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Price cointegration between sovereign CDS and currency option markets in the financial crises of 2007-2013

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Abstract

The sovereign credit default swap (CDS) spreads and exchange rates of the developed economies including the US, Japan, Switzerland and the eurozone with the first three countries' currencies conventionally considered as safe-haven varied in a wide range during the financial crises since late 2007. This raises the question of any interconnectivity between the anticipated sovereign credit risks of these economies and the market expectations of their exchange rates. This paper uses cointegration with a random coefficient in a bivariate vector error-correction model to show evidence of a nonlinear cointegrating relationship between the prices in the sovereign CDS and currency option markets. The empirical results show that the relative sovereign credit risks of these four economies are the risk factors driving the expectations of their exchange rates in the currency option market in the long-run. Disequilibrium from the long-run relationship can trigger significant interactions between the two markets in price discovery. The prices of some sovereign CDS and currency options markets can deviate drastically and persistently from their long-run equilibrium amid central banks' monetary measures and market turbulence.

JEL Classification: F31; G13

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I. Introduction

A sovereign credit default swap (CDS) is an over-the-counter credit protection contract in which a protection seller pays compensation to a protection buyer to make a payment in the case of a pre-defined credit event. For credit protection buyers who pay a fixed premium called the CDS spread, the CDS market offers the opportunity to reduce credit risk. For protection sellers, it offers the opportunity to take credit exposure to an entity and earn income without having to fund the position. Sovereign CDS spreads have been used as a direct measure of the creditworthiness of the underlying sovereign, for example in Pan and Singleton (2008).[1] A change in the credit risk of a sovereign borrower reflected in its sovereign CDS spread can thus be considered as an indicator of the country's economic-political stability, which is linked to country-specific macro-economic variables, such as output growth, foreign exchange reserves, budget deficit, real effective exchange rate deviation, and foreign direct investment. A substantial increase in sovereign risk due to economic-political instability would lead investors to sell securities denominated in the country's currency and to repatriate funds, hence putting downward pressure on the currency and heightening its volatility. The relationship between sovereign risk and exchange rate stability has long been the subject of interest in international finance including those of Eichergreen et al. (1996), Frankel and Rose (1996), Kaminsky et al. (1998), and Kumar et al. (2003), who use macro-economic indicators to estimate the probability of currency crashes.

In view of the linkage between a country's credit risk and the strength of its currency, interactions between emerging market sovereign CDS spreads and corresponding exchange rate expectations anticipated in currency option markets are

[1] The sovereign CDS market expanded rapidly in 2009 and 2010. The gross notion of protection was around US$2 trillion as of 2010. See the IMF's Global Financial Stability Report (Meeting New Challenges to Stability and Building a Safer System, April 2010).

studied by Carr and Wu (2007). Currency option markets have the desirable property of being forward-looking in nature and are thus useful sources of information for gauging market sentiments about future exchange rates. Options, whose payoff depends on a limited range of the expected exchange rate, offer broad information about market expectations. Potential extreme movements of the exchange rate can be inferred from out-of-the-money option prices. Carr and Wu (2007) investigate the relationship between currency option-implied volatilities and sovereign creditworthiness for Mexico and Brazil from 2002-2005. They find that the level and skew of the option-implied volatility display significant co-movement with the sovereign CDS spreads of the two countries. This suggests that the currency option market has consistently set prices considering the probability of a currency crash triggered by a corresponding sovereign default of the two countries.

The subprime crisis in the US during 2007 – 2008 was closely followed by the European sovereign debt crisis which began in 2009 and may still be unfolding. During this period, there have been several bouts of financial turbulence, causing sharp changes in risk assessment globally, with large swings in the developed economies' foreign exchange market. The US dollar (USD) had once depreciated about 30% against the Japanese yen during the subprime crisis. As concerns spread during the European sovereign debt crisis, the euro fell sharply against the USD by about 19% as of April 2010 since November 2009. Hui and Chung (2011) show that the creditworthiness of euro-area countries distinct from other macro-financial factors can affect market expectations on the stability of the euro. They find evidence of information flow from the sovereign CDS market to the USD-euro currency option market during September 2009 - April 2010. The impact has been considerable and even disturbing enough to cause some policymakers (e.g., the Swiss National Bank

(SNB)) to resort to drastic policy action (e.g., changing the country's exchange rate regime in the case of Switzerland).

Given the fact that Japan's and the US's government debt to GDP ratios were the highest (233%) and the third (100%) among the G20 economies at the end of 2011, their level and trend of government debt have raised concerns over their sovereign risk. The IMF also pointed out that Japan and the US may not be immune to the European-debt-crisis-style risks.[2] In addition to the concerns of their sovereign risks, the depreciation of the USD during the crisis period was quite inconsistent with the conventional wisdom that the USD together with the Japanese yen and Swiss franc are safe-haven currencies during financial crises according to the findings in Ranaldo and Söderlind (2010) and Kohler (2010).[3] In view of these observations, the exchange rate movements, in particular in favour of safe-haven currencies, show that the prices in the developed economies' sovereign CDS market and corresponding currency option market may have appreciable impact on each other.

This paper investigates how sovereign risk affects market expectations on the exchange rates of the developed economies including the US, Japan, Switzerland and the eurozone embedded in their currency options. The market expectations of the exchange rates are reflected by the price of risk reversals quoted in the currency option market. The risk reversal is a directional option strategy that takes the view of the skewness of the exchange rate distribution by simultaneously buying an out-of-the-money put and selling an out-of-the-money call. It measures the implied volatility difference between an out-of-the-money put and call at the same (absolute) delta. The delta is a measure of a change in the option price with respect to a small change in the

[2] See IMF's "Global Financial Stability Report" and "World Economic Outlook", April 2012.
[3] There is no well-accepted definition of a safe haven asset. It could mean an asset with low risk or high liquidity and have a common characteristic that one would expect the relative price of such an asset to increase during crises.

underlying exchange rate.[4] Figures 1a and 1d show the generally positive risk reversals of USD-yen and euro-yen options at the 25% delta (25-delta risk reversals) during the period from 2007 to 2013.[5] A positive risk reversal implies that the risk-neutral exchange rate distribution is negatively skewed. This reflects that the USD-put (euro-put) implied volatility is higher than the USD-call (euro-call) implied volatilities.[6] The asymmetry in the implied volatility occurs because market participants think that a depreciation of the USD and euro against the yen is more likely than an appreciation of the same size. One reason for such asymmetry in the expectation of the exchange rates is that only 5% of the Japanese government bonds are held by foreign investors, which is much smaller than 48% of the US Treasury securities held by foreign investors.[7] As foreign investors are more likely to sell a country's government bonds with rising default risk compared with home investors, when both the US and Japan's sovereign credit risk is rising, the US Treasury securities would be under larger selling pressure by foreign investors relative to the Japanese government bonds. This makes the yen safer than the USD.

Figure 2 reports the net notional amounts outstanding (i.e., net protection bought) and average daily amounts of transactions of the CDS contracts of the US, Japan, Switzerland and the four highly indebted European counties including Ireland, Italy, Portugal and Spain as at 9 August 2013. The Japanese sovereign CDS contracts had a total net notional value of US$9.5 billion which is relatively small compared to

[4] The delta of the option is roughly equal to the risk-neutral probability of the underlying ending in-the-money. For example, a 25% delta put option has approximately 25% probability of in-the-money at maturity. The Black-Scholes delta provides a normalised measure of option moneyness where the delta of a European option increases monotonically from 0–100, with the moneyness moving from out-of-the-money to in-the-money.

[5] The option data are from JPMorgan Chase.

[6] A dollar put (call) option against the yen here is a European option of selling (buying) dollars at the contractual option strike price in an exchange of yens at the option maturity.

[7] The figure for the Japanese government bonds is from Bank of Japan as at March 2011 and the figure for the US Treasury securities is from the Bureau of Public Debt as at June 2011.

those of Italy and Spain, but higher than those of the US, Portugal, and Ireland.[8] While the amounts of net notional outstanding of the US and Japanese sovereign CDS are limited, changes in their spreads are commonly used by policy makers to monitor for signals of concerns about their sovereign risks anticipated by market participants.[9]

In this paper, we use cointegration to model the joint behaviour of the sovereign CDS spreads of the US, Japan, Switzerland and the eurozone and the risk reversals in the currency option market of their currency pairs during the financial crisis period of 2007 – 2013. As the relationship between the prices in the two markets has a high degree of persistence, the approach is to incorporate the influence of persistence through the modelling of the joint evolution of the prices using a cointegration framework. We investigate how the sovereign credit risk and exchange rate risk interact with each other by testing the following three hypotheses after controlling other macro-financial factors: (i) in the long-run the relative sovereign credit risks of the four economies are the risk factor driving the expectations of exchange rates in the currency option markets; (ii) in the short-run there are price interactions between the sovereign CDS and currency options markets when disequilibrium occurs; (iii) the short-term price dynamics between the sovereign CDS and currency option markets is not static over time.

