Carry Trades and Currency Crashes*

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Abstract

This paper documents that carry traders are subject to crash risk, i.e. exchange rate movements between high interest rate and low interest rate currencies are negatively skewed. We argue that this negative skewness is due to sudden unwinding of carry trades and increases when global volatility, as measured by the VIX, rises. Carry-trade losses reduce the future crash risk, but increase the price of crash risk. We also document excess co-movement among currencies with similar interest rate. Our findings are consistent with a model in which carry traders are subject to funding liquidity constraints.

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1 Introduction

This paper studies crash risk of currencies for funding-constrained speculators in an attempt to shed new light on the major currency puzzles. Our starting point is the currency carry trade, which consists of selling low interest-rate currencies – "funding currencies" – and investing in high interest-rate currencies – "investment currencies." While the uncovered interest rate parity (UIP) hypothesizes that the carry gains due to the interest-rate differential is offset by a commensurate depreciation of the investment currency, empirically the reverse holds, namely the investment currency appreciates a little on average albeit with a low predictive R^2 (see e.g. Fama (1984)). This violation of the UIP – often referred to as the "forward premium puzzle" – is precisely what makes the carry trade profitable on average. Another puzzling feature of currencies is that dramatic exchange rate movements occasionally happen without fundamental news announcements, e.g. the large depreciation of the US Dollar against the Japanese Yen on October 7th and 8th of 1998, depicted in Figure 1.[1]

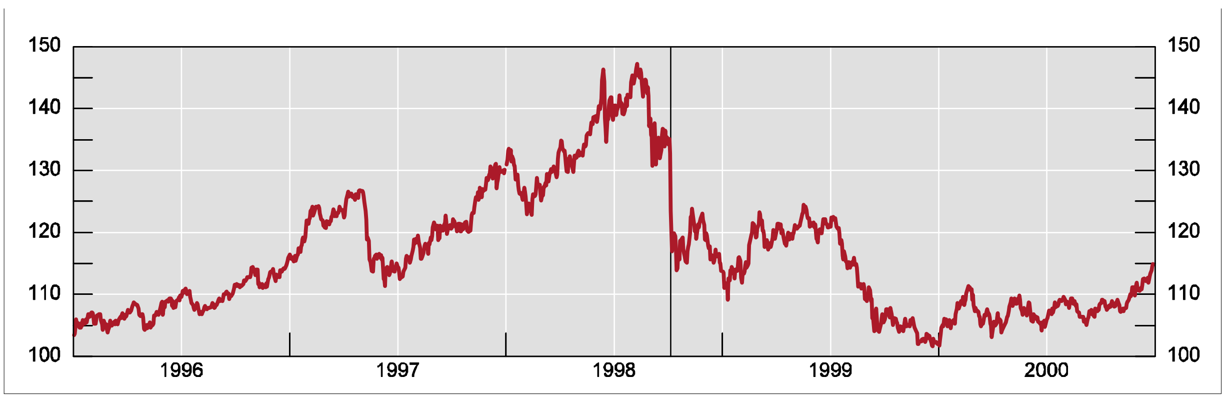

Figure 1: US Dollar/ Japanes Yen exchange rate from 1998 to 2000.

Cutler and Summers (1989) and Fair (2002) document that many abrupt asset price movements cannot be associated with a fundamental news event.

We conjecture that sudden exchange-rate moves unrelated to news can be due to unwinding of carry trades when speculators near funding constraints, and the associated crash risk discourage speculators from trading enough to insure the UIP. This idea is consistent with our findings that: (i) investment currencies are subject to crash risk,

[1] While the LTCM debacle, which occurred between end-August and early-September 1998, is not completely unrelated, it is quite distinct from the US Dollar/Japanese Yen crash on October 7th and 8th 1998. Not also that the Fed's surprise interest rate cut of .5 percent happened only on October 15th.

that is, interest-rate differentials predict negative conditional skewness; (ii) speculators' trade carry, that is, interest-rate differentials predict positive speculator net positions; (iii) speculators' positions increase crash risk and the option-implied price of crash risk; (iv) carry-trade losses increase the price of crash risk, but lower speculator positions and crash risk; (v) an increase in global risk or risk aversion as measured by the volatility of equity options VIX coinsides with reductions in speculator carry positions (unwind) and carry-trade losses; (vi) currencies with similar interest rate co-move with each other, controling for other effects.

Our findings share several features of the "liquidity spirals" arising in the model of Brunnermeier and Pedersen (2008). They show theoretically that securities that speculators invest in have a positive average return and a negative skewness. The positive return is a premium for providing liquidity and the negative skewness arises from an asymmetric response to fundamental shocks: shocks that lead to speculator losses are amplified when speculators hit funding constraints and unwind their positions, further depressing prices, increasing the funding problems, volatility, and margins, and so on. Conversely, shocks that lead to speculator gains are not amplified.

In the currency setting, one can imagine a country suddenly increases its interest rate, perhaps to attract foreign capital. In a frictionless economy, this should lead to an immediate appreciation of the currency – perhaps associated with an inflow of capital – and a future depreciation of the exchange rate such that UIP holds. With liquidity constraints, capital only arrives slowly and the exchange rate only appreciates slowly, disrupted by sudden depreciations as capital is occationally withdrawn.

Also, Plantin and Shin (2007) shows in a dynamic global games framework that carry trades can be destabilizing when strategic complementarities arise, which is the case if (i) speculators' trades occur sequentially in random order, and (ii) as in Brunnermeier and Pedersen (2008), trading requires capital and margins requirements become more stringent when liquidity is tight. Strategic complementarties also play a central role in Abreu and Brunnermeier (2002).

Our empirical study uses time-series data on the exchange rate of eight major currencies relative to the U.S. dollar. For each of these eight currencies, we calculate realized skewness from daily data within (overlapping) quarterly time periods, and we show in the cross section and in the time series that high interest-rate differentials predict negative sknewness, that is carry trade returns have crash risk. Our finding is consistent with the trader saying that "exchange rates go up by the stairs and down by the elevator." We note that this saying must be understood conditionally. Indeed, currencies do not have unconditional skewness – that is, the skewness of a randomly chosen currency pair is zero – because country A's positive skewness is country B's negative skewness. Hence, our finding is that the trader saying holds for investment currencies, while the reverse holds for funding currencies. Further, we find that high interest-rate differentials predict positive speculator positions, consistent with speculators being long the carry trade on average.

We also study the risk premium associated with crash risk, that is, the "price" of crash risk. In particular, we consider the price of a "risk reversal", which is a long position in an out-of-the money call option combined with a short position of an equally out-of-the-money put. If the exchange rate is symmetrically distributed under the risk-neutral measure, then the price of the risk-reversal is zero since the value of being long the call exactly offsets the value of being short the put. On the other hand, if the risk-neutral distribution of the exchange rate is negatively (positively) skewed, the price of the risk-reversal is negative (positive). Hence, the risk reveral measures the combined effects of expected skewness and a skewness risk premium.

In the cross-section, the implied skewness from risk-reversals lines up nicely with our physical skewness measure. The time-series relationship between actual skewness and risk reveral is more surprising: a higher risk reversal predicts a lower future skewness, controlling for the interest rate differential. This finding is related to our finding that carry trade losses lead to lower speculator positons, a higher risk reversal, and a lower future skewness, though we must acknowledge the possible peso problem in estimation.[2] Hence, after a crash, speculators are willing to pay more for insurance, the price of insurance increases, and the future crash risk goes down, perhaps because of the smaller speculator positions. This has parallels to the market for catastrophe insurance as documented by Froot and O'Connell (1999) and Froot (2001).

It is also interesting to study what happens during periods in which liquidity problems are likely to be especially severe, namely when global risk or risk aversion increases, leading to possible redemption of capital from speculators, losses, increased volatility, and increased margins. To measure this, we consider the the implied volatility of the S&P500, the VIX. Note that the VIX, which is traded at the CBOE, is not mechanically linked to exchange rates since it is an equity measure. We show that during quarters in which the VIX increases, the carry trade tends to incur losses and is particularly exposed to crash risk. We also find that risk-reversal prices and carry trade activity (both contemporaneous and predicted future activity) decline during these times. The decrease in the price of risk-reversals could be due to an increase in the price of insurance against a crash risk, or it could simply reflect an objective increase in the probability of a crash. Overall, these findings are consistent with a model in which higher implied volatility heightens margins and tightens funding liquidity, forcing a reduction in carry trade positions.

