Carry Trade Fundamentals and the Financial Crisis

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Abstract

This paper takes the form of an event study surrounding the current financial crisis. It proposes a theoretical relationship which can be used to model traditional carry trade crosses on a daily return basis as a negative function of equity returns and a positive function of market volatility. In order to test this theory, an Arbitrage Pricing Theory framework is adopted which the factor betas of carry trade crosses with respect to equity returns and market volatility. It is shown how the variation in the currency crosses explained by the functional relationship as well as the estimated factor betas have increased significantly in relation to the financial crisis. The results indicate that low yielding currencies (the JPY and CHF) can be successfully modeled as a negative function of equity returns and a positive function of volatility in the market. The results furthermore underpin studies that have shown how carry trading activity is highly sensitive towards sudden sparks of volatility and risk aversion, and thus how carry trade fundamentals are time varying.

International finance, carry trading, financial crisis, currencies,

JEL: F3, F31, G15

1.0 Introduction

One of the most vexing features of today's international financial markets is the carry trade phenomenon which exploits wide global interest rate differentials to earn the spread between low yielding and high yielding currencies. Carry trading consequently violates one of the few fundamental theories we have to explain currency markets; the uncovered interest rate parity (UIP). The UIP states that the expected change in the spot rate must reflect the interest differential between the two currencies. The theory predicts that the country with the high interest rate will see its currency depreciate (i.e. as it is assumed ex ante that the higher interest rate is a compensation for this depreciation). In formal terms:

$$(E)\Delta S = (1+i_h)/(1+i_f)$$

Where $i_{h,}i_f$ are interest rates in "home" and "foreign" respectively. Regarding the UIP, Bilson (1981) is often referred to as the initial study to reject the hypothesis, but also Meese and Rogoff (1983) and Longworth (1981) provide evidence to reject it. However, the evidence against the UIP is not entirely uniform. Chinn and Meredith (2004) manage to differentiate the conclusions from the main bulk of the literature. In their 2004 IMF staff paper, they consequently find that the UIP holds over longer time horizons. Furthermore, they show how failure of UIP to hold in the short run can be attributed to the interaction between shocks on the exchange rate market and endogenous monetary policy reactions.

Under the conditions of the UIP, the interest rate differential should be exactly offset by a change in the spot rate over the investment period in question. In this regard, the mechanics of the carry trade are interesting in the sense that a vigorous pursuit of carry trade by investors can turn into a self-fulfilling violation of the UIP; something which Plantin and Shin (2008) have coined as self-reinforcing arbitrage Brière and Drut (2009). In this way, the pursuit of carry trade will tend to keep low yielding currencies from appreciating against high yielding currencies since the aforementioned are being sold in the carry trade transaction itself.

Moreover, many investors don't actually need to perform the carry trades per se,[1] but simply latch on to the trade in the sense that they, in the spot market, sell the most common funding carry trade currencies (CHF and JPY) against the most common (and liquid) high yielders; for example Gagnon & Chaboud (2007) find evidence of carry trading behavior with respect of the JPY. Specifically, it is the effects and determinants of this latter strategy, or piggy backing if you will, which is of interest to this paper.

It is clear that such activity cannot be expected to create positive returns on a consistent basis, and periods of volatility and sudden reversals of asset prices can prove devastating for carry trade investors since positions are often highly leveraged Brière and Drut (2009). Nevertheless, and given the lingering persistence of wide global interest rate differentials some scholars have attempted to account for the ability to make consistent profits from carry trading. In Olmo & Pilbeam (2008) carry trading is however not found to yield excess returns for the most common carry trading crosses. Curiously, the authors do find excess returns in the context of the GBP/USD cross which is somewhat odd given that interest rate differentials between the US and UK tend to be significantly narrower than other potentially more 'juicy' trades.' Brière and Drut (2009) specifically show how fundamental strategies based e.g. on PPP tend to outperform carry trade strategies in the context of crises. These results are mirrored by Corcoran (2009) who shows, in an arbitrage-pricing-theory (APT) framework, how excess carry trade returns earned by a US investor investing in foreign money market instruments (t-bills) are explained by equity market and exchange rate volatility. This also supports studies by Brunnermeier et al (2008) and Farhi and Gabaix (2008) who show how currency crashes, and essentially sovereign defaults in the context of highly leveraged *high interest rate* economies, can explain carry trade risk premiums.

This paper does not directly attempt to qualify these studies but rather assume, ex ante, that carry trading exists as an integral part of market

[1] E.g. through constructing money market instrument portfolios in high interest rate currencies with borrowed funds in low interest rate currencies.

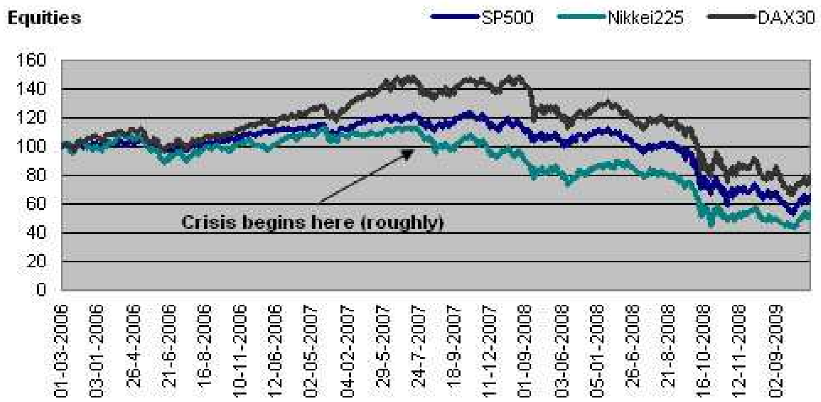
practice and discourse. As such, it is of less importance to the conclusions of this paper that carry trading works (i.e. earns excess returns) than it is important to assume that investors act according to the tenets of carry trading. Specifically, this study takes the form of an event study surrounding the current financial and economic crisis that has gripped global markets.

