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Fluctuations in Exchange Rates and the Carry Trade

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Fluctuations in Exchange Rates and the Carry Trade

This paper examines the relationship between the carry trade and exchange rate volatility. In a carry trade, investors borrow in low-yield currencies and invest in high-yield currencies while bearing the exchange rate risk of depreciation that could undo this profit opportunity. Prior to the onset of the 2007 global financial crisis, the carry trade provided consistently high returns, later offset by large depreciations of high-yield currencies since. Thus, low exchange rate volatility prior to 2007 is often blamed for inducing investors to take on excessive carry trade risks. On the other hand, high levels of exchange rate volatility can be harmful because of currency mismatch – the well-known *fear of floating*. We investigate these issues by examining how volatility and the carry trade are related in the context of recent work by Brunnermeier, Nagel and Pedersen (2009) and Jordà and Taylor (2009).

Keywords: carry trade, exchange rates, foreign exchange market intervention

JEL codes: F31, F37, F42, G15, G17

The financial crisis has ratcheted up a dangerous notch. The currency markets have gone topsy-turvy. The authorities now have to make some pretty big and delicate moves – something like performing microsurgery in a plane in turbulent skies. The yen has risen by 40 percent against the euro since August, with most of that occurring in October. This month, the Australian dollar has also fallen by 25 percent and the pound by 16 percent against the American dollar. Swings of this scale are alarming when they happen in the stock market. But they are petrifying in currency markets, because they make it virtually impossible to price exports or imports.

What's going on?

Edward Hadas and Hugo Dixon. New York Times, October 27, 2008.

1 Introduction

The volatility of the exchange rate is an important policy variable, particularly for many export-oriented economies. For instance, while many countries have *de jure* free-floating regimes, they are often seen intervening in foreign exchange markets to smooth fluctuations of the nominal exchange rate. This *fear of floating* is well-documented in, e.g., Reinhart (2000), Fischer (2001), Calvo and Reinhart (2002) and Reinhart and Rogoff (2004). Moreover, a country that suddenly increases its interest rate may be expected to attract foreign capital in the short-run, which in a frictionless world, would lead to an immediate appreciation of the currency. Depending on the reason for this relative interest rate increase (does it reflect shifts in relative productivity or an attempt to stomp demand-driven inflation?) a central bank may face tough choices that reflect the difficulties of reconciling conflicting goals (see, e.g. Obstfeld, Shambaugh and Taylor, 2005; or Aizenman, Chinn, and Ito, 2008).

On the other hand, low exchange-rate volatility is often blamed for inducing investors to take on excessive carry trade risks (see, e.g. Mishkin, 1997; Goldstein, 2002; and Kawai and Lamberte, 2008). Here, the carry trade refers to a strategy in which the investor tries to profit from the interest rate differential between two countries while bearing the risk of countervailing exchange rate movements. While the

uncovered interest rate parity (UIP) hypothesis suggests that this ex-ante arbitrage opportunity should not exist, meaning that the carry gain should be offset by a corresponding depreciation of the investment currency, the reverse is often found to be the case in what is referred to as the “forward premium puzzle,” see, e.g. Bansal (1997), Bansal and Dahlquist (2000), Verdelhan (2006), Burnside, Eichenbaum and Rebello (2007).

Deviations from UIP, even if persistent, could be reconciled with the observation that dramatic exchange rate realignments (crashes) are often observed when the carry trade unwinds in the absence of obvious shifts in macroeconomic fundamentals. Therefore, persistent carry trade opportunities may be seen as commensurate compensation for risk (see, e.g. Burnside, Eichenbaum, Kleshchelski and Rebello, 2008; Brunnermeier, Nagel and Pedersen, 2009; and Jordà and Taylor, 2009).

This paper investigates the relationship between the carry trade and exchange rate volatility with this backdrop. Our analysis is primarily empirical but with an eye toward some of the theoretical issues we have raised. Specifically, Brunnermeier and Pedersen (2009) suggest that persistent carry trade returns reflect a liquidity premium. Moreover, they argue that negative skewness arises when speculators hit funding constraints that amplify their losses by forcing them to unwind their carry trade positions. Thus, to the extent that volatility reflects fluctuations in market liquidity, we investigate the relationship between carry trade and exchange rate volatility. However, Jordà and Taylor (2009) find that while purchasing power parity (PPP) is a poor predictor of short-run exchange rate fluctuations (see the voluminous literature that followed Meese and Rogoff’s 1983 seminal paper such as Rogoff, 1996; and Taylor 2002), it seems to be a good signal of an impending realignment of the exchange rate. As a consequence, we are interested in separating this effect from our investigation of exchange rate volatility on carry trade fluctuations.

We focus our investigation on recent data for the period December 2000 to March 2009 and therefore include the dramatic episodes in the fall of 2007 and thereafter. The short sample reflects data availability because, unlike other studies (e.g. Burnside et al. 2007, Burnside et al. 2008, Brunnermeier et al. 2009, and Jordà and Taylor, 2009), our focus is purposefully tilted toward Asian economies. Specifically, the

countries we examine are Canada, Germany,¹ Japan, Korea, New Zealand, Norway, Singapore, Sweden, United Kingdom and the United States. Data availability also dictates that it is more convenient to set the U.S. as the home country for our calculations (since bilateral exchange rates with all currencies with the dollar are easily available), even though we are primarily interested in the Asian economies in our data set. Consequently, we focus primarily on panel data techniques to make up for the short time-series length of our sample.

Our investigation follows two empirical paths. First we try to ascertain the drivers of the dynamics of the carry trade with a novel local projection approach (Jordà, 2005) adapted to panels with cointegration (Chong, Jordà and Taylor, 2009). Second, we pursue a forecasting exercise such as a trader would conduct, and evaluate competing models on the basis of trading loss functions (as opposed to the more conventional forecast loss functions based on root mean squared errors, for example). We use formal statistical tests of predictive ability using these loss functions and rolling regressions with Giacomini and White's (2006) approach.