Finally, we document that currencies with similar interest rate comove, controlling for certain fundamentals and country-pair fixed effects. This could be due to common increases and unwinds in the carry trade that lead to common movements in investment currencies, and common opposite movements in funding currencies.

The structure of the paper is the following. Section 2 provides a brief summary of related papers. Section 3 describes the data sources and provides summary statistics.

[2] It should also be noted that the option-implied skewness derived from risk-reversals is immune to peso problems, while the realized skewness measure is not.

Our main results are presented in Section 4. Section 5 concludes.

2 Related Literature

There is an extensive literature in macroeconomics and finance on the forward premium puzzle, which focuses mean return of the carry trade. Froot and Thaler (1990), Lewis (1995) and Engel (1996) are nice survey articles. The forward premium puzzle is also related to Messe and Rogoff (1983)'s finding that exchange rates follow a "near random walk" allowing investors to take advantage of the interest differential without suffering an exchange rate depreciation. It is only a near random walk since high interest bearing currencies even tend to appreciate (albeit with a low goodness of fit) and in the long-run exchange rates tend to converge to its purchasing power parity level.

More recently, Bacchetta and van Wincoop (2007) attribute the failure of the UIP to investors' infrequent revisions of their portfolio decisions. Lustig and Verdelhan (2007) focus on the cross-sectional variation between high and low interest rate currency return and find some correlation to consumption growth risk, but Burnside (2007) argues that this correlation is weak and that it leaves a highly significant excess zero-beta rate unexplained. Burnside, Eichenbaum, Kleshchelski, and Rebelo (2006) (2007) argue, on the other hand, that the return of the carry trade portfolio is uncorrelated to standard risk factors. They attribute the forward premium to market frictions (bid-ask spreads, price pressure, and time-varying adverse selection in Burnside and Rebelo (2007)).

Our analysis is among the first to focus on the skewness of exchange rate movements conditional on the interest rate differential, i.e. on the crash risk of carry trade strategies, perhaps because unconditional currency skewness is zero. Farhi and Gabaix (2008) develop a model in which the forward premium arises because certain countries are more exposed to rare global fundamental disaster events. Their model is calibrated to also match skewness patterns obtained from the FX option price. Instead of focusing on exogenous rare extreme productivity shocks, we provide evidence consistent with a theory that currency crashes are often the result of endogenous unwinding of carry trade activity caused by liquidity spirals. Jurek (2007) computes the Sharpe ratio of the carry over the period 1999-2007 with and without downside protection from put options. He finds a high Sharpe ratio in both cases, though highest without the put options. Ranaldo and Söderlind (2007)'s finding that safe-haven currencies appreciate when stock market volatility increases, can be related to our third set of findings that unwinding of carry trades is correlated with the volatility index, VIX.

Gagnon and Chaboud (2007) focus primarily on the US Dollar to Japanese Yen exchange rate and links the crashes to balance sheet data of the official sector, the Japanese banking sector and the household sector. Galati, Heath, and McGuire (2007) point to additional data sources and net bank flows between countries that are useful for capturing carry trade activity. Klitgaard and Weir (2004) make use of weekly net position data on futures traded on the CME – as we do – and document a contemporaneous (but not predictive) relationship between weekly changes in speculators' net positions and exchange rate moves. Finally, there are numerous papers that study crash risk and skewness in the stock market. Chen, Hong, and Stein (2001) seems to be closest to our study.[3]

3 Data and Definitions

We collect daily nominal exchange rates to the U.S. dollar and 3-month interbank interest rates (Eurodollar LIBOR) from Datastream from 1986 to 2006 for eight major developed markets: Australia (AUD), Canda (CAD), Japan (JPY), New Zealand (NZD), Norway (NOK), Switzerland (CHF), Great Britain (GBP), and the Euro area (EUR). For the period before the introduction of the Euro on 1/1/1999, we splice the Euro series together with the exchange rate of the German mark to the U.S. dollar, and we use German 3-month interbank rates in place of Euro interbank rates. For most tests below we use a quarterly horizon to measure exchange rate changes, and hence 3 months is the appropriate horizon for interest rates to apply uncovered interest parity in straightforward fashion.

We denote the logoritm of the nominal exchange rate (units of foreign currency per dollar) by

$$s_t = \log(\text{nominal exchange rate}).$$

The logoritm of the domestic U.S. interest rate at time t is denoted by i_t and the log foreign interest rate by i_t^*. We denote the return of a investment in the foreign currency investment financed by borrowing in the domestic currency by

$$z_{t+1} \equiv (i_t^* - i_t) - \Delta s_{t+1},$$

where $\Delta s_{t+1} \equiv s_{t+1} - s_t$, is the depreciation of the foreign currency. It is a measure of exchange rate return in excess of the prediction by uncovered interest parity since under UIP, z_t should not be forecastable:

$$E_t [z_{t+1}] = 0 \tag{UIP}$$

Hence, one can think of z as the abnormal return to a carry trade strategy where the foreign currency is the investment currency and the dollar is the funding currency. Much of our analysis focuses on the skewness of exchange rate movements. To that end, we measure the skewness of daily exchange rate changes $(-\Delta s)$ within each quarter t, denoted Skewness_t.

As a proxy for carry trade activity, we use the futures positioning data from the Commodity Futures Trading Commission (CFTC). Our variable Futures_t is the

[3] See also Barberis and Huang (2007) and Brunnermeier, Gollier, and Parker (2007).

net (long minus short) futures position of non-commercial traders in the foreign currency, expressed as a fraction of total open interest of non-commercial traders. Non-commercial traders are those that are classified as using futures not for hedging purposes by the CFTC. This basically means that they are investors that use futures for speculative purposes. We have data from 1986 for five countries (CAD, JPY, CHF, GBP, EUR) and, in our quarterly analysis, we use the last available CFTC positions report in each quarter. A positive futures position is economically equivalent to a currency trade where the foreign currency is the investment currency and the dollar is the funding currency, and, indeed, few speculators implement the carry trade by actually borrowing and trading in the spot currency market. We note, however, that the positioning data is not perfect because of the imperfect classification of commercial and non-commercial traders and, more importantly, because much of the liquidity in the currency market is in the over-the-counter forward market. Nevertheless, our data is the best publicly available data and it gives a sense of the direction of trade for speculators.

Finally, to use data on foreign exchange options to measure the cost of crash risk or, said differently, the risk-neutral skewness. Specifically, we obtain data from J.P. Morgan on quotes of 25Δ 1-month risk reversals. These risk reversals are a long position in a foreign currency call (against U.S. dollars) combined with a short position in a foreign currency put. They are quoted in terms of the implied volatility of the call minus the implied volatility of the put. The label 25Δ refers to how far out of the money the options are, namely the strike of the call is at a call delta of 0.25, and the strike of the put is at a call delta of 0.75 (recall that an at-the-money call with strike at the current forward exchange rate has a call delta of 0.5). Buying a risk reversal provides insurance against foreign currency appreciation, financed by providing insurance against foreign currency depreciation. Thus, a risk reversal provides insurance for the downside risk inherent in a carry trade that invests in the domestic currency financed by borrowing in the foreign currency. Holding risk premia constant, a higher positive skewness would lead to a higher value of this risk reversal, a higher negative skewness would lead to a more negative value of the risk reversal. In other words, the risk reversal quotes tell us about the risk-neutral skewness of foreign exchange movements. Of course, due to risk premia the risk-neutral skewness is not necessarily equal to the physical skewness of exchange rate changes.

4 Results

4.1 Summary Statistics and Simple Cross-Sectional Evidence

We begin by highlighting some basic features of the data in our summary statistics in Table 1. Panel A shows that there is a positive cross-sectional correlation between the average interest-rate differential $i^*_{t-1} - i_{t-1}$ and the average excess return z_t, which points to the violations of UIP in the data. For example, the currency with the most negative average excess return (JPY) of −0.004 also had the most negative average interest rate differential relative to the U.S. dollar of −0.007. The currency with the highest excess return (NZD) of 0.013 also had the highest average interest rate differential of 0.009.

