Linkages, Volatility Transmissions and Contagion in Interest Rate Swap Markets: What Are We Really Picking Up?

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This version: June 2012

Abstract

Using the swap yield and spread data, this paper provides a comprehensive analysis of linkages and volatility transmission across the three major international swap markets namely, Japan, UK and the US. The paper uses a recently developed model to decompose the volatilities of swap yield and swap spreads into two components: long-term and short-term. These components are then utilized to study the strength and direction of the volatility transmission across the three markets. The strength is measured through dynamic correlations of long-term and short-term components, while the direction is measured through causality of these components. In addition, the contagion effect on observed correlations is also examined using economic events relevant to swap markets. The paper presents the following set of empirical findings. First, the analysis shows that the cross-market correlations among the long-term components (Japan and U.S., Japan and UK) are very low implying evidence of weak integration. This finding suggests that the international investors could take advantage of the differential between the low long-term yields of Japanese Government bonds and the high long-term yields of U.S. bonds. The cross-market correlations among the short-term components are high (although switching from highly positive to negative overnight) indicating the transmission of noise components. Second, the contagion effect is found to exist on both the long-term and short-term volatility components of the swap spread but not on the swap rates. Third, in terms of the direction of transmission, the volatility spillovers (both components) are mostly reciprocal across three markets.

Key Words: Financial Integration; Interest Rate Swap; Long-term Volatility; Short-term Volatility; Long-term Correlations; Short-term Correlations;

JEL Classification: C53; G11; G12 ;

ACKNOWLEDGMENT

For valuable comments and suggestions, the authors would like to thank Tarun Chordia and the seminar participants at Macquarie University in Sydney, Midwest Finance Association Conference 2011 in Chicago, Australasian Banking and Finance Conference in Sydney and PhD symposium in Prato, Italy. A special thank goes to Jose Gonzalo Rangel for sharing the computer program to estimate the FS-GARCH volatility model in Rangel and Engle (2012).

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1. INTRODUCTION

The recent global financial crisis has intensified the globalization process, resulting the world economy and international financial markets become more connected and interdependent. This has caused concern to regulatory authorities who complain they have lost autonomy and find it increasingly difficult to formulate independent monetary policies (long term and short-term) especially when markets are very volatile. Concern is also felt by institutional investors whose hedging and diversification strategies depend very much on the nature and strength of the relationships between different financial markets. Therefore, it is important to determine the extent to which interest rates in different countries are correlated and which volatility component (long-term or short term) is dominant in the transmission process.

This study follows the vast literature on market integration, contagion and volatility transmission in financial products both within and across the countries. Given the extensive literature, this study finds some research gaps in the above areas. First, while it is argued that an appropriate volatility specification is needed to describe the patterns of market links and volatility transmission, prior studies rarely utilize volatility components (long-term and short-term) to facilitate the investigation. In effect, the use of aggregate volatility shocks makes it difficult to measure the integration and to identify which volatility component is dominant in the transmission process. Second, a survey of literature in swaps (see Appendix A) as well as in other markets shows that prior literature examines the following issues in isolation: (i) correlations among the markets (ii) contagion effect and (iii) causality. Moreover, the evidence of linkages provided by the prior literature in swaps (Appendix A) and other markets could mislead the investors due to misspecification of volatility.

In contrast, this study provides a comprehensive knowledge of market linkages and volatility transmission with a particular attention to swap markets. We contribute to the existing knowledge in the following ways. First, this is the first study that examines the linkages and volatility transmission across the swap markets by decomposing the aggregate volatility into two components: short-term and long-term.[1] Second, this is the first study that reflects on both the strength (correlations) and, the direction (causality) of volatility transmission on both contemporaneous and Granger causal perspectives. Third, this is the first swap market study that examines the contagion effect, that is, the influence of the relevant crises on swap market linkages. Finally, this study combines relevant approaches in modelling the volatility links among the financial markets, in particular the linkages among three major interest rate swap markets (Japan, the UK and the US).[2]

While the integration theory suggests that swap yield curve should be parallel across the markets, the short-term deviations from no-arbitrage conditions may cause non-parallel shift of term structure of yield or spread. Lekkos et al. (2007) argue that links exist among the swap and derivative markets either due to (i) common variations in the business cycles across economies or (ii) coordinated arbitrage and hedging activities.[3] However, no prior literature in swap explicitly examines the links among the markets from the common variation in business cycle risks. Hence, using the financial integration theory and the World Bank's definition and classification of transmission and contagion, this study addresses the following three research questions (RQs):[4]

RQ1: Does the long-term volatility co-vary across the three major international swap markets?

RQ2: Does the short-term volatility co-vary across the three major international swap markets?

RQ3: Is there any contagion effect in the above three major international swap markets?

The first research question asks whether the long-term volatilities across the swap markets are correlated and, whether the correlation is time varying. This is linked to the World Bank's classification

[1] The prior literature links the short-term component to market skewness risk or noise trading, while the long-term component to business cycle risk. See for instance, Adrian and Rosenberg (2008), Engle and Rangel (2008); Engle et al. (2008); Azad et al. (2011) and Rangel and Engle (2012)].

[2] Economic integration among these three markets is substantially high.

[3] Studies include those of Lekkos and Milas (2001) and Eom et al. (2002).

[4] World Bank classifies the transmission into three categories: (i) the transmission or spillover that takes place both during 'good' times and 'bad' times, (ii) the excess co-movement of shocks that have less relevance to fundamental links (financial links, economic/real links and political links) and (iii) an increased correlation, defined as 'pure contagion' by Forbes and Rigobon (2002), during the 'turmoil period' relative to 'tranquil period'.

of fundamental link and correlations of business cycle risk as defined by some studies.[5] The second research question is related to the World Bank's classification of excess co-movement, also known as correlations of noise component or skewness risk across the markets.[6] Related to third research question, Eom et al. (2002) argue that the trading behaviour led by crisis events is likely to accentuate the integration of swap markets. Hence, it is important to evaluate the influence of those events on the swap market integration. The selected events are explained in the methodology section.

We carry out the empirical analysis on 5-year swap (from three markets: Japan, UK and USA), which is one of the highly liquid swap market segments. The analysis is conducted as follows. First, the study decomposes the aggregate volatility shocks into short-term and long-term components using Factor-Spline-GARCH (hereafter FSG-Spline GARCH) of Rangel and Engle (2012). Second, the strength of the integration is measured through the short-term and long-term volatility correlations using Engle's (2002) Dynamic Conditional Correlation (DCC). These correlations are then utilised to examine the contagion effect. Finally, we model contemporaneous and Granger causality of the volatility components to determine the direction of transmission.

Our findings are as follows. Relating to first and second research questions, the empirical analysis shows that the time-varying long-term correlations between Japan and the UK and between Japan and the US are very low (though the causation is reciprocal) for both the swap rates and spreads. This result implies that the integration is statistically weak, suggesting a non-parallel shift in yield curve or spread. The implication is that this may provide international investors the opportunities to go long Japanese yen interest rate swaps and go short US dollar/pound interest rate swaps to take advantage of the differential between the low long-term yields of Japanese government bonds and the high long-term yields of US/UK bonds. Therefore, the low correlations between Japan and US/UK may cause an increase in the yen swap rate. In regard to the second research question, the pairwise time-varying

[5] Litzenberger (1992) and Lang et al. (1998) show that default risk of swap counterparties co-varies with the business cycle risk.

[6] Adrian and Rosenberg (2008) define market skewness risk as a measure of tightness of financial constraints. The credit spread differentials across the domestic and international markets can be regarded as skewness risk in swaps [Nishioka and Baba (2004)].

short-term correlations are high, although the causation is mixed on Granger causal sense. This result on short term correlations is consistent with the prior findings that use aggregate volatility and we argue that the market linkages detected by prior studies are mainly due to noise component (short term volatility) and are not driven by economic fundamentals (long-term volatility). In regard to the third research question, which examines the 'contagion effect' in swap markets, our analysis demonstrates that most of the crisis events had influences on the correlations of long-term and short-term volatilities across the markets. However, the contagion effect is more evident on the swap spreads but not on the yield curve. That is, credit risk components are more affected than the swap market risk.

The remainder of this paper is organized as follows. Importance of studying the swap market linkages and volatility transmission is discussed in Section 2. To motivate our hypotheses relating to the research questions raised, in Section 3, we review some prior literature on volatility spillovers in swap and, in two-factor (short- and long-term) volatility models. Section 4 describes the data while Section 5 explains the estimation techniques. Section 6 reports the empirical findings and analysis thereof, while Section 7 concludes.

2. IMPORTANCE OF STUDYING SWAP MARKET LINKAGES

Interest rate swap is a highly liquid over-the-counter (OTC) derivative instrument comprising two legs, one paying fixed rate and the other paying floating rate such as the London interbank offered rate (LIBOR). This study focuses on the plain vanilla swap, i.e., fixed-for-floating swap rate. The swap spread causes swap yield (fixed-for-floating rate) curve to be above the Treasury (government bond) yield curve. In theory, this spread at any given maturity reflects the additional risk premium associated with bank sector credit risk compared to government credit risk. Ito (2010) notes that with the efficient pricing of swap and government bonds, swap spreads reveal something about the perception of the systemic risk in the banking sector. Unlike the prior literature in swap (see Appendix A), our study examines the linkages not only in swap yield but also in its credit risk component across the three countries: Japan, UK and USA.

There are several reasons why we examine the linkages of swap markets. The swap markets around the world have experienced rapid growths in the last few years. The recent BIS (2011) survey indicates that the outstanding 'notional principal' has grown from virtually nothing in early 1990s to US$450 trillion in 2011 (see Figure 1). An important observation in this figure is that even after the GFC crisis, the use of interest rate swaps has continued to increase. This is because a large variety of corporations use the swaps to hedge interest rate risk and, to manage their macroeconomic and business risks [ISDA (International Swaps and Derivatives Association, Inc., 2009)]. In terms of notional principal, interest rate swaps surpassed the US treasury debt. Figure 2 shows that swaps represents about 80% of the total OTC interest rate derivatives. Another notable feature of the swap market (in comparison to stocks and bond markets) is that swap rate is used as a benchmark interest rate in some countries [e.g., Australia]. And, a wide range of market participants including investors, hedgers and speculators extensively use swap rate as a reference rate to price corporate bonds and various other securities. Academic literature also uses the swap rate as a better proxy of risk free rate for credit risk pricing [see for instance, Blanco et al. (2005); Xiang et al. (2011)]. This means that the linkage of cross-border swap markets essentially reflects the linkages of interest rates markets including that of government bond markets. Abad and Novales (2004) argue that understanding the swap rate linkages is important as consumption and investment decisions are affected by interest rates at longer maturities. Economic implications are that the measurement and understanding of volatility and correlations in swap markets are expected to provide helpful information on pricing quanto and/or differential swaps [Mahoney (1997)], choosing which instrument is beneficial for the market participants, limiting companies' exposure to external shocks and determining whether the linkages provided by prior literature are either due to economic integration or sharing of noise or both.

Unfortunately, despite its popularity and widespread usage, it is still understudied compared to options and futures. Besides, those studies that examine the linages in swap mostly look at the swap spread but not at the swap yield and their findings are based on aggregate volatility, which could mislead the investors in making hedging and portfolio investment decision.[7] That is, their empirical findings of market linkages could be dominated by the noise component (i.e., short-term component) but not by the true economic integration or macroeconomic fundamentals (i.e., long-term component).

<<<< Figures 1 and 2 around here >>>>

3. PRIOR LITERATURE, MARKET LINKS IN TWO-FACTOR VOLATILITY MODELS AND HYPOTHESES

Finance literature extensively uses the 'volatility transmission hypothesis' to measure the extent of financial integration and information spillover between the markets. Interpreting volatility as a "global factor" [Eom et al. (2002) , p. 6], a proxy for news and the fact that news originating from a market affects various markets simultaneously, there is a large body of literature that examines volatility transmission and linkages. Engle et al. (forthcoming) provide a summary of empirical literature on volatility transmission in different financial markets. Engle et al. (forthcoming) opine that study of volatility linkages is important as it reflects the degree of integration of financial markets and their relative importance of real economies. The benefits and threats of financial integration are summarised under two headings[8]: (i) improved allocation of capital and (ii) risk sharing. On one hand, integration reduces international barriers to movements of capital flows. On the other hand, it causes the events in one market to have economic repercussions in others. As far as swap market is concerned, by accessing the integrated markets, swapping firms benefit from diversifying their interest rate risks but at the same time are exposed to external volatility shocks.

Few studies [e.g., Lekkos and Milas (2001), Eom et al. (2002), In et al. (2003), Lekkos and Milas (2004), Abad and Novales (2004), In (2007) and Lekkos et al. (2007)] also have tested the 'volatility transmission hypothesis' to measure swap market linkages. This literature attempts to search for evidence of volatility transmission across the swap markets with or without an asymmetric term in the

[7] The following studies examine the swap market linkages using swap spread data: Lekkos and Milas (2001), Eom et al. (2002), In et al. (2003), Lekkos and Milas (2004) and In (2007). The only exception is Abad and Novales (2004), who examine the cross-border linkages of swap rates.

[8] For details, see Kose, Prescott, et al. (2003) and Epaulard and Pommeret (2005).

volatility models.[9] Unfortunately, given the fundamental (financial, real and political) links among the economies, most of the previous studies find inconclusive evidence of information transmission between the markets.

