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Intra-Safe Haven Currency Behavior During the Global Financial Crisis*

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Abstract

We investigate intra-safe haven currency behavior during the recent global financial crisis. The currencies we consider are the USD, the JPY, the CHF, the EUR, the GBP, the SEK, and the CAD. We first assess which safe haven currency appreciates the most as market uncertainty increases, i.e. we assess which safe haven currency is the "safest". We then use non-temporal threshold analysis to investigate whether intra-safe haven currency behavior changes, e.g. accelerates or decelerates, as market uncertainty increases. We find that the JPY is the "safest" of safe haven currencies and that only the JPY appreciates as market uncertainty increases regardless of the prevailing level of uncertainty. For all other currencies under study we find significant market uncertainty threshold effects. We extend our analysis to also consider intra-safe haven currency behavior before and after the global financial crisis.

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1. Introduction

In this paper we investigate intra-safe haven currency behavior during the recent global financial crisis.[1] We first assess which safe haven currency is the safest during this period of extreme market uncertainty. To do so we apply standard time-series methods and we follow Habib and Stracca (2012) and many others in using the VIX, the measure of implied volatility of S & P 500 options, as our main indicator of market uncertainty. The currencies we consider are the USD, the JPY, the CHF, the EUR, the GBP, the SEK, and the CAD.[2] Subsequently, we study whether the intra-safe haven currency behavior among these currencies changes, e.g. accelerates or decelerates, when market uncertainty increases beyond identifiable threshold levels. This part of our analysis employs the non-temporal threshold testing procedure originally developed by Hansen (2000).

The literature on safe haven currencies is relatively sparse and relies on different definitions of what constitutes a safe haven currency. Nevertheless, recently important strides have been made towards attempting to explain what drives safe haven currency behavior as well as towards documenting safe haven currency behavior.[3] Habib and Stracca (2012) carry out a monthly frequency analysis of the behavior of 52 currencies

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[1] We define a safe haven currency as a currency that increases its relative value against other currencies as market uncertainty increases. While the definition of a safe haven currency varies across studies, as noted by Coudert, Guillaumin and Raymond (2014) and Kohler (2010), our definition of a safe haven currency is consistent with Habib and Stracca (2012) and Ranaldo and Söderlind (2010). Moreover, we define intra-safe haven currency behavior as currency behavior amongst currencies typically considered as possible safe haven currencies.

[2] The global importance and safe haven properties of the USD are often heralded. For example, Kaul and Sapp (2006) provide evidence that the USD was used as a safe haven currency at the turn of the millennium. In a recent in-depth investigation of the USD, including its safe haven properties, Prasad (2014) suggests that the global importance of the USD will remain. The JPY, the CHF, the EUR, the GBP are also often considered to be safe haven currencies. For example, Ranaldo and Söderlind (2010) find that during episodes of elevated market uncertainty prior to the global financial crisis the JPY, the CHF, the EUR, and the GBP were exhibiting safe haven currency behavior. We also include in our set of currencies to consider the SEK and the CAD as both of these currencies are occasionally considered as safe haven currencies by media and market analysts, see for example Brown (2014) and Ratner (2011).

[3] Ranaldo and Söderlind (2010) observe that the academic literature on the topic of safe haven currency behavior is sparse relative to the attention the topic gets in the media and by financial market practitioners.

over the span of almost a quarter of a century and show that only few country-specific factors such as the net foreign asset position and the size of the stock market, and for advanced countries the interest rate spread vis-à-vis the US, are systematic drivers of safe haven currency behavior.[4] Ranaldo and Söderlind (2010) provide a high-frequency intra-safe haven currency analysis of the behavior of five currencies (CHF, DEM, EUR, JPY, and GBP) against the USD over the 1993 to 2008 period. They show that rising foreign exchange market volatility, rising US bond prices, and falling US stock prices are generally associated with a depreciation of the USD vis-à-vis both the CHF and the JPY. They also find that the safe haven properties of the JPY relative to the USD are particularly pronounced during the recent global financial crisis. Coudert, Guillaumin and Raymond (2014) offer a daily data analysis of the evolution of 26 currencies from both advanced and emerging economies over the 1999 to 2013 period. They find that only the JPY and the USD exhibit safe haven currency properties. Importantly, the findings of Ranaldo and Söderlind (2010), Coudert, Guillaumin and Raymond (2014), and others indicate that safe haven currency behavior materializes in a non-linear fashion.[5]

We attempt to contribute to the safe haven currency literature in two ways. First, we investigate intra-safe haven currency behavior during the global financial crisis in order to answer which safe haven currency is the safest during this period of extreme uncertainty, i.e. which safe haven currency, if any, systematically strengthens against other possible safe haven currencies as market uncertainty rises towards unprecedented

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[4] The comprehensive and currently definite study by Habib and Stracca (2012) suggests that we know relatively little about the drivers or fundamentals of safe haven currencies. It is beyond the scope of our study to attempt to add new insights in regards to what drives safe haven currency behavior.

[5] For example, Coudert, Guillaumin and Raymond (2014) identify ten separate financial crises periods over their 14 year sample and find that safe haven currency behavior is more pronounced during these periods of high market uncertainty.

levels. Second, we turn our focus to non-linearities by first endogenously identifying uncertainty thresholds around which intra-safe haven currency behavior might change and, subsequently, by documenting how said behavior evolves before and after these uncertainty thresholds are surpassed. Since safe haven currency behavior is likely to be particularly pronounced when market uncertainty is high, we focus our analysis on the recent global financial crisis period during which financial stress and market uncertainty rose to unprecedented levels.

In the first part of our analysis we use OLS with heteroskedasticity- and auto-correlation consistent (HAC) standard errors to estimate exchange rate time-series models over the August 1, 2007 to January 31, 2009 financial crisis period, i.e. the crisis period definition suggested by Melvin and Taylor (2009). The focal explanatory variable is the VIX proxy for market uncertainty. Our results suggest that during the global financial crisis the JPY appreciates systematically against all other safe haven currencies under study as market uncertainty increases and thus is the "safest" of safe haven currencies. We also find that increased market uncertainty is, on average, systematically associated with a depreciation of the GBP, the EUR, the CAD, and the SEK vis-à-vis the USD (and thus also against the JPY and the CHF), i.e. during the global financial crisis the JPY exhibits the strongest safe haven currency behavior followed by the CHF and then the USD.[6]

In the second part of our analysis we employ, and extend, the non-temporal threshold testing procedure originally developed by Hansen (2000). The Hansen (2000) test is similar to a standard temporal parameter change test for a single unknown

[6] These findings are broadly consistent with Ranaldo and Söderlind (2010) and their results pertaining to the 1 August 2007 to 31 December 2008 period.

breakpoint (e.g. Andrews 1993). However, instead of analyzing a temporally-ordered data set, we sort the data in a non-temporal fashion according to, in our context, market uncertainty, as measured by the VIX in levels. Doing so allows us to in a non-temporal modeling framework endogenously identify the market uncertainty threshold, or thresholds, if any, around which safe haven currency behavior changes, thereby testing whether the relationship between market uncertainty and safe haven currency behavior is stable across different levels of market uncertainty or whether it depends on the prevailing level of uncertainty.