This paper demonstrates that interconnectivity not only appears between the corporate CDS market and the corresponding stock (or stock option) market, but also exists between the sovereign CDS market and the currency option market. In the corporate sector, Acharya and Johnson (2007) find that the corporate CDS market leads the stock market to anticipate adverse credit information of the reference firm

[8] Details of the structure of the sovereign CDS market are in Pan and Singleton (2008).
[9] For example, see Box 1.2 "How Concerned are Markets About US Sovereign Risks" in the IMF's September 2011 Global Financial Stability Report. However, the US sovereign CDS spread is not considered very reliable for extracting mathematical default probability.

and this finding is linked to informed-trading in credit derivatives. This is reflected by incremental information flow from the corporate CDS market to the stock market. Cao et al. (2010) document that implied volatility of deep out-of-the-money put options of stocks is closely related to corporate CDS spreads, because the options provide investors with similar protections against downside risk. They conclude that stock options play an important role in the price discovery process for firms' credit risk.

This paper is organised as follows. The following section discusses the cointegration and error-correction model. Section III presents the data and examines estimation results for testing the hypotheses. Section IV contains the conclusion.

II. Cointegration and error-correction model

The principal feature of cointegration is that a linear combination of non-stationary variables is stationary. This implies that cointegrated variables do move independently of each other but they are linked by the stationary linear combination. This stationary relationship is regarded as long-run equilibrium among the cointegrated variables. Under this equilibrium, a short-term deviation of a cointegrated variable from the others is expected to be temporary, and this cointegrated variable will gradually revert to the long-run relationship.

This section presents the model to test any cointegration relation between the prices in the currency option and sovereign CDS markets. Such relation can be illustrated by considering a rise in the sovereign CDS spread of the US relative to the CDS spread of another country when the CDS spreads have equilibrium relationship with foreign exchange (against USD) option prices in terms of risk reversals. This triggers a gap between the prices of the two markets. If this gap is large enough, the gap will ultimately be closed by (1) a rise in an appreciation expectation of the foreign currency against USD (an increase in the risk reversal) and/or a fall in the US sovereign CDS spread; or (2) a further increase in the US sovereign CDS spread with a commensurately larger increase in the appreciation expectation; or (3) a fall in the US sovereign CDS spread with a smaller reduction in the appreciation expectation.

The above illustration is a dynamical error-correction model. In the model, the short-term dynamics of the variables in the system are influenced by deviations from equilibrium. Assuming that the US sovereign CDS spread and risk reversal are "integrated of order 1" denoted by $I(1)$ (i.e., non-stationary in levels, but stationary in changes) and cointegrated, a simple error-correction model for the corresponding variables can be expressed as:

$$\Delta y_t = \alpha_y (y_{t-1} - \beta x_{t-1}) + \varepsilon_{yt} \qquad (1)$$

$$\Delta x_t = \alpha_x (y_{t-1} - \beta x_{t-1}) + \varepsilon_{xt} \qquad (2)$$

where y_t and x_t are the risk reversal of the exchange rate of the USD against another country's currency, and their relative sovereign CDS spread respectively at time t, and both α_y and α_x are greater than zero. As specified, the two variables will change in response to stochastic shocks (represented by ε_{yt} and ε_{xt}) and to the previous period's deviation from the long-run equilibrium. If this deviation is positive (with $y_{t-1} - \beta x_{t-1} > 0$), the appreciation expectation of the foreign currency (i.e., risk reversal) rises and the relative US sovereign CDS spread falls. The long-run equilibrium is attained when $y_t = \beta x_t$. It is noted that α_y has to be negative and α_x has to be positive in order to ensure that when a deviation occurs, y_t will adjust downward and x_t will adjust upward subsequently to restore the long-run equilibrium.[10]

[10] The relationship between the error-correction model and the cointegrated variables can also be illustrated by the following argument. By assumptions, Δy_t is stationary (i.e. "integrated of order zero" denoted by $I(0)$), so that the left-hand side of Eq. (1) is stationary. For Eq. (1) being sensible, the right-hand side must be $I(0)$ as well. Given that ε_{yt} is stationary, it follows that the linear combination y_{t-1} -

The parameters α_y and α_x are the speeds of adjustment. In absolute terms, the larger α_y is, the greater the response of y_t to the previous period's deviation from the long-run equilibrium. At the opposite extreme, a very small value of α_y in absolute terms implies that the risk reversal is unresponsive to the last period's equilibrium error. If both α_y and α_x are equal to zero, the long-run equilibrium relationship does not appear and the model is not error-correction or cointegration. Thus, for a meaningful cointegration and error-correction model, at least one of the speeds of adjustment terms in Eqs. (1) and (2) must be nonzero.

The discussion above is unaltered if we formulate a more general model by introducing the lagged changes of each variable into the equations:

$$\Delta y_t = a_{10} + \alpha_y (y_{t-1} - \beta x_{t-1}) + \sum_k b_{1k} \Delta y_{t-k} + \sum_k c_{1k} \Delta x_{t-k} + \varepsilon_{yt} \tag{3}$$

$$\Delta x_t = a_{20} + \alpha_x (y_{t-1} - \beta x_{t-1}) + \sum_k b_{2k} \Delta y_{t-k} + \sum_k c_{2k} \Delta x_{t-k} + \varepsilon_{xt} \tag{4}$$

The above specification is very similar to a vector autoregressive model (VAR). This two-variable error-correction model can be regarded as a bivariate VAR in first differences augmented by the error-correction terms $\alpha_y (y_{t-1} - \beta x_{t-1})$ and $\alpha_x (y_{t-1} - \beta x_{t-1})$. In a vector form, the model can be re-written as:

$$\begin{pmatrix} \Delta y_t \\ \Delta x_t \end{pmatrix} = \begin{pmatrix} a_{10} \\ a_{20} \end{pmatrix} + \begin{pmatrix} \alpha_y \\ \alpha_x \end{pmatrix} \cdot \eta_{t-1} + \sum_{k=1}^{K} \begin{pmatrix} b_{1k} & c_{1k} \\ b_{2k} & c_{2k} \end{pmatrix} \begin{pmatrix} \Delta y_{t-k} \\ \Delta x_{t-k} \end{pmatrix} + \begin{pmatrix} \varepsilon_{yt} \\ \varepsilon_{xt} \end{pmatrix} \tag{5}$$

where $\eta_t = y_t - \beta x_t$. In this model, the cointegrating vector is said to be $(1, \beta)$.

We can basically apply the conventional model specified in Eq. (5) to test the hypotheses. However, the conventional model assumes that the long-run equilibrium (i.e. $y_t = \beta x_t$) does not change over time, which may be too strong for modelling financial time series. Hansen (1992) tested this assumption by checking some published cointegrating regressions. By calculating simple split tests on the variance

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βx_{t-1} must be stationary; hence, the two variables must be cointegrated. This identical argument can also be applied to Eq. (2).

of the regression error, strong evidence for non-constancy of the error variances is found in these cointegrating regressions. In view of this, we employ a generalized error-correction model proposed by Fong et al. (2004). Specifically, the models for country *i* at time *t* with reference to the US's and eurozone's conditions are represented respectively by the following specifications:

$$\begin{pmatrix} \Delta RR(i,US)_t \\ \Delta CDS(i,US)_t \end{pmatrix} = \begin{pmatrix} a_{\Delta RR} \\ a_{\Delta CDS} \end{pmatrix} + \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} \cdot \eta_{US,t-1} + \sum_{k=1}^{K} \Phi_k \begin{pmatrix} \Delta RR(i,US)_{t-k} \\ \Delta CDS(i,US)_{t-k} \end{pmatrix} + \Theta X_t + \begin{pmatrix} \varepsilon_{\Delta RR,t} \\ \varepsilon_{\Delta CDS,t} \end{pmatrix} \tag{6}$$

and

$$\begin{pmatrix} \Delta RR(i,EU)_t \\ \Delta CDS(i,EU)_t \end{pmatrix} = \begin{pmatrix} a_{\Delta RR} \\ a_{\Delta CDS} \end{pmatrix} + \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} \cdot \eta_{EU,t-1} + \sum_{k=1}^{K} \Phi_k \begin{pmatrix} \Delta RR(i,EU)_{t-k} \\ \Delta CDS(i,EU)_{t-k} \end{pmatrix} + \Theta X_t + \begin{pmatrix} \varepsilon_{\Delta RR,t} \\ \varepsilon_{\Delta CDS,t} \end{pmatrix} \tag{7}$$

with the long-run equilibrium errors between the two markets of $\eta_{US,t} = RR(i,US)_t - \beta_t CDS(i,US)_t$ and $\eta_{EU,t} = RR(i,EU)_t - \beta_t CDS(i,EU)_t$ respectively, where *RR*(*i*, US) is the 25-delta risk reversal (i.e., the implied volatility of a put minus that of a call at the 25% delta) of the USD against country *i*'s currency, and *RR*(*i*, EU) is the risk reversal for the euro; *CDS*(*i*, US) is the difference between the sovereign CDS spreads of the US and country *i*, and *CDS*(*i*, EU) is the difference between the sovereign CDS spreads of the eurozone and country *i*; α_1 and α_2 are speeds of cointegration adjustment for *RR* and *CDS*; β_t is a random coefficient in the long-run cointegration relationship following a normal distribution with mean β and variance σ_β^2 (or specifically, $\beta_t = \beta + \xi_\beta$, where $\xi_\beta \sim N(0,\sigma_\beta^2)$); X_t is a vector of exogenous macroeconomic and financial variables; $\varepsilon_{\Delta RR}$ and $\varepsilon_{\Delta CDS}$ are two *r*-correlated error terms with variances $\sigma_{\Delta RR}^2$ and $\sigma_{\Delta CDS}^2$ respectively; a_Y is a constant term for the variable *Y*; and Δ is the first difference operator.