Wongswan (2006) argues that this may be due to (i) methodology and nature of the information proxy and (ii) the data frequency. We take Wongswan's first argument, which requires an appropriate methodology and volatility/risk proxy for examining the information transmission process and contagion across the financial markets. In regard to data frequency, In (2007) suggest the use the daily data to examine the transmission process. A careful review of the literature indicates that prior literature has shown some limitation in obtaining the volatility and hence, the empirical approaches.

First, the literature that uses aggregate volatility model is less motivated by the financial integration theory and so does not provide a clear evidence of market linkages that are consistent with theory. In addition, these aggregate volatility models are *ad hoc* and less conformed to World Bank's definition and classification of transmission.

Referring to the World Bank's definition and classification, the transmission of volatility shocks in swap markets can be classified into three categories: (i) the transmission or spillover that takes place both during 'good' times and 'bad' times, (ii) the excess co-movement of shocks that have less relevance to fundamental links (financial links, economic/real links and political links) and (iii) an increased correlation, defined as 'pure contagion' by Forbes and Rigobon (2002), during the 'turmoil period' relative to 'tranquil period'. The transmission in the first case occurs due to fundamental links while in the second case it is rather difficult to identify the underlying reasons. In this study, we relate this transmission to the short-term volatility which can be characterized as herding behaviour, either rational or irrational, mostly attributed to co-movement of market skewness risk or financial constraints risks, policy mistakes, panics, irrational exuberance and noise trading etc.[10] In the third case, the shocks induce increased cross-market correlations during the crisis period. This phenomenon is referred to as

[9] Asymmetry or leverage effect, in financial markets, implies that bad news have more impact than good news on the conditional volatility.

[10] King and Wadhwani (1990) argue that a failure of market mechanism and mistakes in one market can transmit to the other markets, hence constituting short-term volatility linkages.

'contagion effect' [first discovered by King and Wadhwani (1990)], which has relevance to swap market as well.[11] Unfortunately, based on the aggregate volatility spillover, it is rather difficult to differentiate whether the volatility spillover is due to first or second category of transmission as noted above. In other words, it is difficult to determine which of the two volatility risk components are we really picking up or which is more dominant in the transmission process.

Second, although the previous literature on component GARCH family model(s) captures the short-term volatility or market skewness risk and long-term volatility or business cycle risk, prior literature has paid little attention to the extended utilization of those extracted components. Appendix B lists the literature that uses component GARCH models in different financial markets. Third, a large body of literature including those dealing with swaps (Appendix A) takes a partial look at either the correlations or the causality.

We take into account of the above features in our empirical analysis combined with the World Bank's classification of transmission and contagion. It is to be noted that component GARCH models of Engle and Lee (1999) and Engle and Rangel (2008) provide solutions to the problems arising from first and second limitations. To overcome the correlation limitations, in their study Rangel and Engle (2012) combine the Factor-Spline-GARCH model with the Engle's (2002) DCC approach to decompose the volatility into long-term and short-term and examine the time-varying correlations of short term and long-term volatility . The only missing aspect in their study is the causation/causality of volatility components (i.e., direction of volatility spillovers). Wongswan (2006) uses two-factor volatility models to investigate the information transmission from the developed economies (Japan and US) to the emerging economies (Hong Kong and Thailand). However, Wongswan (2006) focuses only on the long-term (persistent) component and also ignores the correlation and contagion aspects. Nevertheless, the economic significance and meaning of long-term volatility spillover are similar in both Wongswan's (2006) and our approaches. Wang's (2010) empirical approach handles the contemporaneous and Granger-causal link but does not address the first limitation and the degree of integration (correlations

[11] A recent book titled "*Financial Contagion: The Viral Threat to the Wealth of Nations*" [edited by Kolb (2011)] provides a detailed definition of contagion and a summary of the research undertaken so far on contagion.

aspects) in the problem under the third limitation. A simple and important question is: can we combine all these approaches in such a way that we can overcome all the three limitations simultaneously?

In our study, we combine the features from Wongswan (2006), Wang (2010) and Rangel and Engle (2012). Our approach can be described in the following manner. As Figure 3 indicates, we first decompose aggregate volatility shocks (in swap yield curve and spread) into short-term and long-term components. In the second step, short-term and long-term components could be linked to market skewness risk and business cycle risk respectively. However, since many studies find the linkages between short-term volatility and skewness risk and long-term volatility and macroeconomic variables, we do not include these steps in our analysis.[12] Instead, we utilize these components for investigating the dynamic correlations and causality. This allows us to know whether the spillover is due to the synchronization of skewness risk (measured through short-term volatility linkages) or the synchronization of business cycle risk (measured through long-term volatility linkages) or both. The dynamic long-term correlations are later used to examine the contagion effect. Finally, to investigate the directions of spillover, we study the causality on both contemporaneous and Granger causality perspectives. Thus, our comprehensive analysis is practically appealing as it enables us to find the potential drivers of the volatility transmission.

<<<< Figure 3 around here >>>>

Relating to step-by-step procedures shown in Figure 3, the existing literature suggests that two component volatility models outperform one-component models in explaining the volatility of financial markets.[13] Engle, Ghysels and Sohn (2008) suggest that capturing two components has several benefits. For instance, short-term component captures the dynamics of conditional volatility associated with transitory effects of volatility innovations and long-term component characterizes slower variations in the volatility process associated with persistent effects. Adrian and Rosenberg (2008) find that stock

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[12]Such an empirical answer is provided in stock market study by Engle and Rangel (2008) and in swap market study by Azad et al. (2011). We also have confirmed that the long-term volatility systematically co-varies with the macroeconomic variables. The results can be obtained from authors on request.

[13]These include Engle and Lee (1999), Engle and Rosenberg (2000); Alizadeh et al. (2002); Bollerslev and Zhou (2002); Chernov et al. (2003); Adrian and Rosenberg (2008); Christoffersen et al. (2008) Engle and Rangel (2008), Engle et al. (2008) and Nowak et al. (2009) and Rangel and Engle (2012).

returns contain risk premia related to these two components. Both Engle and Rangel (2008) and Adrian and Rosenberg (2008) find that long-term component has a closer link with the business cycle risk (proxied by industrial production and other macroeconomic variables). Hwang and Satchell (2000) argue that, for market regulators the use of long-term volatility or fundamental component of volatility as a measure of risk is more meaningful than the usual measures of the volatility. Indeed, use of long-term volatility as proxy for macroeconomic information is analogous to that of Wongswan (2006). Thus, the market linkages based on long-term volatility can be linked to common variations in the business cycle across economies [Lekkos et al. (2007)].

Business cycle synchronisation theory [14] implies that, as the countries coordinate their macroeconomic policies under market integration, [15] the long-term volatility or business cycle risk should spillover across the markets reciprocally. Therefore the linkages in the case of long-term volatility are, by assumption, driven by macroeconomic fundamentals [Rangel and Engle (Forthcoming)]. One can refer to this as systematic/market-wide spillover linkage [e.g., Campbell and Taksler (2003)]. Based on the above explanation, given the identical risk characteristics, the cross-border swap markets of the same maturities will have identical volatility patterns.[16] And, the shocks affecting a market will spread to the other market(s) immediately.

Nevertheless, the short-term volatility or market skewness risk may or may not spillover reciprocally. That is, the short-term volatility linkage may or may not be as strong as in the case of long-term volatility linkage and, hence shock may or may not transmit from one to the other market(s). One reason is that the short-term volatility does not necessarily reflect the fluctuations in economic fundamentals rather it captures temporary and asymmetric effects, which may be induced by misinterpretation of information, noise trading, failure of market mechanism, idiosyncratic risk, policy

[14] See Zarnowitz (1992) for business cycle theories and Kose, Otrok, et al. (2003) for literature on cross-country links of business cycle fluctuations. Using the latent factor model to estimate common components in macroeconomic aggregates, Kose, Otrok, et al. (2003) among others show that business cycles in major industrialised economies are quite synchronised.

[15] See for instance, Razin and Rose (1994) and Chang (1997).

[16] In contrast to this, if markets are segmented, barriers to arbitrage allow assets traded in different markets to have different expected returns even when their risk characteristics are indifferent [Campbell and Hamao (1992)].

mistakes and market skewness risk specific to a market.[17] The linkages can still take place in Merton (1973)'s intertemporal capital asset pricing model (ICAPM) in which the equilibrium pricing kernel depends on high-frequency volatility, low-frequency volatility as well as the expected return [see for instance, Adrian and Rosenberg (2008)]. Based on the above discussion, relating to research question whether there is volatility transmission across the three major swap markets, we hypothesize that there exists reciprocal/bi-directional transmission (correlation and causation) of volatility among swap markets in Japan, the UK and the US. We first examine the correlation aspect of the transmission and, thus we split the hypothesis into two related testable hypotheses (in alternative forms) as follows:

H1: There exist significant time-varying correlations of long-term volatility components across the countries.

H2: There exist significant time-varying correlations of short-term volatility components across the countries.

Modelling the dynamic correlations is an important process for updating the information on time-varying daily correlation structure and measuring the strength of the integration among the economies. The higher the dynamic correlation coefficient, the closer the co-movement of international swap rates/spreads. It is argued that the correlations are time-varying and dynamic because of economic events, crises and policy changes relevant to the market. The cross-market correlations may increase during crisis period. This phenomenon is referred to as the contagion effect,[18] which was first captured by King and Wadhwani (1990) and later extended by Forbes and Rigobon (2002) and Bekaert et al. (2005). A number of prior studies in different financial markets provide empirical support for time-varying correlation and attribute the contagion effect to economic events and crises.[19] However, no prior literature has explicitly examined the influence of the economic events and crises on swap market linkages. In contrast, the relevant economic events (see Table 3 in the data section for a summary of the events) are expected to bring about contagion effect in swaps. Related to this, we hypothesize that

[17]King and Wadhwani (1990) examine the transmission of mistake/market failure, which can be linked to the short-term volatility linkages in this study.

[18]The book entitled "*Financial Contagion: The Viral Threat to the Wealth of Nations*" edited by Kolb (2011) summarises studies on the financial contagion and its influence on financial markets and overall economic wellbeing of the nations.

[19]See for instance, Bekaert and Harvey (1995); Karolyi and Stulz (1996); Fleming et al. (1998); Fung and Patterson (1999); Forbes and Rigobon (2002) and Bekaert et al. (2005).

H3: There is a contagion effect in the dynamic correlations among the three swap markets.

While the structure of dynamic correlations shows the strength of the integration, it does not necessarily reflect the direction of volatility transmission. If there exists financial integration, then the spillovers should be reciprocal across the markets. With the two-volatility components, we hypothesize that

H4: Long-term volatility spillovers are bi-directional across the countries.

H5: Short-term volatility spillovers are bi-directional across the countries.

4. DATA

To examine the linkages of swap markets via two-factor volatility model, we use the daily 5-year IRS data from the three major swap markets, namely Japan, the UK and the USA. The daily data are used considering the fact that the IT revolution has enabled rapid transmission of shocks from one to the other markets. Our analysis is confined to these three markets as they comprise a large share of the total swap markets. We take 5-year swap maturity for comparison with existing studies [Lekkos and Milas (2001)]. We also take into account of Bicksler and Chen (1986)'s argument that IRS instruments are an effective tool than financial futures and options in hedging against the interest rate risk for horizons beyond 2 or 3 years. According to this argument, the market for this maturity (5-year maturity) is expected to be highly liquid.

All swap data are collected from DataStream. For the UK and the US, we obtain directly the swap spread data [DataStream code: ICGBS5Y for UK and ICUSS5Y for US]. For Japan, we compute the yen swap spread as the difference between 5-year yen swap rate and the constant-maturity 5-year Treasury bond yield [DataStream Code: GVJP05 (CM05) - 5th polynomial]. To reiterate, volatility linkages of swap rates indicate whether shift of swap yield curve is parallel across the countries. Volatility linkages of swap rates can also be related to market risk linkage, while the volatility linkages of swap spread can be related to credit risk linkage. The analysis covers the period from September 1989 to January 2010. Since the dynamic correlation structure implicates the events/crises occurred during the sample period, we separately examine the influence of the crisis dummies on the dynamic correlation structure and we do not conduct sub-sample analysis.

Since the data spans almost the entire history of the swap market, this study considers the Asian financial crisis as the first dummy. Numerous studies provide empirical evidence that, due to cross-border capital flows, the Asian financial crisis caused the contagion in various markets. The second and third crisis dummies are the Russian Government bond default in August 1998 and the Long-Term Capital Management (LTCM) crisis in September the same year. Both these events caused panics among the investors, who desperately sold Japanese and European bonds to buy US Treasury bonds.[20] The fourth crisis dummy is November 1998, the failure of two major Japanese banks [Japan Long-Term Credit Bank (LTCB) and Nippon Credit Bank] resulted in downgrading Japan's sovereign credit rating which in turn adversely affecting the swap market. The fifth crisis dummy relates to the liquidity crisis in November 1999. Responding to concerns over the Y2K millennium date change, liquidity shortage in 1999 also had an adverse impact on the swap market via Treasury markets (swap spreads widened). The Federal Reserve Bank of New York auctioned Y2K options to primary dealers. The implied volatility of Y2K options and a higher demand for these instruments eventually contributed to a drop in the liquidity premium of Treasury securities [Sundaresan and Wang (2009)]. The sixth crisis dummy relates to the US Treasury announcement of debt buybacks in January 2000. This announcement pushed down Treasury yields and widened swap spreads by over 50 basis points in the following four months [Cortes (2003)]. Japan's sovereign credit rating was downgraded in September 2000 and November 2001 [Eom et al. (2002)]. Two dummies are created for Japan's credit rating downgrades. Another crisis dummy is related to mortgage prepayment hedging activity by the US mortgage prepayment hedgers. In July 2003, the mortgage prepayment hedging activity by hedgers also had a negative impact on the swap market (spreads widened). The final crisis dummy relates to recent global financial crisis (GFC), the worst of the financial crises the world experienced in its entire history. The crisis began in February 2007, when market participants recognised that the sub-prime loan

[20] With the Russian Government bond default (and devaluation of rouble) in August 1998, the hedge fund industry suffered huge losses in September 1998. The US Federal Reserve provided a US$3.5 billion rescue plan to bailout LTCM.

problem would be a tough one to tackle and, the crisis became more pronounced from July 2007 [Allen and Carletti (2010)]. In a recent study on the influence of the GFC crisis on the US swap spread, Ito (2010) finds that the credit risk (or default) component of swap increased due to the crisis. Prior literature has not explicitly examined the influence of the above events on swap market linkages. Crisis dummies are summarised in Table 1.

