What determines the yen swap spread?

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1. Introduction

In recent years, a rich empirical literature has unfolded that investigates the drivers of credit spreads on corporate bonds and various derivative instruments such as interest rate swaps (IRS), which are the most important instrument traded. Of concern in the pricing of interest rate swaps (henceforth simply “swaps” since this instrument is the exclusive focus of this paper) is the spread, being the difference between the swap yield and a riskless rate, typically a Treasury or Government bond of similar maturity. The aim of this study is to clarify the risks that drive swap spreads. The results presented, provide clear evidence that swap spreads contain significant components of other types of risks once default and liquidity risks are controlled. These include both pro-cyclical and counter-cyclical elements of business cycle risk, positive risk premia for skewness risk and variable risk premia for correlation risk (between fixed and floating interest rates).

We investigate if Japanese yen denominated interest rate swap spreads price risks in addition to liquidity and default risk. These additional risks include: the time-varying correlation between interest rates of different types and maturities; business cycle risk; and market skewness risk. Our analysis, over a number of different maturities and sample periods, supports the existence of an additional risk premium. We also show that the time-varying correlation between short term market interest rates (e.g., TIBOR) and the longer term Government bond yield (e.g., Gensaki) is of particular importance. Japanese yen swap spreads are shown to contain both pro-cyclical and counter-cyclical elements of business cycle risk, positive risk premia for skewness risk and variable risk premia for correlation risk (between fixed and floating interest rates).

Prior work, including Kobor, Shi, and Zelenko (2005) amongst others, show that the spread expresses the relative price of risk and compensates for both default and liquidity risk (e.g., Cooper & Mello, 1991; Duffie & Huang, 1996; Duffie & Singleton, 1997). However, in contrast to these studies, Feldhütter and Lando (2008) find that the default risk factor and the swap factor have relatively little impact on the swap spread. This suggests the presence of other risks driving the pricing relationship. A cursory look at recent studies in the asset pricing literature suggests that business cycle risk, skewness risk, and correlation risk between the fixed and floating interest rates, should be relevant for better understanding of swap pricing (e.g., Adrian & Rosenberg, 2008; Buraschi, Porchia, & Trojani, 2010; Driessen, Maenhout, & Vilkov, 2009).

In this paper our attention is directed to the Japanese financial markets whose unique institutional characteristics encourage investigation of additional pricing determinates in yen denominated swaps in

1 Many empirical findings in IRS markets are mixed and many puzzles remain. For example, during the period of the Global Financial Crisis (GFC) the 30-year US swap rate fell below that of the equivalent maturity U.S. Treasury bond, a phenomenon now termed the “swap spread puzzle”.

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addition to their role as the third most important market after the US dollar and the euro. As will be discussed in more detail in the next section, this study also employs the unique statistical technique of Adrian and Rosenberg (2008) to estimate the business cycle risk and skewness risk from the stock market return index.

Japan’s decade-long zero interest rate policy is known to have both distorted the yield curve and the term structure of corporate bond yields as well as swap spreads (e.g. Ito, 2007 and Ito, 2008). The flattening of the yen term structure and the subsequent policy actions by monetary authorities to reduce interest rate volatility has therefore reduced the interest rate risk associated with the Japanese business cycle. In addition, these monetary actions can create liquidity distortions in the Government bond term structure, which affect the correlation risk associated with changes in floating rate (short term) and fixed rate (long term) interest rates. Given that swaps have similar features to bonds, Afonso and Strauch (2007) and Asgharian and Karlsson (2008) show that swap spreads vary positively with stock market volatility and hence, the swap spread can contain a systematic risk premium. In a similar sense, correlation risk is also a systematic risk as the co-variation between fixed and floating rates can introduce a risk that should be priced in the swap. Ignoring the dynamics of the correlation structure between underlying interest rates can also lead to serious errors in the pricing model and hedging decisions.

Covrig, Low, and Melvin (2004) and Batten and Covrig (2004) show that skewness risk is present in the short end of the Japanese yield curve, due to pricing distortions associated with the difference between TIBOR and LIBOR interest rates (the Tokyo Interbank Offer Rate and the London Interbank Offer Rate respectively) for unsecured deposits. Thus, determining whether skewness risk is also priced into yen swap spreads is especially important for those market participants who use TIBOR, or LIBOR, based futures contracts to arbitrage, or hedge, the floating rate side of yen interest rate swaps.