We find that the JPY appreciates as market uncertainty increases regardless of the prevailing level of uncertainty whereas all other bilateral USD rates under study appear non-linear in market uncertainty. In case of the CHF, the link between uncertainty and appreciation disappears once uncertainty goes beyond a certain level. By contrast, in the case of the GBP, the EUR, and the SEK, the link between uncertainty and depreciation only materializes or, in the case of the CAD accelerates, once uncertainty reaches a certain (currency specific) level.

To address whether intra-safe haven currency behavior during the global financial crisis is unique to this particular crisis period or of a general nature we extend our analysis to also consider intra-safe haven currency behavior before and after the global financial crisis. More specifically, we extend our analysis to consider the 1 January 1999 to 31 July 2007 pre-crisis period and the 1 February 2009 to 29 February 2012 post-crisis period. We find that the results of the non-temporal threshold analysis differ noticeably across the pre-crisis, crisis, and post-crisis periods. Interestingly, in none of the periods considered do we find the USD to be the "safest" safe haven currency.

Our results hold up against an array of robustness checks, including controlling for exchange rate specific liquidity, controlling for interest rate differentials, as well as employing two alternative measures of market uncertainty.

The rest of the paper is organized as follows. Sections 2 and 3 discuss the data and the empirical framework, respectively. Section 4 presents the results. Section 5 extends the analysis to the pre- and post-financial crisis periods. Section 6 provides robustness checks. Section 7 concludes.

2. Data

Our analysis employs daily data on exchange rates, measures of market uncertainty, and interest rates. All data series cover the 1 January 1999 to 29 February 2012 period.

To measure market uncertainty we follow recent studies such as Habib and Stracca (2012) and others in using the Chicago Board Options Exchange (CBOE) Volatility Index (VIX) as our main indicator of global risk. The VIX is a forward-looking, model-free measure of the near-term (30-day) implied volatility of S&P 500 index options.[7] To check the robustness of our results we also use as alternative measures of market uncertainty the VXO (the CBOE measure of near-term implied volatility of S&P 100 index options) and the VXJ (the Osaka University Center for the Study of Finance and Insurance near-term implied volatility measure of Nikkei 225 index options). Table 1 provides summary statistics for the three market uncertainty measures across the full sample period, the 1999 to 2007 pre-financial crisis period, the 2007 to 2009 financial crisis period, and the 2009 to 2012 post-financial crisis period. Figure 1

[7] For excellent primers on the VIX see Whaley (2009) and Gonzalez-Perez (2013).

provides a plot of the VIX, the VXO, and the VXJ times-series covering the full 1999 to 2012 sample period. As the figure shows, the three implied volatility measures are highly and positively correlated and, furthermore, all indicate that market uncertainty reached unprecedented levels between late 2008 and early 2009.

The exchange rate data consists of bilateral USD spot exchange rates vis-à-vis CHF, JPY, GBP, EUR, CAD, and SEK, respectively, and is obtained from Datastream. Table 2 provides summary statistics for each of the six exchange rate series separately across the full sample period, the 1999 to 2007 pre-financial crisis period, the 2007 to 2009 financial crisis period, and the 2009 to 2012 post-financial crisis period. Figure 2 displays the evolution of these exchange rate series over the full sample period.

Exchange rate specific average daily mean bid-ask spread and daily transaction frequency (number of actual daily trades) purchased from Olsen and Associates form the basis for our liquidity proxy measures.[8]

Interest rates for the US, Switzerland, Japan, Great Britain, the Euro-area, Canada, and Sweden are 3-month LIBOR rates also obtained from Datastream. Summary statistics regarding interest rates are available from the authors upon request.

3. Econometric Methodology

In the first part of our analysis we investigate intra-safe haven currency behavior during the recent global financial crisis and, particularly, attempt to answer which safe haven currency is the safest during such a period of extreme market uncertainty. To do so we use OLS with heteroskedasticity- and auto-correlation consistent (HAC) standard errors

[8] As noted by Banti, Phylaktis, and Sarno (2012), the bid-ask spread is the most widely used liquidity measure. The transaction frequency based measure dates back to Demsetz (1968).

to estimate the following time-series model over the August 1, 2007 to January 31, 2009 financial crisis period:

$$(1) \qquad \Delta s_t = \alpha + \beta \Delta VIX_t + \gamma \Delta s_{t-1} + \varepsilon_t$$

where Δs_t is the first-difference in the log of the spot exchange rate and ΔVIX_t is the first-difference of the VIX. The objective of the second part of our analysis is to shed light on whether safe haven currency behavior changes, e.g. accelerates or decelerates, when market uncertainty increases to certain levels. To address these research questions we employ, and extend, the non-temporal threshold testing procedure originally developed by Hansen (2000). The Hansen (2000) test is similar to a standard temporal parameter change test for a single unknown breakpoint (e.g. Andrews 1993). However, instead of analyzing a temporally-ordered data set, we sort the data in a non-temporal fashion according to, in our context, market uncertainty, as measured by the VIX in levels. Doing so allows us to in a non-temporal modeling framework endogenously identify the market uncertainty threshold, or thresholds, if any, around which safe haven currency behavior changes, thereby testing whether the relationship between market uncertainty and safe haven currency behavior depends on the level of market uncertainty.

Applying the Hansen (2000) non-temporal threshold test to the context of exchange rate behavior and market uncertainty yields the following empirical model:

$$(2) \qquad \Delta s_t = \alpha_L + \beta_L \Delta VIX_t + \gamma_L \Delta s_{t-1} + \varepsilon_{Lt} \text{ if } VIX_t < q$$

$$\Delta s_t = \alpha_H + \beta_H \Delta VIX_t + \gamma_H \Delta s_{t-1} + \varepsilon_{Ht} \text{ if } VIX_t \geq q$$

where q is the VIX threshold value to be estimated by the maximand of the likelihood ratio statistics over all permissible values, and subscripts L and H denote low and high uncertainty regimes, respectively.[9]

This sorting procedure makes the value of VIX the trending variable and, as a result, the asymptotic distribution of the standard temporal change-point test is not reliable. To address this concern our threshold test results are based on the *p*-values computed by the asymptotically correct bootstrap procedure proposed by Hansen (2000). Furthermore, ordering the data as described ignores potential serial correlations in the errors thus the computed standard errors may be under-estimated. To address this concern we include in our regression models lags of the dependent variable as additional explanatory variables. To make sure that the residuals of the final regression do not exhibit serial correlations, we first estimate the threshold parameter and the coefficient estimates to obtain the associated residuals. We then re-order the residuals temporally and perform the test for serial correlations using the re-ordered residuals. As it turns out, including only the first lag of the dependent variable is sufficient to ensure that the errors are free of serial correlation. The GARCH character of the residuals is accounted for using the heteroskedasticity robust standard errors of White (1980).