We find strong corroborating evidence that while exchange rates may be difficult to predict, deviations of the fundamental equilibrium exchange rate help predict large carry trade unwinds of the type described in the opening quote. This can be seen as well when examining the dynamics of the carry trade itself. However, while it is difficult to detect a strong role for volatility using the first of our empirical paths, we find that a more judicious specification (involving a threshold model) can provide useful auxiliary information for carry traders, thus somewhat supporting both Jordà and Taylor's (2009) results and the apparently contradictory results in Brunnermeier et al. (2009).

The paper is structured as follows. We open with a brief description of the data and summary statistics and then continue to discuss the two empirical strategies that we use in this paper, which are somewhat unconventional. The following two sections report the results in each case and offer a commentary on the results. We close with a summary of our results and a brief discussion of their implications for policy makers.

¹ We realize that although we use Germany's data on inflation and interest rates, the euro is determined by the European Central Bank and hence may reflect factors affecting other countries. However, as the largest economy in the euro area, we feel this approximation error is small.

2 Data Description

The criteria for choosing the countries in our sample are data availability for the yields on risk-free government bills, whose returns are the most important determinant for the carry trade. The variables in this data-set include nominal exchange rates expressed in foreign currency units per U.S. dollar; yields on 3-month government bills; the consumer price index (CPI); and the implied volatilities, derived from 3-month FX options for the nominal exchange rate. The exchange rate of the Euro against the U.S. dollar is used to construct the nominal exchange rate of Germany. All data except for the yields on U.K. government bills are obtained from Bloomberg (www.bloomberg.com). The yields on U.K. government bills are collected from the Bank of England. The sample period runs from December 2000 to March 2009, and this range is mainly determined by the data availability for the implied volatilities, which are the main focus of this paper. The nominal exchange rates and the CPIs are logged and the CPIs are seasonally adjusted. All data are observed at monthly frequency and represent the average values of the designated month. Table 1 provides sample mean statistics for the main variables broken down by country.

Several features of the data deserve comment. First, the interest rate differential against the Japanese Yen, often used as the funding currency, is positive (note that the interest rate differential is defined as the difference between the U.S. interest rates and other countries' interest rates), which indicates that there is a profit opportunity in borrowing Yen and investing into U.S. dollar. However due to the depreciation of the U.S. dollar over the sample period, which exactly offsets the interest rate differential, carry traders would not have made any profits. On the other hand, the New Zealand dollar, a typical investing currency, has a sizeable interest rate differential and this profit gain is enforced by the appreciation of the New Zealand dollar thus generating a 1.5% average quarterly return.

Second, although not explicitly reported in Table 1, it is easy to see that there is a positive cross-sectional correlation between changes in exchange rates and carry trade returns. This correlation reinforces the importance of predicting the right direction of exchange rate movements in order to realize the carry trade returns. Third, there is an

even stronger positive cross-sectional correlation between carry trade returns and the interest rate differential. The only exception to this relationship is Singapore. Interestingly, the New Zealand dollar displays the highest interest rate differential along with the highest carry trade returns. Finally, currencies that appreciated the most, such as the Japanese Yen, the New Zealand dollar, and the Norwegian krone also display the highest average volatilities. This suggests that there is good reason for traders to pay attention to the exchange rate volatilities.

Table 1 – Sample Statistics

	Individual Countries									TOT
	CAN	GER	JAP	KOR	NZD	NOR	SIN	SWE	U.K.	
Δe	-0.006 (0.045)	-0.011 (0.049)	-0.006 (0.048)	0.004 (0.057)	-0.006 (0.067)	-0.008 (0.063)	-0.004 (0.025)	-0.004 (0.062)	0.001 (0.051)	-0.005 (0.053)
m	-0.007 (0.045)	-0.012 (0.050)	0.000 (0.049)	-0.001 (0.056)	-0.015 (0.067)	-0.012 (0.063)	-0.001 (0.025)	-0.005 (0.062)	-0.004 (0.050)	-0.006 (0.053)
$i^* - i$	-0.001 (0.002)	-0.001 (0.004)	0.006 (0.004)	-0.005 (0.004)	-0.009 (0.003)	-0.004 (0.006)	0.003 (0.002)	-0.001 (0.005)	-0.004 (0.003)	-0.002 (0.006)
$\pi^* - \pi$	0.001 (0.006)	0.002 (0.006)	0.006 (0.007)	-0.002 (0.008)	-0.001 (0.007)	0.001 (0.010)	0.002 (0.009)	0.001 (0.007)	0.001 (0.007)	0.001 (0.008)
VX	8.610 (3.165)	10.155 (3.008)	10.015 (2.637)	9.268 (7.243)	12.861 (3.484)	11.412 (3.172)	5.246 (1.825)	11.454 (3.163)	8.994 (3.074)	9.779 (4.221)
q	0.846 (0.136)	0.499 (0.145)	5.389 (0.069)	3.085 (0.131)	-1.093 (0.201)	2.442 (0.134)	1.141 (0.059)	2.726 (0.141)	0.119 (0.102)	1.684 (1.829)

Notes: Sample means and sample standard deviations (in parenthesis) for the full sample, December 2000 to March 2009. The units for exchange rate changes, carry return, interest rate differential, and inflation differential are all quarterly changes. Multiplying these by 100 delivers quantities in percentages. VX is the standard deviation of exchange rate changes derived from 3-month FX options. Since raw data for calculating standard deviations is in percentage changes of exchange rates, the unit for VX is also in percentage changes.