It is also worthy of mention that Japan’s unique bank based financial system puts special emphasis on local swap markets: most financial market participants (major, regional and trust banks) trade and use swaps for managing the interest rate risk associated with their balance sheet. Also, income from these transactions has historically provided a significant share of other bank income. The important role that swaps play in the Japanese financial system is also evident by the decision to be the first country to implement the Pittsburgh G20 Summit of 2009 agreement, which required that all standardized over-the-counter derivative (OTC) contracts be traded on exchanges or electronic trading platforms. Though there has been significant focus on efforts in Europe and the U.S., Japan also became the first country to pass laws removing from these many studies are not consistent. For example, Wall and Pringle (1989), Litzenberger (1992), Minton (1997), Gupta and Subrahmanyam (2000) and Gribblatt (2001) find little support for default risk, while liquidity risk seems to be more important. These studies argue that the default risk of a swap is minimal and is easily mitigated (Litzenberger, 1992).

This section reviews the literature related to the other risks that can affect swap prices: business cycle risk, skewness risk and correlation risk in financial markets. These three risks are also characterised as systematic risk. For instance, in a study of the bond market, Elton, Gruber, Agrawal, and Mann (2001) argue that when corporate bond returns move systematically with other assets, such as equity returns, then expected bond returns would require a risk premium to compensate for the non-diversifiability of that risk. There are two reasons why systematic risk exists in bond markets. First, if the expected default loss co-varies with equity prices, that is, the default risk goes up (down) with the fall (rise) in stock prices, then it introduces systematic risk. Second, the reward for risk offered by financial markets is time-varying. If these changes simultaneously affect both bond and stock markets, then these changes introduce a systematic influence (Elton et al., 2001).

Given that swaps have similar features to bonds, Afonso and Strauch (2007) and Asgharian and Karlsson (2008) show that swap spreads vary positively with stock market volatility, and hence, the swap spread can contain a systematic risk premium. In a similar sense, correlation risk is also a systematic risk as the co-variation between fixed and floating rates can introduce a risk that should be priced in the swap. These risks are discussed further below with their relevance to swap markets. Following this discussion, relevant hypotheses are developed.

### 2.1. Business cycle risk in swaps

If asset returns incorporate business cycle risk, expected returns should incorporate rewards for accepting that risk (Adrian and Rosenberg (2008) and Lettau, Ludvigson, and Wachter (2008)). Related to business cycle risk in swaps, Litzenberger (1992) argues that risk allocation between swap counterparties co-varies with the business cycle. Using this argument, Lang, Litzenberger, and Liu (1998) control for the business cycle (proxied by the unemployment rate) in explaining the determinants of swap spreads. They conclude that swap spreads follow the business cycle. A number of other studies, including those of Ito (2007) and Azad, Fang, and Wickramanayake (2011), also note that the swap market is affected by business cycle risk. However, none of these studies has specifically explored whether business cycle risk is a priced risk factor that can explain a substantial proportion of the swap spread.

The pro-cyclical assumption, as in Lang et al. (1998), implies that business cycle risk should increase the swap spread, since it increases the probability of default—which in turn increases the credit risk of the counterparties. Thus, business cycle risk contributes significantly to
the default risk of swap counterparties, thereby increasing the swap spread. A theoretical link between business cycle risk and the probability of default is provided by Genberg and Sulistrova (2008). They assert that business cycle risk reduces the debt/GDP threshold, which eventually raises the level of interest rates. When interest rates rise, it should increase the propensity for corporations to use derivatives to hedge interest rate risk (Beber and Brandt (2009)). Increasing demand for swaps should cause the swap rates to rise and, consequently, the fixed rate payer faces additional counterparty default risk. This translates into an increase in the swap spread. Lekkos and Milas (2001) identify procyclical behaviour of shorter maturities US swap spreads and countercyclical behaviour of longer maturities US swap spreads. However, the question of whether the business cycle risk is a priced risk is not examined by Lekkos and Milas (2001).

The recent study by Adrian and Rosenberg (2008) proxies business cycle risk with the long-term volatility of stock returns. One benefit of this approach is that it addresses the need to incorporate movements in key economic variables, such as the volatility of interest rates, the slope of the yield curve, unemployment, inflation and industrial production (Engle & Rangel, 2008; Adrian & Rosenberg, 2008). The use of stock market volatility as a proxy for the business cycle risk is motivated by Merton (1974) theoretical study on pricing default risk. According to this theory, stock price volatility and the associated higher volatility of firm value increases default risk. The default risk explanation for stock market volatility may also be relevant for swaps since some studies find that stock market volatility and swap spreads are positively correlated (Afonso & Strauch, 2007; Asgharian & Karlsson, 2008). From this viewpoint, it should be possible to extract business cycle risk from stock returns, with this risk expected to be positively correlated with the swap spread.