A limitation of the Hansen (2000) procedure and, by extension, the threshold model described by Equation (2), is that the possibility of multiple non-temporal thresholds is not considered. In our particular context of investigating currency behavior

[9] The permissible threshold values exclude the first and last 1% of the ordered sample.

during a period of extreme market uncertainty we cannot a priori rule out the possibility that safe haven currency behavior changes more than once as market uncertainty approaches abnormal levels. In order to test for the presence of multiple non-temporal thresholds we extend the Hansen (2000) procedure by applying the multiple structural change analysis proposed by Bai and Perron (1998, 2003) to the sorted data. The multiple structural change analysis searches for any number of thresholds present in the data over all possible combinations of break points. The extended model is described as follows:

(3)
$$\Delta s_t = \alpha_1 + \beta_1 \Delta VIX_t + \gamma_1 \Delta s_{t-1} + \varepsilon_{1,t} \text{ if } VIX_t < q_1$$
$$\vdots$$
$$\Delta s_t = \alpha_j + \beta_j \Delta VIX_t + \gamma_j \Delta s_{t-1} + \varepsilon_{j,t} \text{ if } q_j < VIX_t \leq q_{j+1}$$
$$\vdots$$
$$\Delta s_t = \alpha_{m+1} + \beta_{m+1} \Delta VIX_t + \gamma_{m+1} \Delta s_{t-1} + \varepsilon_{m+1,t} \text{ if } q_m < VIX_t$$

where m is the number of thresholds present in the data. To determine the number of thresholds we use the SupF(l+1|l) test for the null of l breaks versus l+1 breaks. The procedure starts from l=0, if it rejects, proceeds to l=1 etc. The number l is considered as the number of breaks present in the data when the test procedure stops rejecting. As before, our threshold test results are based on the *p*-values computed by the asymptotically correct bootstrap procedure proposed by Hansen (2000).

4. Results

The results of estimating Equation (1) over the global financial crisis period August 2007 to January 2009 are reported in Table 3. As the first two columns of Table 3 show, increased market uncertainty during this period is for both the CHF and the JPY associated with a highly significant appreciation, on average, against the USD. Columns three through six show that the opposite is the case for all other currencies under study, i.e. increased market uncertainty is, on average, systematically associated with depreciation of the GBP, the EUR, the CAD, and the SEK vis-à-vis the USD.

This first part of our investigation of intra-safe haven currency behavior during the recent global financial crisis thus indicates that the USD is not the "safest" safe haven currency. Instead, the CHF and the JPY are the "safer" safe haven currencies and, particularly, "safer" than the USD during this period of extreme market uncertainty. The USD is a "safer" safe haven currency only relative to the GBP, the EUR, the CAD, and the SEK.

To determine whether the CHF or the JPY is the "safest" safe haven currency we re-estimate Equation (1) with the bilateral CHF/JPY rate as the dependent variable. The results, displayed in the last column of Table 3, suggest that increased market uncertainty is, on average, systematically associated with an increase in the value of the JPY relative to the CHF. Therefore, the JPY is "safer" than the CHF and thus during the global financial crisis period the JPY appears to be the "safest" of the possible safe haven currencies considered.[10] To find that the JPY as well as the CHF both appreciate against the USD as uncertainty increases is broadly consistent with the results of Ranaldo and

[10] See Botman, Carvalho Filho, and Lam (2013) for a discussion of why the JPY tends to appreciate during episodes of increased market uncertainty and Grisse and Nitschka (2013) for details on the CHF as a safe haven currency.

Söderlind (2010) and their assessment of safe haven currency behavior during the global financial crisis period.

Turning to the investigation of whether safe haven currency behavior changes when market uncertainty increases beyond a certain level we estimate the threshold model described by Equation (2) separately across each of the six bilateral USD rates in our sample. Table 4 reports the results. The first row of Table 4 shows the results of testing the null hypothesis of no break against the alternative of one break. As the row shows, we find evidence of at least one non-temporal break for all bilateral rates under study but the JPY/USD rate. The identified thresholds range from VIX levels of low 30s to low 40s for all but the CHF/USD rate, and low 50s for the CHF/USD rate.[11]

The results of testing the null hypothesis of a single non-temporal break against the alternative of two breaks, reported in the row below, do not indicate that more than a single break is present in the data for any of the five bilateral USD rates considered.[12]

Comparing the results of the non-temporal threshold analysis across the six bilateral USD rates suggests that the currencies under study respond quite differently to increased market uncertainty. The first column reports that for the CHF/USD rate the estimated coefficient associated with VIX changes when VIX is below the identified threshold (of VIX=52.05) is negative and highly significant, whereas the estimated coefficient when VIX is above the identified threshold is insignificant (and positive). In other words, the CHF appreciates against the USD as uncertainty rises but only as long as

[11] To assess if the threshold regression improves the overall fit of the models we compare the adjusted R^2 across the models estimated with and without thresholds. We do so separately for each currency pair under study and find that the threshold model improves the fit in all cases. Additional details are available from the authors upon request.

[12] We test for multiple breaks only for currencies where the null hypothesis of no break against the alternative of one break is rejected.

uncertainty is below a certain level. Once uncertainty exceeds this level, additional increases in market uncertainty do not seem to significantly influence the CHF/USD rate.

By contrast, the next column shows that for the JPY/USD rate, consistent with the insignificant non-temporal threshold for this particular exchange rate, the estimated coefficient associated with VIX is negative and highly significant regardless of whether market uncertainty is high or low (i.e. whether the VIX is above or below the most likely but insignificant threshold of 44.93). Thus, unlike the CHF, the JPY appreciates, on average, against the USD as market uncertainty increases regardless of the level of market uncertainty.

The results reported in the last four columns of Table 4 show that three of the four currencies that we in the first part of our analysis found to, on average, lose value against the USD as uncertainty increases, exhibit a pattern of no discernible connection between changes in market uncertainty and relative value vis-à-vis the USD when uncertainty is low. As the columns three, four and six show, the estimated coefficient associated with VIX changes is insignificant for the GBP/USD, the EUR/USD, and the SEK/USD rate when uncertainty is below the respective threshold. Instead, only when uncertainty exceeds the currency specific threshold is it the case that the GBP, the EUR, and the SEK depreciate significantly against the USD. The CAD results, reported in column five, differ in the sense that the estimated coefficient associated with VIX changes is positive and highly significant regardless of whether the VIX is above or below the identified threshold for the CAD/USD sample, thereby suggesting that the CAD loses value relative to the USD regardless of the level of market uncertainty. The coefficient estimate in question is, however, almost three times larger when uncertainty is above the threshold, suggesting that an increase in uncertainty is associated with a significantly larger CAD depreciation vis-à-vis the USD when uncertainty is high compared to when uncertainty is below the threshold.