This opens the door for an investigation of one of the interesting derivative effects from carry trading activity. One question which thus seems pertinent is the extent to which carry trading activity as measured by movements in the most common funding currencies can say something about general market conditions. Clearly and assuming that carry trading does not create positive returns on an universally consistent basis it would be interesting to gauge the extent to which shifts in *'carry trading behavior'* coincides with other changes in the market. This is exactly what this paper sets out to examine in the context of the credit turmoil which, since August 2007, have crippled liquidity and sent shivers through financial markets. In doing so, it is however important to point out that this paper firmly inserts itself in the tradition of the most recent studies on carry trading activity. These studies are Corcoran (2009) which shows how returns on carry trade are approximated through equity and exchange rate volatility, Cairns et al. (2007) which shows how "low yielders" can be modeled as a positive function of volatility, and finally; Kohler (2007) and Brière and Drut (2009) who show how equities can be modeled as negative beta assets to low yielders. The crucial point however to emphasize is that this paper attempts to model exchange rates as a function of volatility and equity returns and how this might have changed in the context of the current financial crisis. As such, this paper follows the same path as Christiansen et al. (2009) which presents an econometric model to suggest that carry trade crosses and strategies are subject to time-varying systematic risk or more specifically that the fundamentals of carry trade strategies change with market conditions.

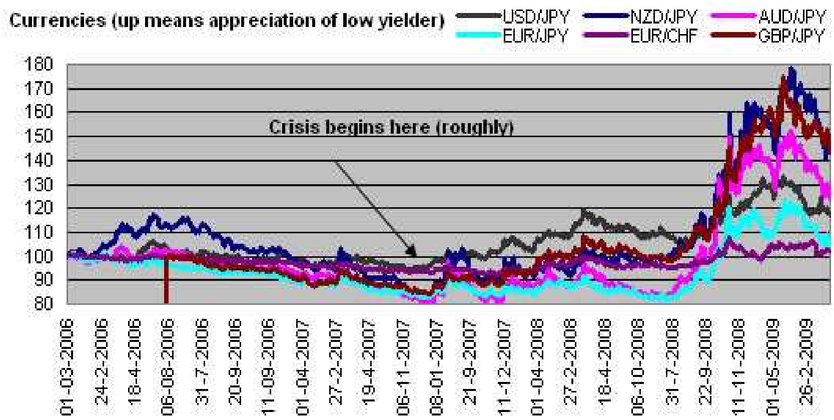
The paper proceeds as follows. Section two presents the theoretical and conceptual framework, section three presents the estimation and results, section four discusses the results and section five concludes.

2.0 Theoretical Framework

Since the end of July 2007 equity markets across the global have weakened significantly and given recent forecasts as e.g. the one propounded in the IMF's 2009 World Economic Outlook, we are going to be stuck in the mire for some time.

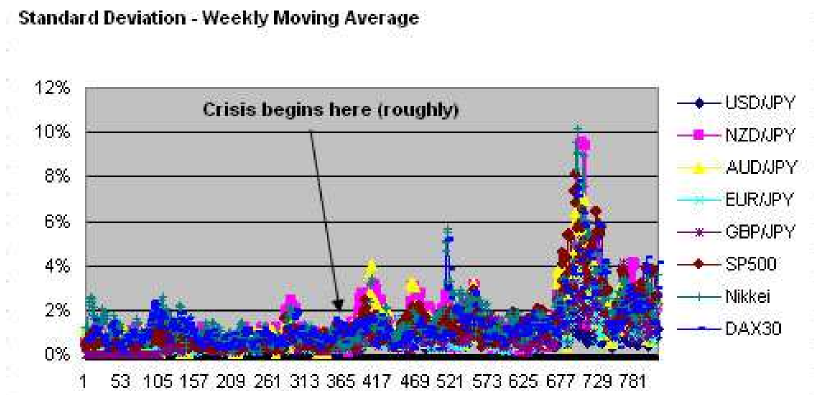


In the context of the credit turmoil, this has led to a discourse surrounding *unwinding* of risky carry trade positions. One key element in this discourse is how the funding currencies for carry trades (here, the JPY and CHF) are being coined as risk sentiment gauges, and thus measures of risk in the market place. The *unwinding* effect in this regard would then, in part, be conjured by investors' and traders' abandonment of highly leveraged spot market positions against the CHF and JPY. One way to operationalize this would be to narrate the CHF and JPY as the famous canaries whose demise were used by coal miners in the 19th century Britain to gauge when it was time to get out of the mine due to the presence of toxic gasses. In this way, CHF and JPY crosses can equally be seen as canaries in the context of financial markets whereby a sudden spike of volatility or a downward correction in risky assets is followed by an appreciation of the funding carry trade currencies as positions are unwound. Formally, the mechanics of such movements would suggest a negative correlation between the CHF and JPY and risky assets which would follow the results in Corcoran (2009), Kohler (2007), Brière and Drut (2009), and Cairns et al. (2007). Moreover, this would also suggest that we should have observed a strengthening across the board of the low yielding currencies since August 2007. This however is not uniformly so, as can be seen below.



As can readily be observed, the beginning of the credit turmoil has seen significant divergence between the JPY and CHF crosses. Yet, this is merely if we look at the levels of the time series. If we look at the daily trend there thus seems to be considerable negative co-movement between equities and the low yielders (in level form). In fact, if we home in on the two graphs above even a scant glance suggest a negative correlation between equities and low yielding currencies. It is exactly this tendency which is of interest in the present context.

Moreover, if we turn the attention to volatility let us first confirm the fact that volatility has increased markedly since the credit turmoil took hold in august 2007.



Both exchange rate volatility, idiosyncratic equity volatility, and general market volatility as measured by the VIX have increased significantly. If we focus the attention on the VIX, and use 01-08-2007 as the starting point of the crisis[2], the result is very clear.

Vix[3]	
Mean(1)	13,15320707
SD(1)	2,448010521
Mean(2)	32,00909953
SD(2)	14,57665003

[2] This data will be used as a breaking point throughout.
[3] Where (1) means period 1 before the crisis and (2) indicates period 2 after the crisis set in.

Consequently, both the mean value and standard deviation of the measure, which can be interpreted as a second derivative effect, have spiked significantly in a post crisis. This suggests that both the *level* and *variation* of volatility have increased. Following the theme of the present study one would expect low-yielding currencies to exhibit a positive relationship with volatility.