<<<< Table 1 around here >>>>

5. ESTIMATION TECHNIQUES

To test our hypotheses developed in Section 2, we follow a two-step procedure. In the first step, we use the Factor-Spline-GARCH (FS-GARCH, hereafter) model of Rangel and Engle (2012) to decompose aggregate IRS volatility for each country into short-term and long-term volatility components. Appendix C provides details of how the volatility components are obtained using FS-GARCH approach of Rangel and Engle. In the second step, we utilize the decomposed volatility components for measuring the dynamic correlations, contagion, contemporaneous and Granger causal links across the swap markets.

5.1 Modelling Dynamic Correlations

To test hypotheses *H1* and *H2*, we need to measure the correlation dynamics. Most often, the Engle (2002)'s Dynamic Conditional Correlation (DCC) model is used to do this. The DCC has two stages. In the first stage, it is customary to use a univariate GARCH model. Since we need to obtain two volatility components, in the first stage we use FS-GARCH model for each country, separately for swap rates and spreads. After obtaining the volatility components, they are used in our second stage, where we construct standardized residuals (residuals standardized by their standard deviations estimated at the first stage, $\eta_t = \frac{\varepsilon_{i,t}}{\sqrt{g_{i,t}}}$ for the short-term component and $\acute{\eta}_t = \frac{\varepsilon_{i,t}}{\sqrt{\tau_{i,t}}}$ for the long-term component) to estimate the time-varying short- and long-term correlations between the markets.

$$H_t = D_t R_t D_t \qquad (1)$$

$$\varepsilon_t = D_t^{-1} r_t \quad (2)$$

$$E_{t-1}[\varepsilon_t \acute{\varepsilon}_t] = R_t = Q_t^{*^{-1}} Q_t Q_t^{*^{-1}} \quad (3)$$

$$Q_t = (1 - \theta_1 - \theta_2) Q + \theta_1 \eta_{t-1} \acute{\eta}_{t-1} \quad (4)$$

where, $H_t = E_{t-1}[r_t \acute{r}_t]$, r_t is the $n \times 1$ vector of swap rate/spread changes at time t. D_t is a ($n \times n$) diagonal matrix of the time-varying standard deviations [$\sqrt{g_{i,t}}$ for short-term component and $\sqrt{\tau_{i,t}}$ for long-term component] obtained from the univariate FS-GARCH models. R_t is a time-varying correlation matrix with ones on its diagonal (Q_t^* is the diagonal component of the square root of the diagonal elements of Q_t) and, on its off-diagonal, are the pair wise correlations [$\rho_{j,k,t}^S = \frac{g_{j,k,t}}{\sqrt{g_t^j g_t^k}}$ for the short-term component and $\rho_{j,k,t}^L = \frac{\tau_{j,k,t}}{\sqrt{\tau_t^j \tau_t^k}}$ for the long-term component, for $j \neq k$]. $\rho_{j,k,t}^S$ is the cross-market short-term correlation coefficient, while $\rho_{j,k,t}^L$ is the cross-market long-term correlation coefficient. $g_{j,k,t}$ and $\tau_{j,k,t}$ respectively, are the conditional and unconditional covariances of two swap markets . The log-likelihood function of the correlation component is as follows:

$$L(\theta) = -0.5 \sum_{t=1}^{T} (log(|R_t|) + \acute{\eta}_t R_t^{-1} \eta_t) \quad (5)$$

Equation (3) can be used to forecast time-varying correlations. The covariance is updated by equation (4). The scale parameters θ_1 and θ_2 represent the effects of previous standardized shock and the persistence of correlations, respectively. Whether the time-varying correlation exists is judged by the significance of either of these parameters.

To test for contagion effect (hypothesis *H3*) on the correlation structure, we regress the daily estimated correlation on crisis dummies using the following specification:

$$\rho_{x,y,t} = \sum_{j=1}^{n} k_j \, D\_crisis_j + \epsilon_t \quad (6)$$

where, $\rho_{x,y,t}$ is the cross-market short-term/long-term correlation coefficient of market x and y on day t. D_crisis_j are the crisis dummies used as proxies for the relevant events that are said to affect the swap market. We picked up these events from review of literature in swaps shown earlier.

5.2 Modelling Causality of Volatility Components

Once measuring the degree of integration through time-varying correlation structure, we proceed on to testing for causality of volatility components (testing for hypotheses *H4* and *H5*).

5.2.1 Contemporaneous Causality

One way to capture the spillover is to jointly model volatility component for all three swap markets on a contemporaneous sense. However, to avoid the dimensionality problem with the multivariate FS-GARCH, we consider the variance causality in structural Vector Auto-Regression (SVAR) framework. Such structural equation system reflects the sequential occurrence of market closing, which is crucial in investigating the characteristics of daily responses among international financial markets [see also, Tsutsui and Hirayama (2004)]. Tsutsui and Hirayama (2004) argue that this approach describes the natural time sequence, trading hour differentials, informational structure and the notion that an event can be affected by past events. It is worth noting that although our specification allows SVAR estimation, the following system of equations can be estimated in seemingly unrelated regression (SUR) framework.[21]

$$\tau_t^{JAP} = \delta_0 + \delta_1 stdinno\_\tau_{t-1}^{JAP} + \delta_2 stdinno\_\tau_{t-1}^{US} + \delta_3 stdinno\_\tau_{t-1}^{UK} + \epsilon_{1,t} \quad (7)$$

$$\tau_t^{UK} = \delta_4 + \delta_5 stdinno\_\tau_{t-1}^{UK} + \delta_6 stdinno\_\tau_t^{JAP} + \delta_7 stdinno\_\tau_{t-1}^{US} + \epsilon_{2,t} \quad (8)$$

$$\tau_t^{US} = \delta_8 + \delta_9 stdinno\_\tau_{t-1}^{US} + \delta_{10} stdinno\_\tau_t^{JAP} + \delta_{11} stdinno\_\tau_t^{UK} + \epsilon_{3,t} \quad (9)$$

where, τ_t^{JAP}, τ_t^{UK} and τ_t^{US} are the long-term volatility of Japan, UK and USA respectively for 5-year swaps. $stdinno\_$ is the standardized innovation (residuals standardized by their standard deviation, i.e.,

[21] Bollerslev (1990) notes that in such multivariate regression framework, the model is thought of as an extension of Seemingly Unrelated Regression (SUR). A multivariate GARCH in BEKK is also used for robustness check. The results can be obtained on request.

long-term volatility) for the respective country. To test for the long-term volatility spillovers in swap markets, for example, from US to Japan, we check whether the coefficient δ_2 in (7) is statistically significant or not. Adopting a similar approach as in long-term volatility spillovers, we examine the transmission of short-term volatilities as follows:

$$g_t^{JAP} = \vartheta_0 + \vartheta_1 stdinno\_g_{t-1}^{JAP} + \vartheta_2 stdinno\_g_{t-1}^{US} + \vartheta_3 stdinno\_g_{t-1}^{UK} + \nu_{1,t} \quad (10)$$

$$g_t^{UK} = \vartheta_4 + \vartheta_5 stdinno\_g_{t-1}^{UK} + \vartheta_6 stdinno\_g_t^{JAP} + \vartheta_7 stdinno\_g_{t-1}^{USA} + \nu_{2,t} \quad (11)$$

$$g_t^{US} = \vartheta_8 + \vartheta_9 stdinno\_g_{t-1}^{US} + \vartheta_{10} stdinno\_g_t^{JAP} + \vartheta_{11} stdinno\_g_t^{UK} + \nu_{3,t} \quad (12)$$

where, g_t^{JAP}, g_t^{UK} and g_t^{US} are the short-term volatility of Japan, the UK and the US respectively for 5-year swaps. $stdinno_$is the standardized innovation (residuals standardized by their standard deviation, i.e., short-term volatility) for the respective country. To test the short-term volatility spillover in swap markets, for example, from the US to Japan, we check whether the coefficient ϑ_2 in (10) is statistically significant or not.

5.2.2 Granger Causality

As a robustness check, we test whether the results from the contemporaneous causality are similar to those of Granger causality. To test for causality of long-term and short-term volatility components in Granger causal framework, we use the modified Wald (MWald) test of Toda and Yamamoto (1995).[22] The MWald test has three advantages. First, it can be used in possibly integrated and cointegrated system without pre-testing for cointegration. Second, computationally the MWald test is very simple [Rambaldi and Doran (1996)]. Third, the MWald test has comparable performance in size and power to that of error correction model (ECM) based LR tests if there are 50 or more observations [Zapata and Rambaldi (1997)].

Let d_{max} be the maximum order of integration in the system. The MWald test for linear restrictions on the parameters of a VAR(*k*) has an asymptotic χ^2 distribution when a VAR$(k + d_{max})$

[22] For comparison, we also conducted pair-wise Granger causality tests. The results are same and hence not reported.

is estimated. The appropriate lag length *k* for each country in VAR must be determined using some information criteria. In this study, we use Bayesian Information Criteria (BIC). If, for example, the lag length *k* is 2 and $d_{max} = 0$, we need to estimate a VAR(2), using the following system:

$$\begin{bmatrix} vc_t^{JAP} \\ vc_t^{UK} \\ vc_t^{US} \end{bmatrix} = \vec{a}_0 + a_1 \begin{bmatrix} vc_{t-1}^{JAP} \\ vc_{t-1}^{UK} \\ vc_{t-1}^{US} \end{bmatrix} + a_2 \begin{bmatrix} vc_{t-2}^{JAP} \\ vc_{t-2}^{UK} \\ vc_{t-2}^{US} \end{bmatrix} + \begin{bmatrix} \epsilon_{vc^{JAP}} \\ \epsilon_{vc^{UK}} \\ \epsilon_{vc^{US}} \end{bmatrix} \qquad (13)$$

where, vc_t^i is a measure of volatility component (long-term and short-term volatility), $\vec{a}_0$ is a vector of constant (intercept), a_1 and a_2 are 3×3 matrices of coefficients.[23] To test that the UK interest rate swap volatility (vc_t^{UK}) does not Granger-cause Japanese IRS volatility (vc_t^{JAP}) the null hypothesis becomes $H_0: a_{12}^{(1)} = a_{12}^{(2)} = 0$, where $a_{12}^{(m)}$ are the coefficients of vc_{t-n}^{UK} for, $n = 1, 2$ in the first equation of the system and we test that vc_{t-1}^{UK} and vc_{t-2}^{UK} do not appear in the vc_t^{JAP} equation. To test the null hypothesis for the reverse causality i.e., the hypothesis that Japanese IRS volatility (vc_t^{JAP}) does not Granger-cause the IRS volatility of UK (vc_t^{UK}) the null hypothesis becomes $H_0: a_{21}^{(1)} = a_{21}^{(2)} = 0$, where $a_{21}^{(m)}$ are the coefficients of vc_{t-n}^{JAP} for, *n* = 1,2 in the second equation of the system and we test that vc_{t-1}^{JAP} and vc_{t-2}^{JAP} do not appear in the vc_t^{UK} equation. The null hypotheses for other combinations of countries, i.e., Japan-US and UK-US, can be constructed similarly.

The joint hypotheses can be easily tested within the *F*-test or *Chi-square* test framework [see Brooks (2008) for details]. That is, instead of investigating the significance of individual coefficient, we test whether the joint tests on all of the lags of a particular variable in equation (13) is significant or not.

6. RESULTS AND DISCUSSION

6.1 Preliminary Analysis

This sub-section presents the first set of empirical results. For comparison of the volatility patterns, we start our analysis by looking at the decomposed volatilities obtained from FS-GARCH

[23] One may suggest taking the standardized innovations of volatility components to check the robustness of the results. In the empirical analysis, we used this alternative measure to examine the Granger causal link of volatility components. However, both analyses provided similar conclusions.

model of Rangel and Engle (2012). The estimation results for the three markets are reported in Table 2. For each country, we use its daily swap rate and spread changes data for 5-year swap. In Table 2, α and β indicate the ARCH and GARCH effects, while *c* indicates the asymmetric effect in the short-term component. For all swap markets, the coefficients of the GARCH components (α and β) are statistically significant and standard ($\alpha + \beta < 1$) in terms of magnitude. Coefficient *c* is statistically significant for all markets indicating the evidence of asymmetric effect in the short-term component.[24] As regard to the knot point, *k*, which indicates the cyclical effects in the series, we tried up to 20 knot points to determine the optimal knots for the FS-GARCH. The parameters ω_j(1 to *k*) indicate the statistical significance of those knot points. The analysis shows that Japan and the UK swap markets are more affected by cyclical effects than the US. Japan has a minimum BIC at 11-knot points for both rates and spreads, while the UK has minimum BIC at 12-knot points for rates and 10-knots for spreads. Not all the knot points in the case of Japan and the UK are significant. Further discussion on the association between Japan and the UK in terms of knot-points will be presented. The US has the minimum BIC at 5-knot points for rates and 8-knots for spreads. It is clear that the US swap market is characterized to have less affected by cyclical fluctuations. The variation in the number of knots can be attributed to the market volatility pattern of the respective swap market as well as to their responses to business cycle fluctuations during the sample period.