Compared with a conventional error-correction model, the model used in this paper generalizes the assumption of a constant cointegration (i.e., β) to that of a random cointegration (i.e., β_t). In other words, when the variance of β_t (i.e., σ_{β}^{2}) in this specification is zero, the model is reduced to the conventional error-correction model. When this variance is different from zero, the cointegration relationship (i.e., β_t) is allowed to be time varying. This extension is closely related to the literature of long-run nonlinearity under the framework of cointegration. For examples, Hansen (1992) develops a cointegration model with errors displaying non-stationary variances. Gregory and Hansen (1996), Kejiriwal and Perron (2008, 2010), Esteve et al. (2013), and Zhang and Li (2013) allow for regime shifts in the long-run equation. Balke and Fomby (1997), Hansen and Seo (2002), and Al-Abri and Goodwin (2009) assume that the long-run equilibrium error follows a threshold autoregression which allows the time series to move freely within a given range but mean-reverting outside the range.

Therefore, this simple extension can serve two purposes. First, the new long-run specification provides more flexibility than the conventional one when modelling multivariate financial time series linked by nonlinear long-run relationships. In addition to the observable patterns recognized by the literature, (e.g., regime switching or structural break due to interventions), any unobservable nonlinear patterns are reflected in the variance of the random cointegration. Secondly, this model helps to study how the two markets interact in short-run over time in the presence of a nonlinear long-run relationship. This is achieved by estimating a time-varying conditional correlation from this new specification. As discussed in Fong et al. (2004), the new specification can be viewed as a conventional error correction plus heteroskedastic error terms when the random part of the random cointegration (e.g., $\eta_{US,t}^{*} = RR(i,US)_t - \xi_{\beta} CDS(i,US)_t$) is specified in the two error terms (i.e., $\varepsilon_{\Delta RR}$ and

$\varepsilon_{\Delta CDS}$) in Eqs. (6) and (7). Its characteristic is thus similar to Bauwens et al. (1997), Silvapulle and Podivinsky (2000), and Kurita (2013) who specify their cointegrated VAR models with generalized autoregressive conditional heteroskedasticity (GARCH) and ARCH errors.

III. Results of model estimations

3.1 Data, summary statistics and cointegration tests

For the purpose of comparison, we use the perspectives of USD-based and euro-based investors respectively in the analysis. We obtain weekly over-the-counter 25-delta risk reversals of USD-yen, USD-euro, USD-Swiss franc, euro-yen, and euro-Swiss franc options at the 3-month maturity, and the 5-year sovereign CDS spreads of the eurozone, Japan, Switzerland and the US from July 2007 to May 2013.[11] The tenors of these derivative instruments are commonly used as benchmarks of their respective markets. The eurozone CDS spread is the median sovereign CDS spread of the eleven eurozone countries.[12] As currency option prices reflect market expectations of the exchange rate between two economies' currencies, CDS spreads are thus expressed as the differences (in short "relative CDS spreads") between the CDS spreads of the US and individual economies (i.e., the CDS spread of the US minus that of another country) from the perspective of USD-based investors. Similarly, from the perspective of euro-based investors, the relative CDS spreads are expressed as differences between the eurozone and those of individual economies. These time series are depicted in Figure 1. Note that the USD-euro risk reversal and the US-

[11] The CDS data are from Bloomberg.

[12] These countries include Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Portugal, the Netherlands and Spain. There is no active sovereign CDS on Cyprus, Luxembourg, Malta, Slovakia, and Slovenia.

eurozone relative CDS spread can offer both USD- and euro-based investors' perspectives at the same time.

As shown in Figure 1, the risk reversals and relative CDS spreads move similar in trend during most of the time. In some cases, they could however deviate to an extent that the deviation is almost enough to break the long-run cointegrating relationship between the two markets. To see this more clearly, a scatter plot of them, which reflects their unconditionally linear long-run relationship, is depicted in Figure 3. For examples, the linear relationship between the USD-yen risk reversal and the US relative CDS spread (Figure 3a) appears to be strong, but it is undermined by some outliers on the top right hand corner to some extent. The linear relationship between the euro-yen risk reversal and eurozone relative CDS spread (Figure 3d) appears to be undermined by the outliers (on the top left hand corner) to a larger extent, but the linear relationship remains noticeable from most of the observations. Between the USD-Swiss franc and the US relative CDS spreads (Figure 3b), the relationship seems to be ambiguous given that the correlation between the two markets is negative.

Table 1 provides summary statistics for these time series of the data in level and changes. Over the sample period, the average sovereign CDS spreads of the US are 31.30 bps, 83.40 bps, and 8.53 bps lower than those of Japan, the eurozone, and Switzerland respectively, while the average risk reversals of the yen, euro, and Swiss franc against the USD are +1.88% points, –1.30% points, and –0.28% points respectively. The average sovereign CDS spread of the eurozone are 48.21 bps and 92.07 bps higher than those of Japan and Switzerland respectively, while the average risk reversals of the yen and Swiss franc against the euro were 3.24% points and 1.07% points respectively.

Table 1 also reports the Augmented Dickey-Fuller (ADF) and Phillip-Perrons (PP) test results. Using a maximum of four lags (i.e., a 4-week period), both tests fail to reject at the 5% level the presence of a unit root for all levels of the risk reversals and relative CDS spreads. In addition, both tests for the first differences are significant at the 5% level. Thus, the levels of risk reversals and relative CDS spreads appear to be non-stationary while the changes appear to be stationary. This suggests that all pairs of risk reversals and relative CDS spreads are $I(1)$ (i.e., integrated of same order 1), which satisfies the requirement for the variables being cointegrated.

To test cointegration between the relative sovereign CDS spreads and risk reversals, we use the Engle-Granger single-equation test and the Johansen cointegration trace test. The methodology proposed by Engle and Granger (1987) is regarded as an easy and super-consistent method of estimation, which determines whether the residuals of the linear combination among the cointegrated variables estimated from the ordinary least squares method are stationary. The Johansen cointegration test allows testing for cointegration with unknown cointegrating vectors, estimating both the cointegrating vectors and determining the number of cointegrating relationships. It is noted that there can be at most one independent linear combination that is stationary in a two-variable case.

Table 2 reports the both cointegration tests between the risk reversals and relative CDS spreads. In the Engle-Granger test, we employ the ADF and PP tests to check whether the residuals of the regression of the risk reversals on relative CDS spreads are stationary. The critical values of the tests are based on MacKinnon (1996) and the lag length is determined by the Schwartz criterion. The results for the Swiss franc against the USD and euro are significant at the 10% level, while the others are statistically significant at the 5% level. Thus, we reject the null hypothesis that the relative CDS spreads and risk reversals are not cointegrated in favour of the alternative hypothesis that there is at least one cointegrating vector.

In the Johansen test, we find that only the cointegrating relationship between the USD-euro risk reversal and the US relative CDS spreads is conclusive since only one cointegrating vector exists between the two markets (i.e., rejecting the null hypothesis of none but not rejecting the null of having at most one cointegrating vector at the 5% significant level). The Johansen test results of the other pairs however are found to be inconclusive (i.e., rejecting or not rejecting both hypotheses of none and at most one cointegrating vector at the same time).

The two tests' results suggest different conclusions, attributable to the fact that some long-run relationships between the risk reversals and sovereign relative CDS spreads are undermined by the outliers observed during the crisis periods as shown in Figure 3. Attfield (2003) finds that the Johansen cointegration test usually over-rejects the null hypothesis of no cointegration between multivariate time series in the presence of structural break or heteroskedasticity. Maki (2013) suggests that the Engle-Granger approach also suffers the same problem, however, it is generally regarded as one of the less problematic tests when the residual has a GARCH effect. His simulation results show that the empirical size is only slightly higher than the nominal size when using the Engle-Granger approach. In view of this, we do not reject the hypothesis that cointegration exists in all our data and proceed to the step of estimation. If this assumption is too strong, the generalized error-correction model, despite controlling for impacts of outliers, will show insignificant coefficients of the long-run cointegration.