Notional evidence of carry trade dynamics is easy to find. Daily readership of Bloomberg's financial news stream will thus often present market participants with headlines such as *Yen Falls as Asian Stock Gains Boost Confidence in Carry Trades*[4], which is indicative of the relationship described above. Moreover and apart from an account of the theatricals of financial markets such reports also highlight two other points. First of all, it indicates that the argument upon which this paper builds its case is already formalized in the daily market discourse. Secondly, it suggests that the relationship is one which, at the very least, can be tracked on a short term frequency basis. Consequently, this paper studies daily returns within a, for traditional empirical purposes, relatively short period. Following the points above the inquiry begins with the following expression for the functional relationship between the return of a funding currency in a carry trade transaction (the JPY and CHF in this case).

$$R_{fx} = f(-R_e, \sigma)$$

Where the subscript "fx" indicates that the left hand side is an exchange rate. In order for the expression above to make intuitively sense the currency pair should be quoted as number of high yielding currency to low (i.e. directly). Thus, if the USD/JPY is traditionally quoted as amount of JPY to USD (e.g. 110), the expression used here will be (1/[USD/JPY])[5] in order to convey the idea of the low yielders as negative beta assets at the same time as they are a positive function of volatility. Theoretical impetus for the choice of this functional form can be found in Zimmerman et al.

[4] 2008 Bloomberg News Article.
[5] i.e. amount of USD per JPY

(2003) who point towards two important points. One the one hand they detail how stock market volatility is higher in down periods (bad news spawn more volatility than comparable good news). Given that volatility is supposed to adversely affect carry trade returns this supports the findings by Brière and Drut (2009) and Corcoran (2009). Secondly, they also question the merits of international diversification by showing that in down periods when volatility is high and when economic activity is shrinking, we also observe a significant increase in correlation amongst international securities Zimmerman et al. (2003).

There may be reason to believe that this functional form has general validity across time, but in the context of the present study we can amend the expression in one crucial way. Consequently, and bearing in mind that this study takes the form of an event study in the sense that it studies pre and post crisis dynamics, we can deduce the following expression;

$$E\left\langle R_{fx} \middle| \theta \right\rangle = f(-R_e, \sigma)$$

Consequently, the functional form of the expectation of the return of a low yielder in a carry trade transaction becomes conditional on the value of (θ). The parameter (vector) θ indicates that we are in a crisis. Clearly, the vector θ is rather innocuous in the present context and will not be subject to direct analysis, but following the remarks above it must incorporate measures such as volatility, equity returns, as well as real economic variables all imbued in order to identify a period of recession or crisis.

To operationalize the proposition above, this paper follows the intuition from Arbitrage Pricing Theory Ross (1976) and the one adopted in Cocoran (2009) by letting the return on a carry cross (quoted directly) to be modeled as a linear combination of k factors.

$$R_{fx} = \alpha_i + \beta_{i1} I_1 + \beta_{i2} I_2 + ... + \beta_{ij} I_j + e_{ij}$$

$$E[e_i e_j] = 0$$

In our present cast, the proposed functional form will be the following;

$$R_{fx} = \alpha_i + \beta_{i1} I_1 + \beta_{i2} I_2 + e_{ij}$$

With;

R_{fx} equal to the return on a low yielding carry trade currency (e.g. a long USD/JPY position when quoted directly).

α_i equal to the expected value of R_{fx} if the risk factors are equal to 0. In this case and with the method adopted here of using first differences of daily values $E(\alpha_i) = 0$; we assume mean reversion in the first difference.

I_1 is equal to the return vector of an equity index.

I_2 is equal to the vector of the VIX (high value) in changes.

In a standard APT framework and following Cocoran (2009) one would first estimate the factor betas using the approach of Fama and Macbeth (1973) through time series regression and then move into the cross-section in order to estimate the factor prices (risk premiums). In this study the focus will be on the first stage, as it were, of this approach and thus the value of the factor betas. This leads to the estimation of the following equation.

$$\ln\left(\frac{\gamma_t}{\gamma_{t-1}}\right) = \alpha_0 + \beta_1 \ln\left(\frac{R_{m_t}}{X_{m_{t-1}}}\right) + \beta_2 \ln\left(\frac{Vix_t}{Vix_{t-1}}\right) + e_t$$

Which we can rewrite as;

$$\Delta\gamma = \alpha_0 + \beta_1 \Delta R_m + \beta_2 \Delta Vix + e_t$$

The functional form which incorporates the variables in changes (continuous compound) is chosen in order to avoid stationarity issues when performing time series analysis on level form variables. The value for the VIX is the change in the value of the *high value* on a daily basis. This is used in order to capture the peak level of volatility in the VIX and whether the carry currency pairs react to sharp reversals in implied market volatility.

Since this paper studies the relationships sketched above in relation to an event in the form of the current crisis, the stability of the proposed relationship will also be investigated. It is thus interesting for this study to break up the expression above into one in a pre crisis framework and one in a post crisis framework. This takes us into the world of econometric tests for parameter stability Chow (1960), Gujarati (2003) and Greene (2003 pp. 130-147).

A first simple test involves the entire estimation of the regression following Chow (1960) and indicates whether there has been a structural break in the parameters without telling us which of the estimated parameters that have changed. Consider consequently the following approach Gujarati (2003) and assume the generic regression for the whole period as stated above and then amend it with the following regressions for period one and two respectively;

$$\Delta\gamma^* = \alpha_0{}^* + \beta_1{}^*\Delta R_m{}^* + \beta_2{}^*\Delta Vix^* + e_t{}^* \text{ and}$$

$$\Delta\gamma^{\cdot\cdot} = \alpha_0{}^{\cdot\cdot} + \beta_1{}^{\cdot\cdot}\Delta R_m{}^{\cdot\cdot} + \beta_2{}^{\cdot\cdot}\Delta Vix^{\cdot\cdot} + e_t{}^{\cdot\cdot}$$

Where (*) indicates a regression for period 1 and (¨) indicates a regression for period 2. The mechanics of the Chow Test assumes that $\alpha_0 = \alpha_0{}^* = \alpha_0{}^{\cdot\cdot}$ in all three estimations but also more importantly that $\beta_1 = \beta_1{}^* = \beta_1{}^{\cdot\cdot}$ as well as $\beta_2 = \beta_2{}^* = \beta_2{}^{\cdot\cdot}$. In performing the Chow Test we test whether the residual sum of squares (RSS) from the original regression is statistically different from the sum of the RSS from the two period regressions. Formally, the test is conducted by calculating the following F-value:

$$F = \frac{(RSS_R - RSS_{UR})/k}{(RSS_{UR})/(n_1 + n_2 - 2k)} \sim F_{[k,(n_1+n_2-2k)]}$$

Where RSS_R is the residual sum of squares from the original full sample size regression and RSS_{UR} is the sum of residual sum of squares from the two separate period regressions. If the F statistic is sufficiently large, we reject the null of no structural break.