3 Statistical Design

The available data described in the previous section restrict the empirical methods that we can pursue. For this reason, we will conduct the analysis in two parts. First, we investigate the dynamic interactions of the UIP and PPP conditions, and volatility with exchange rates using quarterly data. We aggregate the data to reflect the availability of

interest rates on three-month maturity government debt and the implied volatility measure, which as the previous section described, is derived from three-month options contracts on exchange rates. Our approach consists in using fixed-effects panel data tools, which later on we expand to construct impulse responses by local projections (Jordà, 2005 and 2009). Second, we determine the predictive ability of each of the competing factors considered from the perspective of a carry trader whose trades are constrained by three-month holding periods, but who is allowed to make trades every month. This approach respects the constraints of our data while allowing for a monthly frequency analysis. This is necessary to obtain sufficient out-of-sample observations to conduct credible tests of predictive ability using Giacomini and White (2006) procedures with a somewhat more realistic situation.

3.1 Design of the Local Projection Analysis

In order to pursue the first objective we find it convenient to think of the multivariate process characterizing a bilateral relationship before scaling the set-up to our panel of countries. Accordingly, let e_τ denote the logarithm of the nominal exchange rate in quarter τ , expressed in currency units per \$U.S. Let p_τ denote the logarithm of the consumer price index so that $\pi_\tau = \Delta p_\tau$ denotes the quarterly inflation rate. Interest rates on three-month government debt (on a quarterly basis) are denoted as i_τ and the implied volatility from three-month options contracts on exchange rates signed by $(i_\tau^* - i_\tau)$ as VX_τ (we use the sign of the interest rate differential between investment and funding currency because volatility is a strictly positive variable). Finally, p_τ^* , π_τ^* and i_τ^* will refer to the corresponding quantities for the base country, in this case, the U.S.

These variables can be thought of as forming part of the vector time series

$$\Delta y_{\tau+1} = \begin{bmatrix} \Delta e_{\tau+1} \\ \pi_{\tau+1}^* - \pi_{\tau+1} \\ i_{\tau+1}^* - i_{\tau+1} \\ VX_{\tau+1} \end{bmatrix} \quad (1)$$

where the levels of the first two entries are I(1) variables which will be cointegrated if the PPP condition holds with cointegrating vector $q_\tau = e_\tau + p_\tau^* - p_\tau$ – this is, of course, the real exchange rate. Therefore, an investigation of the dynamic properties of this system would in principle require an impulse response analysis based on its vector error correction (VECM) representation. Notice that the last two variables in this system, the interest rate differential $i_{\tau+1}^* - i_{\tau+1}$ and $VX_{\tau+1}$, appear in the levels because they are stationary. It is not common to have mixed orders of integration within the variables in a system, however, this poses no difficulty from a statistical point of view and the problem is well posed.

Because the rather short time-series dimension of our panel, we cannot use a system's estimator on (1) to obtain impulse responses because it requires estimation of many parameters and availability of degrees of freedom that are not simple at our disposal. Instead, we focus on the local projections of Jordà (2005, 2009) extended to the panel context. In particular, it is of interest to determine the response of the carry trade (i.e. $m_{j,\tau+1} \equiv \Delta e_{j,\tau+1} + i_{j,\tau}^* - i_{j,\tau}$) to fluctuations in the inflation differential, the PPP condition, the UIP condition captured by $i_\tau^* - i_\tau$, and the volatility VX_τ . Chong, Jordà and Taylor (2009) show that this can be accomplished with the following series of fixed-effect panel regressions:

$$m_{j,\tau+h} = \alpha_j^h + \beta_e^h \Delta e_{j,\tau} + \beta_\pi^h (\pi_{j,\tau}^* - \pi_{j,\tau}) + \beta_q^h (q_{j,\tau} - \bar{q}) + \beta_i^h (i_{j,\tau}^* - i_{j,\tau}) + \beta_v^h VX_\tau + \sum_{k=1}^K \gamma_k^h \Delta y_{j,\tau-k} + u_{j,\tau} \quad (2)$$

for $h = 1, \dots, H$. Specifically, Chong, Jordà and Taylor (2009) show that for the stationary variables, for example

$$LP(e_{\tau+h}, VX_\tau) = \beta_v^h \quad (3)$$

and similarly for $i_{j,\tau}^* - i_{j,\tau}$. However, the local projections due to a PPP shock are

$$LP(e_{\tau+h}, q_\tau) = (\beta_e^h + \beta_\pi^h) + \beta_q^h \quad (4)$$

where β_q^h captures the portion of the local projection due to adjustment to the long-term equilibrium PPP condition captured by q , but where the total local projection depends also from any short-term frictions in the terms $\beta_e^h + \beta_\pi^h$, which need to be added to β_q^h to obtain the complete response. The results associated with this analysis are reported in greater detail in section 4.

3.2 Design of the Predictive Ability Tests

The second part of our analysis presents a more realistic practical scenario in which a trader is interested in pursuing the carry trade and considers how best to achieve predictable positive returns. Our trader will face a number of constraints that are dictated by the data, such as three month holding periods and trades at one-month horizons only. These are clearly far longer than the daily frequency that likely characterizes such trades. On the other hand, we will not include trading costs in our analysis. Our results are meant to be suggestive rather than a realistic trading strategy.

Our starting point will be predictive regressions based on expression (2) but where the frequency of the data is monthly rather than quarterly, and hence indicated with a t subscript. In particular, the ex-post profits of a carry trade can be characterized as

$$m_{t+3} = (e_{t+3} - e_t) + (i_t^* - i_t)$$

where notice that $(i_t^* - i_t)$ refers to the interest rate differential in government instruments that mature in three-months and hence known at time t . The only variable that needs to be predicted in the previous expression is e_{t+3} and a natural way to do this is by adapting expression (2) as follows:

$$\begin{aligned} e_{j,t+3} - e_{j,t} = & \delta_j + \psi_e (e_{j,t} - e_{j,t-3}) + \psi_\pi (\pi_{j,t}^* - \pi_{j,t}) + \\ & \psi_q (q_{j,t} - \bar{q}_j) + \psi_i (i_{j,t}^* - i_{j,t}) + \psi_v VX_t + u_{j,t+3} \end{aligned} \quad (5)$$

Notice that this expression is perfectly valid for forecasting but would otherwise be problematic if we wanted to draw inferences about the specific coefficient estimates. The reason is that the residuals will have peculiar moving average structures due to the overlapping intervals of our specification.