It is also apparent from Table 1 and Figure 2 Panel A, that there is a clear negative cross-sectional correlation between skewness and the average interest-rate differential. We see that the countries line up very closely around the downward sloping line, with an R^2 of 81.25%. For example, skewness is positive and highest for JPY (a "funding currency"), which also has the most negative interest rate differential. Skewness is most negative for AUD (an "investment currency"), which has the second-highest interest rate differential. This negative correlation between interest rate differentials and skewness shows that carry trades are exposed to negative skewness. An investor taking a carry trade investing in AUD financed by borrowing in USD during our sample period would have earned both the average interest rate differential of 0.006 plus the excess FX return on AUD relative to USD of 0.009, but would have been subject to the negative skewness of −0.322, on average, of the daily return on the carry trade. An investor engaging in carry trades borrowing in JPY and investing in USD would have earned the interest rate differential of 0.007 plus the gain from the excess return of the USD relative to JPY of 0.004, but would have been subject to negative skewness of −0.318.

The summary statistics also show that speculators are on average carry traders since there is a clear positive correlation between the average interest rate differential and the average net futures position of speculators in the respective currency. For example, speculators are most short JPY, which has the most negative average interest rate differential.

Finally, the last row of Panel A shows the average value of risk reversals, for the subset of our sample from 1998 to 2006 for which we have risk reversal data. Recall that the risk reversals provide a measure of the risk-neutral skewness in currency changes. The table and Figure 2 Panel B show that countries with low interest rates tend to have positive risk-neutral skewness skewness, while countries with high interest rates tend to have negative risk reversal.

Our simple cross-sectional findings already provide new interesting evidence on a clear relationship between interest rates and crash risk. One might wonder, however, whether this is driven by fundamental differences across countries that lead to differences in both their interest rate and their currency risk. To control for country-specific effects, our analysis to follow focuses on time series evidence with country-fixed effects. As we shall see, the interest rate-skewness link is also strong in the time series and several new intereting results arise. Indeed, the link between actual and risk neutral skewness is more intricate in the time series, perhaps between of liquidity crisis that come and go.

4.2 Carry Predicts Currency Crashes

To link the interest rate differential to currency trades and crash risk, we perform some simple predictive regressions in Table 2. We confirm that our data is consistent with the well-known violation of the UIP. We see this is the case in the first column of Table 2, which has the results of the regression of the return on a foreign currency investment financed by borrowing in USD in quarter $t+\tau$, on the interest rate differential in quarter t

$$z_{t+\tau} = a + b\,(i_t^* - i_t) + \varepsilon_t$$

We use a series of univariate pooled panel regressions with country fixed effects, which means that we work with within-country time-variation of interest rate differentials and FX excess returns. We later consider a more dynamic vector-autoregressive specification. The table reports only the slope coefficient b. The results show the familiar results that currencies with high interest rate differentials to the USD have predictably high returns over the next quarters. This violation in UIP is also apparent from Figure 3, which plots the exchange rates and interest rate differentials.

In this table, and most of our analysis below, and in line with most of the literature on UIP, we look at interest rate differentials and currency excess returns expressed relative to the USD. Carry traders, however, do not necessarily take positions relative to the USD. For example, to exploit the high interest rates in AUD and the low interest rates in JPY in recent years, carry traders may have taken a long position in AUD, financed by borrowing in JPY (or the synthetic equivalent of this position with futures or OTC currency forwards). Our analysis nevertheless sheds light on the profitability of such a strategy. The AUD in recent years offered higher interest rates than USD, so our regressions predict an appreciation of the AUD relative to the USD. The JPY in recent years offered lower interest rates than USD, and hence our regressions predict a depreciation of the JPY relative to the USD. Taken together, then, our regressions predict a depreciation of the JPY relative to the AUD. Thus, while we do not directly form the carry trade strategies that investors might engage in, our regressions are nevertheless informative about the conditional expected payoffs of these strategies (and also their conditional skewness).

The second column in Table 2 reports similar regressions, but now with speculators' futures positions as the dependent variable. The positive coefficient for quarter $t+1$ indicates that there is carry trade activity in the futures market that tries to exploit the violations of UIP. When the interest rate differential is high (relative to the time-series mean for the currency in question), futures traders tend to take more long positions in that currency, betting on appreciation of the high interest rate currency. In the same way as the estimated coefficients in column 1 decline towards zero with increasing forecast horizon, the estimated coefficients for futures positions in column 2 also decline towards zero. Unlike column 1, however, we obtain only marginally significant coefficient estimates, indicating that there is quite a lot of statistical uncertainty about the time-variation of futures positions in relation to movements in the interest rate differential. This somewhat noisy link between interest rates and speculator positions is also seen in Figure 5.

The third column looks at conditional skewness. Negative conditional skewness can be interpreted as a measure of "crash risk" or "downside risk" inherent in carry trade strategies. We regress our within-quarter estimates of the skewness of daily FX rate changes in quarter $t + \tau$ on the interest rate differential at the end of quarter t. We see that interest-rate differentials is a statistically highly significant negative predictor of skewness, and the coefficients decline to zero only slowly as the forecast horizon is extended. This implies that carry trades are exposed to crash risk: In times when the interest rate differential is high, and therefore carry trades look particularly attractive in terms of conditional mean return, the skewness of carry trade returns is also particularly negative. Thus, in times of high interest rate differentials, carry trade investors are long currencies might "go up by the stairs", but occasionally "come down by the elevator". The interest rate-skewness link is clear from the time-series plots in Figure 4.

The regressions in Table 2 are univariate forecasts with the interest rate differential as predictor. It would also be interesting to know the dynamic relationships between interest rate differentials, FX rate changes, futures positions, and skewness. To shed light on this question, we estimate a third-order vector autoregressions with z_t, $i_t^* - i_t$, Skewness_t, and Futures_t with quarterly data from 1986-2006 for the five currencies for which we have futures positions data. Figure 6 reports impulse response function estimated from this VAR(3) system for shocks to the interest rate differential. The shocks underlying the impulse responses are based on a Choleski decomposition with the ordering $i_t^* - i_t$, z_t, Skewness_t, and Futures_t, the most important assumption being that shocks to the interest rate differential cause changes in the other three variables but shocks in the other three variables do not affect the VAR innovation of the interest rate differential. The figure also shows 90% confidence intervals, which are bootstrap confidence adjusted for bootstrap bias following Kilian (1998). The top left graph shows that after a positive shock to the interest rate differential, the interest rate differential keeps rising for about four quarters, before it slowly reverts back to the mean. The top right graph shows that positive shocks to the interest rate differentials also lead to appreciation of the foreign exchange rate. For this graph we have cumulated the impulse responses of the excess return over the forecast horizon, so that the impulse response for quarter τ shows the total effect of the predictable exchange rate returns from quarter $t + 1$ to $t + \tau$ on the FX rate.

We can interpret this impulse response of the exchange rate as a slow response – or, short-term under-reaction – to the change in interest rates, although we must acknowledge that a VAR has a limited ability to capture an immediate response and that this depends on our particular specification. It is also of interest to consider whether there is evidence for long-term over-reaction. Over-reaction corresponds to a hump-shaped impulse-response where the exchange rate increases too much, and then comes down. We do not find evidence of this. Another expression of over-reaction would be that the exchange rate appreciates more than the present value of the interest-rate effect. The horizontal line in Figure X is the present value of the interest-rate differential, and, as we can see, the total estimated exchange rate change is within that line, again evidence against over-reation. This contrasts with the popular concern that seems to exist that carry trade activity creates “bubbles” that drive FX rates away from fundamentals, followed by subsequent crashes as the FX rate drops back towards its fundamental value. Our results do not rule out that this may happen in some instances, and our statistical power is limited and subject to our specification, but our results suggest that, at least on average, carry trade activity seems to push FX rates towards fundamentals. This would be consistent with the conjecture by Grossman (1995) that capital flows, and therefore also FX rates, react sluggishly to shocks in interest rate differentials, and that carry trade activity essentially helps to speed up the adjustment. Our analysis additionally shows that carry traders are exposed to "crash" risk in the form of negative skewness of carry trade returns, which may constitute one of the reason why carry traders demand a risk premium, and, therefore, why the adjustment of FX rates to interest rate shocks does not happen instantaneously.