Another more rigorous approach is to follow Gujarati (2003) and Greene (2003, pp. 130-147) and apply dummy variables to check which of the parameters that change and how much. In this way, I specify the following regression to be estimated.

$$Y = \alpha_0 + \beta_1(\alpha_1 D_t) + \beta_2 \Delta R_m + \beta_3 \Delta Vix + \beta_4 (D_t \Delta R_m) + \beta_5 (D_t \Delta Vix) + e_t$$

Where D_t is dummy variable which takes the value of 0 if we are in period one (pre-crisis) and 1 if we are in period 2 (post crisis). An estimated parameter for β_1, β_4 or β_5 significantly different from 0 indicates a structural break for the beta value of the intercept, market return, and volatility respectively. In this case, the new parameter coefficient estimated for period 2 will be given by $\alpha_0 + \beta_1$ for the intercept, $\beta_2 + \beta_4$ for the market return, and $\beta_3 + \beta_5$ for volatility Gujarati (2003). This approach allows us to scrutinize specific change in parameters across periods and is a valuable addition to the observation of changes in the overall coefficient of determination (R-sq) of the regression across periods.

2.0 Estimation and Results

Thomson Datastream was used to pull data on 6 currency pairs considered to be traditional carry trade crosses. Of the six, one CHF crosses and five JPY crosses have been used.[6] Furthermore three major stock indices from three main regions in the form of the SP500, the Nikkei 225 and the DAX 30 were chosen as the market(s). As for the term for the volatility term it will be proxied through the use of The CBOE Volatility Index (VIX) which is a measure of market volatility calculated through the use of options on the SP500[7]. The data series consists of daily values (returns) of the seven currency crosses and the three stock market indices from 01-03-2006 to 04-02-2009 of a total of 817 daily observations[8]. These data sets form the basis of the estimation below.

In order to set the stage for the estimations above it would be interesting initially to have a look at simple correlations (of the time series in changes) and see whether these confirm the theoretical framework described above. Specifically, it is interesting to observe whether there has been a change in a post crisis perspective. This initial evidence seems to provide a solid foundation for the hypotheses stated (see appendix). If we look at the full sample, all currency crosses are positively correlated with the VIX index and this correlation has increased markedly in a post crisis perspective. The mean increase in correlation with the VIX for all currency pairs, in a post crisis perspective, is a sound 173%. In terms of the currency pairs' correlation with the equity indices it is, for the most part, negative. Only the NZD/JPY's and AUD/JPY's positive correlation with the SP500 cloud the picture. In a post crisis perspective however, the results are unequivocal with the negative correlation for all currencies, Except the NDZ/JPY and AUD/JPY, having increased on average with 258%, 125% and 152% for the Nikkei 225, Dax and SP500[9] respectively.

[6] USD/JPY, NZD/JPY, AUD/JPY, EUR/JPY, EUR/CHF, and GBP/JPY.
[7] Daily data was obtained from the Chicago Board of Options Exchange's website (daily values at high).
[8] Since the VIX does not display observations on all the sample days, all time series have been cut to fit the schedule of the VIX.
[9] Excluding the NZD/JPY and AUD/JPY since these do not exhibit a negative correlation with the SP500 in the first place.

After these initial results, we turn to the estimation of the following relationship using OLS.

$$\Delta\gamma = \alpha_0 + \beta_1 \Delta R_m + \beta_2 \Delta Vix$$

Thus, the estimation of the currency crosses' factor betas shall be approximated by the following equation for a total of 18 regressions (3 stock market indices, 6 currency crosses and one volatility parameter). In the expression above, the estimated parameters (β_1, β_2) will be the main result to gauge. Given the theme of the present study and the fact that all currencies are quoted directly one would expect negative signs for β_1 and positive sign for β_2. First, the full sample regressions will be reported and then the investigation turns to the split dataset and the tests for structural stability.

The results for 18 regressions are reported in the tables in the appendix. An initial observation which yields strong support for the theory sketched above is the increase in the models' r-square values. The important point here is to focus the attention on the difference between pre- and post-crisis. In percentage points[10] the average increase in R-square values is 14%, 27% and 17% for the regressions including the SP500, the Nikkei 225 and the Dax30 respectively. This suggests, with some force, how the proposed relationship is particularly strong in a context of a financial and economic crisis. All R-square values calculated in a post-crisis perspective are significant at 1% (which was not always the case in the pre-crisis regressions), and their values indicate a relatively strong explanatory power. Especially, there are 13 regressions in the post-crisis context which have R-square values above 0.2 which, in the present context, must be considered a strong result since we are dealing with first differenced daily time series.

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[10] Since by definition; 0<r-sq<1.

Turning to the estimated coefficients and the idea of the currency crosses as negative beta assets to equities as well as the hypothesis that they can be modeled as a positive function of volatility, the waters get increasingly muddier.

With regards to the Nikkei 225 and the DAX the factor prices of the currency crosses all correspond with the theoretical framework as they have negative beta values which increase markedly in the second period estimations. The results are more disappointing for the SP500 in this regard where only the USD/JPY and GBP/JPY conform to the relationship proposed with negative beta values that are higher (and statistically significant) in the second period estimation. In terms of the estimations in relation to the VIX, the results are strong and unequivocal. In the full sample regression most currency pairs are successfully modeled as a positive function of volatility which is consistent with market carry trade fundamentals in which investors buy into relative low yielding currencies (unwinding carry trade positions) when volatility spikes. This result is intensified when we look at the difference between period one and two. Both in connection to the level of statistical significance and in relation to the value (and signs) of the estimated coefficients do we observe a strength in the models' ability to model the currency pairs as a positive function of volatility. The only exceptions here are the regressions for the NZD/JPY and AUD/JPY in relation to the Nikkei 225 where the parameter estimated for the VIX is not statistically significant.

In summary, there appears to be strong evidence for the proposed theoretical relationship above in which, conditional on crisis dynamics, relative low yielding currencies can be modeled as negative beta assets to equities and positive functions of volatility. In order however to quantify this result, the investigation now turns to the examination of parameter stability across the two periods.