Given forecasts of $e_{j,t+3} - e_{j,t}$ from expression (5), we consider two predictive evaluation exercises. It is common to compute the root mean squared error (RMSE) from the proposed model to compare it with a null model, either in absolute terms or in the context of a predictive ability test in the tradition of Diebold and Mariano (1995) and subsequent papers. In our case, the natural null model is the ubiquitous random walk model (see Meese and Rogoff, 1983), which appears to be invincible for forecasting exchange rates. However, a trader is not really interested in getting the forecast of exchange rates exactly right. In fact, a forecast that would allow the trader to determine which currency to invest in and which currency to fund with would result in very healthy profits even if the forecasts, in RMSE terms, were no better than a random walk's. For this reason, we report a second set of predictive ability tests in which we compare the actual returns of a carry trade strategy. Specifically, let $d_{j,t+3} = \text{sign}(\hat{m}_{t+3})$ where $\hat{m}_{t+3} = (\hat{e}_{t+3} - e_t) + (i_t^* - i_t)$ and \hat{e}_{t+3} is a forecast based on, say, a model such as (5); and $\text{sign}(\hat{m}_{t+3}) = 1$ if $\hat{m}_{t+3} > 0$, -1 otherwise. Then realized returns can be defined as

$$\hat{\mu}_{t+3} = d_{j,t+3} m_{t+3} \quad (6)$$

Below we report predictive ability tests based on expression (6) as well.

The formal procedures to determine predictive ability testing are based on Giacomini and White (2006). These tests have the advantage of permitting heterogeneity and dependence in the forecast errors, which is clearly our case. Further, the asymptotic derivations are based on the evaluation sample going to infinity while maintaining the estimation sample fixed. This conditionality on the estimation procedure is important because our evaluation is based on a fixed-window rolling sample over the evaluation sample. Moreover, because of this conditional argument,

the tests are well defined for nested models, unlike some of the more recent versions of the Diebold and Mariano (1995) test such as West (1996), McCracken (2000), for example.

The particulars of this testing procedure are as follows. Let $\{L_{t+3}^g\}_{t=R}^{T-3}$ denote the forecast loss function associated with the sequence of forecasts for time $t+3$, where R denotes the fixed size of the rolling estimation sample going from $t=1$ to $T-3$, and let $g=0,1$, that is g is an index that denotes with a 1 the model under consideration and with a 0 the null model that forms the basis for comparison. Then the test statistic:

$$GW_{1,0} = \frac{\Delta\bar{L}}{\hat{\sigma}_L / \sqrt{P}} \xrightarrow{d} N(0,1) \quad (7)$$

where

$$\Delta\bar{L} = \frac{1}{P} \sum_{t=R}^{T-3} (L_{t+3}^1 - L_{t+3}^0); \quad \hat{\sigma}_L = \sqrt{\frac{1}{P} \sum_{t=R}^{T-3} (L_{t+3}^1 - L_{t+3}^0)^2}$$

and P refers to the number of observations out-of-sample used in the evaluation. Notice that when it is suspected that there is heterogeneity and/or serial correlation in the residuals, Giacomini and White (2006) recommend a HAC estimator for $\hat{\sigma}_L$. This framework is quite flexible because it permits specification of numerous loss functions.

The more traditional loss function is based on the RMSE and can be defined as

$$L_{t+3}^g = (\hat{m}_{t+3}^g - m_{t+3})^2; \quad g = 1,0 \quad (8)$$

However, a trader is probably more concerned about ascertaining that predicted returns are statistically higher with the proposed model in which case the loss function is

$$L_{t+3}^g = \hat{\mu}_{t+3}^g; \quad g = 0,1 \quad (9)$$

But raw returns are too crude a measure of investment performance, in which case calculating the Sharpe ratio seems more sensible, giving rise to the loss function

$$L_{t+3}^g = \frac{\hat{\mu}_{t+3}^g}{\sqrt{\frac{1}{P} \sum (\hat{\mu}_{t+3}^g - \bar{\mu}^g)^2}}; \quad g = 0,1 \quad (10)$$

Finally, we consider the skewness of the carry trade. It has often been remarked (Brunnermeier et al. 2009, Sy and Tabarraei 2009) that carry trade profits are persistently positive subject to occasional crashes: “going up the stairs and coming down in an elevator.” Thus, it seems important to compare investment strategies that, while having similar rates of return, nevertheless produce distributions with different skew. These results in a loss function that can be defined as

$$L_{t+3}^g = \frac{\sqrt{P(P-1)}}{P-2} \frac{(\hat{\mu}_{t+3}^g - \bar{\mu}^g)^3}{\left(\frac{1}{P} \sum (\hat{\mu}_{t+3}^g - \bar{\mu}^g)^2\right)^{3/2}}; \quad g = 0,1 \quad (11)$$

4 The Dynamics of the Carry Trade

This section investigates the dynamics of carry trade profits with the local projection approach described in Section 3. Specifically, our results are based on the collection of fixed-effect panel regressions described in expression (1), replicated here for convenience,

$$m_{j,\tau+h} = \alpha_j^h + \beta_e^h \Delta e_{j,\tau} + \beta_\pi^h (\pi_{j,\tau}^* - \pi_{j,\tau}) + \beta_q^h (q_{j,\tau} - \bar{q}) + \beta_i^h (i_{j,\tau}^* - i_{j,\tau}) + \beta_v^h VX_\tau + \sum_{k=1}^K \gamma_k^h \Delta y_{j,\tau-k} + u_{j,\tau}$$

and with $LP(m_{t+h}, x_\tau) = \beta_x^h$ for $x \in \{\Delta e, (\pi^* - \pi), q, (i^* - i), VX\}$ and $h = 1, \dots, 6$ quarters. Ultimately, we are more interested in the drivers of the forecasting results

reported in the next section and thus less interested in a conventional structural impulse response analysis. Moreover, causative interpretation of impulse responses would have required unverifiable structural identification assumptions (such as the well-known Cholesky decomposition for a particular Wold causal ordering) that we are unwilling to make.