3.2 Exogenous macro-financial variables

Recent research finds that sovereign credit risk interacts strongly with global and regional financial risk factors. Longstaff et al. (2010) show that sovereign CDS spreads are primarily driven by common factors, including the US stock and high-yield bond markets and global risk premiums, whereas Pan and Singleton (2008) find that the spreads are related to investors' risk appetite associated with global event risk, financial market volatility and macroeconomic policy. Therefore, it is important to indentify whether the sovereign CDS spreads and risk reversals of the four economies in this study remain cointegrated in the presence of other macro-financial factors. To address this issue, we employ a set of macro-financial factors as control variables, including the following factors:[13]

(i) *Interest rate differential*. In a currency carry trade, an investor borrows in a low yielding currency and invests in a high yielding currency. To realize the carry in the trade, investors are required to hold the position for some time. The risk to the carry trade is an adverse price movement in the level of the exchange rate, i.e., a currency crash. As found in Brunnermeier et al. (2009), the expected exchange rate movements between high-interest-rate and low-interest-rate currencies are negatively skewed due to the crash risk of sudden unwinding of carry trades and reflected in the risk reversals of their out-of-the-money currency options. Therefore, if the interest rate differential of the two currencies $(r_{USD} - r_{other})$ or $(r_{euro} - r_{other})$ increases, the risk reversal is expected to increase as a result of hedging against the crash risk. We use the 1-month LIBORs for the interest rate differential.

(ii) *US dollar volatility.* The implied volatility of an exchange rate is essentially linked to the anticipated uncertainty on the values of both currencies in the

[13] We obtain data for these additional variables from Bloomberg.

pair. Therefore, we use the US dollar index (DXY), a weighted average of the dollar's value relative to a basket of foreign currencies, to capture the actual volatility attributable to the dollar factor. We proxy the volatility of the US dollar (R^2_{USD}) as the ex-post squared return of the index.

(iii) *Global risk appetite.* We use the market volatility index (*VIX*) of the US S&P 500 index (EURO STOXX 50 index) to gauge the global risk appetites of USD-based (euro-based) investors in the financial market.[14] An increase in the VIX index is usually associated with heightened volatility across different asset classes in particular equities. Currency option-implied volatility shares commonality with the VIX index as a measure of investors' aversion to volatility exposure and hence their willingness to put capital at risk.

(iv) *Funding liquidity constraint.* Another potential determinant of the risk reversals is the sudden unwinding of currency carry trades. We follow Brunnermeier et al. (2009) and use the USD (euro) TED spread (*TED*), the difference between the 3-month interbank rate and the yield of the 3-month Treasury bill (German bunds), to capture traders' funding liquidity constraint. When funding liquidity is tight, as reflected by a widened TED spread, traders are forced to repatriate funds to a safer currency.

(v) *Macro-financial condition.* To capture the broad changes in the macro-financial condition, we include two measures from the stock and bond markets that have been used by Collin-Dufresne et al. (2001) and Cao et al. (2010). Regarding the stock market variables, we use the weekly returns of the S&P 500 index (*US stock return*), STOXX European 600 index (*EU stock return*),

[14] Collin-Dufresne et al. (2001) and Zhang et al. (2009) use the US's VIX index as a measure of market-level volatility and find a strong relationship with firm-level credit spreads. Pan and Singleton (2008) view the VIX index as a measure of investors' risk aversion for the event risk in credit markets.

Swiss Market Index, and Nikkei 225 (*Country's stock return*). Conventionally, a negative stock market return indicates a weaker economic outlook and puts downward pressure on the corresponding currency. For the bond market variables, we use the term spreads between 10-year and 2-year yields of the US Treasury bonds (*US term spread*), German bunds (*EU term spread*), Switzerland government bonds, and Japan government bonds (*Country's term spread*). Collin-Dufresne et al. (2001) interpret the term spread (i.e., the slope of a yield curve) as a proxy for the overall state of an economy. An upward sloping yield curve indicates future economic growth, whereas a flattening yield curve reflects a poor economic prospect.

3.3 Estimation method and empirical results

Following Fong et al. (2004), we use the maximum likelihood method for estimations. All risk reversals and relative CDS spreads are first transformed by using the standard score (i.e., $z = (x - \mu)/\sigma$) which is the number of standard deviations of observations above the mean. Given that the risk reversals and relative CDS spreads have very different scales, this standardization makes the pass-through between the risk reversal and relative CDS spreads among selected currency pairs comparable. Initial values of the estimates are derived from the least squares method. To estimate Eqs. (6) and (7), we choose an autoregressive order of four (i.e., the parameter *K*), which assumes that all autoregressive impacts of risk reversals and relative CDS spreads are insignificant after four weeks. All coefficients of each error correction model are estimated in one-step but the estimation results for the long-run and short-run are reported separately in the Tables 3 and 4. To check the models' adequacy, we first standardize the residuals in Eqs. (6) and (7) by the time-varying volatility estimated from the heteroskedastic error terms. We then conduct the Ljung-Box test for zero autocorrelations and cross-correlations between the two time series of standardized residuals. Since the reference distribution for the test statistics is not known in our case, the test results are benchmarked against the Chi-squared distribution. Diagnostic test statistics are reported in Tables 4 and 5.

The diagnostic test statistics show that all estimated models are generally adequate. Except for the Euro-yen's risk reversal, all test statistics are less than the benchmark at the 10% level of significance, suggesting no significant autocorrelations in the standardized residuals and no significant cross-correlations between risk reversals and relative CDS spreads. The exception one, whose residual autocorrelation is 27.656, is only slightly more than the benchmark (i.e. 23.5), so we still consider this estimated model marginally acceptable.

Given the existence of cointegration between the risk reversals and relative CDS spreads, Table 3 reports the estimated cointegrating vectors. In the full specifications, for USD-based investors, the coefficients β of the US sovereign CDS spread relative to those of Japan, the eurozone and Switzerland are 0.6766, 0.9560, and 4.4072 respectively, in which the last coefficient for Switzerland is insignificant. Their corresponding variance estimates (i.e., σ_{β}^2) are 3.0037^2, 1.6735^2, and 4.4639^2 respectively. For euro-based investors, the coefficient β of the eurozone sovereign CDS spread relative to those of Japan and Switzerland is 0.7444 and 1.0239 respectively. The corresponding variance estimates are 7.9722^2 and 3.9888^2 respectively.

The results in Table 3 have some interesting implications. Basically, they are all positive, suggesting that an increase in the US (the eurozone) sovereign CDS spreads will increase the risk reversals of the other currencies against the USD (the euro) in the long-run. Regarding the magnitudes of these coefficients, all significant β

values are generally less than unity in the full specifications, implying a unity increase in the relative CDS spread ultimately generates a less-than-unity increase in the risk reversal when the exogenous macro-financial variables remain equal. This suggests that the relative sovereign credit risks contribute only a part of the price dynamics in the currency option market in the long-run. Moreover, among these βs, the coefficient for the euro-Swiss franc is the largest, reflecting that the euro-Swiss franc risk reversal exhibits the largest long-run sensitivity to the eurozone relative CDS spread. The long-run sensitivity of the USD-Swiss franc risk reversal, however, is found to be statistically insignificant to the US relative CDS spread, which is consistent with the ambiguous linear relationship shown in Figure 3b. The finding supports the first hypothesis that the relative sovereign credit risks of the four economies are the risk factors driving the expectations of their exchange rates in the currency option market in the long-run, while the USD-Swiss franc exchange rate is an exception statistically.

Table 4 presents the estimates for the short-term dynamics of the error-correction model, including the speeds of the adjustment (i.e., α_1 and α_2), and the coefficients of the short-term dynamics and exogenous macro-financial variables. The speeds of adjustment for the relative CDS spreads are all significantly positive as expected, except for the Japan's one. The estimates (α_1) for the US CDS spreads relative to those of Japan, the eurozone, and Switzerland are 0.0077, 0.0432, and 0.0438 respectively. Similarly, the estimates for the eurozone CDS spread relative to those of Japan and Switzerland are 0.0151 and 0.0171 respectively. This suggests that except for Japan, the relative CDS spreads will subsequently adjust upward to restore the long-run equilibrium when a deviation occurs, with 1.51-4.38 percent of a deviation from the long-run equilibrium tending to dissipate in one week. For risk reversals, the speeds of adjustment (α_2) are generally negative with the estimates of the USD-yen (-0.0275), USD-euro (-0.0029), USD-Swiss franc (-0.0000,) euro-yen (+0.0033), and euro-Swiss franc (-0.0271). However, only those for the USD-yen and euro-Swiss franc are found to be significant. The results demonstrate that the risk reversals of the USD-yen and euro-Swiss franc will subsequently adjust downward to restore the long-run equilibrium, with an average of 2.7 percent of a deviation from the equilibrium tending to be eliminated in one week.