As a first approximation, the *chow test* Chow (1960), Gujarati (2003) and Greene (2003) will be performed based on the F-test showed above. As noted, RSS_R is the residual sum of squares from the original full sample size regression and RSS_{UR} is the sum of residual sum of squares from the two separate period regressions. $(n_1 + n_2 - 2k)$ is equal to (395+420)-(2*3) = 809 and the critical values of the F is 2.1, 2.61 and 3.78 for 10%, 5% and 1% level of significance respectively. The null is that there is no structural break which means that a significant F-value would indicate that a structural break is present as per reference to rejection of the null. In the table below the computed F value is shown for all the 18 regressions.

chow-test stats[11]	USD/JPY	NZD/JPY	AUD/JPY	EUR/JPY	GBP/JPY	EUR/CHF
Sp500	579.99	573.23	578.31	582.96	514.45	564.09
Nikkei 225	581.97	553.70	585.75	582.99	510.86	559.04
Dax30	576.93	555.66	559.85	567.30	501.07	552.62

The F-statistics computed above strongly support the results of a structural break in the regressions around at the advent of credit crisis. They are consequently all well within the confines of statistical significance at 1%.

These F-statistics however tell us nothing about which of the estimated parameters that have changed. This is of interest in the present context since we have two explanatory variables (equity returns and the VIX) and it would be useful to know which of these two variables that is to blame, as it were, for the structural break. Moreover, it would be nice to rule out the possibility that the structural break is due entirely to a change in the level of the currencies, which would be captured by a significant change in the intercept. In this way, we proceed with the following estimation.

$$Y = \alpha_0 + \beta_1(\alpha_1 D_t) + \beta_2 \Delta R_m + \beta_3 \Delta Vix + \beta_4 (D_t \Delta R_m) + \beta_5 (D_t \Delta Vix) + e_t$$

The output of these regressions is reported in its entirety in the appendix and by nature, it is a bit difficult to get an immediate overview.[12] The following points are worth paying attention to. First of all, all the intercepts and the respective period dummies used to capture any structural break due to a change in the average daily change of the currencies are statistically insignificant.[13] This is in line with the expectations noted above.

In terms of regressions where both the parameters for the VIX and the equity index are significant, there are 7. These are the USD/JPY, the EUR/JPY, and GBP/JPY to the DAX and Nikkei 225 respectively as well as the EUR/CHF to the Nikkei 225. This indicates that the effect from changes in volatility and equity returns have been greater in a post-crisis perspective. In these regressions the average increase in the beta parameter for the VIX is 0.03 and for the equity dummies the number is -0.11 for the Nikkei 225 and 0.15 for the DAX. These numbers may appear small, but it is worth remembering in this case that we are talking about daily returns and thus an interval where small changes have a potentially high impact. In terms of the SP500, the results are poor in so far as goes the fact that none of regressions exhibit statistically significant dummies for both the VIX and the equity indices. In fact, none of the regressions show a significant increase in the beta value for the equity index whereas, in many of the cases, the VIX dummy variable is significant. This suggests that the relationship between the SP500 and the carry trade crosses in question here have not changed much even if the models' ability to explain the variation (the R-sq) has indeed increased.

The results for the VIX dummy are, in general, strong. Only in two of the 18 regressions do we observe that there has *not* been a structural break in the estimated coefficient for the VIX. This indicates that the effect from changes in volatility on the currency crosses and thus a carry trade position has increased significantly since the advent of the credit crisis.

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[11] The Vix is of course included in all these regressions too.
[12] With 18 regressions consisting each of 6 explanatory variables there are 108 parameters to deal with. As such, the reader is advised to read the whole paper before digging into the specifics of this regression output.
[13] Except for the GBP/JPY to the Nikkei 225 and Vix, but since the second period intercept has a p-value of more than 0.1 I do not consider this to be a credible result.

The result is less robust for the equity parameters although it seems that, in the cases where the dummies are significant, the change is relatively high. Consider for example the dummy for the Nikkei 225 index to the NZD/JPY, AUD/JPY and EUR/JPY which shows that the beta value of these currencies to the Nikkei 225 have increased (in negative values) by 0.235, 0.364, and 0.189 respectively. In general, the results concerning structural breaks with respect to equity betas are unequivocal in the sense that the dummies for the Nikkei 225 are all significant whereas the picture is more clouded for the DAX and SP500. This indicates that the findings by Hau, H, & H, Rey (2006) whereby higher returns on domestic equity market are associated with a depreciation of the home currency are perhaps showing up in these estimations.

3.0 Discussion

The estimation above presents several interesting results. As a first initial summary the results significantly underpin the theoretical framework sketched earlier. Not only do the vast majority of the currency crosses exhibit negative beta values to the three main stock indices but also, at the same time, they can be modeled as positive functions of market volatility.

In terms of the differentiation between the two periods and thus the real objective of this study, the results quite strong. It is important, I think, in this respect to point to the fact that the r-square values for period 2 are markedly higher than in period 1. Given that the present study deals with daily returns it strongly suggests that that the proposed relationship has intensified in strength after the financial crisis took hold. This supports the findings of Christiansen et al. (2009) that the strength of carry trade fundamentals is time varying.

It is also important to point out that the tests for structural break do not test for the strength of the relation as measured by the R-sq, but rather the value of the estimated parameters. This investigation produced decidedly murkier results, but still indicates that key relationships have intensified.

Especially, it seems as if the carry crosses' functional relationship with volatility has increased significantly. Also, all the currency crosses' negative relationship with the Nikkei 225 index has increased in a post-crisis perspective. Consequently, the results which show carry trade currency pairs as negative beta assets seem particularly strong in the context of the Nikkei 225 index. However, it is also clear that if we look at the full sample period, not only the JPY crosses show negatively significant beta values to the Nikke but so do the EUR/CHF. This strong result is echoed with the DAX 30 where strong results are presented for other currency indices than the EUR/JPY and EUR/CHF. In relation to the SP500 the results were somewhat more meager with the notable exception of the USD/JPY which has exhibited a strong structural break around the summer 2007. In overall terms, one could distinguish between the currency pairs by looking at their respective coefficients of determination. In this way, some of the currency pairs clearly offer a higher degree of explanatory power and thus, by derivative, a more believable act as negative beta assets and positive functions of volatility. Examples here would be (GBP/JPY and EUR/CHF to the DAX 30, the EUR/CHF, AUD/JPY, and NZD/JPY to the Nikkei 225 as well as the USD/JPY to the SP500 and DAX30).

Here, at the brink of the paper, (at least) three overall questions impose. The first is the question of structural stability of beta values or more specifically the sign of the estimated parameters. The second is the dodgier question of causality between currency pair and equity index and the third relates to the statistical issue of heteroscedasticity in the regressions.