The bottom left graph shows that the forecasted futures positions correspond closely to the forecasted interest rate differentials in the top left graph, consistent with higher interest rate differentials leading to more carry trade activity. Finally, the bottom right graph confirms that conditional skewness gets more negative following a positive shock to the interest rate differential, followed by slow reversion towards the mean. Overall, the VAR results confirm the basic facts from the univariate forecasting regressions.

To illustrate the crash risk visually, we estimate the distribution of excess currency return z_t conditional on the interest rate differential $i^*_{t-1} - i_{t-1}$. Figure 7 plots kernel-smoothed density estimates with observations in the sample split into three groups based on the interest rate differential. The top panel plots the distribution of quarterly returns, with observations split into $i^*_{t-1} - i_{t-1} < -0.005$, $-0.005 \leq i^*_{t-1} - i_{t-1} \leq 0.005$, and $i^*_{t-1} - i_{t-1} > 0.005$. The bottom panel plots the distribution of weekly returns with cutoffs for $i^*_{t-1} - i_{t-1}$ at -0.01 and 0.01 (the higher number of observations with weekly data allow us to move the cutoffs a bit further into the tails). Focusing on the top panel, it is clearly apparent that when the interest rate differential is highly positive, the distribution of FX rate excess returns has a higher mean, but also strong negative skewness, with a long tail on the left. When the interest rate differential is negative, we see the opposite, although somewhat more moderate, with a long tail to the right. Interestingly, even though the mean is higher with higher interest rate differentials, the most negative outcomes are actually most likely to occur in this case. Similarly, extremely positive realizations are most likely to occur when interest differentials are strongly negative. The bottom graph with weekly data shows broadly similar patterns. Hence, while our regressions focus on skewness measures derived from daily FX rate changes, the negative relationship between interest rate differentials and skewness also shows up at weekly and quarterly frequencies.

4.3 Predictors of Currency Crashes Risk and the Price of Crash Risk

We have seen that interest-rate differentials predicts skewness, and we next look for other predictors of skewness and of the price of skewness. In particular, we focus on how the level of carry trade activity and recent losses of carry trade strategies affect physical and risk-neutral conditional skewness. Table 3 presents regressions of skewness measured within quarter $t+1$, or risk reversals measured at the end of quarter t, on time-t variables. These regressions are again pooled panel regressions with country fixed-effects. The first column once again that $i_t^* - i_t$ is a strong negative predictor of future skewness. In addition, the regression show that skewness is persistent, and that futures positions are negatively related to future skewness. The second column further shows that the past currency return z_t negatively predicts skewness. This can be interpreted as currency gains leading to larger speculator positions and larger future crash risk. We also so that the currency gain variable "drives out" the futures position variable, because the futures positions at the end of quarter t are strongly positively related to excess returns z_t during that quarter (not reported in the table). Perhaps the past return is a better measure of speculator positions given the problems with the positioning data from CFTC. Taken together, the results imply that crash risk of currencies is particularly high following high returns. Times when past returns are high also tend to be times when futures positions are high. This points to the possibility that part of the skewness of carry trade payoffs may be endogenously created by carry trade activity. Gains on carry trades leads to further build-up of carry trade activity, which then also increases the potential impact on FX rates of an unwinding of those carry trades after losses, and which manifests itself in the data as negative conditional skewness.

In the third column we add risk reversals to the regression, and we obtain a surprising result. Controlling for interest rate differentials and the other variables in the regression, the relationship between risk reversals and future skewness is negative. This means that, everything else equal, a higher price for insurance against downside risk predicts *lower* future skewness. The bi-variate correlation between risk reversals and skewness (untabulated) is positive however, and so controlling for the other variables, in particular the interest rate differential, gives rise to the somewhat surprising negative coefficient.

The third and fourth columns in the table shows the regression of risk reversals on the other variables. As the table shows, risk reversals have a negative relationship to $i_t^* - i_t$, just like physical/actual skewness in the first three columns. Although for risk reversals the relationship is not statistically significant, the point estimate suggests that risk reversals and physical skewness may have a common component related to to $i_t^* - i_t$. A stark difference exists, however, in their relationship to z_t. When a currency has had a high excess return in quarter t, this predicts negative future physical skewness, but positive risk reversals, and thus risk-neutral skewness, at the end of quarter t. Evidently, there is a wedge the physical and risk-neutral skewness, i.e. a skewness risk premium, that varies negatively on the recent excess return of the currency. This again points to the possibility that skewness is endogenously created by carry trade activity: when recent carry trade return are strongly negative, carry trades get unwound, and there is less crash risk in the future. But part of the unwinding happens by carry traders buying insurance against the downside risk of carry trades, which drives up the price of insurance against crash risk, despite the fact that there is less negative conditional physical skewness.

4.4 Liquidity Risk and Unwinding of Carry Trades

Our analysis so far raised the possibility that unwinding of carry trades could explain some of the skewness of carry trades, and that the negative skewness of carry trade payoffs combined with the threat of forced unwinding could be a deterrent from engaging in large highly-levered carry trade activity that would help eliminate UIP violations. To better understand these interrelationships, we try to identify states of the world in which speculators are likely to be in to unwind positions due to losses, capital redemptions, increased margin, in reduced risk tolerance.

Identifying such states of the world empirically is not an easy task. Ideally, we would want a measure for speculators' willingness and ability to put capital at risk, but that could depend on many (largely unobservable) factors, including tightness of margin constraints, value-at-risk limits, recent returns of carry trade strategies, liquidity spillovers from other markets, the amount of risk capital devoted to carry trade strategies, and others. We use the CBOE VIX option volatility index as an observable proxy that should be correlated with at least several of these factors. Prior research has shown that the VIX index is a useful measure of the "global risk appetite", not only in equity, and equity-options markets, but also in corporate credit markets Collin-Dufresne and Martin (2001), and in other, seemingly unrelated markets. For example, Pan and Singleton (2007) find that the VIX is strongly related to the variation in risk premiums in sovereign credit default swaps. Moreover, many of the financial crises of recent years, for example the Russian/LTCM crisis of 1998, or the financial market turmoil in Summer 2007, we accompanied by strong increases in the VIX.

We define some new variables for the purpose of looking at how payoffs of carry trades relate to movements in the VIX. For that we need to account for the direction of the trade (i.e., whether the foreign or USD is the funding/investment currency). In our previous analysis, this was not necessary, because the interest rate differential, futures positions, and payoffs from exchange rate movements switch signs when the direction of the trade is reversed. But the VIX, our explanatory variable in this section, does not change sign accordingly. For that reason, we convert currency excess returns, futures positions, and risk reversals into the return of a carry trade investing in the higher interest rate (investment) currency,

$$CRet_t = z_t \times sign\left(i_t^* - i_t\right),$$

the futures position in the investment currency

$$CFut_t = Futures_t \times sign\left(i_t^* - i_t\right),$$

and the price of insurance against a crash in the investment currency

$$RiskRev_t = RiskRev_t \times sign\left(i_t^* - i_t\right).$$

To provide a first perspective, Figure 8 plots the kernel-smoothed distribution of CRet_t, at quarterly (top graph) and weekly (bottom graph) frequency, with observations grouped by the contemporaneous change in VIX, ΔVIX_t. As the top graph shows, the distribution is much more dispersed and also much more skewed to the left when ΔVIX_t is high. In other words, payoffs of carry trades are subject to substantially higher volatility, and considerable crash risk in times when the VIX rises. A similar pattern, albeit somewhat more moderate, is apparent at weekly frequency in the bottom graph. This dependence of the skewness and volatility of carry trade returns on VIX suggests that the crash risk of carry trades is particularly present in times of decreasing global risk appetite, as measured by increases in the VIX.