Overall, the results of our analysis of intra-safe haven currency behavior during the global financial crisis suggest that the JPY appreciates systematically against all other safe haven currencies under study as market uncertainty increases and thus is the "safest" of the safe haven currencies. Moreover, the JPY appreciates as market uncertainty increases regardless of the prevailing level of uncertainty whereas all other bilateral USD rates under study appear non-linear in regards to market uncertainty. In case of the CHF, the link between uncertainty and appreciation disappears once uncertainty reaches a certain level. By contrast, in the case of the GBP, the EUR, and the SEK, the link between uncertainty and depreciation only materializes or, in the case of the CAD accelerates, once uncertainty reaches a certain (currency specific) level.

Overall, these results confirm the importance of considering non-linearities when analyzing safe haven currencies. At the same time, they also further highlight the role of the JPY as the "safest" safe haven currency in the sense that the JPY is the sole stand-out currency where the link between currency strength and uncertainty is not dependent on uncertainty levels. More broadly, to find that market uncertainty can systematically influence currency behavior suggests that market uncertainty should constitute an important element in our understanding, and modeling, of exchange rates. Especially considering that market uncertainty, as measured by the VIX, exhibits some degree of predictability in the sense that the lagged variable of VIX is statistically significant in a simple predictive regression.[13]

5. Extension

In this section we extend our analysis to also consider intra-safe haven currency behavior before and after the global financial crisis. Doing so allows us to address whether the pattern of intra-safe haven currency movements and market uncertainty changes discussed in the previous section is of a general nature or unique to the global financial crisis period.

Table 5 reports the results of estimating Equation (1) across the 1 January 1999 to 31 July 2007 period. As the table shows, all but the CAD appreciate, on average, against the USD as market uncertainty increases.[14] With the exception of the SEK appreciation, the observed appreciations are all highly significant. Comparing the magnitude of the coefficient estimates suggest that the CHF appreciates the most against the USD, followed by the EUR and the JPY. As such, the CHF is the "safest" safe haven currency and, as the last second- and third-last columns of Table 5 show, significantly "safer" than both the EUR and the JPY.

The results of the threshold analysis (Equation 2) of the 1999 to 2007 period are reported in Table 6. We first test the null hypothesis of no break against the alternative of one break and find evidence of at least one non-temporal break in the case of the CHF/USD, the JPY/USD, the GBP/USD, and the EUR/USD rate. When we then test the

[13] Results of the predictive regression of VIX are not included for brevity but available upon request.
[14] The only currency losing value relative to the USD as uncertainty increases is the CAD. The CAD depreciation is highly significant.

null hypothesis of a single break against the alternative of two non-temporal breaks we accept the null for all but the JPY/USD rate. Testing the null hypothesis of two breaks against the alternative of three non-temporal breaks for the JPY/USD does not indicate the presence of more than two breaks.

The results of splitting up the sample according to the respective significant non-temporal thresholds for the four bilateral USD rates where at least one significant threshold exists suggest that safe haven currency behavior, i.e. in these four cases characterized by an appreciation against the USD as market uncertainty increases, for the CHF and the JPY accelerates, and for the GBP and the EUR does not occur, until uncertainty rises beyond the currency specific thresholds.

The results of estimating Equation (1) across the post-crisis period February 2009 to February 2012, and the associated test for non-temporal breaks, are reported in Table 7. The table shows that during the recent post-crisis period only the JPY strengthens, on average, against the USD as uncertainty increases. By contrast, all other currencies under study lose value against the USD as uncertainty increases. The results of the non-temporal threshold analysis of the post-crisis period show that for none of the six bilateral USD rates under study do we reject the null hypothesis of no break against the alternative of at least one break, i.e. for this period we find no evidence that non-temporal uncertainty breaks are present in the data.

Comparing the findings of this section to those pertaining to the 2007 to 2009 global financial crisis period in regards to intra-safe haven currency behavior and which currency is the "safest" we note the following. The USD is in none of the periods the "safest" safe haven currency. However, while an increase in market uncertainty during the pre-crisis period is associated with a significant depreciation of the USD against most of the currencies considered in our study, during the crisis period increased uncertainty is associated with an appreciation of the USD against all but the CHF and the JPY, and after the crisis all but the JPY. In terms of which currency is the “safest”, the JPY is the “safest” during the crisis and post-crisis periods. Generally, the CHF and the JPY tend to be the consistently “safer” currencies across the entire 1999 to 2012 period, with the exception of the 1999 to 2007 pre-crisis period during which increased market uncertainty is associated with a depreciation of JPY vis-à-vis the EUR.

Similarly, the results of the non-temporal threshold analysis differ noticeably across the pre-crisis, crisis, and post-crisis periods. For both the pre-crisis and the crisis period we typically identify significant uncertainty thresholds for the bilateral USD rates under study around which the intra-safe haven currency behavior pattern changes. In all but one instance of the significant uncertainty threshold (CHF/USD during the global financial crisis) is it the case that safe haven currency behavior either doesn’t occur until uncertainty is beyond a certain threshold level or accelerates once such level is reached. By contrast, we find a complete absence of uncertainty thresholds when analyzing the post-crisis period. Yet, in all but one instance during the post-crisis period (SEK/USD) do we find that currency movements and changes in market uncertainty are significantly related. In other words, while safe haven currency behavior during the pre-crisis and crisis periods typically appears to either commence or strengthen when uncertainty becomes relatively high, safe haven currency behavior during the most recent period materializes, and remains stable, regardless of the prevailing level of uncertainty. That currency markets during the post-crisis period react to increases in uncertainty even when uncertainty is low may suggest that the post-crisis period is generally characterized by an overall reduction in risk tolerance.

6. Robustness

In order to test the robustness of our results we use an alternative definition of the global financial crisis period, control for exchange rate specific liquidity, control for interest rate differentials, and employ two alternative measures of market uncertainty.

First, we redo our analysis using the global financial crisis period definition of Fratzscher (2009). According to Fratzscher (2009), the crisis period is 1 July 2008 to 31 January 2009, i.e. the crisis starting date according to this alternative definition occurs 11 months later compared to our baseline definition while the end date is the same. As it turns out, the results of estimating Equation (1) on the shortened sample of only 147 daily observations (compared to 378 when considering the baseline crisis period definition) are remarkably similar to the previously discussed baseline results (Table 3). The only difference is that increased market uncertainty during this shortened crisis period is for the CHF now associated with only a marginally significant appreciation, on average, against the USD. The threshold analysis, as described in Equation (2), of the alternative crisis period yields very similar results for all the bilateral USD currency pairs in regards to the threshold levels that are identified as the most likely thresholds. None of the thresholds, however, is significant at conventional levels. This is unsurprising considering the much smaller sample size and associated reduction in the power of the threshold test.