On the first question this paper clearly falls outside the norm as it takes the form of an event study with daily returns over a relatively short time span. Considerable ink has been devoted by finance scholars in determining the estimation period which best approximates a stabile beta value (using the CAPM). At a first glance such studies are not directly replicable in the present context. In this way, this study uses an APT framework to investigate the factor betas of currencies. Using the results from the CAPM literature, studies have shown that 4-6 years (about 300 observations with weekly returns) provide the strongest result Alexander and Chervany (1980). It has also been shown how extreme betas are shown to be less stable over time than betas drifting closer to the mean Alexander and Chervany (1980). These methodological glitches notwithstanding, it is interesting in the context of the present study. As such, one should be careful making general extrapolations on the basis of the findings above. On the other hand though, and given the strength of the results, effort should be put into pinning down which of these relationships hold up for scrutiny over time. Special attention should be devoted to pinning down the relationship $E\left\langle R_{fx} \middle| \theta \right\rangle = f(-R_e, \sigma)$ and what actually constitutes a reasonable proxy for the vector (θ). Given the theme of this study, volatility clearly seems to be a key variable. Finally, the stability of the relationship should also be held up against the findings by Christiansen et al. (2009) and thus the time varying aspect of the functional relationship.

Turning to the issue of causality, it is ironic that this study began with a model in which the currency crosses were used to model the equity returns. In this way, it would perhaps be best to leave this issue alone all together. One can consequently always quibble about causality in the context of statistical analysis even to such an extent to make the actual results secondary to the inquiry. This mistake will not be made here. In the regressions estimated above the idea has been to model carry trade crosses as a function of a number of carry trade fundamentals that were postulated. However, this does not mean that one could not achieve interesting results by switching the order of variables. Granger causality tests (Granger (1969)) could of course be performed to formally ascertain the arrows of causality but in essence, the Granger test itself says very little about what really constitutes causality more than it merely provides a binary analysis of what affects what.

Finally, there is the issue of heteroscedasticity which seems to be an inbuilt issue of this study's methodology. The problem with heteroscedasticity in the context of OLS estimation and the Gaussian linear model is well known as it can create biased estimates of the beta parameters and underestimate the standard errors depending on the severity of the residuals' unequal variance. Consider consequently the regression framework estimated above;

$$\Delta\gamma^{*} = \alpha_0^{*} + \beta_1^{*}\Delta R_m^{*} + \beta_2^{*}\Delta Vix^{*} + e_t^{*} \text{ and}$$

$$\Delta\gamma^{\cdot\cdot} = \alpha_0^{\cdot\cdot} + \beta_1^{\cdot\cdot}\Delta R_m^{\cdot\cdot} + \beta_2^{\cdot\cdot}\Delta Vix^{\cdot\cdot} + e_t^{\cdot\cdot}$$

In order for the Chow test to be strictly valid and following Gujarati (2003) and Greene (2003) a prerequisite for using the Chow test is that;

$$V\left(e_t^{*}\right) = V\left(e_t^{\cdot\cdot}\right)$$

However, given that the nature of the theoretical framework itself is built on the premise that volatility in one period is larger (different) than in the other, the issue here becomes a rather difficult one to deal with directly. In this way, a central prerequisite for this study will almost always be:

$$E\left[V\left(e_t^{*}\right)\right] \neq E\left[V\left(e_t^{\cdot\cdot}\right)\right]$$

This means de-facto presence of unequal variance in the two sub-periods. Gujarati (2003) performs a simple test to check whether there is a statistically significant difference between the variance of the residuals in the two estimation periods of the trial example.[14] The computed F-stat is found to reject the null of equal variance and thus the Chow test should not be used. Still, Gujarati (2003) is not adamant that this poses a serious issue. This is echoed in Greene (2003) where it is argued that as long as the sample size is large enough, unequal variance should not pose a major issue. Moreover in the present study all p-values, standard errors,

[14] GDP regressed on income and savings.

and f-stats are highly significant to support the proposed relationship which should give us some confidence despite the obvious methodological and, as it were, practical issue with heteroscedasticity. The individual scholar should decide whether she believes that the method above can be applied or whether more elaborate techniques should be deployed to test for structural breaks in the estimated time series. Here for example; Christiansen et al. (2009) deploys a considerably more advanced econometric framework.

4.0 Conclusion

The principles of carry trading and how to bet against the patchy theory of uncovered interest rate parity are well known. Moreover, carry trading and the effect of investors pursuing it, have almost turned in to an urban legend on financial markets where many derivative effects of *'carry trading behavior'* are cited. This paper has attempted to scrutinize and essentially pin down the idea of carry trade fundamentals in relation to the ongoing financial crisis. Using an Arbitrage Pricing Theory framework it has been shown how the factor betas of carry trade currencies with respect to equity returns and market volatility have changed with the advent of the financial crisis. It has furthermore been shown how the R-sq values of the estimations have increased markedly in the context of the financial crisis. The results indicate that low yielding currencies (the JPY and CHF) can be successfully modeled as a negative function of equity returns and a positive function of volatility in the market.

It has consequently been shown how the JPY and CHF, often cited as the traditional funding currencies in carry trades, exhibit strong negative correlations and factor betas to equities (SP500, Nikkei 225 and DAX 30) and positive factor betas to market volatility measured by the VIX. This lends evidence to the idea of the CHF and JPY as risk sentiment gauges and how this relationship strengthens in the context of a period of heightened volatility. In this regard it is important to watch the currency pairs with significant negative beta values with respect to equities and positive beta values for volatility; (GBP/JPY and EUR/CHF to the DAX 30, the EUR/CHF, AUD/JPY, and NZD/JPY to the Nikkei 225 as well as the USD/JPY to the SP500 and DAX30).

The key point to take away from this study is that the financial crisis has intensified the link between carry trade currencies and risky assets as well as volatility. However, it is equally important to emphasize how carry trade strategies will be especially sensitive to reversals in the context of a financial crisis Brière and Drut (2009). This also means that while it may seem tempting to hedge equity positions through long positions in carry trade currencies one has to be careful of reversals and the fact that these fundamentals are ultimately time varying.

Further studies on this topic should attempt to widen the time span of the sample to gauge the general validity of the results and thus follow in the steps of Christiansen et al. (2009) as well as attempt to make forecasts of daily exchange rate and/or stock returns based on the relationships cited above.