<<<< Table 2 around here >>>>

Figures 4.1~4.6 provide a visual inspection of two volatility components: daily short-term and long-term volatilities respectively of the 5-year swap spreads for the three markets. The short-term component (dotted line) is associated with the temporary fluctuations and market skewness risk and, the long-term component (solid line) is associated with the slow-moving trend that characterises the unconditional volatility and business cycle risk. It is evident that, in contrast to the US markets, the Japanese and the UK swap markets were very volatile during the early stages of swap market development. It is also found that volatility increases during the middle and last parts of the sample

[24] That is, bad news induces short-term volatility more than the good news.

periods of this study. Similar findings are also reported by Gupta and Subrahmanyam (2000), who find that the swap market was volatile during 1991-93. It is also found that volatility increases during the middle and last parts of our sample periods.

<<<< Figures 4.1~4.6 around here >>>>

Now we move on to examine the sample correlation between the short-term and long-term volatility components. Tables 3 and 4 show the correlation matrices of volatility components for swap rates and spreads, respectively. In Tables 3 and 4, for both volatility components, the correlation between Japan and the UK are very high. These results are consistent with the (business) cyclical effects (knot-points) as observed in Table 4. For both volatility components, the correlations between the US and Japan are very low indicating less integration between these markets. The correlations between the UK and the US are high only for the swap spreads in Table 4.

<<<< Tables 3 and 4 around here >>>>

6.2 Final Results and Discussion

This sub-section presents empirical results relating to our objective, which is to examine the swap market links of three major markets. The results are discussed separately for swap rates and swap spreads. The results include the following: (i) the DCC time-varying correlations characterizing the strength of the integration, (ii) the contagion effect on the time-changing correlations, (iii) contemporaneous volatility spillovers, and (iv) Granger causal links of volatility components under modified WALD test procedure.

6.2.1 Correlations and Contagion

First we measure the strength of integration using dynamic correlations of long-term and short-term volatility components across the three countries. This is done separately for the (i) swap rate and (ii) swap spread. Then, the results on the contagion hypothesis are reported.

6.2.1.1 Swap Rate

Statistical significance of the DCC correlation parameters for swap rates is reported in Table 5. Both the parameters θ_1 and θ_2 in Table 5 (panel A) for long-term correlations are statistically insignificant for the following country pairs: Japan–UK and Japan–US. This implies that the strength of integration of long-term volatility or business cycle risk is weak among those country pairs. Figures 5.1 and 5.3 provide the same conclusion. These results indicate that the coefficients of daily time-varying long-term correlations of Japan–UK (Figure 5.1) and Japan–US (Figure 5.3) are below 0.15 and are stable over time. Since the time-varying long-term correlations of Japan–UK and Japan–US are not statistically significant, we reject the first hypothesis (H1). However, for the correlation of UK–US both the long-term correlation parameters θ_1 and θ_2 in Table 5 (panel A) are statistically significant. The coefficient of correlation is also high, daily 0.5 on average (see Figure 5.5). This implies that a high level of integration between these two swap markets exists in terms of long-term volatility or business cycle risk. Hence, the first hypothesis (H1) could not be rejected for the long-term correlations between the UK and the US.

<<<< Table 5 around here >>>>

<<<< Figures 5.1~5.6 around here >>>>

The time-varying short-term volatility correlations between all country pairwise (see Figures 6.1, 6.3 and 6.5) are very high and their corresponding DCC parameters are also statistically significant (see panel B of Table 5). Figures 6.1, 6.3 and 6.5 reveal that the time-varying short-term correlations in swap rates are highly volatile and unstable ranging from highly positive to highly negative over the entire period. Hence, the second hypothesis (H2) could not be rejected implying that the time-varying short-term correlations are significant across the countries.

<<<< Figures 6.1~6.6 around here >>>>

Little evidence is found for contagion effect in swap rates (hypothesis H3) with the exception of the global financial crisis period. During this period, some spikes are observed in the long-term correlations of Japan-UK (Figure 5.1) and Japan-US (Figure 5.3). It is evident that the crises that are mentioned in Table 1 have had little impact on the dynamic correlations of the swap rates for the following pairwise: Japan–UK and Japan–US. Because of these findings, we do not examine the influence of crisis dummies on their correlations. The UK–US long-term and short-term correlations experienced the spikes throughout the whole sample period.

6.2.1.2 Swap Spread

As shown in Table 5, the estimated coefficient value of swap spread is similar to that of swap rates in regard to dynamic correlations (hypotheses H1 and H2) but different to that of swap rates in terms of contagion effect (hypothesis H3). None of the DCC parameters is significant for Japan–UK and Japan–US correlations implying that the degree of integration is weak. The correlation coefficient is below ± 0.05 for both long-term (see Figures 5.2 and 5.4) and short-term components (see Figures 6.2 and 6.4). Using the aggregate volatility model, namely E-GARCH, Eom et al. (2002) also detect low-correlation between the yen and dollar swap spreads. However, they do not examine the dynamic correlations. In regard to hypothesis H3, clear spikes are noticed at times of relevant economic and financial crises, mentioned in Table 3. These findings motivate us to look at the contagion effect, if any, on the time-varying correlations between Japan-UK and Japan-US. Related to this, panel A in Table 6 suggests that Japan's short-term and long-term correlations with the UK and the US are affected by most crisis dummies with the exception of the following dummies: (i) Asian financial crisis (AFC) (ii) mortgage prepayment hedging activity in the US in July 2003 and (iii) the GFC. Japan's sovereign credit rating downgrade in September 2000 is found to have no influence on the correlation between Japan and the UK. However, Japan's sovereign credit rating downgrade in November 2001 is found to have an effect on the correlation between Japan with the UK and the US. We also estimated regressions in different combinations by constructing a sample of country specific, region-specific and global shocks. The results are shown in panel B of Table 6. Regional and global shocks (e.g., AFC, Russian Govt. bond default, LTCM and GFC) are categorised as common shocks, while LTCB, NCB and Japan's credit rating downgrade, US liquidity crisis, US Treasury announcement of debt-buyback and mortgage prepayment hedging activity in 2003 are categorised as country specific shocks. However, the results remain unchanged after the classification. These findings reveal that of the common shocks, Russian Government bond default and LTCM crises caused more panics (contagion effect) in swaps than the regional shock (AFC) and the recent global financial crisis (GFC). One of the reasons, as discussed in the next section, is the absence of interdependencies in terms of policy reforms during the crisis (i.e., dominance of domestic policy). As always, regardless of the type (short- or long-term), the correlations between the UK and the US are very high and their corresponding DCC parameters are statistically significant (see panels A and B in Table 5). Although the visual inspection does not clearly reflect the contagion effect, the regression analysis shows that their correlation structure is affected by most of the crisis dummies indicating that regional crises are important only for the countries involved (see Table 6).

<<<< Table 6 around here >>>>

The short-term and long-term correlations between the UK and the US are high on average thereby offering less hedging and diversification benefits between these two swap markets.

6.2.1.3 Weak Integration and Its Implications

The weak integrations between Japan and the UK and, between Japan and the US indicate that swap markets are informationally inefficient and/or there are influences of market reforms and domestic policy [Forbes and Rigobon (2002); Bekaert et al. (2005)].[25] Bekaert et al. (2005) argue that if the markets are truly integrated for most of the sample period, the correlations should increase during the crisis period as they seek integrated policies. However, the rapid drop in correlation during the GFC (global financial crisis) is an indication of the dominance of independent policies. There are several explanations for weak integration between swap markets. King and Wadhwani (1990) argue that the less integration between two markets could be due to country specific shocks such as policy mistakes, a failure of market mechanism and idiosyncratic changes. Another explanation for the weak integration could be the market segmentation as postulated by Bekaert and Harvey (1995). Others argue that (swap) market integration can be incomplete because of limited benefits under the

[25] With the zero interest rate policy, Japanese economy, particularly, her interest rates were less responsive to shocks in other markets. This feature also contributed to the weak integration of Japanese swap markets with other economies like the UK and the US.

integration [Epaulard and Pommeret (2005)] or of issues pertinent to the relevant financial markets to deepen the integration [Kim et al. (2006)].

The low correlation (or weak integration) between long-term components across the countires has important implications for the international fund managers/investors. For example, the international investors can go long in yen interest rate swap (i.e. pay fixed rate) and go short in US dollar interest rate swap. This strategy allows the investors to construct a spread position between Treasury bonds in the two countries: Japan and the US. This is to take advantage of the differential between the low long-term yields of Japanese Government bonds and the high long-term yields of U.S. bonds and also the low correlation between the yen and US swap rates [Eom et al (2002)].

As such, this low correlation of long term volatility between Japan-US could eventually cause the yen swap rate to rise due to an increase in demand for fixed rate yen swaps. Early studies [for example, Eom et al. (2002)] did not investigate whether (time-varying) low correlations have any influence on the yen swap rate. In our GMM regression analysis (in Table 7), the results show that the time-varying correlation between yen and the dollar swap rates has a significant influence on the rise of yen swap rate, although the correlation between yen and the sterling swap rate is found to be insignificant even after including an exogenous correlation (correlation between the dollar and the sterling swap rate). It seems that being the largest economy the US's correlations with other swap markets have the most significant influence on the yen swap market.[26]

<<<< Table 7 around here >>>>

6.2.2 Contemporaneous Spillovers of Volatility Components

To trace the source of volatility transmission, this sub-section reports the results relating to contemporaneous spillovers of volatility components. This will help us in testing hypotheses H4 and H5. Moreover, as commonly known, as the correlations do not necessarily signify causation, it is important to study the direction of volatility spillover. Tables 8 and 9 report an analysis of

[26] This paper provides only preliminary results. Future research may include other control variables to see why the correlation between Japan and the UK is not significant.

contemporaneous volatility transmissions of volatility components (hypotheses H4 and H5*)*. In these tables, column 2 provides the results relating to H4 (long-term volatility spillovers are bi-directional across the countries) and column 3 provides the results relating to H5 (short-term volatility spillovers are bi-directional across the countries). In columns 2 and 3, all the coefficients in equations (7) to (9) are significant suggesting that volatility does spill over between the markets reciprocally. That is, in a contemporaneous sense, the volatility transmission from one to other markets exists in a reciprocal manner. This indicates that the markets are fundamentally linked even though the degree of linkage (dynamic correlation) is found to be weak for long-term component (except between the UK and the US, for which the degree of linkage is strong). Thus, hypotheses H4 and H5 (bi-directional long-term and short-term volatility spillovers) cannot be rejected. With regard to contemporaneous transmission, most of the prior studies either find significant uni-directional spillover running from the US to other countries or no reciprocal spillovers at all. For instance, Eom et al. (2002) and In (2007) find that dollar swap spreads Granger-cause the yen swap spreads but not vice versa, and In (2007) finds no reciprocal spillovers between Japanese and the UK swap markets. Only Lekkos and Milas (2001) find the influences operating in both directions between the UK and the US. The absence of evidence on a reciprocal spillover could be attributed to the use of aggregate volatility in this study.

<<<< Tables 8 and 9 around here >>>>

6.2.3 Granger Causality of Volatility Components

This sub-section reports the results of the lead-lag relationship of volatility components. In one way, this allows one to check the robustness of the results from the contemporaneous causality using Granger causality tests. In another way, this allows one to distinguish transmission of information flow between the contemporaneous sense and Granger causality sense. To determine the lag order, k, for equation (13), a series of regressions are run with the lag order starting from one and ending at 20. According to Schwarz Bayesian Information Criterion (SBIC), swap rates required one lag for long-term volatility and two lags for short-term volatility, while swap spreads required one lag for both volatility components.

Table 10 indicates the results for the swap rates, while Table 11 indicates the results for the swap spreads, both under Granger causal link perspectives. In Table 10, a bi-directional causality of long-term component is found to exist between all country pairings. Causality of short-term component is found only between Japan and the UK. The US short-term volatility Granger causes the UK's short-term volatility but not Japan's short-term volatility. However, neither Japan nor the UK Granger causes the US's short-term volatility. These are the main distinctions with the contemporaneous spillovers. The standard causality (pair-wise causality) tests also provide the similar results in terms of the causal links and hence not reported.

In Table 11, a bi-directional causality is found to exist only between Japan and the UK and uni-directional causality is found to run from the US to Japan and the UK. Neither Japan nor the UK Granger causes the US. The standard causality (pair-wise causality) tests also provide the similar results in terms of the lead-lag relationship.

