0.19	-0.06	4.64	3652.00

Table 2: **Carry Trade Characteristics across FX Volatility Top Quantiles, 1995–2008.** Across the top quantiles of FX volatility, this table shows the correlation between the carry trade excess return and the stock return (first column), the correlation between the carry trade excess return and the bond return (second column), the annualized average carry trade excess return, and the number of observations. Based on a GMM test using Newey and West (1987) standard errors, */** indicates that the correlation is significantly different from the full sample (in last line) correlation at the 10%/5% level of significance.

	CT on 10 currencies 1995–2008	CT on 10 currencies 2003–2008	CT on 20 currencies 2003–2008
γ	2.49**	17.06	7.14**
c	1.25**	0.33**	0.56**
Low regime			
SP	0.03**	0.02	0.15**
SP_{t-1}	0.04**	0.05**	0.17**
TN	-0.01	-0.07*	-0.12**
TN_{t-1}	-0.03	-0.02	-0.05
z_{t-1}	0.03	0.07**	-0.02
α	0.00**	0.00**	0.00**
High regime			
SP	0.20**	0.19**	0.23**
SP_{t-1}	0.26**	0.25**	0.22**
TN	-0.20	-0.18	-0.59**
TN_{t-1}	-0.13	-0.08	-0.57**
z_{t-1}	-0.22**	-0.19**	-0.27**
α	-0.00*	-0.00**	-0.00**
R^2	0.18	0.32	0.25
nObs	3653.00	1567.00	1567.00
High–Low regime			
SP	0.18**	0.17**	0.08
SP_{t-1}	0.22**	0.20**	0.05
TN	-0.20	-0.11	-0.48**
TN_{t-1}	-0.11	-0.06	-0.52**
z_{t-1}	-0.24**	-0.26**	-0.25**
α	-0.00**	-0.00**	-0.00**

Table 3: **Parameter Estimates from the Smooth Transition Regression, Using FXV_{t-1} as Regime Variable.** The table shows the parameter estimates arising from estimating the logistic smooth transition regression model on carry trade excess returns. Based upon Newey and West (1987) standard errors, */** indicates that the parameter is significantly different from zero at 10%/5% level of significance.

	AUD	CAD	CHF	EUR	GBP	JPY	NOK	NZD	SEK
γ	[2.50]	[2.50]	[2.50]	[2.50]	[2.50]	[2.50]	[2.50]	[2.50]	[2.50]
c	2.24**	2.28**	2.17**	1.95**	1.89**	1.01**	1.64**	2.26**	1.26**
Low regime									
SP	0.03*	0.02**	-0.08**	-0.06**	-0.03**	-0.03**	-0.04**	0.03**	-0.03
SP _{<i>t</i>-1}	0.07**	0.06**	-0.05**	-0.01	-0.01	0.00	0.02	0.06**	0.05**
TN	-0.00	0.01	0.23**	0.18**	0.11**	0.10**	0.14**	0.01	0.13**
TN _{<i>t</i>-1}	0.02	-0.03	0.12**	0.09**	0.05**	0.17**	0.07**	0.07**	0.13**
z_{t-1}	0.03	-0.00	-0.03	-0.00	0.02	0.01	0.05*	0.03	0.05*
α	-0.00	0.00	-0.00	-0.00	0.00	-0.00**	0.00	0.00	0.00
High regime									
SP	0.27**	0.19**	-0.01	0.08**	0.14**	-0.14**	0.10**	0.23**	0.13**
SP _{<i>t</i>-1}	0.43**	0.21**	0.05	0.11**	0.14**	-0.11**	0.20**	0.33**	0.17**
TN	0.09	-0.03	0.24	0.12	-0.14	0.19	-0.34	0.01	0.07
TN _{<i>t</i>-1}	-0.20	-0.05	-0.05	0.01	-0.03	0.08	-0.05	-0.10	-0.16
z_{t-1}	-0.34**	-0.06	0.01	0.03	-0.00	-0.00	-0.14*	-0.16	-0.10
α	-0.00	-0.00	0.00	-0.00	-0.00*	0.00	-0.00	-0.00	-0.00
R^2	0.16	0.13	0.05	0.05	0.06	0.05	0.06	0.10	0.06
nObs	3651.00	3651.00	3651.00	3651.00	3651.00	3651.00	3651.00	3651.00	3651.00
High-Low regime									
SP	0.24**	0.17**	0.08**	0.14**	0.17**	-0.11**	0.14**	0.20**	0.16**
SP _{<i>t</i>-1}	0.35**	0.15**	0.10**	0.13**	0.14**	-0.11**	0.18**	0.28**	0.12**
TN	0.10	-0.04	0.01	-0.06	-0.25	0.09	-0.48**	-0.00	-0.06
TN _{<i>t</i>-1}	-0.22	-0.02	-0.17	-0.08	-0.09	-0.09	-0.12	-0.17	-0.30
z_{t-1}	-0.37**	-0.06	0.05	0.03	-0.03	-0.01	-0.19*	-0.19**	-0.15
α	-0.00	-0.00	0.00	-0.00	-0.00*	0.00	-0.00	-0.00	-0.00