Comparing the coefficients of the risk reversal and relative CDS spread in each currency pair, the USD-yen is the only currency pair in which the risk reversal will adjust but not the relative CDS spread when a deviation from the long-run relationship occurs. According to Gonzalo and Granger (1995) and further explored by Ammer and Cai (2011) and Palladini and Portes (2011), if one market always lags the other, then the speed of adjustment of the lagging market should be different from zero. This is because the lagging market takes time to remove pricing errors while the leading market has already reflected all information in the prices. From this perspective, the US relative sovereign CDS spreads can be viewed as leading the USD-yen currency options in price discovery. Except for the euro-Swiss franc, the other currencies are found the other way round such that any sharp change in the long-run relationship will lead to adjustments in their relative CDS spreads in the short-run, suggesting that their currency option markets tend to lead the sovereign CDS markets.[15] For the euro-Swiss franc pair, any disequilibrium will result in changes in both their risk reversal and relative sovereign CDS spread simultaneously, suggesting a two-way price discovery process. Since the coefficient of the relative CDS spread (i.e. 0.0171) is smaller than that of the risk reversal (i.e. -0.0271) in absolute terms,

[15] During the period of September 2009 – April 2010, Hui and Chung (2011) find that there was one-way information flow from the eurozone sovereign CDS market to the USD-euro currency option market. This may reflect the price dynamics of the two markets during a short period of time right after the European sovereign debt crisis emerged in September 2009.

the sovereign CDS market appears to lead the currency option market "more" in price discovery.[16]

The analyses of α_1 and α_2 support the second hypothesis that cointegration plays a significant role in explaining the short-run interactions between the risk reversals and relative CDS spreads when disequilibrium from the long-run relationship occurs. In terms of price discovery, it is more common to see an one-way lead-lag process rather than a two-way price interaction between the two markets.

As shown in Table 3, all variance estimates (i.e., σ_β^2) are significantly different from zero, which suggest that the long-run equilibrium would exhibit nonlinear patterns. While this nonlinearity could lead to various degrees of heteroskedasticity in the two markets in the short-run, we check the estimated conditional correlations derived from the model. Figure 4 shows that the conditional correlations between the prices of the two markets are generally positive (except the USD-yen pair in some periods of time) and time varying in particular during the global financial crisis in 2008 and the European sovereign debt crisis during 2011 (except the USD-Swiss franc pair). The positive correlation is consistent with the intuition that an increase in the relative CDS spread of the US (the eurozone) will cause a rise in the risk-reversals as market participants will pay high option premiums (i.e., high option-implied volatilities) to buy USD-put (euro-put) for hedging currency risk.

[16] The suggestion of "the sovereign CDS market leads more" can be shown more clearly by using a simple measure proposed by Gonzalo and Granger (1995). The measure is defined as the ratio of the speed of adjustment in the two markets $\alpha_2/(\alpha_2 - \alpha_1)$, with a lower bound of 0 and upper bound of 1. This ratio can be interpreted as the fraction of overall price movements in a currency options market relative to overall movements in a sovereign CDS market. When the ratio is close to 1, it implies that the currency options market leads in price discovery, and the sovereign CDS market follows in price discrepancy corrections. When the estimated measure is closer to 1/2 than either extreme, both markets contribute to price discovery, and there is no clear evidence on which market leads. When it is close to 0, the sovereign CDS market leads the currency options market. In our case, the ratio for the euro-Swiss franc pair is 0.39.

The conditional correlation between the USD-yen risk reversal and the US-Japanese relative CDS spread (see Figure 4a) is smaller than those of the other currency pairs and moves within a narrow range of -0.1 and 0.1 except during the period of 2008 Q3 – 2009Q1 when the global financial crisis intensified after the Lehman default. During these three quarters, the correlation falls sharply to negative and then rises back to the positive values. As shown in Figure 1a, the risk reversal had surged for a short period of time in 2008 Q4, implying that market participant anticipated a stronger yen against the USD during the period.[17] However, the relative US CDS spread decreased during the same period. The result reflects that the short-term relation between the relative CDS spread and risk reversal for the USD-yen pair is relatively weak and the positive relationship may not hold during market turbulence.

From the euro-based investors' perspective as shown in Figures 4c, 4d and 4e, the correlation between the euro-yen risk reversal and the eurozone-Japan relative CDS spread (see Figure 4d) rise substantially when the European sovereign debt crisis intensified in mid-2011. This suggests that the positive relationship between the currency option market and sovereign CDS market tended to strengthen during the period. However, regarding the cases of the euro-USD (see Figure 4c) and the euro-Swiss franc (see Figure 4e), their positive correlations weaken during the same period, falling from a normal level of 0.4 in 2011 Q2 to 0.2 and -0.6 respectively in 2011 Q4. The former case may be due to the unresolved US debt-ceiling discussions which raised the spectre of a potential technical default by the federal government (failure to pay the interest and/or principal of US treasury securities on time).[18] Therefore, both

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[17] Nirei and Sushko (2011) find that yen appreciations would be magnified during times of higher interest rate differential between the US and Japan and higher level of VIX. They also find that extreme episodes of yen appreciation could be larger and more persistent than episodes of yen depreciation.
[18] In the summer of 2011, the credit rating agencies including the Fitch, Moody's and Standard & Poor's (S&P's) expressed concerns about very large budget deficits and rising indebtedness of the US

the USD and euro were anticipated by market participants having risk of depreciation, such that their risk reversal became less correlated to the relative CDS spread for three quarters.

For the euro-Swiss franc case, as the European sovereign debt crisis deepened during the summer in 2011, a sharp risk re-appraisal triggered a selloff in risky assets and prompted investors to seek safe havens. As a result, the Swiss franc came under tremendous upward pressure. The rising risk reversal shows that the market had never been so one-sided in betting on a stronger Swiss franc (see Figure 1e). Hence, in view of the potential impact on the economy and increasing risk of deflation, the SNB decided on 6 September 2011 to curb further appreciation of the currency. A series of interventions in the spot, forward, and option markets brought the Swiss franc below 1.2 as a cap against the euro and forced the volatility of the exchange rate sharply lower. Such measure pushed the conditional correlation to negative values for three quarters from 2011 Q4 to 2012 Q2.

The results of the conditional correlations support the third hypothesis that the short-term price dynamics between the sovereign CDS and currency option markets is not static over time. These provide us with interesting implications. First, after controlling for effects of nonlinear cointegration and exogenous macro-financial variables, we find that the short-term correlation between the relative sovereign CDS spreads and risk reversals is generally positive, which is consistent with the intuition that an increase in the relative CDS spread of the US (the eurozone) will raise the risk reversals such that high option premiums (i.e., high option-implied volatilities) are paid for USD-puts (euro-puts). This implies that the currency option prices of the currency pairs in this study incorporate sovereign credit risks. Secondly, monetary

government. Despite a settlement to raise the borrowing limit, S&P's lowered the credit rating of the US from AAA to AA+ on 5 August 2011, deciding pessimistic about its fiscal outlook.

measures adopted by central banks (e.g., the exchange rate cap introduced by the SNB in September 2011) and market turbulence (e.g., the Lehman default in September 2008) have substantial impact on the conditional correlation, resulting in drastic and persistent price deviations between the two markets from the long-run equilibrium. Thirdly, the short-term relation between the relative CDS spread and risk reversal for the USD-yen pair is relatively weak compared with the other currency pairs.

IV. Conclusion

The sovereign CDS spreads and exchange rates of the developed economies including the US, Japan, Switzerland and the eurozone with the first three countries' currencies conventionally considered as safe-haven varied in a wide range when the global financial crisis emerged in late 2007 and the European sovereign debt crisis began in late 2009. This raises the question of any interconnectivity between the anticipated sovereign credit risks of these economies and the market expectations of their exchange rates during the crises. This paper uses cointegration with a random coefficient in a bivariate vector error-correction model to show evidence of cointegration between the prices in the currency option and sovereign CDS markets of these four economies. The estimation results find that their relative sovereign credit risks are the risk factors driving the expectations of their exchange rates in the currency option market in the long-run, while the USD-Swiss franc exchange rate is an exception statistically.

Disequilibrium from the long-run relationship triggers significant interactions between the two markets in price discovery. In particular, the relative sovereign CDS spreads of the US (the eurozone) move ahead of the currency risk reversals of the USD-yen (the euro-Swiss franc) in the short-run. We also find that, the price changes in the sovereign CDS and currency option markets is positively correlated in general after controlling for the nonlinear cointegrating relationship and the exogenous macro-financial factors, implying that the currency option prices of these economies incorporate their sovereign credit risks. However, during the crisis periods, the positive correlations for some economies weaken noticeably, leading to the drastic and persistent price deviations from the long-run equilibrium amid central banks' monetary measures and market turbulence.

References

Acharya, V.V., Johnson, T.C., 2007. Insider trading in credit derivatives. *Journal of Financial Economics* **84** (1): 110-141.

Al-Abri, A., Goodwin, B.K., 2009. Re-examining the exchange rate pass-through into import prices using non-linear estimation techniques: Threshold cointegration. *International Review of Economics and Finance* **18**: 142-161.

Ammer, J., Cai, F., 2011. Sovereign CDS and bond pricing dynamics in emerging markets: Does the cheapest-to-deliver option matter?. *Journal of International Financial Markets, Institutions and Money* **21**: 369-387.

Attfield, J., 2003. Structural Breaks and Convergence in Output Growth in the EU. University of Bristol Discussion Paper No. 03/544.

Balke, N.S., Fomby, T.B., 1997. Threshold cointegration. *International Economic Review* **38** (3): 627-645.