Second, we consider the role of liquidity by adding to Equations (1) and (2) exchange rate specific liquidity proxy measures (average daily mean bid-ask spread and, in turn, trading frequency). Not surprisingly, considering that Mancini Griffoli and Ranaldo (2012) and others have found liquidity to be an important driver of currency fluctuations during the global financial crisis, we find some significant liquidity effects, most notably that the CHF tends to depreciate against the USD as liquidity in the CHF/USD market increases, but only when uncertainty is relatively low (i.e. below the endogenously identified threshold). Importantly, adding the liquidity proxy measures does not qualitatively change our previously discussed findings in regards to the influence of uncertainty on exchange rates.

Third, we redo our analysis of intra-safe haven currency behavior during the baseline global financial crisis period after including in Equations (1) and (2) as additional explanatory variables the country-specific interest rate differential vis-à-vis the US.[15] The addition of interest rate controls does not qualitatively change our results. The previously documented pattern of intra-safe haven currency behavior remains. The threshold results are similarly unchanged, except we in addition to the thresholds identified in the baseline analysis now also find evidence of a single marginally significant threshold in case of the JPY/USD rate. Comparing the coefficient estimates associated with VIX changes across the low and high uncertainty JPY/USD sub-samples, as defined by the marginally significant uncertainty threshold, suggests that while the JPY appreciates as uncertainty increases regardless of the level of market uncertainty, an

[15] As mentioned by Habib and Stracca (2012), inclusion of the interest rate differential addresses the possibility of carry trade effects.

increase in uncertainty is associated with a larger JPY appreciation vis-à-vis the USD when uncertainty is high compared to when uncertainty is below the threshold.

Fourth, we redo our analysis of intra-safe haven currency behavior during the August 2007 to January 2009 baseline crisis period using instead of the VIX two alternative measures of market uncertainty. These alternative measures of market uncertainty are the VXO (the CBOE measure of near-term implied volatility of S&P 100 index options) and the VXJ (the Osaka University Center for the Study of Finance and Insurance near-term implied volatility measure of Nikkei 225 index options). When estimating Equations (1) and (2) using the VXO instead of the VIX, our previously discussed baseline results are unchanged. This is not surprising, considering that the VIX and the VXO series are highly and positively correlated. When replacing the VIX with the VXJ, the so-called "Japanese VIX", the sign of the VXJ coefficient estimates resulting from estimating Equation (1) across the six bilateral USD currency pairs under study once again suggest that increased market uncertainty during the financial crisis period is for both the CHF and the JPY associated with an appreciation against the USD while increased market uncertainty is associated with a depreciation of the GBP, the EUR, the CAD, and the SEK vis-à-vis the USD. Unlike the baseline results, however, only the VXJ coefficient estimates for the JPY/USD, the CAD/USD, and the SEK/USD rates are highly significant whereas the remaining three VXJ coefficient estimates are all slightly below significance at conventional levels. The estimation of Equation (2) with the VXJ in place of the VIX identifies a single significant threshold for four of the exchange rate series (JPY/USD, GBP/USD, CAD/USD, and SEK/USD). In all four cases do we find that the link between uncertainty and currency movement either doesn't materialize until or accelerates as uncertainty reaches the (currency specific) level.

7. Conclusion

In this paper we investigate intra-safe haven currency behavior during the recent global financial crisis and beyond. The objective of our investigation is two-fold. The first objective is to assess if one of the currencies typically considered to be a possible safe haven currency increases its relative value against the other possible safe haven currencies in our sample as market uncertainty increases. In other words, we attempt to answer which safe haven currency is the "safest". Our findings of this part of our study suggest that during the global financial crisis the JPY appreciates significantly vis-à-vis all other possible safe haven currencies considered as market uncertainty increases, thereby implying that the JPY is the "safest" safe haven currency during this recent period of extreme market turmoil. We find the CHF and the USD to be the "second-most safe" and "third-most safe" safe haven currency, respectively, i.e. the CHF appreciates significantly against all but the JPY and the USD appreciates significantly against all but the JPY and the CHF as uncertainty rises.

The second objective of our investigation is to asses if safe haven currency behavior changes as market uncertainty increases beyond certain threshold levels of uncertainty. Our application of the Hansen (2000) testing procedure to this research question allows us to in a non-temporal modeling framework endogenously identify the market uncertainty threshold, or thresholds, if any, around which safe haven currency behavior changes occur and thereby test whether the previously described relationship between market uncertainty and safe haven currency behavior is stable across different levels of uncertainty. The results of our non-temporal threshold analysis reveal significant uncertainty threshold levels around which intra-safe haven currency behavior changes occur for all the possible safe haven currencies considered with the notable exception of the JPY for which no evidence of thresholds is found. In other words, our results suggest that the JPY appreciates as market uncertainty increases regardless of the prevailing level of uncertainty. By contrast, in case of the CHF, the link between uncertainty and appreciation disappears once uncertainty goes beyond a certain level and, in case of the GBP, the EUR, and the SEK, the link between uncertainty and depreciation only materializes or, in the case of the CAD accelerates, once uncertainty reaches a certain level.

Overall, the results of our study offer three important insights. First, our results provide a ranking of the relative safety of the possible safe haven currencies considered before, during, and after the global financial crisis. Second, our results add to our understanding of safe haven currency behavior in showing that safe haven currency behavior is not necessarily neither linear nor continuous in market uncertainty but possibly systematically dependent on the prevailing level of uncertainty. Third, and more generally, our results suggest that market uncertainty can influence currency behavior in a systematic fashion and, therefore, market uncertainty should constitute an important element in our understanding, and modeling, of exchange rates.

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Figure 1: VIX, VXO, and VXJ Series