Table 4: **Parameter Estimates from the Smooth Transition Regression, 1995–2008, Using FV_{t-1} as Regime Variable.** The table shows the parameter estimates arising from estimating the logistic smooth transition regression model separately for excess returns from 9 currencies. Based upon Newey and West (1987) standard errors, */** indicates that the parameter is significantly different from zero at 10%/5% level of significance. The γ parameter is fixed to 2.5.

Regime variable:					
	FXV	TED	VIX	Bid-ask spread	All
γ_{FXV}	2.83**				1.68**
γ_{TED}		1.86*			1.68**
γ_{VIX}			11.84**		0.39
γ_{BA}				2.38**	-0.22
c	1.19**	1.31**	2.35**	1.81**	0.81**
Low regime					
SP	0.03**	0.02	0.05**	0.04**	0.02*
SP _{t-1}	0.04**	0.04**	0.05**	0.06**	0.03**
TN	0.00	0.05	-0.04	-0.03	0.04
TN _{t-1}	-0.03	-0.02	-0.05**	-0.03	-0.02
z _{t-1}	0.02	0.04	-0.00	-0.02	0.03
α	0.00**	0.00**	0.00**	0.00**	0.00**
High regime					
SP	0.20**	0.19**	0.19**	0.20**	0.19**
SP _{t-1}	0.25**	0.24**	0.26**	0.23**	0.24**
TN	-0.25	-0.35*	-0.17	-0.15	-0.30*
TN _{t-1}	-0.09	-0.17	-0.10	-0.30	-0.13
z _{t-1}	-0.18**	-0.20**	-0.23**	-0.11	-0.18**
α	0.00**	-0.00**	-0.00**	-0.00**	-0.00**
R ²	0.21	0.22	0.20	0.18	0.23
nObs	3132.00	3132.00	3132.00	3132.00	3132.00
High-Low regime					
SP	0.17**	0.17**	0.14**	0.16**	0.17**
SP _{t-1}	0.21**	0.21**	0.20**	0.17**	0.21**
TN	-0.25	-0.40**	-0.13	-0.12	-0.34*
TN _{t-1}	-0.06	-0.15	-0.05	-0.27	-0.11
z _{t-1}	0.20**	-0.23**	-0.23**	-0.09	-0.21**
α	0.00**	-0.00**	-0.00**	-0.00**	-0.00**

Table 5: **Parameter Estimates from the Smooth Transition Regression, 1997–2008, Using Different Regime Variables.** The table shows the parameter estimates arising from estimating the logistic smooth transition regression model on carry trade excess returns. Based upon Newey and West (1987) standard errors, */** indicates that the parameter is significantly different from zero at 10%/5% level of significance.

	Standard specification	With Order flow
γ	[2.5]	[2.5]
c	1.01**	0.91**
Low regime		
SP	-0.03**	-0.02
SP_{t-1}	0.01	0.01
TN	0.11**	0.08**
TN_{t-1}	0.21**	0.20**
Order flow		0.06**
z_{t-1}	-0.01	-0.00
α	-0.00**	0.00**
High regime		
SP	-0.13**	-0.11**
SP_{t-1}	-0.11**	-0.10**
TN	0.25	0.15
TN_{t-1}	0.11	0.11
Order flow		0.07
z_{t-1}	0.03	0.02
α	0.00	-0.00*
R^2	0.06	0.09
nObs	3130.00	3130.00
High-Low regime		
SP	-0.11**	-0.09**
SP_{t-1}	-0.11**	-0.11**
TN	0.14	0.06
TN_{t-1}	-0.10	-0.09
Order flow		0.01
z_{t-1}	0.04	0.02
α	0.00	-0.00

Table 6: **Parameter Estimates from the smooth Transition Regression, JPY/USD Exchange Rate, 1997–2008, Using FXV_{t-1} as Regime Variable.** The table shows the parameter estimates arising from estimating the logistic smooth transition regression model. Based upon Newey and West (1987) standard errors, */** indicates that the parameter is significantly different from zero at 10%/5% level of significance.

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