<<<< Tables 10 and 11 around here >>>>

7. CONCLUSION

To examine the market links and volatility transmission across three major international swap markets (Japan, UK and USA), this study develops and tests five hypotheses. First hypothesis tests for the correlation of the business cycle risk (proxied by long-term volatility) and second hypothesis tests for the correlation of the skewness risk (proxied by short-term volatility) across three major swap markets. The observation is that business cycle risk is mostly country specific as the time-varying long-term correlations across the swap markets are non-dynamic. This also indicates weak time-varying integration. Although swap market integration is weak, the low level of dynamic correlation does not worsen the benefits of hedging. Second hypothesis shows that the skewness risk can vary across markets but still they may converge. Third hypothesis tests for the contagion effect, which is found to be more evident on the swap spread than on the swap rate. Fourth and fifth hypotheses examine the direction of volatility spillovers of long-term and short-term components, respectively.

To test for the above hypotheses, unlike the previous literature, the study uses step by step procedure of measuring the international swap market linkages. This study makes a number of contributions. First we decompose the aggregate volatility shocks into two components to provide an economic explanation of the volatility components. For example, these components are linked to business cycle risk and skewness risk in the swap markets. Second, these components are utilized to separately study the strength (correlations) and direction (causality) of the volatility transmission across the three major international swap markets. The empirical approach adopted in this study is, therefore, more parsimonious than the existing literature on volatility transmission because one can understand easily which component(s) is (are) dominant in the transmission process as well as specify the potential driving forces of this transmission.

Finally, unlike most prior literature, this study provides implications for market participants (borrowers and investors/speculators) in hedging and diversifying the interest rate risk. Using the long-term correlations, the hedgers can establish the limits of geographical diversification of lending/investment activities and allocate the swap's business cycle risk exposure to different markets. The correlation structure indicates that Japanese swap market can be a good hedge for other markets or quanto swap as Japanese swap rate and spread (long-term component) are less correlated with those of either the UK or the US. Moreover, we found that low level of correlation increased the demand for Japanese swap. This could have contributed to the carry-trade, which is not focused in this study. Future research may try to link the insignificant correlations to the carry-trade and examine the profit from arbitrage based on quanto swap.

APPENDIX A: SELECTED STUDIES ON VOLATILITY SPILLOVERS AND LINKAGES IN SWAP MARKETS

This appendix provides a summary of the selected studies on volatility spillovers and swap market linkages. Of the literature noted in this table, Lekkos and Milas (2001) and Lekkos and Milas (2004) examine the linkages using the first moments, while other studies examine the linkages using both first and second moments.

Authors	Sample	Methods Used	Findings
Lekkos and Milas (2001)	Weekly UK and US swap spread data (3-, 7- and 10-year maturities) from May 1991 to February 1999.	Vector autoregression (VAR) and impulse response functions based on VAR	One way spillover from the US to the UK across various maturities. No reciprocal spillover is detected.
Eom et al. (2002)	Daily and weekly Japanese and US swap spread data (2-, 3-, 5-, 7- and 10-year maturities) from January 30, 1990 to December 29, 2000.	GJR-GARCH, Granger causality	One way spillover from the US to Japan across various maturities. No reciprocal spillover is detected.
In, Brown and Fang (2003a)	Daily Japanese, UK and US swap spread data (3-, 5- and 10-year maturities) from January 8, 1996 to June 29, 2001.	Vector autoregression (VAR) and impulse response functions based on VAR	Bi-directional spillover exists between the US and UK market but neither of these markets has spillover effect on Japanese market and no spillover from the Japanese market to the UK or the US.
Lekkos and Milas (2004)	Weekly UK and US swap spreads data (3-, 7- and 10-year maturities) from June 1991 to June 2001.	Multivariate smooth transition Autoregression (STVAR)	Bi-directional spillover exists between the US and UK. However, spillover is stronger from the US to the UK in different regimes but not vice versa.
In (2007)	Daily Japanese, UK and US data from January 8, 1996 to June 29, 2001.	VAR E-GARCH	One way spillover from the US swap market to Japanese and UK swap markets. Reciprocal spillover exists only between Japanese and the UK swap markets.

APPENDIX B: SELECTED STUDIES ON DECOMPOSITION OF VOLATILITY IN FINANCIAL MARKETS

This appendix shows how the volatility is decomposed in existing literature. S=short-term; *l*=long-term; *as*= asymmetric short-run; *al*=asymmetric long-run; *hf* = high-frequency volatility; *lf* = low-frequency volatility; *ahf* = asymmetric high-frequency volatility; and ε_t follows an *iid* sequence with mean zero and variance one.

Authors	Decomposition of h_t	Type of study
Engle and Lee (1999); Christoffersen Jacobs, Ornthanalai, and Wang (2008)	Additive decomposition $h_t = s + l + \varepsilon_t$	Stock returns, options pricing
Adrian and Rosenberg (2008)	Additive decomposition $h_t = as + al + \varepsilon_t$	Asset pricing and portfolio returns
Becker and Clements (2007) Engle and Rangel (2008), Engle, Ghysles and Sohn (2008), Azad et al. (2011)	Multiplicative decomposition $h_t = (hf).(lf).\varepsilon_t$	Time series and cross sectional stock and bond markets returns and volatility, swap market volatility in relation to macroeconomic-risk
Nowak, Andritzky, Jobst, and Tamirisa, (2009).	Multiplicative decomposition $h_t = (determinstic).(stochastic).\varepsilon_t$	Event study
Rangel and Engle (2012)	Multiplicative decomposition $h_t = (ahf).(lf).\varepsilon_t$	Correlations in stock markets

APPENDIX C: FS-GARCH FOR ESTIMATING VOLATILITY COMPONENTS

The FS-GARCH methodology of Rangel and Engle (2012) is explained below:

$$\Delta r_{i,t} = \sqrt{h_{i,t}}\varepsilon_{i,t} = \sqrt{g_{i,t}\,.\,\tau_{i,t}}\varepsilon_{i,t}; \quad \varepsilon_{i,t}\,\big|\,\Phi_{t-1} \sim N\,(0,1) \qquad \text{(C.1)}$$

$$g_{i,t} = \left(1 - \alpha_i - \beta_i - \frac{c_i}{2}\right) + \alpha_i\left(\frac{\varepsilon_{i,t-1}^2}{\tau_{i,t-1}}\right) + c_i\left(\frac{\varepsilon_{i,t-1}^2}{\tau_{i,t-1}}\right) I_{r_{i,t-1}} < 0 + \beta_i g_{i,t-1} \qquad \text{(C.2)}$$

$$\tau_{i,t} = \gamma_{o,i} exp\left(\gamma_{1,i} t + \sum_{j=1}^{k} \omega_{j,i}\,((t - t_{j-1})_+)^2\right) \qquad \text{(C.3)}$$

where, $\Delta r_{i,t}(= r_{i,t} - r_{i,t-1})$ measures the changes in the swap rates $(\Delta SR_{i,t} = SR_{i,t} - SR_{i,t-1})$ and swap spread ($\Delta SS_{i,t} = SS_{i,t} - SS_{i,t-1}$) for countries $i = 1,2,3$ (i.e., Japan, UK and USA) on day *t*. The aggregate volatility risk $h_{i,t}$ is decomposed into two components: (i) $g_{i,t}$ and (ii) $\tau_{i,t}$, where $g_{i,t}$ and $\tau_{i,t}$ characterize the short-term volatility and long-term volatility components, respectively, on day *t* for country *i*. Short-term volatility is a temporary phenomenon and is quickly mean-reverting, while low-frequency volatility is slowly mean-reverting. Despite its persistency, $g_{i,t}$ does not have long-term impact on $h_{i,t}$ but it is the $\tau_{i,t}$ to have persistent impact on $h_{i,t}$. Φ_{t-1} denotes an extended information set including the history of swap rates/spread changes up to day $t-1$. Given the estimates for $\gamma = (\gamma_o\;\gamma_1)'$ and $\omega_j, (j = 1 \text{ to } k)$ a sequence of $\{t_j\}_{j=1}^{k}$ (where $t_1 > 1$ and $t_k \leq T$, denotes a division of the time horizon *T* in *k* equally spaced intervals) can be estimated. The spline fits a smooth curve to a sequence of points $\left\{\tau_{t_j}\right\}_{j=1}^{k}$. These points/values for the low-frequency/long-term volatility at times $\{t_j\}_{j=1}^{k}$ are unobserved and based on the spline parameters. In choosing "optimal" number of knots *k*, similar to Engle and Rangel (2008), we use BIC (Bayesian Information Criteria). *k* governs the cyclical pattern in $\tau_{i,t}$. Large values of *k* imply more frequent cycles. The coefficient, $\{\omega_j\}$, measures the "sharpness" (i.e., the duration and strength) of each cycle. Equation (C.2) allows short-term volatility to accommodate the asymmetric/leverage effects where bad news (negative shocks) raises the future short-term volatility *more than* good news (positive shocks). The term $I_{r_{i,t-1}} < 0$ in equation (C.2) is an indicator function of negative shocks. Engle and Lee (1999) argue that this asymmetric effect is mainly a temporary behaviour. Therefore, short-term/short-term component may capture the asymmetric effect. The usual log likelihood function is used [see also Rangel and Engle (2012) for the log likelihood function].

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Figure 1: Growth of Interest Rate Swaps

This figure shows the growth of IRS in 'notional principal', which is used as a reference to determining the net interest payments in a swap contract. The figure is based on semi-annual data collected from Bank for International Settlement (BIS 2011). The left axis indicates the amount of notional principal in trillion US dollars.

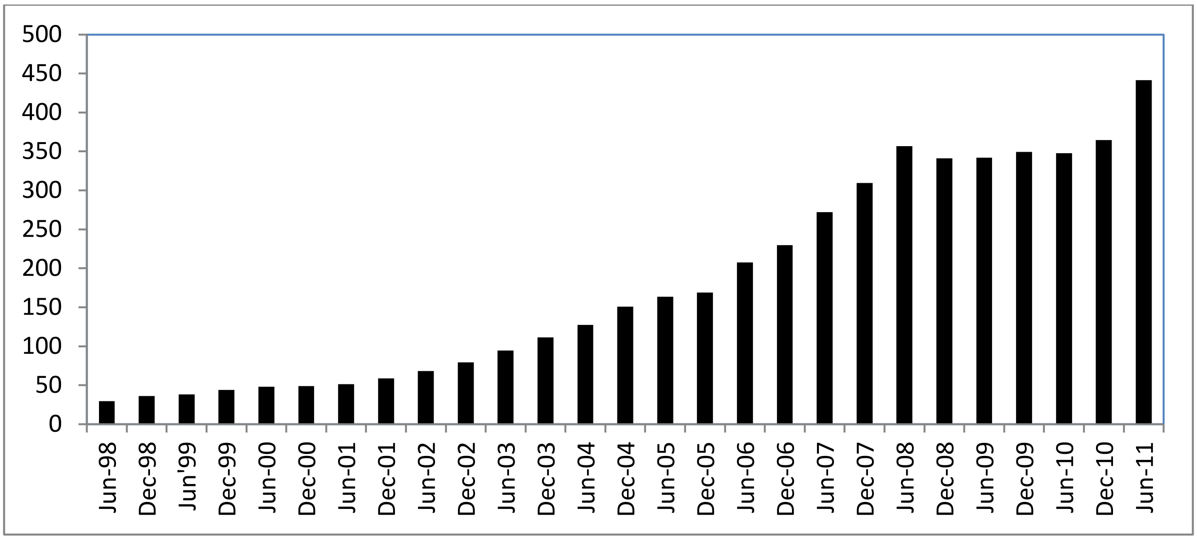


Figure 2: Share of Interest Rate Swap Market in Relation to Other OTC Products

This figure shows the percentage share of the IRS markets in comparison to over-the-counter (OTC) interest rate derivatives and OTC derivatives. The solid line indicates the share of IRS in relation to the OTC interest rate derivatives, while the dotted line indicates the share of IRS in relation to OTC derivatives. The graph is based on semi-annual data collected from Bank for International Settlement (BIS 2010), BIS Quarterly Review: December 2010. The vertical axis indicates the percentage of IRS compared to other OTC interest rate derivatives.