Table 2 – Local Projection Estimates

Model Specification:

$$m_{j,\tau+h} = \alpha_j + \beta_e \Delta e_{j,\tau} + \beta_i (i_\tau^* - i_{j,\tau}) + \beta_\pi (\pi_\tau^* - \pi_{j,\tau}) + \beta_q (q_{j,\tau} - \bar{q}) + \beta_v VX_{j,\tau} + \sum_{k=1}^K \gamma_k^h \Delta y_{j,\tau-k} + u_{j,\tau}$$

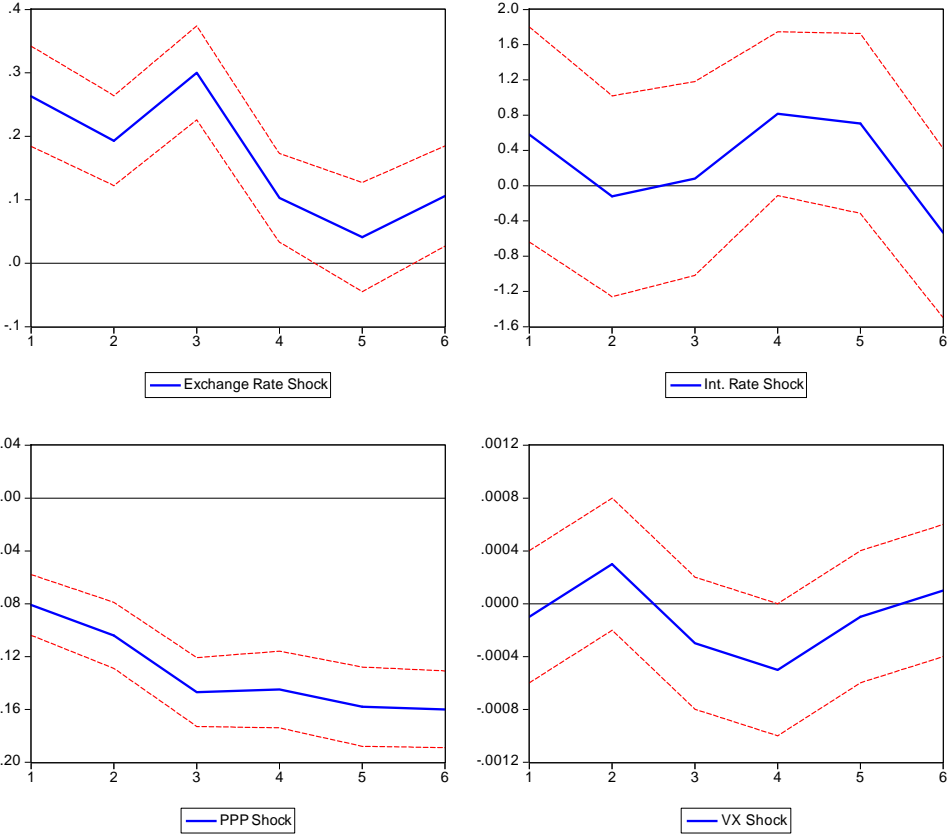
Regressors	Dependent Variables					
	$m_{j,\tau+1}$	$m_{j,\tau+2}$	$m_{j,\tau+3}$	$m_{j,\tau+4}$	$m_{j,\tau+5}$	$m_{j,\tau+6}$
$\Delta e_{j,\tau}$	0.263 (0.079)	0.193 (0.071)	0.300 (0.074)	0.103 (0.070)	0.041 (0.086)	0.106 (0.079)
$(i_\tau^* - i_{j,\tau})$	0.580 (1.22)	-0.122 (1.14)	0.081 (1.10)	0.816 (0.93)	0.705 (1.02)	-0.535 (0.96)
$(\pi_\tau^* - \pi_{j,\tau})$	0.071 (0.451)	0.781 (0.554)	-0.621 (0.467)	1.261 (0.599)	-0.285 (0.487)	0.977 (0.449)
$(q_{j,\tau} - \bar{q})$	-0.081 (0.023)	-0.104 (0.025)	-0.147 (0.026)	-0.145 (0.029)	-0.158 (0.030)	-0.160 (0.029)
VX_τ	-0.0001 (0.0005)	0.0003 (0.0005)	-0.0003 (0.0005)	-0.0005 (0.0005)	-0.0001 (0.0005)	0.0001 (0.0005)
R^2	0.092	0.096	0.146	0.153	0.144	0.158
Obs.	340	331	322	313	304	295

Notes: Robust standard errors in parenthesis. Fixed-effects, panel data estimates. Sample: December 2000 to March 2009. Quarterly frequency data.