Table 4 presents pooled panel regressions with country fixed-effects. The first two columns show that CFut_t and CFut_{t+1} are both significantly negatively related to ΔVIX_t, meaning that carry trades are unwound in times when the VIX increases. At the same time, as shown in columns 3 and 4, risk reversals are also negatively related to ΔVIX_t. The price of insurance of carry trades against crash risk therefore increases in times of rising VIX. The previous evidence from Figure 8 suggests that at least part of this may be driven by more negative physical skewness [CHECK SIGN], but part of it may also be driven by an increase in the price of crash risk insurance in times when the global risk appetite decreases. Finally, column 5 shows that carry trades losses money on average in times of rising VIX.

Taken together, unwinding of carry trades in response to decreases in global risk appetite can jointly explain the results in Table 4 and Figure 8: When traders risk tolerance declines, carry trades are unwound which leads to a reduction in the futures positions in investment currencies, an increase in the price of insurance against crash risk, and bad payoffs of carry trades. The dependence of carry trade payoffs on changes in the VIX, which, according to prior research is driven by a large extent by variations in "risk appetite", also suggests that part of the movement in investment and funding currencies are driven by changing risk tolerance of traders, and that crashes may occur endogenously as part of the trading process with leveraged and imperfectly capitalized traders.

4.5 Predictable co-movement of FX rates

If part of the movements in investment and funding currencies are driven by changing risk tolerance of traders, then this should also affect the co-movement of FX rates. For example, if carry traders unwind in response to declining risk tolerance, and their unwinding has price impact, then this should cause funding currencies to co-move positively with funding currencies, and investment currencies with investment currencies. Thus, everything else equal, currencies with similar interest rates should co-move closely, while currencies with very different interest rates should have little, or even negative co-movement.

To test this, we calculate the pairwise correlation of daily FX rate changes within non-overlapping 13-week periods, and we regress these correlations on $|i_1^* - i_2^*|$, the absolute interest rate differential between the countries in each pair at the start of the 13-week period. The results are shown in Table 5. Of course, some countries might have similar interest rates and highly correlated FX rates for reasons other than the effects of carry trades. We control for these other reasons in several ways. First, we include $\rho(i_1^*, i_2^*)$ as a control variable, the correlation of 5-day interest rate changes, estimated with overlapping windows, within each 13-week period. This variable proxies for correlated monetary policy. Second, we also run a specification where we include country-pair fixed effects. This should take care of other unobserved time-constant reasons for a country-pair to have high or low correlation of FX rates. For example, CAD and AUD FX rates have a high correlation, due to the common exposure of their economies to mining, but this common exposure is largely absorbed by the fixed effect. Finally, to make sure that the results are not driven by the exposure of all exchange rates to a common factor, and time-variation in the volatility of this common factor which could lead to common variation in all pairwise correlations, we include either time dummies or the cross-sectional average of all pairwise correlations of daily FX rate changes within each non-overlapping 13-week periods, denoted by "Average $\rho(\Delta s_1, \Delta s_2)$".

The estimates in Table 5 show that there is a strong negative relationship between $|i_1^* - i_2^*|$ and the FX rate correlation. A reduction of 1% in the interest rate differential is associated with an increase of the FX rate correlation of more than 0.1. The results are fairly similar for all specifications shown in the table. In particular, the specification with country-fixed effects shows that this relationship holds even if we only consider within-country-pair variation. In other words, when the interest rate differential for a given country pair is lower than it is on average for this country pair, then the correlation of the FX rate is higher than it is on average for this country pair. This feature of the data is also consistent with the view we suggested above that the build-up and unwinding of carry trades associated with changes in traders' risk tolerance has an effect on FX rates.

5 Conclusion

This paper provides a strong link between currency carry and currency crash risk: investing in high interest-rate currencies has negative skewness. We document that speculators invest in high-carry currencies and argue that currency crashes are linked to the sudden unwinding of these carry trades. Consistent with models in which the erosion of capital increases insurance premia, we find that the price of protecting against a crash in the aftermath of one increases despite the fact that a subsequent crash is less likely. Further, we document that currency crashes are positively correlated with increases in implied stock market volatility. This is consistent with a setting in which higher volatility leads to lower available speculator capital due to higher margins and capital requirements and other effects, inducing traders to cut back on their carry trade activities. Finally, our finding that currencies with similar interest rate co-move with each other, controling for other effects, further suggests that carry trades affects exchange rate movements. Overall, we argue that our findings call for new theoretical macroeconomic models in which risk premia is affected by funding and liquidity constraints, not just shocks to productivity, output, or the utility function.

Table 1: Summary Statistics

	AUD	CAD	JPY	NZD	NOK	CHF	GBP	EUR
Panel A: Means								
Δs_t	-0.003	-0.002	-0.003	-0.005	-0.002	-0.004	-0.004	-0.004
z_t	0.009	0.004	-0.004	0.013	0.007	-0.001	0.009	0.003
$i^*_{t-1} - i_{t-1}$	0.006	0.002	-0.007	0.009	0.005	-0.004	0.005	-0.001
Futures positions	-	0.059	-0.097	-	-	-0.067	0.052	0.031
Skewness	-0.322	-0.143	0.318	-0.297	-0.019	0.144	-0.094	0.131
Risk reversals	-0.426	-0.099	1.059	-0.467	0.350	0.409	0.009	0.329
Panel B: Standard deviations								
Δs_t	0.049	0.028	0.062	0.050	0.053	0.063	0.049	0.059
z_t	0.050	0.029	0.064	0.053	0.053	0.064	0.049	0.060
$i^*_{t-1} - i_{t-1}$	0.006	0.004	0.005	0.007	0.008	0.006	0.005	0.006
Futures positions	-	0.248	0.242	-	-	0.296	0.272	0.202
Skewness	0.712	0.585	0.627	0.685	0.472	0.438	0.528	0.510
Risk reversals	0.436	0.343	1.204	0.466	0.515	0.550	0.391	0.534

Notes: Quarterly data, 1986-2006 (1998-2006 for risk reversals). Δs_t is the quarterly change in the foreign exchange rate (units of foreign currency per U.S. dollar), z_t is the return from investing in a long position in the foreign currency financed by borrowing in the domestic currency, Futures positions refers to the net long position in foreign currency futures of noncommercial traders. Risk reversals are the implied volatility difference between 1-month foreign currency call and put options, as described in the text.

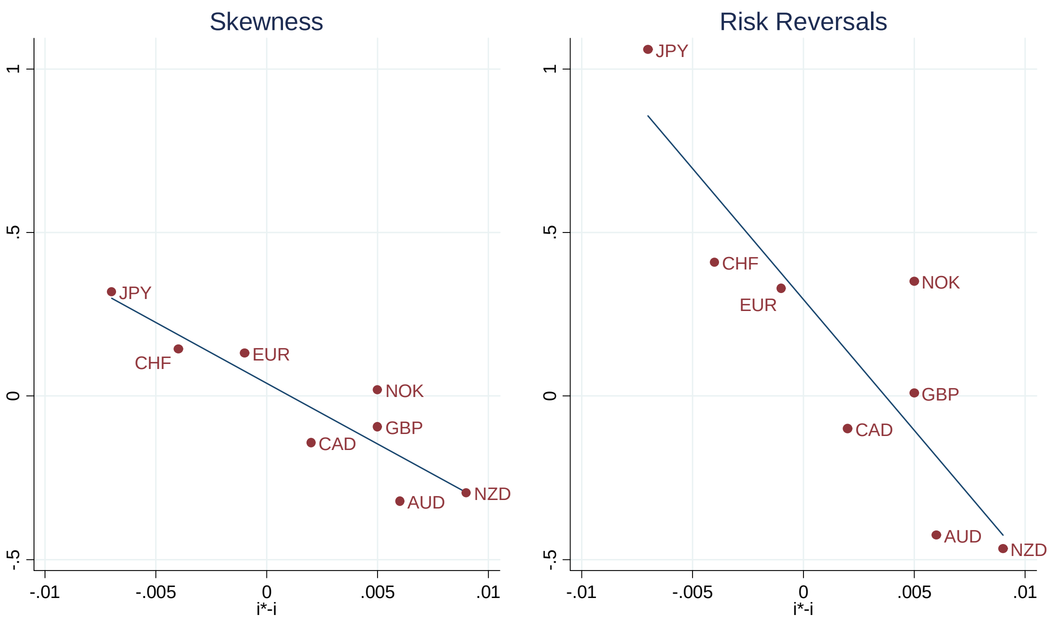

Figure 2: Crosssection of skewness (Panel A) and risk-reversals (Panel B) for different interest differentials $i^* - i$.