Bauwens, L., Deprins, D., Vandeuren, J-P., 1997. Modelling interest rates with a cointegrated VAR-GARCH model. CORE Discussion Paper 9780.

Brunnermeier M.K., Nagel, S., Pedersen L.H., 2009. Carry trades and currency crashes. *NBER Macroeconomics Annual 2008* **23**: 313-347.

Carr, P., Wu, L., 2007. Theory and evidence on the dynamic interactions between sovereign credit default swaps and currency options. *Journal of Banking and Finance* **31** (8): 2383-2403.

Cao, C., Yu, F., Zhong, Z., 2010. The information content of option-implied volatility for credit default swap valuation. *Journal of Financial Markets* **13** (3): 321-343.

Collin-Dufresne, P., Goldstein, R.S., Martin J.S., 2001. The determinants of credit spread changes. *Journal of Finance* **56** (6): 2177-2207.

Eichengreen, B., Rose, A.K., Wyplosz, C., 1996. Exchange market mayhem: The antecedents and aftermath of speculative attacks. *Economic Policy* **21**: 249-312.

Engle, R.F., Granger, C.W.J., 1987. Co-integration and error correction: Representation, estimation and testing. *Econometrica* **55**: 251-276.

Esteve, V., Navarro-lbanez, M., Prats, M.A., 2013. The Spanish term structure of interest rates revisited: Cointegration with multiple structure breaks, 1974-2010. *International Review of Economics and Finance* **25**: 24-34.

Fong, P.W., Li, W.K., 2004. Some results on cointegration with random coefficients in the error correction form: estimation and testing. Journal of Time Series Analysis **25** (3): 419-441.

Frankel, J., Rose, A., 1996. Currency crashes in emerging markets: An empirical treatment. *Journal of International Economics* **41** (3-4): 351-366.

Gonzalo, J., Granger, C., 1995. Estimation of common long-memory components in cointegrated systems. *Journal of Business & Economic Statistics* **13** (1): 27-35.

Gregory, A.W., Hansen, B.E., 1996. Residual-based tests for cointegration in models with regime shifts. *Journal of Econometrics* **70**: 99-126.

Hansen, B.E., 1992. Heteroskedastic cointegration. *Journal of Econometrics* **54**: 139-158.

Hansen, B.E., Seo, B., 2002. Testing for two-regime threshold cointegration in vector error-correction models. *Journal of Econometrics* **10**: 293-318.

Hui, C. -H and Chung T. -K, 2011. Crash risk of the euro in the sovereign debt crisis of 2009–2010. *Journal of Banking and Finance* **35**: 2945-2955.

Kaminsky, G., Lizondo, S., Reinhart, C.M., 1998. Leading indicators of currency crises. International Monetary Fund Staff Papers 45, 1-48.

Kejiriwal, M., Perron, P., 2008. The limit distribution of the estimates in cointegrated regression models with multiple structural changes. *Journal of Econometrics* **146:** 59–73.

Kejiriwal, M., Perron, P., 2010. Testing for multiple structural changes in cointegrated regression models. *Journal of Business and Economic Statistics* **28:** 503–522.

Kohler, M., 2010. Exchange rates during financial crises. BIS Quarterly Review, March 2010, 39-50.

Kumar, M., Moorthy, U., Perraudin, W., 2003. Predicting emerging market currency crashes. *Journal of Empirical Finance* **10** (4): 427-454.

Kurita, T., 2013. Exploring the impact of multivariate GARCH innovations on hypothesis testing for cointegrating vectors. *Communications in Statistics – Simulation and Computation* **42**: 1785-1800.

Longstaff, F.A., Pan, J., Pedersen, L.H., Singleton, K.J., 2010. How sovereign is sovereign credit risk? *American Economic Journal: Macroeconomics*, forthcoming.

MacKinnon, J.G., 1996. Numerical distribution functions for unit root and cointegration tests. *Journal of Applied Econometrics* **11**(6):601-618.

Maki, D., 2013. The influence of heteroskedastic variances on cointegration tests: A comparison using Monte Carlo simulations. *Computational Statistics* **28**: 179-198.

Nirei, M., Sushko, V., 2011. Jumps in foreign exchange rates and stochastic unwinding of carry trades. *International Review of Economics and Finance* **20**: 110-127.

Palladini, G. Portes, R., 2011. Sovereign CDS and Bond Pricing Dynamics in the Euro-area. NBER Working Paper No. 17586.

Pan, J., Singleton, K.J., 2008. Default and recovery implicit in the term structure of sovereign CDS spreads. *Journal of Finance* **63** (5): 2345-2383.

Ranaldo, A., Söderlind, P., 2010. Safe haven currencies. *Review of Finance* **14** (3): 385-407.

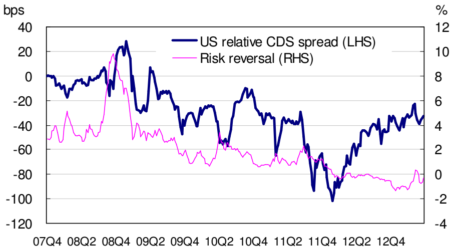
Silvapulle, P.S., Podivinsky, J.M., 2007. The effect of non-normal disturbances and conditional heteroskedasticity on multiple cointegration tests. *Journal of Statistical Computation and Simulation* **65**: 173-189.

Zhang, B.Y., Zhou, H., Zhu, H., 2009. Explaining credit default swap spreads with the equity volatility and jump risks of individual firms. *Review of Financial Studies* **22** (12): 5099-5131.

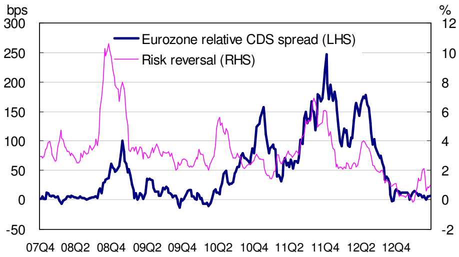
Zhang, B., Li, X.M., 2013. Has there been any change in the comovement between the Chinese and US stock markets? *International Review of Economics and Finance*, forthcoming.

Figure 1: Relative sovereign CDS spreads and risk reversals[1]

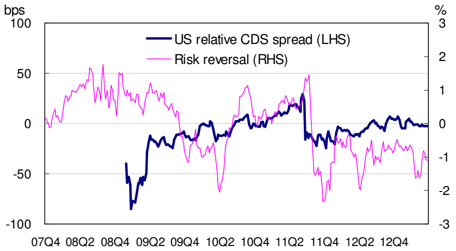
a. Difference between US and Japanese sovereign CDS spread and risk reversal of USD-yen



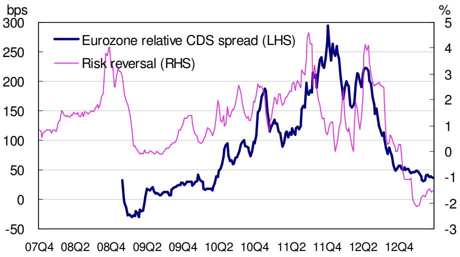
d. Difference between eurozone and Japanese sovereign CDS spread and risk reversal of euro-yen



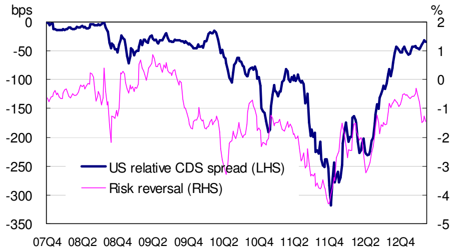
b. Difference between US and Swiss sovereign CDS spread and risk reversal of USD-Swiss franc[2]



e. Difference between eurozone and Swiss sovereign CDS spread and risk reversal of euro-Swiss franc[2]



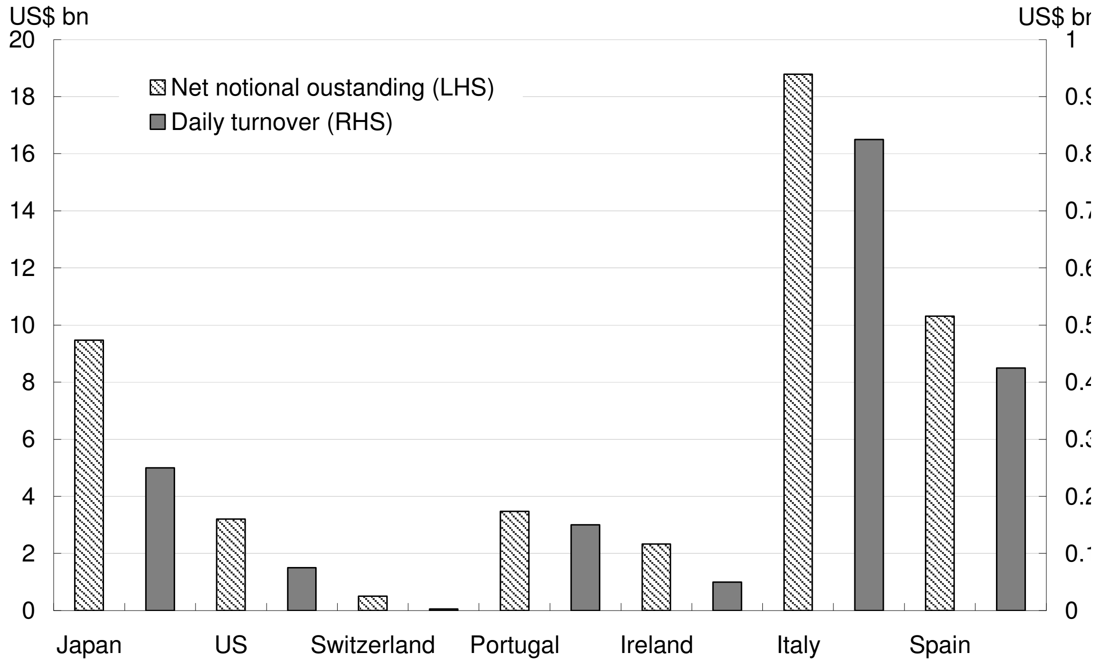
c. Difference between US and eurozone sovereign CDS spread and risk reversal of USD-euro[3]