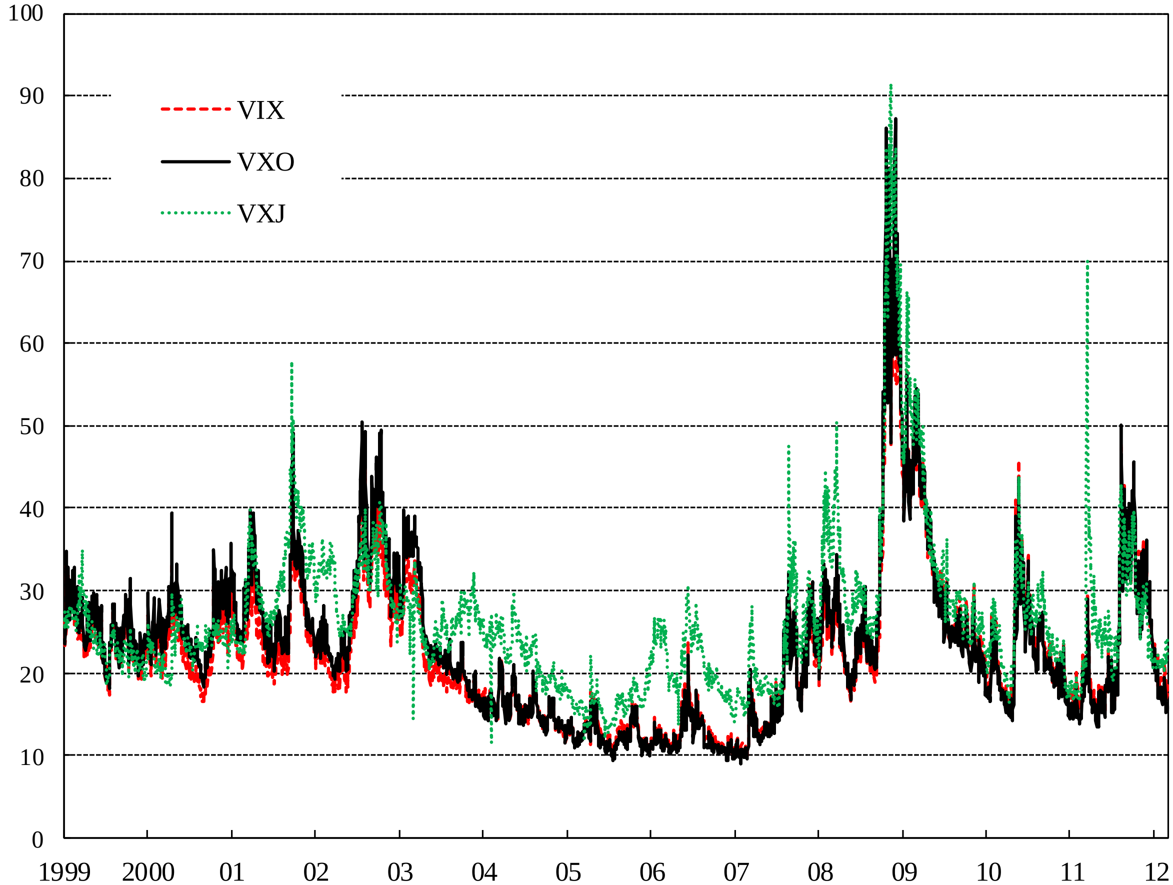

Figure 2: Exchange Rate Series

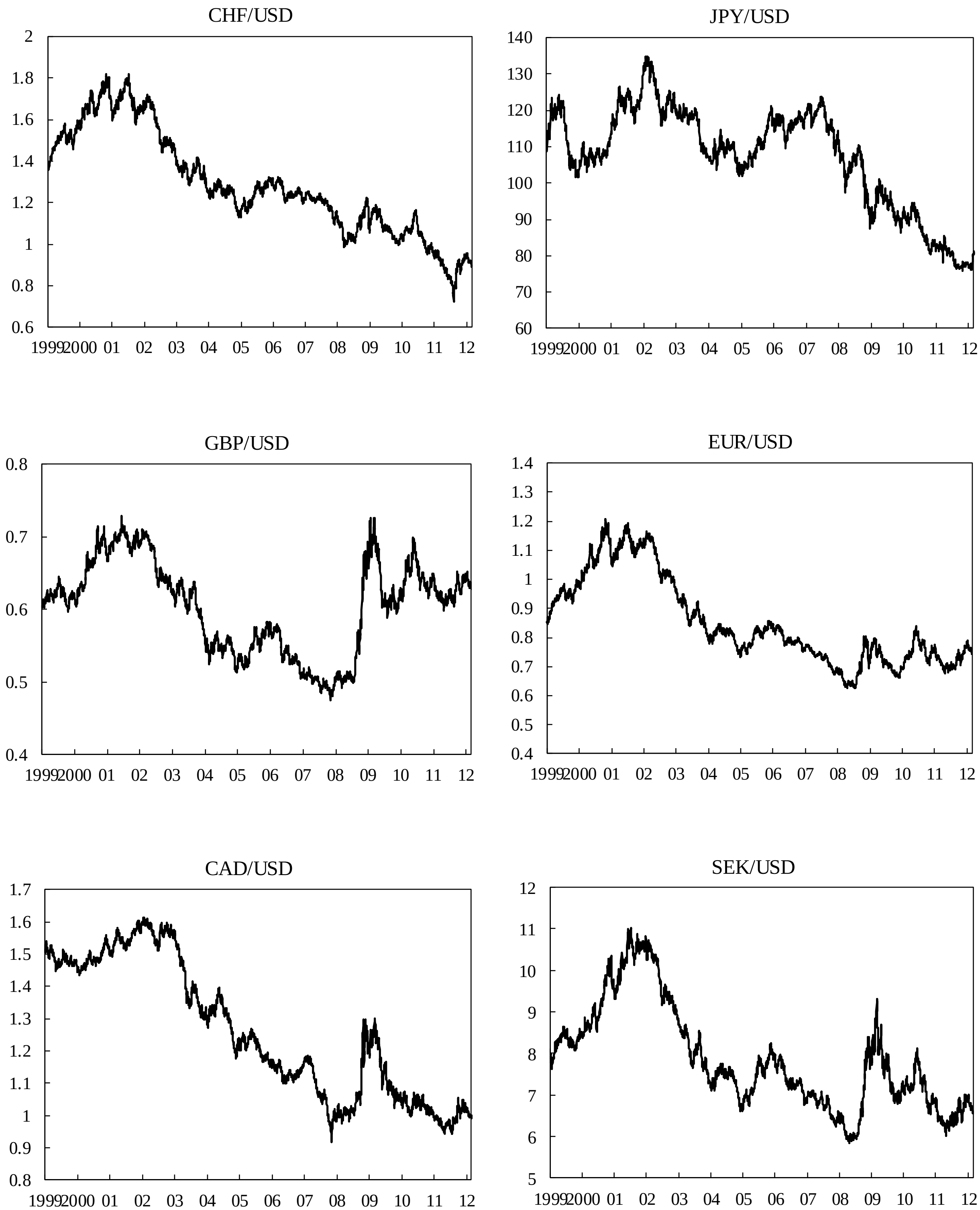

Table 1	**Descriptive Statistics for VIX, VXO, and VXJ Series**											
	1 Jan 1999 to 29 Feb 2012			1 Jan 1999 to 31 Jul 2007			1 Aug 2007 to 31 Jan 2009			1 Feb 2009 to 29 Feb 2012		
	VIX	VXO	VXJ	VIX	VXO	VXJ	VIX	VXO	VXJ	VIX	VXO	VXJ
Start of Period	24.46	23.53	26.59	24.46	23.53	26.59	21.22	21.68	24.66	43.06	41.13	51.24
End of Period	18.43	16.11	24.08	23.52	25.18	26.46	44.84	45.85	55.8	18.43	16.11	24.08
Percent Change	-24.65	-31.53	-9.44	-3.84	7.01	-0.49	111.31	111.49	126.28	-57.20	-60.83	-53.01
Mean	22.45	23.22	26.54	20.01	21.21	24.18	30.55	31.99	37.78	25.22	24.50	27.68
Max	80.86	87.24	91.45	45.08	50.48	63.73	80.86	87.24	91.45	52.65	54.51	70.09
Min	9.89	9.05	11.52	9.89	9.05	11.52	16.12	15.45	20.51	14.62	13.45	16.37
Standard Deviation	9.11	10.03	9.44	6.82	8.28	6.23	14.65	15.50	16.26	7.98	8.45	8.12