Figure 1 reports the dynamic response of $m_{\tau+h}$ to Δe_τ , q_τ , $(i_\tau^* - i_\tau)$ and VX_τ (the responses to $\pi_{j,\tau}^* - \pi_{j,\tau}$ and the total PPP response are omitted in the figure for brevity but reported in table 2) along with one standard-error bands. Because we use no transformation, the coefficients displayed can be read directly as resulting from 1

unit impulses, that is, for Δe_t it is a 1% depreciation in the currency; for q_t it is a 1% deviation from the long-run PPP equilibrium; for $(i_t^* - i_t)$ it is a 1% increase in U.S. interest rates relative to abroad; and for VX_t a unit increase in volatility (the sample mean is approximately 10 units).

Figure 1 – The Dynamics of Carry Trade Profits



Notes: Local projections estimates based on expression (2) in the paper with fixed-effect panel estimates. Marginal one standard error-bands displayed along with coefficient estimates. Each graph displays the response of carry trade profits to a one unit shock in each of the variables displayed.

It is worth noting that the response to q is particularly important for several reasons. First, because it measures the deviation from long-run real exchange rate equilibrium (which could originate from any number of factors related to movements in exchange

rates and/or relative prices), it has a more convenient and direct causative interpretation. Second, Jordà and Taylor (2009) focus on this variable as being critical in predicting carry trade profits over the volatility index of Brunnermeier et al. (2009). The statistical design in this section provides a more convenient basis for comparing the relative merits of these two variables in our data-set and hence elucidates on the claims made by these papers.

The results in figure 1 are revealing. It is well understood that exchange rates are persistent but here it is clear that naïve carry trade investment strategies have successful runs that last many periods. This is presented in the top-left panel of figure 1, where even a year after impact, the currency continues to depreciate in a substantial manner. This likely explains the first part of the euphemism “going up the stairs and coming down the elevator” so often associated with the carry trade. The second component of the carry trade is the interest rate differential between the investment and funding currencies displayed in the top-right panel of figure 1. Although a disturbance to this differential is difficult to pinpoint in a statistical sense, it is clear that its effects are quantitatively substantial: on impact a 1% depreciation in the currency has a 0.26% effect on carry trade profits whereas a 1% impact on the interest rate differential has a 0.58% effect instead.

The bottom-left panel contains the response of the carry trade that is most revealing: that to disturbances in the fundamental equilibrium exchange rate. This response has the correct sign and is accurately estimated suggesting a return to long-run equilibrium with a half-life of one year and almost 80% after six quarters. As Chong, Jordà, and Taylor (2009) argue, the manner in which the response is estimated, isolates short-run frictions from the true speed-of-adjustment to PPP and captures more accurately responses that are often estimated to have far longer half-lives in the literature. These results are also consistent with those in Jordà and Taylor (2009). Instead, the bottom-right panel in figure 1 shows that for conventional values of volatility, the effect on carry trade profits is rather small and imprecisely estimated. Moreover, economically, the importance of this variable seems low. Even a 40 unit jump would be associated with less than a 1% drop in carry trade profits. No doubt that the quarterly frequency of the data represents too much time aggregation to permit measuring meaningful

volatility effects. For this reason, we defer making any conclusions to the next section, where the analysis is done at a monthly frequency.

5 Predictability of Carry Trade Profits

If currencies eventually return to their fundamental equilibrium exchange rate and if volatility in foreign exchange markets portends carry trade unwinds, can these variables be used to construct a predictive model that produces positive carry trade returns, with lower risk and zero or even positive skewness (i.e. no peso problems) relative to a naïve carry trade investment strategy that solely focuses on arbitraging the interest rate differential between two countries? This section focuses on answering this question with formal out-of-sample predictive ability tests based on forecast loss functions that replicate conventional investment performance measures.

Table 3 – Estimates of the Three Linear Models

Regressors	VAR	VECM	VECM-X
$(e_{j,t-3} - e_{j,t-6})$	0.233 (0.000)	0.271 (0.000)	0.264 (0.000)
$(i_{t-3}^* - i_{j,t-3})$	-1.991 (0.001)	-2.569 (0.000)	-2.133 (0.008)
$(\pi_{t-3}^* - \pi_{j,t-3})$	0.731 (0.021)	0.533 (0.061)	0.580 (0.039)
$(q_{j,t-3} - \bar{q})$	-	-0.134 (0.000)	-0.136 (0.000)
$VX_{j,t-3}$	-	-	-0.0003 (0.363)
R^2 within	0.065	0.164	0.165
Observations	846	846	846

Notes: Sample: December 2000 to March 2009, monthly.

The basis of our analysis is expression (5), where changes in bilateral exchange rates are expressed as a linear projection of past values of exchange rates; the inflation differential; the long-run PPP equilibrium condition; the interest rate differential; and

the volatility proxy VX . The analysis considers the following three linear models: (1) the model that relies on lagged exchange rates and the inflation and interest rate differentials, labeled VAR; (2) a model that extends the VAR model to include the PPP condition labeled VECM; and (3) a model that extends VECM with lagged values of VX labeled VECM+X. These three models will be pitched against the ubiquitous random walk model investigated in the celebrated Meese and Rogoff (1983) paper. Full sample, monthly panel estimates of these models with three-month holding periods are reported in table 3.

Table 4 – Tests of Nonlinearity

Specification of the auxiliary regression:

$$(e_{j,t} - e_{j,t-3}) = \alpha_j + \rho(e_{j,t-3} - e_{j,t-6}) + \gamma_\pi (\pi_{t-3}^* - pi_{j,t-3}) + \gamma_q (q_{j,t} - \bar{q}) + \sum_{h=1}^4 \beta_h |i_{t-3}^* - i_{j,t-3}|^h + \sum_{h=1}^4 \delta_h VX_{j,t-3}^h + u_{j,t}$$

fixed-effects, panel-estimation.