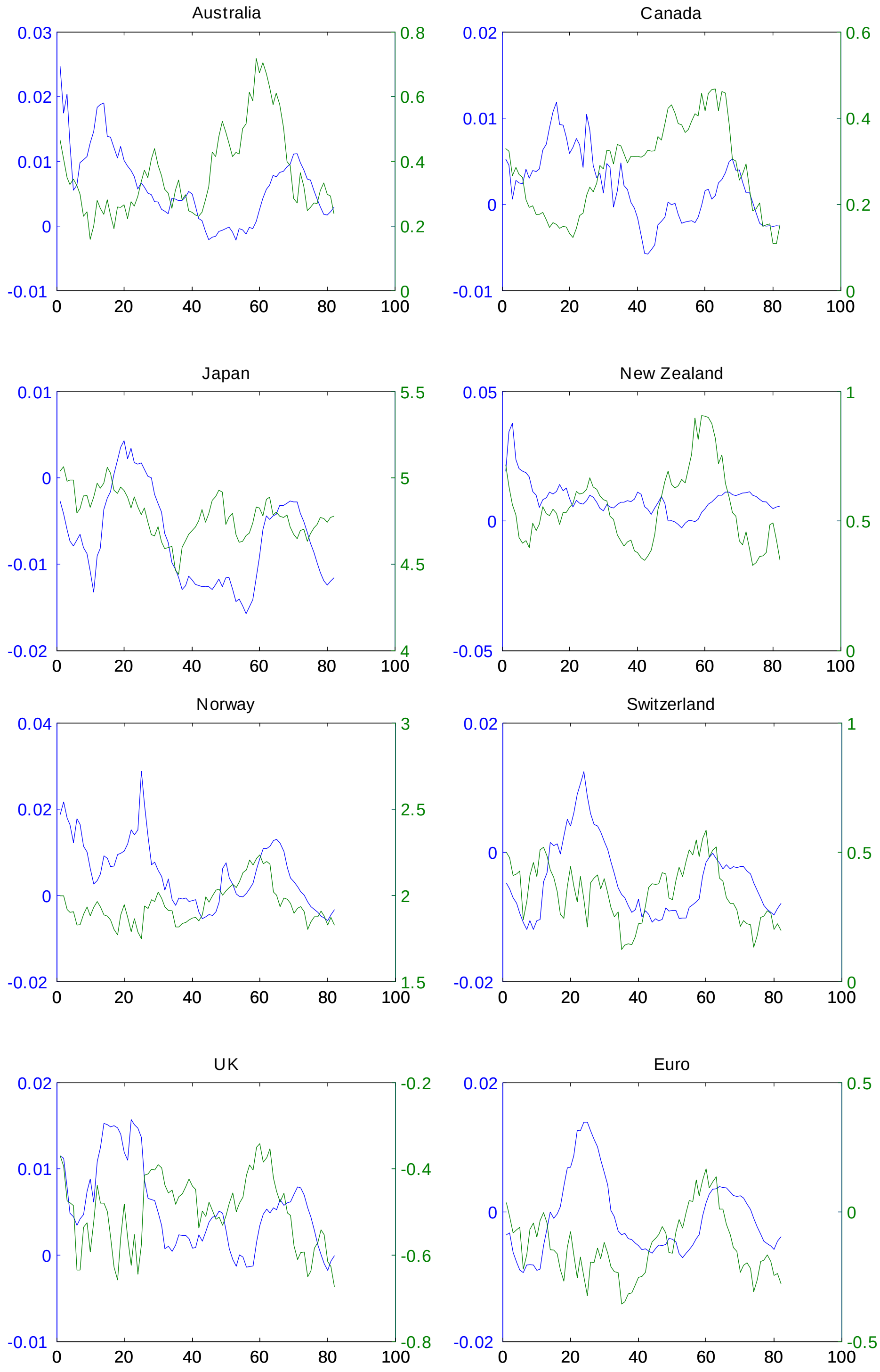

Figure 3: Log interest rate differentials (blue, left axis) and log FX rate (green, right axis)

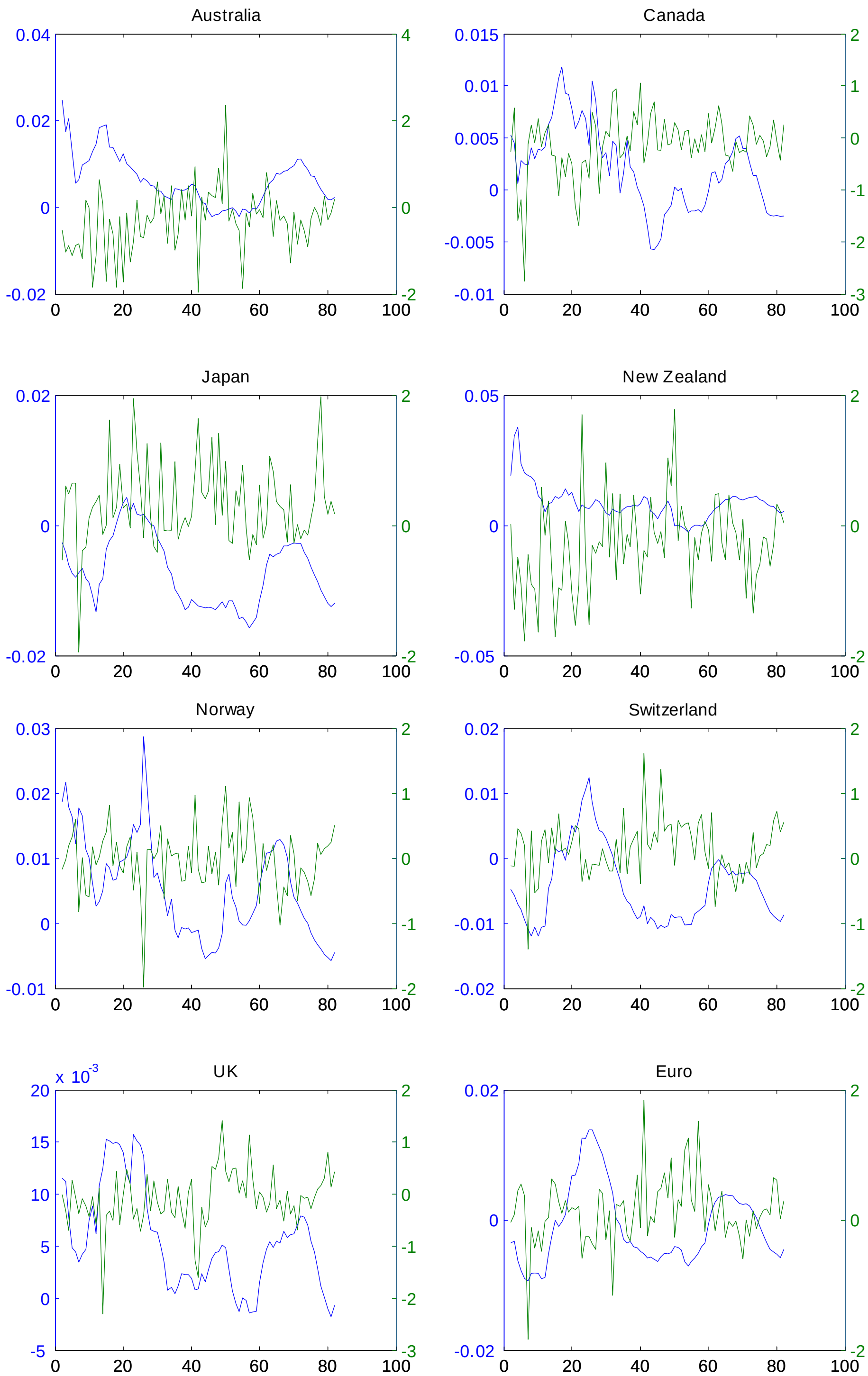

Figure 4: Lagged log interest rate differentials (blue, left axis) and quarterly skewness of daily log FX rate changes (green, right axis)