Notes:
1. Risk reversal is the implied volatility of an out-of-the-money USD (euro) put minus that of an out-of-the-money USD (euro) call at the 25% delta.
2. The Switzerland's sovereign CDS spreads is only available since January 2009 in the data source (JP Morgan Chase).
3. The USD-euro risk reversal and the US-eurozone sovereign CDS spreads can offer perspectives of both USD- and euro-based investors at the same time.

Sources: JP Morgan Chase and Bloomberg.

Figure 2. Net notional amounts outstanding and average daily turnover of sovereign CDS contracts of the US, Japan, Switzerland and the four highly indebted European countries

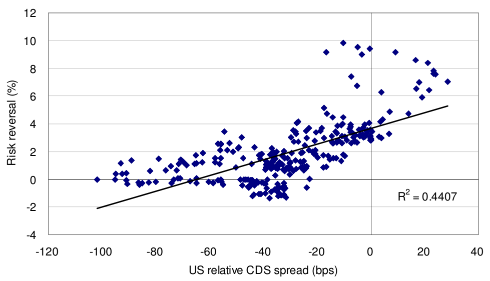


Notes:

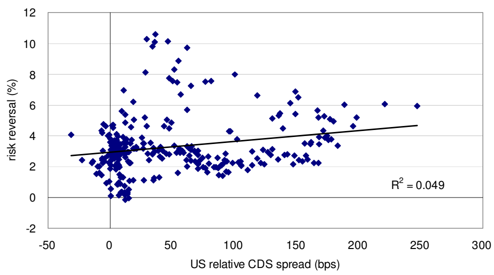
1. The data are from Depository Trust and Clearing Corporation. See www.dtcc.com.
2. Net notional amounts outstanding are the aggregate net protection bought (or equivalently sold) across counterparts. Except for Switzerland, the net notional outstanding shown is as at 9 August 2013 and the average amounts of daily turnover are the average during the period from 20 December 2012 to 19 March 2013.

Figure 3: Scatter plot of relative sovereign CDS spreads and risk reversals

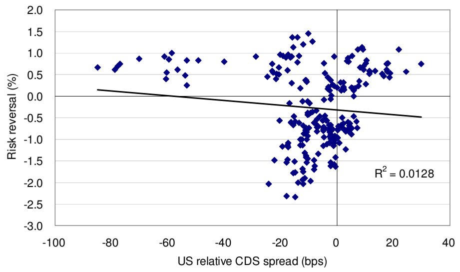
a. Difference between US and Japanese sovereign CDS spread and risk reversal of USD-yen



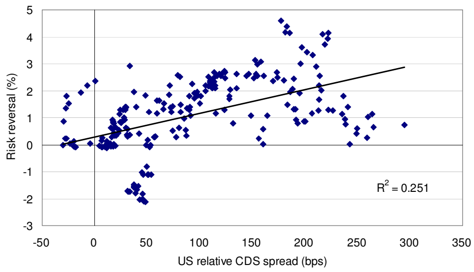
d. Difference between eurozone and Japanese sovereign CDS spread and risk reversal of euro-yen



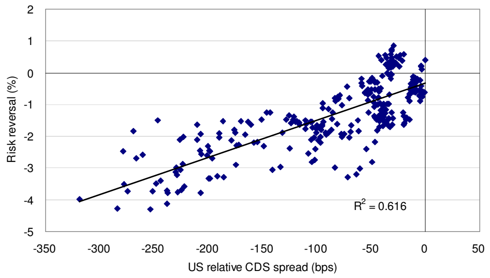
b. Difference between US and Swiss sovereign CDS spread and risk reversal of USD-Swiss franc



e. Difference between eurozone and Swiss sovereign CDS spread and risk reversal of euro-Swiss franc



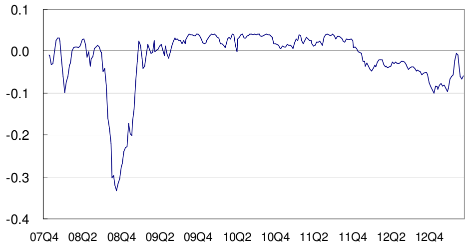
c. Difference between US and eurozone sovereign CDS spread and risk reversal of USD-euro[2]



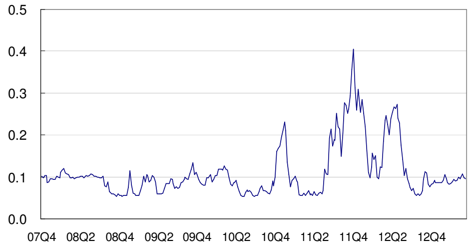
Notes:
1. Risk reversal is the implied volatility of an out-of-the-money USD (euro) put minus that of an out-of-the-money USD (euro) call at the 25% delta.
2. The USD-euro risk reversal and the US-eurozone sovereign CDS spreads can offer perspectives of both USD- and euro-based investors at the same time.

Figure 4: Estimated conditional correlation between risk reversals and relative CDS spreads in short-run[1]

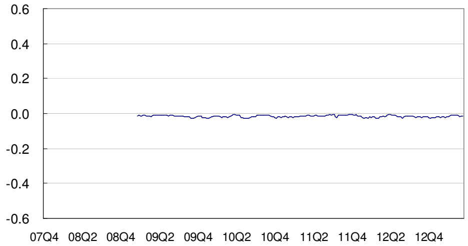
a. Between US-Japanese relative CDS spread and USD-yen risk reversal



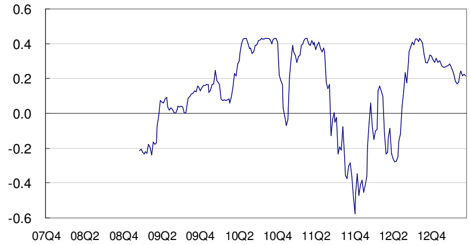
d. Between eurozone-Japanese relative CDS spread and euro-yen risk reversal



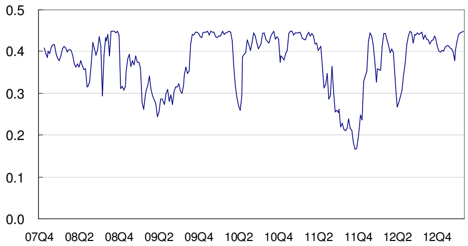
b. Between US-Swiss relative CDS spread and USD-Swiss franc risk reversal[2]



e. Between eurozone-Swiss relative CDS spread and euro-Swiss franc risk reversal[2]



c. Between US-eurozone relative CDS spread and USD-euro risk reversal[3]



Notes:
1. Risk reversal is the implied volatility of an out-of-the-money USD (euro) put minus that of an out-of-the-money USD (euro) call at the 25% delta.
2. The estimated conditional correlation begins in January 2009 because the Switzerland's sovereign CDS spreads is only available since January 2009 in the data source (JP Morgan Chase).
3. The USD-euro risk reversal and the US-eurozone sovereign CDS spreads can offer perspectives of both USD- and euro-based investors at the same time.