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6.0 Data and Graphs

Correlation Matrices

Full Sample

#	USD/JPY	NZD/JPY	AUD/JPY	EUR/JPY	GBP/JPY	EUR/CHF
Vix	0,355256366	0,174129	0,240750341	0,326564	0,392726518	0,32993936
Sp500	-0,300479864	0,115559	-0,053187031	-0,19866	-0,350007209	-0,2241003
Nikkei 225	-0,293748069	-0,39113	-0,640958967	-0,55027	-0,441874591	-0,5312755
Dax30	-0,450682853	-0,13498	-0,295130437	-0,43626	-0,559866936	-0,4160669

Period 1

#	USD/JPY	NZD/JPY	AUD/JPY	EUR/JPY	GBP/JPY	EUR/CHF
Vix	0,149672151	0,066999	0,082318735	0,173884	0,209176906	0,27332206
Sp500	-0,097482843	0,023719	0,034686339	-0,11193	-0,105107472	-0,17254
Nikkei 225	-0,042092326	-0,1417	-0,282688015	-0,20346	-0,161343266	-0,31571
Dax30	-0,124319825	-0,14025	-0,114981163	-0,2116	-0,282909743	-0,3489963

Period 2

#	USD/JPY	NZD/JPY	AUD/JPY	EUR/JPY	GBP/JPY	EUR/CHF
Vix	0,468596586	0,228258	0,317089617	0,410511	0,477242619	0,38218628
Sp500	-0,337082447	0,129386	-0,059964892	-0,20638	-0,36486902	-0,2287173
Nikkei 225	-0,350858839	-0,43308	-0,696440933	-0,60522	-0,467573305	-0,5659824
Dax30	-0,527008823	-0,13142	-0,322330276	-0,47228	-0,588362883	-0,4266842

Factor Betas

Factor Betas estimates are tested against the null that the parameter is equal to 0. The intercept is excluded as it is insignificant for all the regressions (according to expectations). As for level of significance for the individual parameters, we have * for 1%, ** for 5 %, and *** for 10%; no asterisk indicate a failure to reject the null. The parameter VIX is naturally included three times for each of the three groups since it is included as a variable in three different regression contexts. Note that because of data retrieval issues, the sample size for the GBP/JPY is reduced to 710 observations for the full sample regression and 289 and 420 observations for the period 1 and period 2 regressions respectively.

Full Sample						
#	USD/JPY	NZD/JPY	AUD/JPY	EUR/JPY	GBP/JPY	EUR/CHF
Sp500	-0.074*	0.238*	0.070**	-0.031	-0.133*	-0.021**
Vix(SP500)	0.031*	0.071*	0.063*	0.043*	0.049*	0.018*
Nikkei 225	-0.073*	-0.304*	-0.488*	-0.241*	-0.193*	-0.100*
Vix(Nikkei 225)	0.032*	0.010	0.003	0.021*	0.045*	0.010*
Dax30	-0.167*	-0.043	-0.214*	-0.216*	-0.337*	-0.085*
Vix(Dax30)	0.014*	0.035*	0.022**	0.014**	0.014**	0.007*

Period 1						
#	USD/JPY	NZD/JPY	AUD/JPY	EUR/JPY	GBP/JPY	EUR/CHF
Sp500	-0.003	0.139**	0.154**	-0.002	0.030	0.001
Vix(SP500)	0.011**	0.018***	0.020*	0.013*	0.017*	0.009*
Nikkei 225	-0.002	-0.100*	-0.177*	-0.071*	-0.052**	-0.049*
Vix(Nikkei 225)	0.012*	0.005	0.002	0.010*	0.013*	0.007*
Dax30	-0.022	-0.151**	-0.080	-0.083*	-0.132*	-0.064*
Vix(Dax30)	0.009***	-0.007	0.001	0.004	0.003	0.002*

Period 2						
#	USD/JPY	NZD/JPY	AUD/JPY	EUR/JPY	GBP/JPY	EUR/CHF
Sp500	-0.054*	0.293*	0.116**	0.001	-0.104*	-0.011
Vix(SP500)	0.053*	0.117*	0.110*	0.074*	0.082*	0.028*
Nikkei 225	-0.068*	-0.335*	-0.541*	-0.261*	-0.185*	-0.106*
Vix(Nikkei 225)	0.052*	0.016	0.007	0.034*	0.070*	0.013*
Dax30	-0.167*	0.021	-0.190*	-0.209*	-0.325*	-0.079*
Vix(Dax30)	0.030*	0.072*	0.054*	0.034*	0.036*	0.015*

R-square values for the 18 regressions above:

Full Sample	USD/JPY	NZD/JPY	AUD/JPY	EUR/JPY	GBP/JPY	EUR/CHF
Sp500	0.148*	0.081*	0.063*	0.109*	0.189*	0.115*

Nikkei 225	0.158*	0.154*	0.411*	0.322*	0.256*	0.305*
Dax30	0.213*	0.032*	0.093*	0.196*	0.318*	0.182*

Period 1	USD/JPY	NZD/JPY	AUD/JPY	EUR/JPY	GBP/JPY	EUR/CHF
Sp500	0.022**	0.012***	0.020**	0.030*	0.045*	0.075*
Nikkei 225	0.022**	0.021**	0.080*	0.058*	0.055*	0.140*
Dax30	0.023*	0.021**	0.013***	0.047*	0.081*	0.124*

Period 2	USD/JPY	NZD/JPY	AUD/JPY	EUR/JPY	GBP/JPY	EUR/CHF
Sp500	0.233*	0.132*	0.114*	0.169*	0.248*	0.148*
Nikkei 225	0.248*	0.190*	0.486*	0.395*	0.313*	0.345*
Dax30	0.308*	0.052*	0.125*	0.244*	0.365*	0.203*

Dummy Regressions

USD/JPY - SP500				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.000	-0.178	0.859
Period Dummy	0.000	0.000	0.717	0.474
Change SP500	-0.003	0.065	-0.043	0.966
Change VIX (high)	0.011	0.007	1.667	0.096
Dummy*Vix	0.042	0.009	4.743	0.000
Dummy*Sp500	-0.051	0.067	-0.765	0.445

USD/JPY - Nikkei 225				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.000	-0.182	0.855
Period Dummy	0.000	0.000	0.657	0.511
Change Nikkei 225	-0.002	0.031	-0.081	0.936
Change VIX (high)	0.012	0.005	2.123	0.034
Dummy*Vix	0.040	0.008	5.348	0.000
Dummy*Nikkei 225225	-0.065	0.034	-1.911	0.056