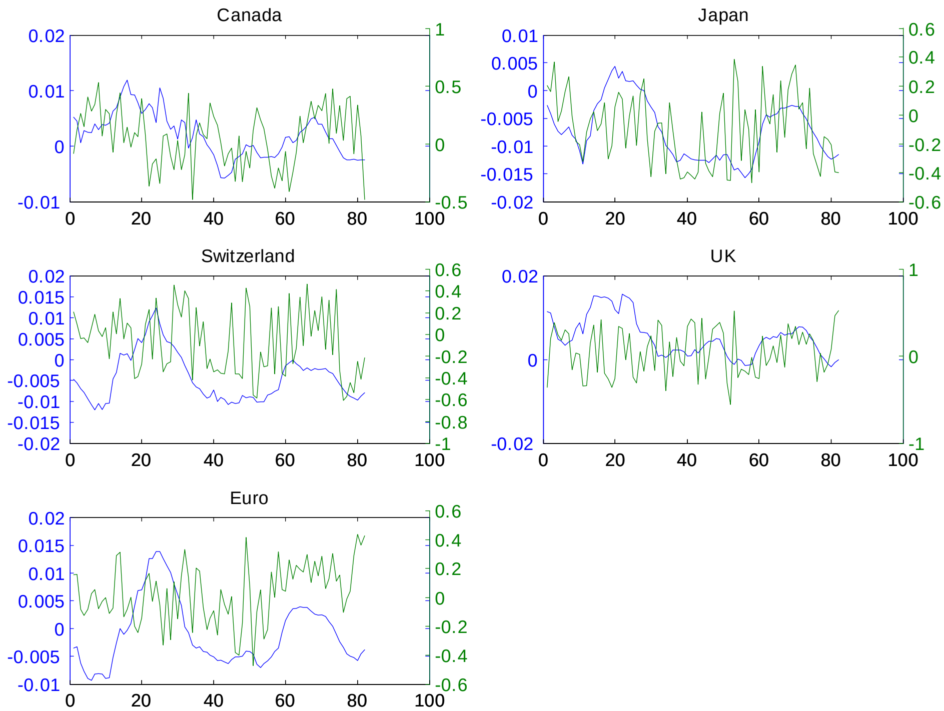

Figure 5: Log interest rate differentials (blue, left axis) and futures positions of noncommerical traders (green, right axis)

Table 2: Future excess FX rate changes, futures positions, and skewness regressed on $i_t^* - i_t$

	FX rate	Futures	Skewness
$t+1$	2.17	8.26	-23.92
	(0.78)	(5.06)	(3.87)
$t+2$	2.24	8.06	-23.20
	(0.70)	(5.08)	(3.71)
$t+3$	2.24	5.96	-23.65
	(0.70)	(4.68)	(3.87)
$t+4$	1.50	6.41	-23.28
	(0.63)	(4.44)	(4.65)
$t+5$	1.11	5.87	-23.49
	(0.52)	(3.47)	(5.05)
$t+6$	0.76	4.72	-22.24
	(0.48)	(2.52)	(5.00)
$t+7$	0.68	4.27	-21.23
	(0.49)	(1.91)	(4.09)
$t+8$	0.44	2.81	-16.96
	(0.55)	(2.12)	(4.03)
$t+9$	0.27	0.46	-12.90
	(0.63)	(2.41)	(3.45)
$t+10$	-0.04	-0.96	-11.14
	(0.78)	(3.26)	(3.74)

Notes: Panel regressions with country-fixed effects and quarterly data, 1986-2006. The regressions with $\text{Futures}_{t+\tau}$ as the dependent variable we include CAD, JPY, CHF, GBP, and EUR only (currencies for which we have futures positions data since 1986). Standard errors in parentheses are robust to within-time period correlation of residuals and are adjusted for serial correlation with a Newey-West covariance matrix with 10 lags.

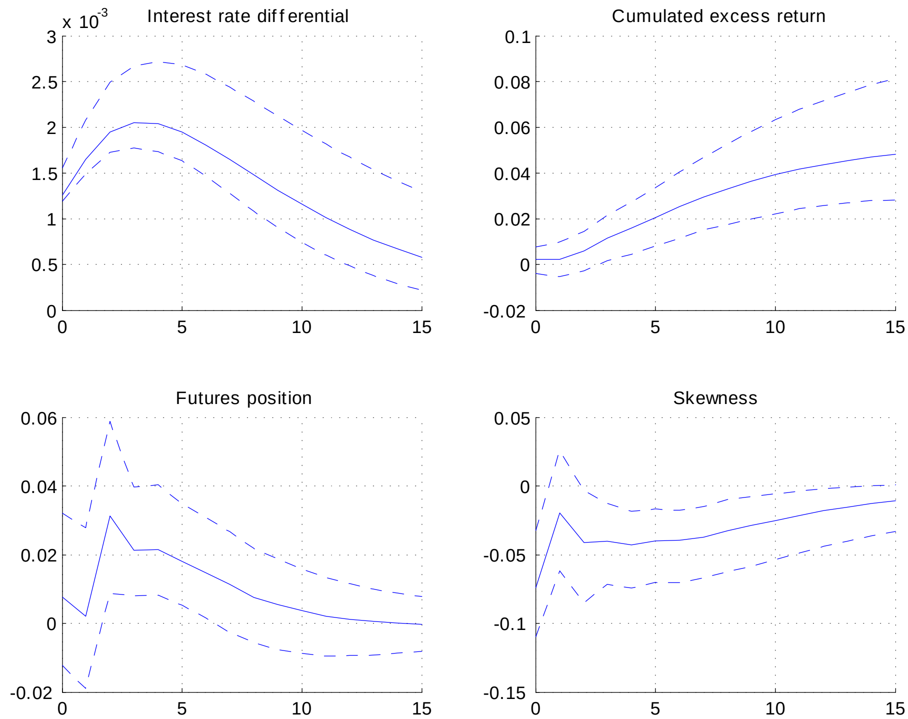

Figure 6: Impulse response functions from VAR(3) for shock to interest rate differential with 90 percent confidence intervals

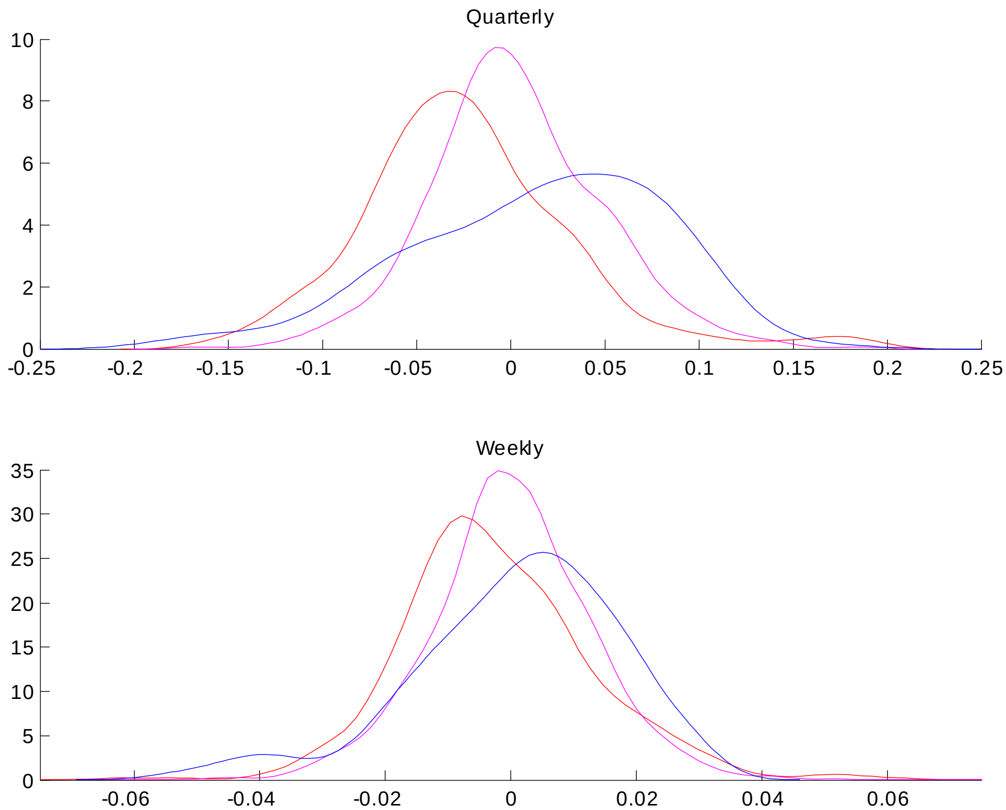

Figure 7: Kernel density estimates of distribution of foreign exchange returns depending on interest rate differential. Interest rate differential groups quarterly: $<$ -0.005 (red), -0.005 to 0.005 (magenta), $>$ 0.005 (blue); weekly: $<$ -0.01 (red), -0.01 to 0.01 (magenta), $>$ 0.01 (blue).