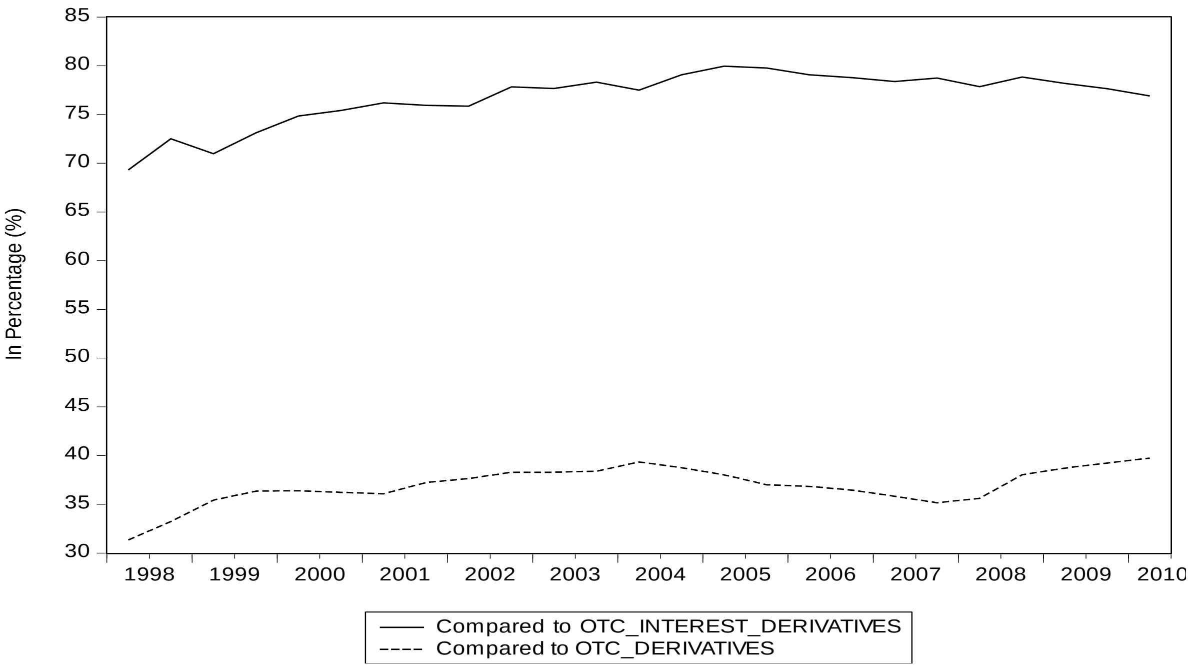
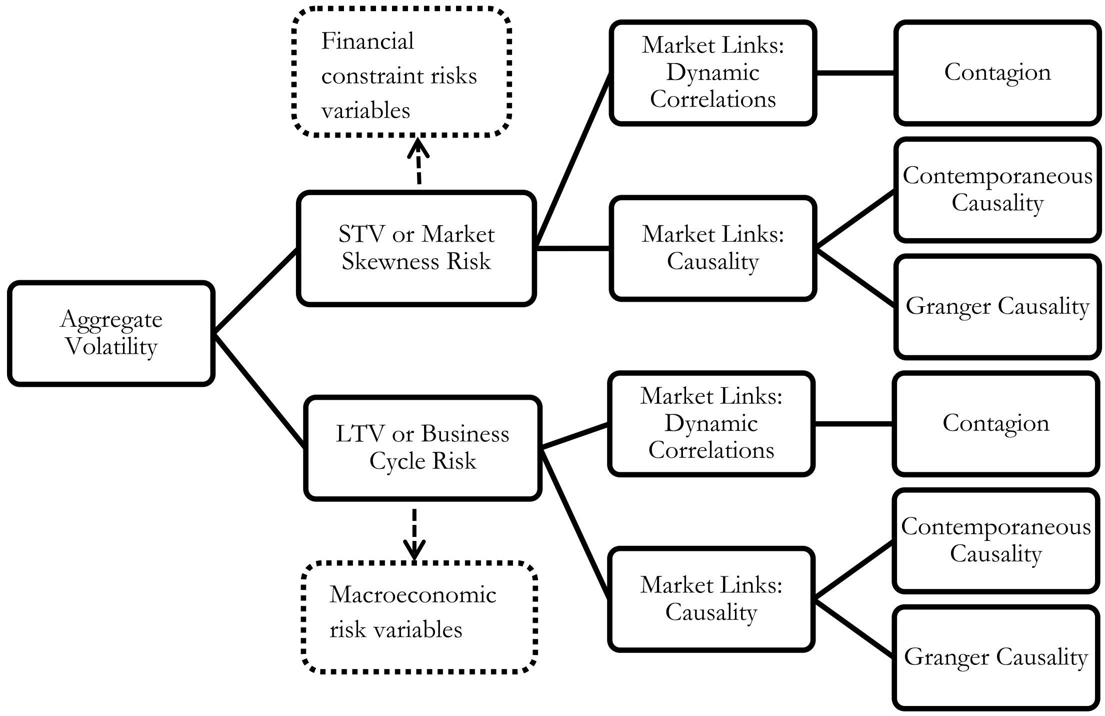


Figure 3: Process of Measuring Market Links in Two-Component Volatility Model

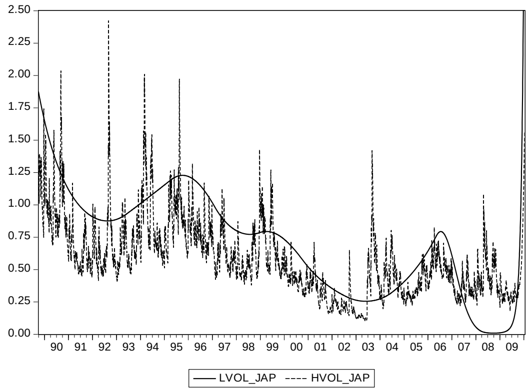
This figure indicates the step-by-step procedures adopted in this study to measure the swap market links via volatility spillovers, correlation dynamics and contagion effect on the dynamic correlations. As can be seen from the diagram, in contrast to existing analysis of volatility spillovers, this study neither goes directly to the analysis of market linkages nor stops the analysis at the high and low-frequency volatility estimation. STV stands for short-term volatility, while LTV stands for long-term volatility.



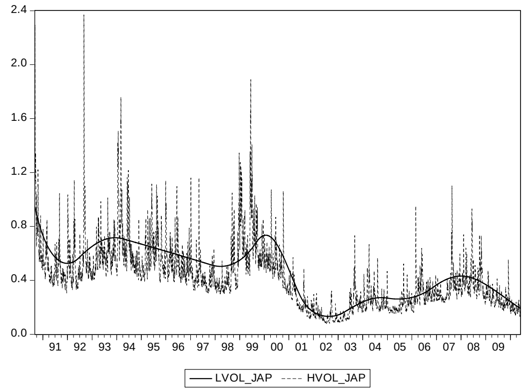
Figures 4.1~4.6: Time-Varying Daily Short- and Long-term Volatilities

The following set of figures show the estimated daily short- and long-term volatility components of swap rates and spreads for the period from September 1989 to January 2010 for 5-year swaps. The short-term component is estimated using equation (C.2) and the long-term component is estimated using equation (C.3). LVOL stands for long-term volatility, while HVOL stands for high-frequency or short-term volatility.

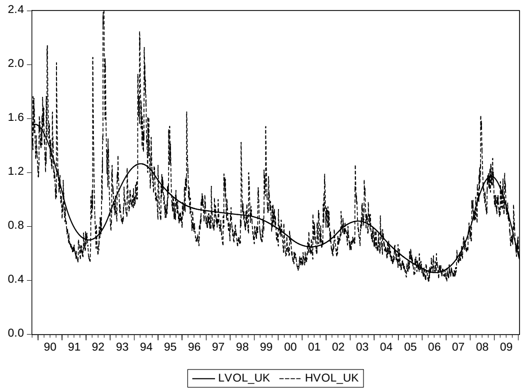
4.1 Volatility Components of Japan (Rates)



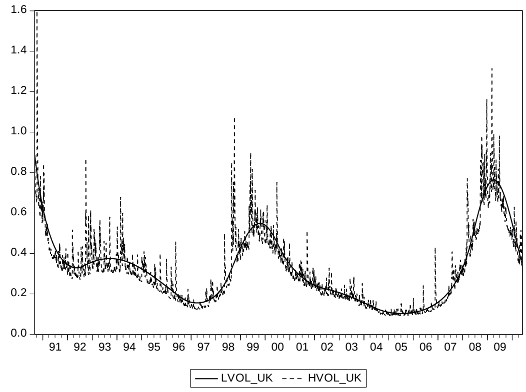
4.2 Volatility Components of Japan (Spread)



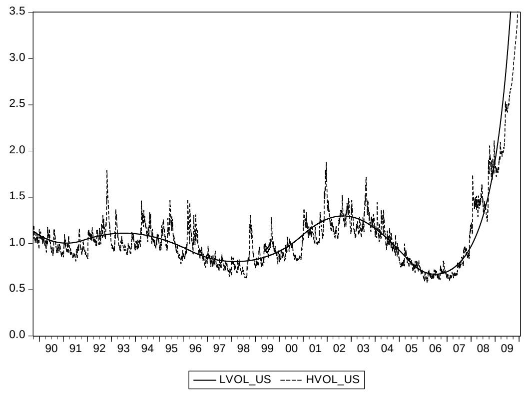
4.3 Volatility Components of UK (Rates)



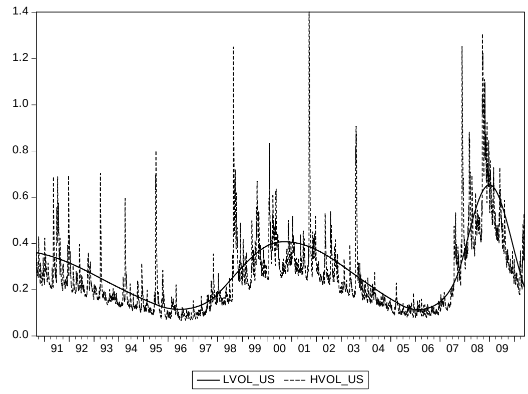
4.4 Volatility Components of UK (Spread)



4.5 Volatility Components of US (Rates)



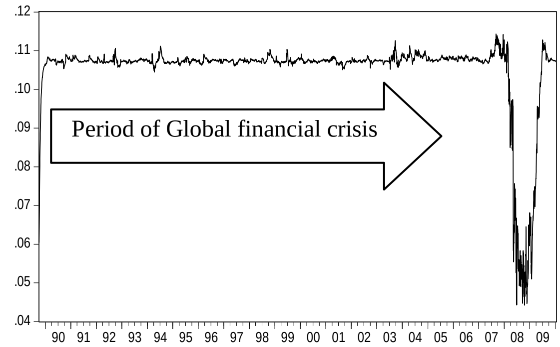
4.6 Volatility Components of US (Spread)



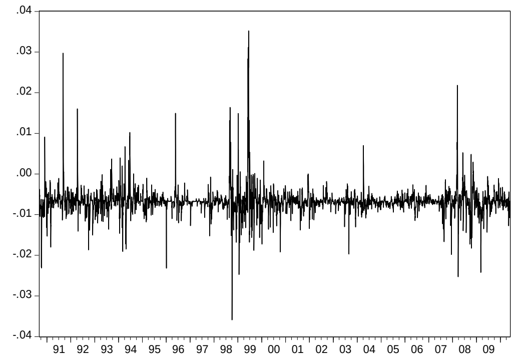
Figures 5.1~5.6: Time-Varying Long-term Correlations

The following set of figures show the time-varying daily low-frequency/long-term correlations for the swap rates and spreads. The dynamic correlations are estimated using equation (3).

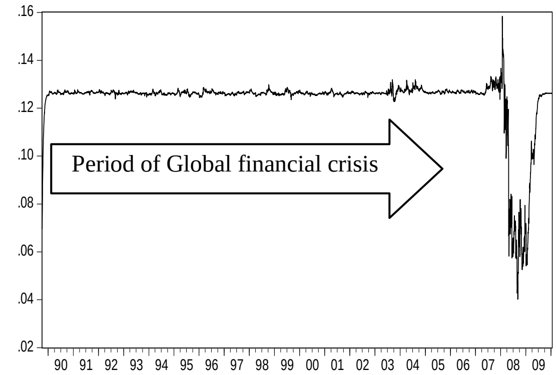
5.1 Japan and UK (Rates)



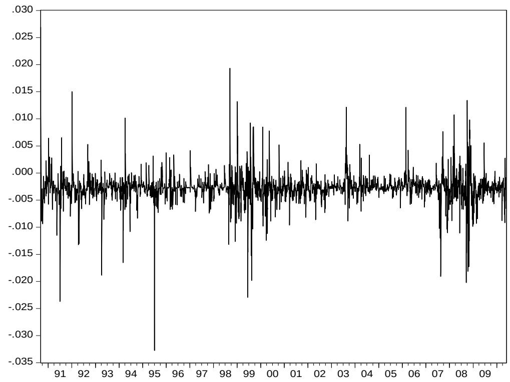
5.2 Japan and UK (Spread)



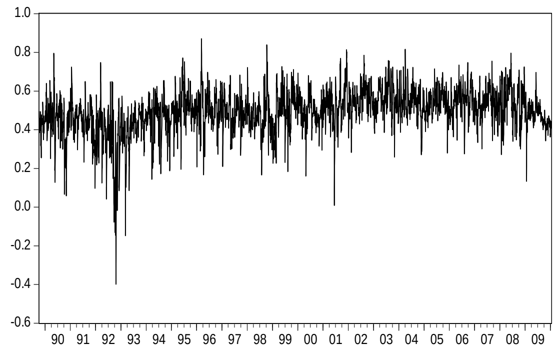
5.3 Japan and US (Rates)



5.4 Japan and US (Spread)



5.5 UK and US (Rates)



5.6 UK and US (Spread)

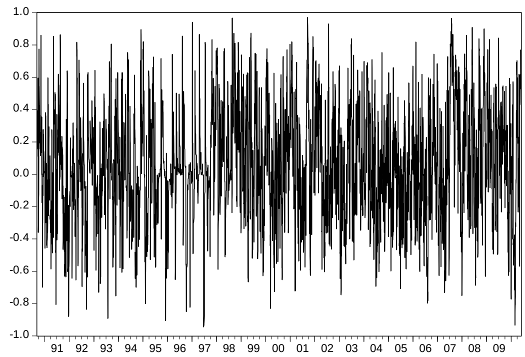
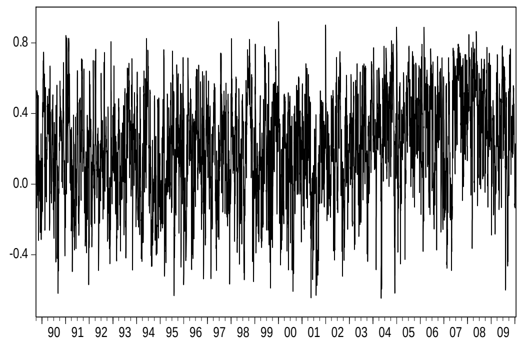


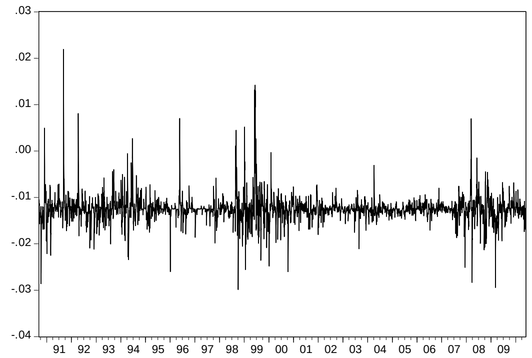
Figure 6.1~6.6: Time-Varying Short-term Correlations

The following set of figures indicates the time-varying daily short-term/high-frequency correlations for the swap rates and spreads. The dynamic correlations are estimated using equation (3).