Table 2 **Descriptive Statistics for Exchange Rate Series**

	1 Jan 1999 to 29 Feb 2012						1 Jan 1999 to 31 Jul 2007					
	CHF/USD	JPY/USD	GBP/USD	EUR/USD	CAD/USD	SEK/USD	CHF/USD	JPY/USD	GBP/USD	EUR/USD	CAD/USD	SEK/USD
Start of Period	1.37	111.32	0.60	0.85	1.52	7.98	1.37	111.32	0.60	0.85	1.52	7.98
End of Period	0.90	81.23	0.63	0.75	0.99	6.62	1.20	118.47	0.49	0.73	1.07	6.73
Percent Change	-34.0	-27.0	4.0	-11.7	-34.9	-17.1	-12.3	6.4	-18.5	-14.0	-29.8	-15.7
Mean	1.29	107.37	0.60	0.85	1.26	7.86	1.43	115.20	0.60	0.92	1.37	8.36
Max	1.82	134.81	0.73	1.21	1.61	11.02	1.82	134.81	0.73	1.21	1.61	11.02
Min	0.72	75.82	0.47	0.63	0.92	5.84	1.13	101.60	0.49	0.72	1.04	6.60
Standard Deviation	0.25	13.93	0.06	0.15	0.21	1.23	0.19	7.16	0.06	0.14	0.17	1.17
	1 Aug 2007 to 31 Jan 2009						**1 Feb 2009 to 29 Feb 2012**					
	CHF/USD	JPY/USD	GBP/USD	EUR/USD	CAD/USD	SEK/USD	CHF/USD	JPY/USD	GBP/USD	EUR/USD	CAD/USD	SEK/USD
Start of Period	1.20	119.14	0.49	0.73	1.05	6.72	1.14	89.40	0.69	0.77	1.23	8.22
End of Period	1.16	89.89	0.69	0.78	1.23	8.35	0.90	81.23	0.63	0.75	0.99	6.62
Percent Change	-3.7	-24.6	40.4	7.2	16.7	24.2	-21.0	-9.1	-9.3	-2.2	-19.7	-19.5
Mean	1.11	105.70	0.54	0.69	1.06	6.66	1.00	86.44	0.64	0.73	1.05	7.07
Max	1.22	119.63	0.73	0.80	1.30	8.45	1.19	101.07	0.73	0.84	1.30	9.32
Min	0.99	87.36	0.47	0.63	0.92	5.84	0.72	75.82	0.59	0.66	0.94	6.01
Standard Deviation	0.063	7.603	0.066	0.047	0.090	0.713	0.099	6.871	0.026	0.037	0.074	0.616

TABLE 3 **Time-Series Analysis: 1 Aug 2007 to 31 Jan 2009**

Coefficients	CHF/USD	JPY/USD	GBP/USD	EUR/USD	CAD/USD	SEK/USD	CHF/JPY
Constant	-0.01	-0.06*	0.07	0.01	0.02	0.04	0.04
	(-0.34)	(-1.71)	(1.62)	(0.16)	(0.54)	(0.80)	(0.96)
ΔVIX	-2.16***	-7.32***	2.54***	1.56**	5.60***	3.70***	5.29***
	(-3.62)	(-12.11)	(3.41)	(2.53)	(8.09)	(4.37)	(6.40)
Δs(-1)	2.98	-6.43	9.38	9.27	7.28	-5.64	0.44
	(0.41)	(-1.42)	(1.37)	(1.45)	(1.18)	(-0.94)	(0.07)
Observations	378	378	378	378	378	378	378
Sum of Squared Errors	0.025	0.021	0.024	0.022	0.026	0.038	0.031
R-Squared	0.042	0.393	0.059	0.031	0.217	0.077	0.184
Heteroskedasticity Test	0.000	0.001	0.000	0.004	0.000	0.001	0.001
Breusch-Pagan Test	0.927	0.148	0.592	0.573	0.042	0.809	0.195

NOTES:

(a) ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.
(b) t statistics based on White'sheteroskedasticity robust srandard errors in ( ) below the coefficient estimates.
(c) Heteroskedasticity test reports p-values of White's (1980) test.
(d) Breusch-Pagan test reports p-values of the null of no serial correlations up to the fourth order.
(e) Estimated model and variables defined in Equation (1) of main text.

TABLE 4	**Non-Temporal Threshold Analysis : 1 Aug 2007 to 31 Jan 2009**					
	CHF/USD	JPY/USD	GBP/USD	EUR/USD	CAD/USD	SEK/USD
Threshold analysis						
SupF(1|0)	18.88*	14.64	41.99***	40.69***	27.06**	48.50***
Threshold	52.05	44.93	43.27	32.82	34.74	32.24
SupF(2|1)	14.56	-	7.31	6.37	9.98	5.09
Threshold	33.10		25.78	21.55	19.41	23.44
Coefficients						
Constant(low)	-4.56	-2.36	-6.36	-0.03	-4.01	-4.77
	(-0.86)	(-0.46)	(-0.98)	(-0.01)	(-0.65)	(-0.78)
Constant(high)	33.93	-14.25*	19.18**	13.52	11.95	-9.41
	(1.41)	(-1.67)	(2.06)	(1.48)	(1.33)	(-1.24)
ΔVIX(low)	-3.11***	-6.71***	0.30	-0.84	3.38***	0.45
	(-4.70)	(-13.10)	(0.49)	(-1.57)	(5.84)	(0.69)
ΔVIX(high)	0.66	-8.89***	7.51***	5.35***	9.53***	8.92***
	(0.47)	(-5.71)	(4.75)	(4.40)	(5.89)	(5.03)
Δs(-1)(low)	0.00	-0.02	0.02	-0.03	-0.01	-0.02
	(0.08)	(-0.55)	(0.63)	(-0.79)	(-0.29)	(-0.44)
Δs(-1)(high)	-0.10	-0.32	0.31	0.11	0.16	0.25
	(0.08)	(-0.55)	(0.63)	(-0.79)	(-0.29)	(-0.44)
Low Uncertainty Sample						
Observations	328	312	306	287	290	286
Sum of Squared Errors	0.019	0.012	0.011	0.010	0.013	0.013
R-Squared	0.091	0.395	0.006	0.011	0.132	0.005
High Uncertainty Sample						
Observations	50	66	72	91	88	92
Sum of Squared Errors	0.007	0.009	0.011	0.012	0.013	0.024
R-Squared	0.093	0.436	0.282	0.197	0.389	0.242

NOTES:

(a) ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.
(b) t statistics based on White's heteroskedasticity robust srandard errors in ( ) below coefficient estimates.
(c) Significance of SupF tests based on fixed regressor bootstrap of Hansen (2000) with 10,000 replications.
(d) Estimated model and variables defined in Equation (2) of main text.