USD/JPY - Dax				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.000	-0.123	0.902
Period Dummy	0.000	0.000	0.455	0.649
Change DAX	-0.022	0.046	-0.483	0.629

Change VIX (high)	0.009	0.007	1.359	0.175
Dummy*Vix	0.021	0.009	2.261	0.024
Dummy*dax30	-0.145	0.050	-2.937	0.003

NZD/JPY - SP500				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.001	-0.495	0.621
Period Dummy	0.002	0.001	1.665	0.096
Change SP500	0.139	0.144	0.963	0.336
Change VIX (high)	0.018	0.015	1.192	0.234
Dummy*Vix	0.099	0.020	5.047	0.000
Dummy*Sp500	0.154	0.149	1.039	0.299

NZD/JPY - Nikkei 225				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.001	-0.394	0.694
Period Dummy	0.001	0.001	0.857	0.392
Change Nikkei 225	-0.100	0.067	-1.491	0.136
Change VIX (high)	0.005	0.012	0.383	0.702
Dummy*Vix	0.011	0.016	0.693	0.489
Dummy*Nikkei 225225	-0.235	0.074	-3.182	0.002

NZD/JPY - DAX				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.001	-0.203	0.839
Period Dummy	0.001	0.001	1.121	0.262
Change DAX	-0.151	0.109	-1.390	0.165
Change VIX (high)	-0.007	0.017	-0.403	0.687
Dummy*Vix	0.078	0.022	3.605	0.000
Dummy*dax30	0.172	0.118	1.457	0.145

AUD/JPY - SP500				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.001	-0.638	0.524
Period Dummy	0.001	0.001	1.336	0.182
Change SP500	0.154	0.138	1.117	0.264
Change VIX (high)	0.020	0.015	1.340	0.181

Dummy*Vix	0.091	0.019	4.849	0.000
Dummy*Sp500	-0.038	0.142	-0.268	0.789

AUD/JPY - Nikkei 225				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.001	-0.620	0.535
Period Dummy	0.000	0.001	0.456	0.648
Change Nikkei 225	-0.177	0.052	-3.397	0.001
Change VIX (high)	0.002	0.009	0.166	0.868
Dummy*Vix	0.006	0.013	0.439	0.661
Dummy*Nikkei 225225	-0.364	0.058	-6.328	0.000

AUD/JPY - DAX				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.001	-0.428	0.669
Period Dummy	0.001	0.001	0.861	0.389
Change DAX	-0.080	0.100	-0.802	0.423
Change VIX (high)	0.001	0.015	0.065	0.948
Dummy*Vix	0.053	0.020	2.660	0.008
Dummy*dax30	-0.110	0.109	-1.016	0.310

EUR/JPY - SP500				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.000	-0.872	0.383
Period Dummy	0.001	0.001	1.216	0.224
Change SP500	-0.002	0.085	-0.018	0.986
Change VIX (high)	0.013	0.009	1.408	0.160
Dummy*Vix	0.061	0.011	5.345	0.000
Dummy*Sp500	0.002	0.087	0.024	0.981

EUR/JPY - Nikkei 225				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.000	-0.970	0.332
Period Dummy	0.000	0.001	0.707	0.480
Change Nikkei 225	-0.071	0.035	-2.011	0.045
Change VIX (high)	0.010	0.006	1.550	0.122
Dummy*Vix	0.024	0.009	2.773	0.006
Dummy*Nikkei 225225	-0.189	0.039	-4.857	0.000

EUR/JPY - DAX				
Parameters	Coefficients	SE	T-stat	P-value

Intercept	0.000	0.000	-0.718	0.473
Period Dummy	0.000	0.001	0.766	0.444
Change DAX	-0.083	0.059	-1.410	0.159
Change VIX (high)	0.004	0.009	0.466	0.641
Dummy*Vix	0.029	0.012	2.485	0.013
Dummy*dax30	-0.125	0.064	-1.955	0.051

EUR/CHF - SP500				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.000	-0.793	0.428
Period Dummy	0.000	0.000	1.045	0.296
Change SP500	0.001	0.037	0.018	0.985
Change VIX (high)	0.009	0.004	2.262	0.024
Dummy*Vix	0.019	0.005	3.789	0.000
Dummy*Sp500	-0.012	0.038	-0.313	0.754

EUR/CHF - Nikkei 225				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.000	-0.839	0.401
Period Dummy	0.000	0.000	0.585	0.559
Change Nikkei 225	-0.049	0.016	-3.078	0.002
Change VIX (high)	0.007	0.003	2.424	0.016
Dummy*Vix	0.007	0.004	1.744	0.082
Dummy*Nikkei 225225	-0.057	0.017	-3.289	0.001

EUR/CHF - DAX				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.000	-0.484	0.629
Period Dummy	0.000	0.000	0.577	0.564
Change DAX	-0.064	0.026	-2.459	0.014
Change VIX (high)	0.002	0.004	0.568	0.571
Dummy*Vix	0.012	0.005	2.367	0.018
Dummy*dax30	-0.015	0.028	-0.511	0.609

GBP/JPY - SP500				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.001	-0.813	0.417
Period Dummy	0.001	0.001	1.830	0.068
Change SP500	0.030	0.110	0.274	0.784

Change VIX (high)	0.017	0.011	1.495	0.135
Dummy*Vix	0.065	0.014	4.605	0.000
Dummy*Sp500	-0.134	0.113	-1.190	0.234

GBP/JPY - Nikkei 225				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.001	-0.787	0.431
Period Dummy	0.001	0.001	1.680	0.093
Change Nikkei 225	-0.052	0.057	-0.914	0.361
Change VIX (high)	0.013	0.009	1.451	0.147
Dummy*Vix	0.058	0.012	4.969	0.000
Dummy*Nikkei 225225	-0.132	0.061	-2.176	0.030

GBP/JPY - DAX				
Parameters	Coefficients	SE	T-stat	P-value
Intercept	0.000	0.001	-0.566	0.572
Period Dummy	0.001	0.001	1.430	0.153
Change DAX	-0.132	0.078	-1.689	0.092
Change VIX (high)	0.003	0.011	0.234	0.815
Dummy*Vix	0.034	0.014	2.429	0.015
Dummy*dax30	-0.193	0.083	-2.320	0.021