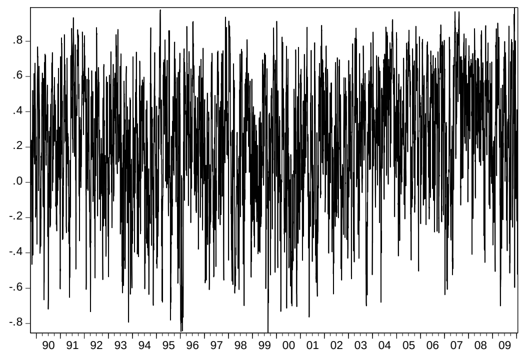
6.1 Japan and UK (Rates)



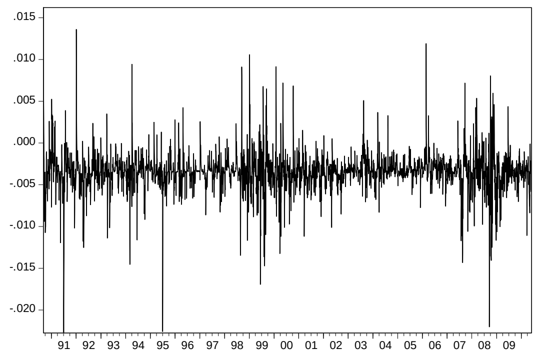
6.2 Japan and UK (Spread)



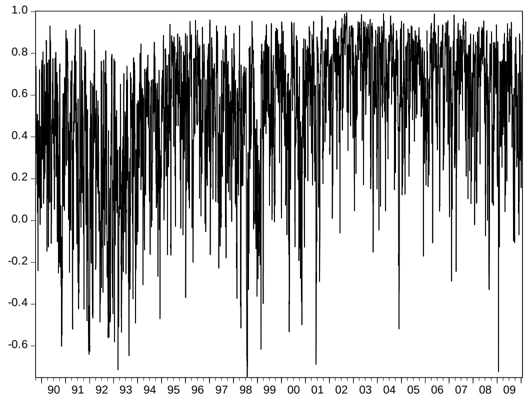
6.3 Japan and US (Rates)



6.4 Japan and US (Spread)



6.5 UK and US (Rates)



6.6 UK and US (Spread)

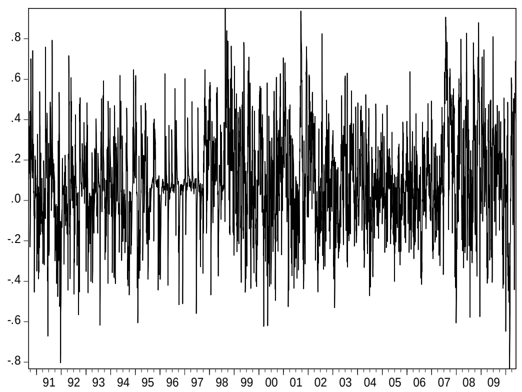


Table 1: Crisis Dummies

This table indicates the crisis dummies that affected the swap market. The last column indicates prior studies that mentioned the economic events related to swap markets. ‡ Many empirical studies provide evidence that, due to cross-border capital flows, Asian financial crisis (AFC) and Global financial crisis (GFC) caused contagion in markets. LTCB stands for Long-Term Credit Bank and NCB stands for Nippon Credit Bank. * indicates that liquidity shortage was due to Y2K (millennium date change).

Crisis Events (Dummies)	Periods	Source/Reference
Asian financial crisis (AFC)	July 1997 – July 98	‡
Russian Government bond default (RGBD)	August 1998	Apedjinou (2005)
Long-Term Capital Management (LTCM) crisis	September 1998	Apedjinou (2005)
Failure of Japan's LTCB and NCB	November 1998	Eom et al. (2002), Ito (2007)
Liquidity shortage* (Liq_Crisis)	November 1999	Sundaresan and Wang (2009)
US Treasury announcement of debt buybacks (US_DB)	January 2000	Apedjinou (2005), Cortes (2006)
Japan's sovereign credit rating downgrade (JP_Down_2000)	September 2000	Eom et al. (2002)
Japan's sovereign credit rating downgrade (JP_Down_2001)	November 2001	Eom et al. (2002)
Mortgage prepayment hedging by the US mortgage holders (Mortgage_Hedge)	July 2003	Cortes (2006)
Global financial crisis (GFC)	July 2007 – Jan 2010	‡, Ito (2010)

Table 2: Estimation Results of Factor-Spline-GARCH

This table shows the estimation results of Factor-Spline-GARCH based on a model with Gaussian innovations. The model specification is provided in Equations (C.1) through (C.3) in Appendix C. The results are based on the 5-year swap maturity and the sample covers the daily observations from September 1989 to June 2010. α and β are the ARCH and GARCH effects, respectively, in the Factor-Spline-GARCH model, while c indicates the asymmetric effect of volatility on the short-term component. $\omega_j (j = 1 \text{ to } k)$ are the coefficients that measure the duration and strength of business cycles. *, ** and *** indicate level of significance at 10%, 5% and 1% respectively. Standard errors of the estimated coefficients are in parentheses.

Parameters	Japan swap rate	Japan swap spread	UK swap rate	UK swap spread	USA swap rate	USA swap spread
α	**0.1364*** **	**0.1801*** **	**0.0649*** **	**0.1281*** **	**0.0411*** **	**0.1823*** **
	(0.00784)	(0.0149)	(0.0041)	(0.0113)	(0.0053)	(0.0086)
β	**0.8694*** **	**0.7199*** **	**0.9083*** **	**0.7821*** **	**0.9293*** **	**0.8198*** **
	(0.0062)	(0.0145)	(0.0057)	(0.0187)	(0.0078)	(0.0071)
c	**-0.0495*** **	0.0280	**-0.0238*** **	**-0.099*** **	**-0.0109** **	**-0.121*** **
	(0.0087)	(0.0210)	(0.0052)	(0.0118)	(0.0051)	(0.0082)
ω_1	0.0132	**0.0495*** **	**0.0346*** **	**0.0508*** **	**0.0092*** **	-0.0049
	(0.0144	(0.0003)	(0.0014)	(0.0041)	(0.0009)	(0.0035)
ω_2	0.0004	**-0.0656*** **	**-0.0785*** **	**-0.064*** **	**-0.0128*** **	0.0019
	(0.0226)	(0.0002)	(0.0015)	(0.0063)	(0.0015)	(0.0050)
ω_3	-0.0146	0.0154	**0.0926*** **	0.0006	**0.0093*** **	**0.0307*** **
	(0.0159)	(0.0006)	(0.0009)	(0.0042)	(0.0011)	(0.0031)
ω_4	-0.017	-0.0003	**-0.0789*** **	**0.0680*** **	**-0.0146*** **	**-0.045*** **
	(0.0156)	(0.0004)	(0.003)	(0.0050)	(0.0011)	(0.0031)
ω_5	**0.0344** **	**0.0222*** **	**0.03815*** **	**-0.114*** **	**0.0337*** **	**0.0097*** **
	(0.0160)	(0.0017)	(0.006)	(0.0058)	(0.0015)	(0.0028)
ω_6	**-0.0371** **	**-0.0929*** **	-0.0075	**0.0761*** **	—	0.0020
	(0.0166)	(0.0052)	(0.0074)	(0.0058)		(0.0029)
ω_7	**0.0258* **	**0.1540*** **	-0.0077	**-0.029*** **	—	**0.0552*** **
	(0.0154)	(0.0089)	(0.0081)	(0.0062)		(0.0040)
ω_8	**0.0243* **	**-0.1148*** **	**0.0257*** **	**0.0420*** **	—	**-0.133*** **
	(0.0138)	(0.0104)	(0.0086)	(0.0068)		(0.0067)
ω_9	**-0.0278* **	**0.0532*** **	**-0.0398*** **	-0.0052	—	—
	(0.0151)	(0.0096)	(0.0093)	(0.0066)		
ω_{10}	**-0.1842*** **	**-0.0451*** **	**0.0262** **	**-0.114*** **	—	—
	(0.0315)	(0.0121)	(0.0106)	(0.0084)		
ω_{11}	**0.7273*** **	0.0065	**0.0329** **	—	—	—
	(0.0833)	(0.0238)	(0.0128)			
ω_{12}	—	—	**-0.1167*** **	—	—	—
			(0.020)			

Table 3: Sample Correlation of Volatility Components (Swap Rates)

This table shows the correlation between short and long-term volatilities of the three major swap markets. The analysis covers the daily data from September 1989 through January 2010. LVOL stands for long-term volatility, while HVOL stands for high-frequency or short-term volatility.

	LVOL_JAP	LVOL_UK	LVOL_US	HVOL_JAP	HVOL_UK	HVOL_US
LVOL_JAP	1	0.4122	-0.0045	0.6964	0.3451	-0.0866
LVOL_UK	0.4122	1	0.0861	0.5302	0.7746	0.1474
LVOL_US	-0.0045	0.0861	1	-0.0776	0.0722	0.9411
HVOL_JAP	0.6964	0.5302	-0.0776	1	0.5681	-0.0608
HVOL_UK	0.3451	0.7746	0.0722	0.5681	1	0.1880
HVOL_US	-0.0866	0.1474	0.9411	-0.0608	0.1880	1

Table 4: Sample Correlation of Volatility Components (Swap Spreads)

This table shows the correlation between short and long-term volatilities of the three major swap markets. The analysis covers the daily data from September 1989 through January 2010. LVOL stands for long-term volatility, while HVOL stands for high-frequency or short-term volatility.

	LVOL_JAP	LVOL_UK	LVOL_US	HVOL_JAP	HVOL_UK	HVOL_US
LVOL_JAP	1	0.3715	-0.1075	0.7429	0.3331	-0.0796
LVOL_UK	0.3715	1	0.7870	0.3105	0.9289	0.5789
LVOL_US	-0.1075	0.7870	1	-0.0740	0.7477	0.7592
HVOL_JAP	0.7429	0.3105	-0.0740	1	0.3046	-0.0180
HVOL_UK	0.3331	0.9289	0.7477	0.3046	1	0.6387
HVOL_US	-0.0796	0.5789	0.7592	-0.0180	0.6387	1

Table 5: Time-varying DCC Parameters

This table shows the coefficient, standard error and the level of significance of the two DCC parameters, θ_1 and θ_2. See equations (1)-(4) and related discussion. θ_1 indicates the effects of previous standardized shocks and θ_2 indicates the correlation persistence. Panel A shows the long-term component, while Panel B shows the short-term component. Standard errors of the estimated coefficients are in parentheses. *** indicates that the time-varying correlation is significant at 1%. The analysis covers the daily data from September 1989 through January 2010.

Panel A: Long-term Component

Correlation Parameters	Swap Rates			Swap Spreads		
	JAP-UK	JAP-US	UK-US	JAP-UK	JAP-US	UK-US
θ_1	0.0305	0.0362	**0.2410*****	0.2304	0.2326	**0.2469*****
	(0.3269)	(0.2372)	(6.14E-06)	(134.3956)	(226.0454)	(0.00088)
θ_2	0.9371	0.9287	**0.7572*****	0.7167	0.7192	**0.7531*****
	(0.8373)	(0.5953)	(5.41E-06)	(186.4402)	(308.7348)	(0.00088)

Panel B: Short-term Component

Correlation Parameters	Swap Rates			Swap Spreads		
	JAP-UK	JAP-US	UK-US	JAP-UK	JAP-US	UK-US
θ_1	**0.2415*****	**0.2388*****	**0.2371*****	0.2267	0.2298	**0.2465*****
	(4.03E-06)	(0.01997)	(0.0154)	(140.0296)	(324.9965)	(2.16E-06)
θ_2	**0.7584*****	**0.7612*****	**0.7629*****	0.7146	0.7173	**0.7534*****
	(4.12E-06)	(0.01998)	(0.0154)	(202.8614)	(459.9212)	(2.15E-06)

Table 6: Influence of Crisis/Events on the Dynamic Correlation of Swap Spread

This table shows the influence of crisis dummies on the correlation structure of the swap spread across three markets. Results are based on the following regression model:

$$\rho_{x,y,t} = \sum_{j=1}^{n} k_j \, D\_crisis_j + \epsilon_t$$

where, the dependent variable $\rho_{x,y,t}$ is the pair-wise cross-market short-term/long-term correlation coefficient of market *x* and *y* on day *t*. D_crisis_j are the crisis dummies used as proxies for the relevant events that are said to affect the swap market. Standard errors of the estimated coefficients are in parentheses and are corrected for autocorrelation and heteroscedasticity by using the Newey-West method. Sample covers the daily data from November 21, 1995 to January 19, 2010. ** and *** indicate level of significance at 5% and 1%, respectively.