TABLE 5 **Time-Series Analysis: 1 Jan 1999 to 31 Jul 2007**

Coefficients	CHF/USD	JPY/USD	GBP/USD	EUR/USD	CAD/USD	SEK/USD	CHF/JPY	CHF/EUR	EUR/JPY
Constant	-0.01	0.00	-0.01	-0.01	-0.02*	-0.01	-0.01	0.00	-0.01
	(-0.57)	(0.25)	(-1.02)	(-0.69)	(-1.81)	(-0.71)	(-0.71)	(0.28)	(-0.78)
ΔVIX	-2.32***	-1.03***	-0.81***	-1.40***	0.96***	-0.23	-1.29***	-0.92***	-0.37
	(-8.68)	(-3.69)	(-3.98)	(-5.76)	(5.45)	(-0.88)	(-4.11)	(-6.75)	(-1.16)
Δs(-1)	-8.15***	-4.67**	-2.39	-5.91***	-3.81*	-4.46**	-2.98	-23.24***	-0.44
	(-3.82)	(-1.96)	(-1.03)	(-2.71)	(-1.72)	(-1.97)	(-1.02)	(-5.23)	(-0.15)
Observations	2155	2155	2155	2155	2155	2155	2155	2155	2155
Sum of Squared Errors	0.090	0.080	0.055	0.080	0.042	0.096	0.107	0.017	0.106
R-Squared	0.045	0.011	0.008	0.019	0.016	0.002	0.011	0.085	0.001
Heteroskedasticity Test	0.681	0.000	0.063	0.656	0.846	0.004	0.000	0.000	0.000
Breusch-Pagan Test	0.726	0.069	0.568	0.133	0.671	0.215	0.137	0.061	0.458

NOTES:

(a) See notes to Table 3.

TABLE 6 **Non-Temporal Threshold Analysis: 1 Jan 1999 to 31 Jul 2007**

		CHF/USD	JPY/USD	GBP/USD	EUR/USD	CAD/USD	SEK/USD
Threshold analysis							
	SupF(1|0)	37.88***	25.22***	23.24*	32.30***	11.96	6.20
	Threshold	25.90	25.78	25.62	19.95	14.56	11.83
	SupF(2|1)	8.45	12.90**	2.89	7.45	-	-
	Threshold	18.02	18.94	12.73	25.90		
	SupF(3|2)	-	5.06	-	-	-	-
	Threshold		18.93				
Coefficients							
	Constant(low)	-7.83***	0.01	-1.46	-5.05*	-1.97	1.94
		(-3.21)	(0.38)	(-0.55)	(-1.65)	(-0.49)	(0.24)
	Constant(high)	-10.80**	0.09***	-6.89	-6.31**	-4.69*	-5.23**
		(-2.47)	(2.69)	(-1.44)	(-2.06)	(-1.78)	(-2.21)
	Constant(medium)	-	-0.07***	-	-	-	-
			(-2.82)				
	ΔVIX(low)	-1.53***	-0.48	-0.31	-0.04	0.13	-0.59
		(-5.57)	(-1.03)	(-1.37)	(-0.12)	(0.33)	(-0.86)
	ΔVIX(high)	-5.12***	-2.05***	-2.43***	-2.75***	1.28***	-0.15
		(-8.45)	(-4.21)	(-5.66)	(-7.42)	(6.34)	(-0.53)
	ΔVIX(medium)	-	-0.98**	-	-	-	-
			(-1.96)				
	Δs(-1)(low)	-0.01	-0.52	-0.02	-0.02	-0.04**	-0.09**
		(-0.60)	(-0.15)	(-1.31)	(-1.37)	(-2.05)	(-2.16)
	Δs(-1)(high)	-0.03	1.00	-0.01	0.00	-0.01**	-0.00**
		(-0.60)	(0.23)	(-1.31)	(-1.37)	(-2.05)	(-2.16)
	Δs(-1)(medium)	-	-13.73***	-	-	-	-
			(-3.32)				
Low Uncertainty Sample							
	Observations	1741	1015	1725	1121	601	216
	Sum of Squared Errors	0.071	0.030	0.045	0.036	0.013	0.008
	R-Squared	0.023	0.002	0.001	0.003	0.001	0.003
High Uncertainty Sample							
	Observations	414	427	430	1034	1554	1939
	Sum of Squared Errors	0.018	0.019	0.010	0.044	0.029	0.088
	R-Squared	0.178	0.033	0.082	0.058	0.030	0.003
Medium Uncertainty Sample							
	Observations	-	714	-	-	-	-
	Sum of Squared Errors	-	0.030	-	-	-	-
	R-Squared	-	0.025	-	-	-	-

NOTES:

(a) See notes to Table 4

TABLE 7 **Time Series Analysis and Non-Temporal Threshold Analysis: 1 Feb 2009 to 29 Feb 2012**

	CHF/USD	JPY/USD	GBP/USD	EUR/USD	CAD/USD	SEK/USD
Coefficients						
Constant	-0.03	-0.01	-0.01	0.00	-0.02	-0.03
	(-1.04)	(-0.54)	(-0.68)	(-0.08)	(-1.14)	(-0.91)
ΔVIX	2.03***	-2.01***	3.49***	4.75***	6.28***	7.62***
	(3.29)	(-3.66)	(10.94)	(12.06)	(18.27)	(13.67)
Δs(-1)	-0.94	0.40	1.48	-0.89	-6.16*	-2.53
	(-0.23)	(0.10)	(0.40)	(-0.25)	(-1.95)	(-0.70)
Threshold analysis						
SupF(1|0)	7.18	4.59	5.35	6.26	10.72	7.80
Threshold	32.86	21.12	35.06	17.43	32.86	33.92
Observations	775	775	775	775	775	775
Sum of Squared Errors	0.053	0.034	0.028	0.034	0.025	0.061
R-Squared	0.028	0.042	0.140	0.201	0.379	0.265
Heteroskedasticity Test	0.177	0.000	0.325	0.062	0.003	0.000
Breusch-Pagan Test	0.440	0.349	0.526	0.099	0.696	0.209

NOTES:

(a) Estimated models and variables defined in Equations (1) and (2) in main text.
(b) For all other notes see Notes to Tables 3 and 4.