Table 3: Forecasting crashes and the price of crash risk

	Skewness_{t+1}	Skewness_{t+1}	Skewness_{t+1}	RiskRev_t	RiskRev_t
$i_t^* - i_t$	-28.51	-22.18	-27.34	-15.51	-30.70
	(11.59)	(12.59)	(11.52)	(29.20)	(25.91)
z_t		-3.34	-2.11		7.87
		(0.60)	(0.69)		(1.39)
Futures_t	-0.26	0.13	0.18	1.16	0.27
	(0.12)	(0.15)	(0.14)	(0.19)	(0.12)
Skewness_t	0.12	0.18	0.17	0.10	-0.02
	(0.05)	(0.05)	(0.05)	(0.09)	(0.10)
RiskRev_t			-0.16		
			(0.04)		
R^2	0.12	0.18	0.21	0.20	0.41

Notes: Panel regressions with country-fixed effects and quarterly data, 1998-2006, AUD, CAD, JPY, CHF, GBP, and EUR only. Standard errors in parentheses are robust to within-time period correlation of residuals and are adjusted for serial correlation with a Newey-West covariance matrix with 6 lags. The reported R^2 is an adjusted R^2 net of the fixed effects.

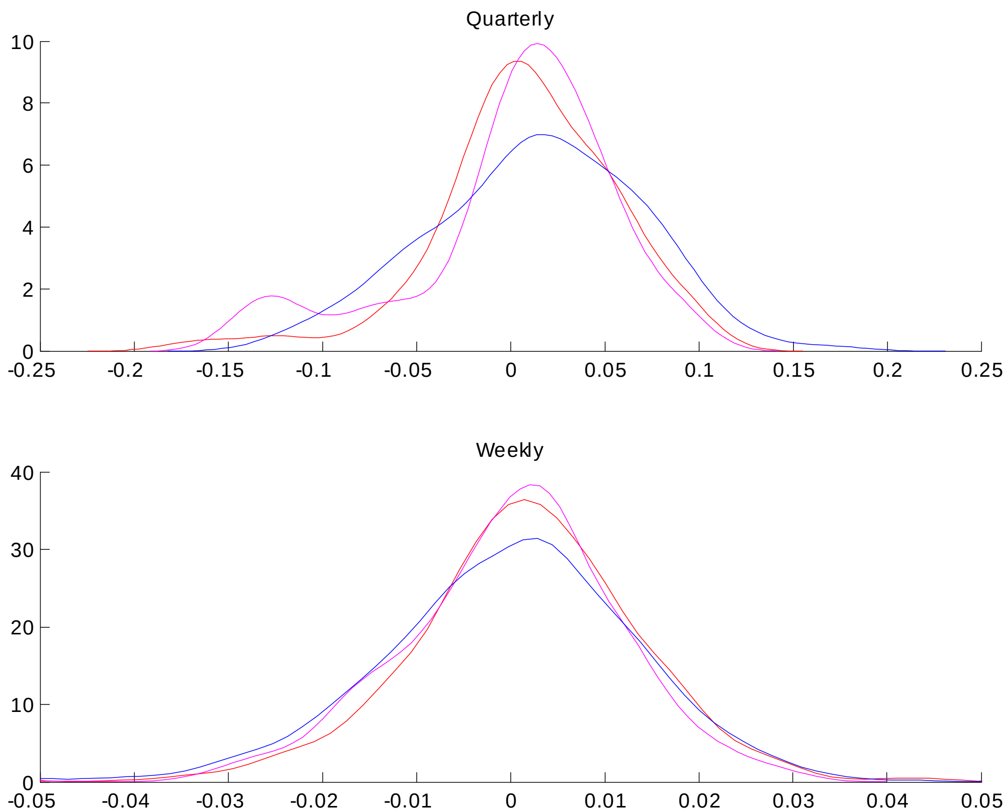

Figure 8: Kernel density estimates of distribution of carry trade returns conditional on contemporaneous change in VIX. Change in VIX groups quarterly: $<$ -0.25 (red), -0.25 to 0.25 (magenta), $>$ 0.25 (blue); weekly: $<$ -0.1 (red), -0.1 to 0.1 (magenta), $>$ 0.1 (blue).

Table 4: Sensitivity of weekly carry trade positions, price of skewness insurance, and carry trade returns to changes in VIX

	ΔCFut$_t$	ΔCFut$_{t+1}$	ΔCRiskRev$_t$	ΔCRiskRev$_{t+1}$	CRet$_t$	CRet$_{t+1}$
ΔVIX$_t$	-1.47	-1.30	-5.29	-2.71	-0.43	0.01
	(0.77)	(0.58)	(2.64)	(3.40)	(0.11)	(0.11)
CFut$_{t-1}$	-0.09	-0.11				
	(0.01)	(0.01)				
CRiskRev$_{t-1}$			-0.14	-0.10		
			(0.02)	(0.01)		
R^2	0.05	0.06	0.07	0.03	0.00	-0.00

Notes: Panel regressions with country-fixed effects and weekly data, 1992-2006 (1998-2006 for risk reversals), AUD, CAD, JPY, CHF, GBP, and EUR only. ΔCFut$_t$ is the weekly change in futures positions multiplied by the sign of $i_t^* - i_t$, ΔCRiskRev$_t$ is the weekly change in risk reversals multiplied by the sign of $i_t^* - i_t$, CRet$_t$ is the carry trade return, i.e. z_t multiplied by the sign of $i_t^* - i_t$. CAD, JPY, CHF, GBP, and EUR only (only currencies for which we have futures positions data since 1986). Standard errors in parentheses are robust to within-time period correlation of residuals and are adjusted for serial correlation with a Newey-West covariance matrix with 12 lags for futures, 6 for risk reversals, and 4 for returns. The reported R^2 is an adjusted R^2 net of the fixed effects.

Table 5: Correlation of FX rate changes and magnitude of interest rate differentials

	(1)	(2)	(3)	(4)
$\lvert i_1^* - i_2^* \rvert$	-10.89	-6.62	-16.39	-13.41
	(3.81)	(3.62)	(4.05)	(6.41)
$\rho(i_1^*, i_2^*)$	0.63	0.28	0.70	0.32
	(0.16)	(0.08)	(0.17)	(0.08)
Average $\rho(\Delta s_1, \Delta s_2)$	2.54	2.56		
	(0.08)	(0.08)		
Time Fixed Effects			Yes	Yes
Country-Pair Fixed Effects				Yes
	0.18	0.36	0.05	0.03

Note: Panel regressions, 1992-2006. The dependent variable is the pairwise correlation of daily FX rate changes, estimated within non-overlapping 13-week periods. $|r_1 - r_2|$ is the absolute pairwise interest rate differential at the start of the 13-week period. $\rho(r_1, r_2)$ is the correlation of 5-day interest rate changes, estimated with overlapping windows, within each 13-week period. Average $\rho(\Delta s_1, \Delta s_2)$ is the cross-sectional average of all pairwise correlations of daily FX rate changes within each non-overlapping 13-week periods. The reported R^2 is an adjusted R^2 net of the fixed effects.

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