Panel A: All shocks

	Long-term Correlation			Short-term Correlation		
	JAP-UK	JAP-US	UK-US	JAP-UK	JAP-US	UK-US
AFC	-0.0002	2.79E-05	-0.0009	-0.0002	0.0001	0.0883**
	(0.0003)	(0.0003)	(0.0006)	(0.0002)	(0.0003)	(0.0453)
RGBD	**0.0025****	**-0.0019*****	**-0.0014*****	**0.0016****	**-0.0020*****	**0.2481*****
	(0.0010)	(0.0004)	(0.0004)	(0.0007)	(0.0004)	(0.0448)
LTCM	**0.0047*****	**0.0023*****	0.0001	**0.0033*****	**0.0013*****	**0.5014*****
	(0.0011)	(0.0005)	(0.0040)	(0.0008)	(0.0003)	(0.0246)
LTCB_NCB	**-0.0009*****	**-0.0006*****	**-0.0031*****	**-0.0009*****	**-0.0006*****	**0.3475*****
	(0.0002)	(0.0001)	(0.0005)	(0.0002)	(0.0001)	(0.0416)
Liq_Crisis	**-0.0009*****	**-0.0004*****	**-0.0014****	**-0.0008*****	**-0.0005*****	-0.1560
	(0.0003)	(0.0001)	(0.0007)	(0.0003)	(0.0001)	(0.1044)
US_DB	**-0.0021****	-0.0003	**-0.0018*****	**-0.0024****	-0.0003	**0.330*****
	(0.0009)	(0.0006)	(0.0004)	(0.0010)	(0.0007)	(0.0601)
JP_Down_2000	5.54E-06	**-0.0014*****	**0.0041*****	1.49E-05	**-0.0017*****	-0.0123
	(0.0003)	(0.0004)	(0.0007)	(0.0003)	(0.0004)	(0.1000)
JP_Down_2001	**-0.0004****	**-0.0016*****	**-0.0026*****	**-0.0004*****	**-0.0017*****	0.0173
	(0.0002)	(0.0002)	(0.0004)	(0.0001)	(0.0001)	(0.0418)
Mortgage_Hedge	-0.0002	-0.0003	-0.0003	-0.0001	-0.0002	0.0886
	(0.0003)	(0.0002)	(0.0004)	(0.0003)	(0.0002)	(0.0746)
GFC	-0.0001	-0.0003	-0.0015	-0.0001	-0.0003	**0.0971****
	(0.0004)	(0.0003)	(0.0010)	(0.0003)	(0.0003)	(0.0453)
Adjusted R^2	0.0165	0.0118	0.0071	0.0150	0.0138	0.0479
F-stat	6.9736***	5.2718***	3.5665***	6.4502***	6.0007***	18.9611***

Table 8 continued on the next page.

Panel B: Common and Country Specific Shocks

	JAP-UK	JAP-US	UK-US	JAP-UK	JAP-US	UK-US
Common Shocks						
AFC	-0.0002	0.0001	-0.0008	-0.0002	0.0001	0.0838
	(0.0003)	(0.0003)	(0.0006)	(0.0002)	(0.0003)	(0.0451)
RGBD	**0.0025****	**-0.0019*****	**-0.0013****	**0.0016****	**-0.0019*****	0.2435
	(0.0011)	(0.0004)	(0.0004)	(0.0008)	(0.0004)	(0.0455)
LTCM	**0.0047*****	**0.0023*****	0.0002	**0.0033*****	**0.0013*****	0.4968
	(0.0012)	(0.0006)	(0.0036)	(0.0008)	(0.0003)	(0.0250)
GFC	0.00002	-0.0002	-0.0015	0.00004	-0.0002	0.0926
	(0.0004)	(0.0003)	(0.0010)	(0.0003)	(0.0003)	(0.0452)
Adjusted R^2	0.0149	0.0088	0.0052	0.0108	0.0076	0.0339
F-stat	14.5249***	8.9456***	5.6793***	10.7663***	7.8549***	32.3085***
Shocks from Japan						
LTCB_NCB	**-0.0009*****	**-0.0005*****	**-0.0027*****	**-0.0009*****	**-0.0006*****	**0.3159*****
	(0.0002)	(0.0001)	(0.0006)	(0.0001)	(0.0001)	(0.0473)
JP_Down_1	0.00001	**-0.0014*****	**0.0045*****	0.00003	**-0.0016*****	-0.0439
	(0.0003)	(0.0003)	(0.0006)	(0.0003)	(0.0004)	(0.1113)
JP_Down_2	**-0.0004*****	**-0.0015*****	**-0.0022*****	**-0.0004*****	**-0.0017*****	-0.0143
	(0.0002)	(0.0002)	(0.0004)	(0.0001)	(0.0001)	(0.0636)
Adjusted R^2	0.0005	0.0032	0.0022	0.0008	0.0061	0.0052
F-stat	0.6447	4.7988***	3.6293**	0.9833	8.2879***	7.2433***
Shocks from US						
Liq_Crisis	**-0.0009****	**-0.0003*****	**-0.0010*****	**-0.0008*****	**-0.0004*****	**-0.1880***
	(0.0004)	(0.0001)	(0.0006)	(0.0003)	(0.0001)	(0.1140)
US_DB	**-0.0021****	-0.0003	-0.0014	**-0.0023****	-0.0002	**0.2979*****
	(0.0010)	(0.0005)	(0.0004)	(0.0010)	(0.0006)	(0.0599)
Mortgage_Hedge	-0.0002	-0.0002	0.0001	-0.0001	-0.0001	0.0565
	(0.0003)	(0.0002)	(0.0003)	(0.0003)	(0.0002)	(0.0792)
Adjusted R^2	0.0019	0.0002	0.0003	0.0042	0.0003	0.0069
F-stat	3.2426**	0.2317	0.3264	6.0178***	0.3127	0.2980***

Table 7: Low-correlations and Swap Rate

This table shows the regression results relating to the proposition that the low-correlation is expected to increase the yen swap rate. The dependent variable is the 5-year yen swap rate changes and the independent variables are: time-varying correlations between Japan and the UK (Japan_UK), time-varying correlations between Japan and the US (Japan_US) and a control variable, which is time-varying correlations between the US and the UK (US_UK). *M1* and *M2* indicate the regressions (1) without and (2) with control variables. The Generalized Method of Moment (GMM) is used to (i) reduce the estimation problem arising out of the serial correlation problem in the residuals particularly due to volatility aggregates of the spline measure [see also, Rangel and Engle (Forthcoming)] and (ii) to avoid the endogeneity problem associated with simultaneous causality and possible correlation of errors with the regressors. These problems occur because of using the lagged dependent variable (lagged swap rate changes) as well as the spline-smoothing in FS-GARCH [Rangel and Engle (2012)]. These two problems may lead to inconsistency of OLS estimation and hence, the GMM is preferred. In parentheses are the *t*-statistics, which are adjusted for autocorrelation and heteroskedasticity by using the Newey-West method and pre-whitening based on Schwarz Bayesian Information Criteria (SBIC) automatic lag selection. The Hansen's *J*-statistics (*p*-values for this test are reported in parentheses) examines the validity of the instruments with the null hypothesis that the instruments are uncorrelated with residuals. In most cases, up to four lags of the explanatory variables and of lagged swap rates changes are taken as instruments. * and ** denote 10%, and 5% significance levels, respectively. The analysis covers the daily data from September 1989 through January 2010.

	M1	M2
Constant	0.0627	-0.0075
	(0.8736)	(-1.5511)
Japan_UK	-1.1714	-0.1891
	(-1.4236)	(-1.5789)
Japan_US	**0.4861****	**0.1689***
	(2.0494)	(1.7459)
US_UK	–	**0.0113***
		(1.7553)
Hansen's *J*-stat	1.1506	5.4455
(*p*-value)	(0.7649)	(0.6058)

Table 8: Contemporaneous Spillover of Volatility Components (Swap Rates)

This table shows the direction of contemporaneous volatility spillovers of long-term and short-term volatility components using the standardised innovations. The results are based on equations (7)–(9) for long-term volatility and equations (10)–(12) for short-term volatility. Equations (7)–(12) are estimated through SUR. So as to determine the causal flow, results are arranged pairwise, for instance, US to Japan and then Japan to US. ***, ** and * indicate the coefficients are significant at 1%, 5% and 10% respectively. In parentheses are the standard errors of the estimated coefficients, which are corrected for autocorrelation and heteroskedasticity by using the Newey-West method. The analysis covers the daily data from September 1989 through January 2010.

Direction	Long-term Volatility	Short-term Volatility
USA to Japan	**1.54E-08*****	**1.91E-05*****
	(3.62E-09)	(7.29E-06)
Japan to USA	**0.8072*****	**0.9823*****
	(0.0185)	(0.0049)
UK to Japan	**1.36E-09****	**8.96E-06***
	(5.62E-10)	(5.38E-06)
Japan to UK	**0.5368*****	**0.1622*****
	(0.1364)	(0.0368)
USA to UK	**0.5298*****	**0.1396*****
	(0.1338)	(0.0199)
UK to USA	**0.8187*****	**0.9879*****
	(0.0213)	(0.0042)

Table 9: Contemporaneous Spillover of Volatility Components (Swap Spreads)

This table shows the direction of contemporaneous volatility spillovers of long-term and short-term volatility components using the standardised innovations. The results are based on equations (7)–(9) for long-term volatility and equations (10)–(12) for short-term volatility. Equations (7)–(12) are estimated through SUR. So as to determine the causal flow, results are arranged pairwise, for instance, US to Japan and then Japan to US. *** and * indicate the coefficients are significant at 1% and 10% respectively. In parentheses are the standard errors of the estimated coefficients, which are corrected for autocorrelation and heteroskedasticity by using the Newey-West method. The analysis covers the daily data from September 1989 through January 2010.

Direction	Long-term Volatility	Short-term Volatility
USA to Japan	**3.17E-13*****	**0.00036*****
	(7.59E-14)	(7.68E-05)
Japan to USA	**0.8302*****	**0.4332*****
	(0.0077)	(0.0950)
UK to Japan	**1.01E-09*****	**3.33E-06***
	(1.15E-10)	(1.75E-06)
Japan to UK	**0.5116*****	**0.1156*****
	(0.0252)	(0.0167)
USA to UK	**0.5587*****	**1.2206*****
	(0.0292)	(0.1625)
UK to USA	**0.8108*****	**0.9918*****
	(0.0080)	(0.0014)

Table 10: Granger Causal Links of Volatility Components (Swap Rates)

The table reports the results using the modified Wald Test (MWALD) of Granger causality (see equation 13 for details). The analysis covers the daily data from September 1989 through January 2010. Results are based on variance causality and do not differ from those of standardised innovations.

Null Hypothesis	Long-term Volatility		Short-term Volatility	
	Chi-square	*p* value	*Chi-square*	*p* value
USA does not Granger cause Japan	**$X^2(2)$ =415.791**	<0.001	$X^2(3)$ =6.1456	0.1047
Japan does not Granger cause USA	**$X^2(2)$ =2714.484**	<0.001	$X^2(3)$ =3.3910	0.3352
UK does not Granger cause Japan	**$X^2(2)$ =360.892**	<0.001	**$X^2(3)$ =11.2726**	0.0103
Japan does not Granger cause UK	**$X^2(2)$ =2378.258**	<0.001	**$X^2(3)$ =29.7676**	<0.001
USA does not Granger cause UK	**$X^2(2)$ =749.680**	<0.001	**$X^2(3)$ =7.3055**	0.0628
UK does not Granger cause USA	**$X^2(2)$ =1307.845**	<0.001	$X^2(3)$ =6.0035	0.1114

Table 11: Granger Causal Links of Volatility Components (Swap Spreads)

The table reports the results using the modified Wald Test (MWALD) of Granger causality (see equation 13 for details). The analysis covers the daily data from September 1989 through January 2010. Results are based on variance causality and do not differ with those of standardised innovations.

Null Hypothesis	Long-term Volatility		Short-term Volatility	
	Chi-square	*p* value	*Chi-square*	*p* value
USA does not Granger cause Japan	**$X^2(2)$ =13.5904**	0.0035	**$X^2(2)$ =10.6036**	0.0141
Japan does not Granger cause USA	$X^2(2)$ =1.3329	0.7213	$X^2(2)$ =1.9441	0.5841
UK does not Granger cause Japan	**$X^2(2)$ =11.1895**	0.0107	**$X^2(2)$ =9.3845**	0.0246
Japan does not Granger cause UK	**$X^2(2)$ =30.4577**	<0.001	**$X^2(2)$ =28.9928**	<0.001
USA does not Granger cause UK	**$X^2(2)$ =29.8319**	<0.001	**$X^2(2)$ =28.6390**	<0.001
UK does not Granger cause USA	$X^2(2)$ =2.1303	0.5458	$X^2(2)$ =2.4985	0.4756