Table 1: Descriptive statistics for risk reversals and relative sovereign CDS spreads

	10-delta 3-month risk reversal against USD						10-delta 3-month risk reversal against euro			
	Japanese yen		Swiss franc		Euro		Japanese yen		Swiss franc	
Statistic	*Level*	*Change*	*Level*	*Change*	*Level*	*Change*	*Level*	*Change*	*Level*	*Change*
Mean	1.88	-0.01	-0.28	-0.01	-1.30	0.00	3.24	-0.01	1.07	-0.02
Median	1.51	-0.04	-0.47	0.01	-1.31	0.01	2.96	-0.02	1.13	-0.01
Maximum	9.82	1.72	1.45	0.81	0.85	1.22	10.61	2.12	4.60	1.53
Minimum	-1.35	-1.15	-2.34	-1.08	-4.30	-0.82	-0.14	-1.70	-2.12	-1.63
Std. Dev.	2.17	0.34	0.90	0.24	1.11	0.27	1.82	0.44	1.40	0.35
Skewness	1.30	0.65	-0.07	-0.59	-0.43	0.55	1.46	0.34	-0.18	-0.02
Kurtosis	5.22	6.80	1.96	6.22	2.75	5.74	6.30	6.51	2.97	7.27
ADF test statistic	-1.68	-12.35**	-2.70	-11.25**	-2.22	-8.82**	-2.10	-12.26**	-2.33	-11.05**
Phillips-Perron test statistic	-1.80	-12.02**	-2.52	-11.25**	-2.18	-14.00**	-2.48	-12.62**	-1.95	-10.71**
Observations	285	284	227	226	285	284	306	305	227	226
	Difference between US and country's sovereign CDS spreads						Difference between Eurozone and country's sovereign CDS spreads			
	Japan		Switzerland		Eurozone (median)		Japan		Switzerland	
Statistic	*Level*	*Change*	*Level*	*Change*	*Level*	*Change*	*Level*	*Change*	*Level*	*Change*
Mean	-31.30	-0.13	-8.53	0.16	-83.40	-0.11	48.21	0.00	92.07	-0.01
Median	-31.61	-0.05	-4.81	-0.11	-48.99	-0.08	19.35	0.04	74.31	-0.54
Maximum	28.45	24.55	29.68	20.36	0.08	44.31	247.33	43.38	294.44	-42.04
Minimum	-101.84	-30.41	-84.94	-37.68	-318.79	-49.77	-31.63	-49.14	-30.31	-34.77
Std. Dev.	25.25	5.75	18.20	4.95	74.97	11.36	57.25	11.47	78.54	11.54
Skewness	-0.38	-0.41	-1.81	2.13	-1.10	-0.29	1.13	-0.07	0.53	0.26
Kurtosis	3.07	7.64	7.55	21.08	3.13	6.61	3.26	6.06	2.21	5.04
ADF test statistic	-2.12	-16.05**	-2.42	-14.29**	-1.66	-13.81**	-2.00	-14.28**	-1.48	-12.69**
Phillips-Perron test statistic	-2.23	-16.05**	-2.48	-14.37**	-1.55	-13.70**	-1.85	-14.19**	-1.18	-12.66**
Observations	285	284	227	226	285	284	306	305	227	226

Notes: 1. ** and * indicate significance at levels of 5% and 10% respectively. 2. Both tests check the null hypothesis of unit root existence in the time series, assuming nonzero mean in the test equation.

Table 2: Tests for cointegration between risk reversals and relative sovereign CDS spreads

	USD-based risk reversal			Euro-based risk reversal	
	Japanese yen	**Euro**	**Swiss franc**	**Japanese yen**	**Swiss franc**
Engle-Granger single-equation test					
(Null hypothesis: residual has an unit root)					
ADF test statistic	-2.96**	-3.79**	-2.77*	-2.95**	-2.77*
Phillips-Perron test statistic	-2.90**	-2.94**	-2.53	-2.96**	-2.86*
Johansen Cointegration Trace Test					
Null hypothesis: zero cointegrating vector	4.39	13.88**	28.37**	7.55	7.73
Null hypothesis: at most 1 cointegrating vector	1.36	1.12	5.11**	2.66	0.67

Notes:
1. ** and * indicate significance at a level of 5% and 10% respectively.
2. The cointegration test uses the Augmented Dickey-Fuller and Phillips-Perron tests to check the null hypothesis that the residuals of the regression of a risk reversal on a relative CDS spread are non-stationary assuming nonzero mean in the test equation. The critical value of the test is obtained from MacKinnon (1996).

Table 3: Estimates of cointegrating vectors (i.e., the long-run part of equations (6) and (7))

	USD-based risk reversal (i.e. the long-run part of equation (6))			Euro-based risk reversal (i.e. the long-run part of equation (7))	
	Japan / yen	**Eurozone / euro**	**Switzerland/ Swiss franc**	**Japan / yen**	**Switzerland/ Swiss franc**
Full specification					
β	0.6766**	0.9560**	4.4072	0.7444*	1.0239*
σ_β	3.0037**	1.6735*	4.4639*	7.9722*	3.9888*

Note: ** and * indicate significance at a level of 5% and 10% respectively.

Table 4: Estimation results of the bivariate vector error-correction model in equations (6) and (7)

	USD-based risk reversal/ US relative CDS spread (i.e., equation (6))						Euro-based risk reversal (i.e., equation (7))			
	Yen	**To Japan**	**Euro**	**To Eurozone**	**Swiss franc**	**To Switzerland**	**Yen**	**To Japan**	**Swiss franc**	**To Switzerland**
	ΔRR_t	ΔCDS_t	ΔRR_t	ΔCDS_t	ΔRR_t	ΔCDS_t	ΔRR_t	ΔCDS_t	ΔRR_t	ΔCDS_t
Short-term variable										
Speed of adjustment η_{t-1} (i.e. α_1 and α_2)	**-0.0275****	0.0077	-0.0029	**0.0432***	-0.0000	**0.0438***	0.0033	**0.0151***	**-0.0271***	**0.0171***
ΔRR_{t-1}	**0.2792****	-0.0128	**0.2995***	-0.001	**0.3539***	0.0387	**0.2805***	0.0057	**0.3426***	**0.048***
ΔRR_{t-2}	**0.0981****	-0.0335	**-0.1564***	0.0381	**-0.1726***	0.0301	**0.0828***	0.0335	-0.0464	**-0.0548***
ΔRR_{t-3}	**-0.1087****	**0.1171***	**0.2086***	**0.0845***	**0.1852***	-0.0078	0.0059	0.0101	-0.0612	**0.075***
ΔRR_{t-4}	**-0.0872****	0.0819	**-0.1286***	-0.0108	**-0.0925***	**0.0737***	**-0.1405***	**0.0592***	**-0.0809***	-0.018
ΔCDS_{t-1}	-0.0035	**0.0693***	-0.0936	0.245*	-0.0339	**0.142***	**0.0926***	**0.1539***	**0.2104***	**0.2429***
ΔCDS_{t-2}	**0.0689****	-0.0354	**-0.1532***	**-0.117***	**0.0775***	-0.0678	0.0031	-0.0363	**-0.3246***	**-0.1058***
ΔCDS_{t-3}	**-0.0571****	**0.1044****	0.0795	-0.0334	-0.0165	**-0.1301***	0.0516	-0.0245	0.1076	0.0426
ΔCDS_{t-4}	**-0.0371***	-0.0438	-0.0075	-0.0302	-0.0246	**-0.1398***	-0.0171	-0.016	-0.0841	-0.0421
Const	-0.0069	-0.002	-0.0041	0.0078	-0.0115	**0.0268***	0.0008	0.0047	-0.0002	**0.0096***
Interest rate differential	0.5597	-0.6787	-0.0264	0.1691	-0.3714	**-6.4639***	**2.6122***	**1.4315***	**5.1011***	**2.6763***
Dollar squared return	-0.0038	-0.0229	**-0.0901***	-0.0005	**-0.0966***	-0.0155	**0.0363***	-0.0031	0.028	-0.0049
US or EU volatility index	0.0147	-0.0108	-0.0022	**-0.065***	0.0354	0.0042	**0.0703***	**-0.0571***	**0.1397***	**-0.0647***
US or EU Ted spread	**-0.1077****	**0.0499****	-0.0154	**0.1102***	-0.0436	-0.0183	**-0.1466***	0.0166	**-0.2649***	-0.0243
US or EU stock return	**-0.8728****	0.8978	0.8149	-0.0933	-1.8774	**-5.9743***	-1.1388	-1.1074	-0.457	**-2.6000***
US or EU term spread	**0.017****	0.0239	**0.0301***	-0.0077	-0.0097	**-0.1034***	**-0.0244***	**0.0262***	0.0104	-0.0099
Country's stock return	0.0143	-0.013	-0.0049	**-0.0293***	-0.0001	**-0.158***	-0.01	0.0229	**-0.142***	0.0274
Country's term spread	0.0083	0.0142	0.0299	**0.027***	-0.0341	0.0095	-0.009	0.0008	**0.1595***	**-0.0423***
Variance related										
σ_{CDS} and σ_{RR}	0.0403	**0.0979****	**0.4481***	**0.2117***	0.0283	**0.2392***	**0.2025***	**0.1414***	**0.19***	**0.1078***
r	**0.2156****		**0.1106***		**0.1006***		0.0543		**0.4304***	
Ljung-Box test statistic										
Residuals' autocorrelation	4.5902	6.0496	18.247	0.8065	3.317	2.3064	27.656	14.125	17.877	7.6968
Residuals' cross-correlation	16.55		19.4		11.04		17.61		15.87	

Notes: 1. ** and * indicate significance at a level of 5% and 10% respectively. 2. The two Ljung-Box tests check the null hypotheses of jointly zero residuals' autocorrelations and jointly zero residuals' cross-correlations respectively up to lag 4 (i.e. the fourth week). The test statistics can be roughly compared to the Chi-squared distribution. With the degree of freedom of 16 (= 22 x 4), the critical value is 23.5 at a 10% confidence level.