Nonlinearity hypothesis:

- (a) $\beta_1 = \dots = \beta_4 = 0$
- (b) $\delta_1 = \dots = \delta_4 = 0$
- (c) $\beta_1 = \dots = \beta_4 = \delta_1 = \dots = \delta_4 = 0$

Summary of results:

Hypothesis	F-test	Value
(a) Nonlinearity in $ i_{t-3}^* - i_{j,t-3} $	F(3,826) [p-value]	0.61 [0.6090]
(b) Nonlinearity in $VX_{j,t-3} VX_{j,t-3}$	F(3,826) [p-value]	16.62 [0.0000]
(c) Nonlinearity in both	F(6,826) [p-value]	9.43 [0.0000]

Brunnermeier, Nagel and Pedersen (2009) and Jordà and Taylor (2009) in addition investigate nonlinear alternatives. Their approach is to allow for threshold effects under the view that when UIP deviations are small (or volatility is low as will be our case), then exchange rates are difficult to predict and closer in behavior to a random walk. However, outside this “tranquility” band, it may be expected that exchange rates will revert to their equilibrium levels. For this purpose, we tested our data for evidence of nonlinearity with a general test as suggested in Granger and Teräsvirta (1993). The results of these tests are reported in table 4 and provide firm evidence against the null of linearity.

Consequently, we expand our medley of linear models with a threshold model based on deviations of VX from its median. There is no way to formally ascertain whether this choice of nonlinearity is best, however, we find that this particular form lends itself to easier interpretation and full-sample estimates reported in table 5 suggest that it is a very viable alternative. In fact, as we will demonstrate shortly, this is our preferred specification.

Table 5 – Estimates of the Threshold Model

Regressors	Regime	
	$VX < \theta$	$VX \geq \theta$
$(e_{j,t-3} - e_{j,t-6})$	0.193 (0.002)	0.252 (0.000)
$(i_{t-3}^* - i_{j,t-3})$	0.813 (0.325)	-4.063 (0.001)
$(\pi_{t-3}^* - \pi_{j,t-3})$	0.422 (0.137)	0.420 (0.389)
$(q_{j,t-3} - \bar{q})$	-0.119 (0.000)	-0.136 (0.000)
$VX_{j,t-3}$	-0.0011 (0.025)	0.0012 (0.032)
R^2 within	0.107	0.174
Observations	443	403

Notes: Sample: December 2000 to March 2009, monthly.

Before we discuss our formal tests of predictive ability to compare the performance of our alternative models, it is useful to look at a summary of out-of-sample performance measures based on a fixed-window rolling regression that starts December 2000 to December 2004 and rolls from March 2005 (owing to our three month holding period) until March 2009. Table 6 calculates out-of-sample average annual carry trade returns, annualized Sharpe ratios, skewness, and the proportion of correctly called long-short positions. Notice that the out-of-sample period includes the turbulent period of the second half of 2008 and the first quarter of 2009 during which carry trade unwinds saw crashing returns to currency speculation.

Table 6 – Summary of Sample Statistics for Fixed-Window, Rolling-Sample, Out-of-Sample Panel Forecasts and Associated Giacomini-White (2006) Statistics

(a) Summary Statistics

	RW	VAR	VECM	VECM+X	Threshold
RMSE	0.059	0.055	0.053	0.054	0.055
Annual Return	-4.51%	4.72%	3.87%	5.00%	5.43%
Annual Sharp Ratio	-0.43	0.40	0.36	0.43	0.50
Skewness	-0.99	0.87	0.91	1.06	1.05
Direction Correctly Called	42.3%	55.5%	51.9%	53.8%	57.9%

Notes: RW refers to the null random walk model; VAR, VECM and VECM+X are the three linear models described in the text. “Threshold” refers to the nonlinear threshold model using VX as the threshold variable. Estimation sample for first window: December 2000 to December 2004. Prediction window: March 2005 to March 2009.

(b) Giacomini-White (2006) Statistics

	VAR	VECM	VECM+X	Threshold
Annual Return	1.80	2.91	3.08	2.89
Annual Sharp Ratio	1.85	2.88	3.10	2.94
Skewness	1.28	0.42	0.67	0.37
Direction Correctly Called	5.98	6.20	7.31	8.72

Notes: The numbers reported are t-ratios whose asymptotic distribution is $N(0, 1)$. Hence, the usual 1.96 critical value for the 95% confidence level applies. Estimation sample for first window: December 2000 to December 2004. Prediction window: March 2005 to March 2009.

The results are quite illuminating. Although a naïve carry trade strategy had produced persistently positive returns over the previous five years, such a strategy would have suffered considerably during the March 2005-2009 period, with a negative 4.51% return and negative skew of -0.99. In part this is explained by the high error-rate in picking the long-short positions for the carry trade with only 42.3% of positions correctly called. In contrast, our simple linear models perform rather well and the inclusion of VX clearly improves their performance. All exhibit positive returns and positive skews although the Sharpe ratios suggest that carry trade strategies based on these models would be rather risky. The nonlinear threshold model performs best, with an annualized rate of return of 5.43%; a Sharpe ratio of 0.50, positive skew of 1.05 and correctly calling the long-short position 57.9% of the time.

Although these results look very promising, we ask ourselves whether they might be the result of a lucky sequence of draws or whether they truly reflect a statistically measurable improvement in performance. As we explained in section 3.2 our focus is not based on traditional measures of forecasting performance based on RMSE but instead investment performance measures that reflect the type of predictive ability and investor may be most interested in. Thus table 6, panel (b) summarizes the ability to predict the long-short direction correctly by comparing actual returns with the returns that would have been realized using our candidate models to determine the long-short position as described in expression (6). All these tests consider are the null model the random walk model. The results suggest that except for the VAR model, all alternatives dominate the random walk in a statistically significant way although differences across these models are probably small.

But is this realistic enough? Presumably investors do not consider individual bilateral trades but a portfolio and to the extent that a portfolio helps diversify risk, we may expect to improve on some of the bilateral results just reported. To this aim, we consider three types of portfolios: (1) a portfolio that invests an equal amount across all currencies in our sample against the dollar, which we call the equal-weights (EW) portfolio; (2) a portfolio where the weights are determined dynamically in proportion to the expected returns to the carry for each currency against the dollar, which we call the returns-weighted (RW) portfolio; and (3) a portfolio that invests in the three

currencies against the dollar expected to have the highest returns, which we call the top-3 (T3) portfolio. The results of these experiments are reported in table 7.

Table 7 – Portfolio Performance. Out-of-Sample, Fixed-Window Rolling Regressions. Summary Statistics

Estimation sample for first window: December 2000 to December 2004. Prediction window: March 2005 to March 2009.

(a) Equal-Weights Portfolio

	RW	VAR	VECM	VECM+X	Threshold
Mean	-0.0116	0.0115	0.0094	0.0121	0.0132
S. Deviation	0.0420	0.0385	0.0345	0.0382	0.0384
Skewness	-2.2895	1.5597	2.3828	2.3703	2.3007
Kurtosis	6.3021	4.9002	7.6659	7.1810	6.6529
C. Variation	-3.6338	3.3458	3.6882	3.1693	2.9147
Ann. Return	-4.54%	4.68%	3.79%	4.91%	5.38%
Ann. Sharpe	-0.5504	0.5978	0.5423	0.6311	0.6862

(b) Returns-weighted portfolio

	RW	VAR	VECM	VECM+X	Threshold
Mean	-0.0114	0.0150	0.0115	0.0121	0.0162
S. Deviation	0.0506	0.0415	0.0400	0.0416	0.0466
Skewness	-4.2348	1.6969	3.3985	2.4404	3.4822
Kurtosis	17.8197	6.1447	13.6144	8.4676	15.5956
C. Variation	-4.4401	2.7677	3.4657	3.4486	2.8712
Ann. Return	-4.48%	6.13%	4.69%	4.91%	6.66%
Ann. Sharpe	-0.4504	0.7226	0.5771	0.5799	0.6966

(c) Best three portfolio

	RW	VAR	VECM	VECM+X	Threshold
Mean	-0.0129	0.0185	0.0107	0.0115	0.0202
S. Deviation	0.0603	0.0518	0.0475	0.0503	0.0551
Skewness	-2.4592	1.5660	2.3598	1.8422	1.7983
Kurtosis	7.4165	4.4723	7.6758	5.3789	5.0294
C. Variation	-4.6744	2.7942	4.4323	4.3780	2.7323
Ann. Return	-5.06%	7.62%	4.35%	4.67%	8.31%
Ann. Sharpe	-0.4279	0.7158	0.4512	0.4568	0.7320

Notes: Equal-weights portfolio refers to investing in each currency in our sample in equal proportion; Returns-weighted portfolio refers to investing in each currency in proportion to the expected return on that currency; Best-three portfolio refers to the portfolio that invests an equal amount to the three currencies expected to have the highest rate of return.

These results further confirm the dominance of our preferred nonlinear threshold model based on VX . Notice that in every case, this model achieves the highest out-of-sample returns (5.38% for EW; 6.66% for RW; and 8.31% for T3) with much

improved Sharpe ratios of 0.69 for EW; 0.70 for RW; and 0.73 for T3, which should be compared with returns of 5.43% and a Sharpe ratio of 0.50 from table 6.

We do not expect hedge funds will rush to replicate these investment strategies. However, these results conclusively suggest that volatility is indeed a very important determinant of carry trade profits and therefore it is to be expected that a central bank's desire to keep exchange rate volatility low is likely to inadvertently modify incentives for carry trade investors.

6 Conclusion

Central banks in export-oriented economies with *de jure* floating exchange rates face continuous fluctuations of their currency in a market of astonishing size and where transactions happen at warp speed. Management of the exchange in a manner consistent with broad domestic macro-economic objectives, an inherently difficult task, is further complicated by the gyrations in foreign exchange markets induced by carry traders. While a stable exchange rate may be desirable for exporters, that same stability may generate unwanted carry trade activity and compound risks of currency collapses. This paper investigated carry trade incentives from the perspective of individual investors as a way to examine empirically what role does exchange rate volatility play in such decisions.

The critical component in determining carry trade profits is a good prediction of exchange rates. At least since Meese and Rogoff (1983) the profession has been well aware of the futility of such an enterprise. However, recent work by Jordà and Taylor (2009) and Brunnermeier et al. (2009) suggests that measurably profitable carry trade strategies can be devised when the fundamental equilibrium exchange rate and foreign exchange volatility are taken into account. Our paper corroborates some of these findings but more importantly, elucidates the specific contribution of each factor.

While an exploratory analysis about the drivers of the carry trade suggests that foreign exchange volatility plays a rather minor role relative to the fundamental equilibrium exchange rate (thus confirming Jordà and Taylor's 2009 findings) we find

that a more sophisticated approach (based on nonlinear specifications) rescues the relevance of volatility in determining future carry trade profitability. The first analysis relies on a novel panel local projection approach whereas the second is predicated on an out-of-sample predictive ability evaluation exercise based on investment loss functions rather than the more traditional statistical loss functions.

Nonlinearity in volatility turns out to be a very important factor in our analysis. We find that within a band of “tranquility” (defined by the level of foreign exchange volatility), exchange rates behave like a random walk although persistent carry trade profits can still be had owing to the limited variation in the currency. Outside of this band, reversion of exchange rates to their long-run fundamental equilibrium levels can cause dramatic carry trade wipe-outs that to some extent can be moderated by trading in the direction of purchasing power parity. Thus a piece of the puzzle is put together but surely the question of how central banks in small open economies oriented towards exporting should conduct optimal monetary policy deserves further research that accounts for the financial factors that we have highlighted in this paper.

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