This relationship is an extension of the pro-cyclical pattern of swap spreads as identified by Lang et al. (1998) in the US market. They argue that unlike common stocks and bond returns, which usually contain counter-cyclical elements as shown in many studies (Campbell & Cochrane, 1999; Fama & French, 1989), swap spreads contain pro-cyclical elements. Pro-cyclical also implies that the higher (lower) the business cycle risk, the higher (lower) the swap spread. Lang et al. (1998) argue that pro-cyclical is somewhat linked to the Black (1987) hypothesis, which suggests that the higher the business cycle risk, the higher the level of investment activity. The high (low) level of business cycle risk increases (decreases) preferences for fixed-income assets, which motivates (or frustrates) derivative activities (Caillietteau & Mali, 2007; Loeys & Panigirtzoglou, 2005). Given hedgers’ preferences, if a particular swap maturity has a higher exposure to business cycle risk than other maturities, specific maturity dealers and swap makers would demand an extra premium to cover the additional risk. Therefore, business cycle risk would increase the swap spread of that maturity. Based on the above discussion this study develops the first hypothesis as follows:

**H1.** The swap spread is positively associated with business cycle risk.

### 2.2. Skewness risk in swaps

Since asset returns are non-normal, higher-order moments (and co-moments) matter in determining risk premiums (e.g. Chung, Johnson, & Schill, 2006). In this paper we argue that one of the higher moments, namely skewness risk, is an important for swap counterparties to consider in determining the swap spread. The key preference-based explanation follows from Kraus and Litzenberger (1976) and Harvey and Siddique (2000), and implies that skewness risk is priced as investors dislike it. The inter-temporal hedging of volatility risk as in Adrian and Rosenberg (2008) indicates that skewness risk is priced because of the time variation of volatility in asset returns. In other words, the time variation in volatility drives the time variation in skewness. Recent work on skewness risk in emerging market equity and bond markets, which typically are not covered in the developed county studies includes: Adcock and Shutes, 2005; Kodongo and Ojah, 2014; Ngene, Hassan and Alam; 2014; and Zinna, 2014.

Using this proposition, Adrian and Rosenberg (2008) proxy skewness risk with the time-varying short-term volatility of daily stock returns. In a similar fashion, skewness risk in swaps can be measured using stock market data. In this paper we extract the ideas of skewness risk from a number of studies relevant for swap markets (Adrian & Rosenberg, 2008; Batten & Covrig, 2004; Covrig et al., 2004; Ito & Harada, 2004; and Nishioka & Baba, 2004).

Adrian and Rosenberg’s (2008) explanation is applicable to any financial product, with skewness risk providing a measure of the tightness of financial constraints. They also note that the increase in skewness risk makes financial constraints more binding and so the distribution of asset returns becomes non-normal (skewed). In swaps, this could be related to the firms’ limited access to funding or borrowing restrictions, in particular the issuing of bonds for financing new investment. That is, financially constrained firms are expected to pay a higher spreads than their counterparties.

Although not empirically tested as is done in this paper, Nishioka and Baba (2004) argue that skewness risk exists in the swap market because of the credit risk premium differential across domestic and offshore markets. An example is the ‘Japan premium’ that was due to the credit quality deterioration of Japanese issuers (Batten & Covrig, 2004; Covrig et al., 2004; Ito & Harada, 2004).

The ‘Japan premium’ or the difference in credit risk/spread is an indication of market-wide skewness risk. When a swap product is exposed to skewness risk, an existence or increase of skewness risk induces cross-border counterparties to demand higher spreads. And hedgers, who are interested in hedging their positions, are ready to pay for insurance against possible increases in skewness risk. Therefore, if there is a significantly higher skewness risk in swaps, then swap spreads should contain a risk premium component related to this risk. This implies that theoretical studies should incorporate this risk into pricing models and empirical analysis should examine whether there is a risk premium attached to skewness risk. Based on the explanation provided above, the second hypothesis is developed as follows:

**H2.** The swap spread is positively associated with market skewness risk.

### 2.3. Correlation risk in swaps

Although correlation risk has been mentioned in the prior literature on swaps (e.g.Mahoney, 1997; Sultan, 2006), it has not been modelled extensively. The choice of correlation risk is attributed to the notion that the correlations between assets change over time. Consequently, a hedge ratio should be adjusted to account for the most recent information relating to the correlation (Engle, 2002). In the case of swaps, the correlations between the underlying interest rates (fixed and floating rates) also change, requiring swap users and dealers to price correlation risk. The rationale behind pricing correlation risk in swaps is that the changing nature of the correlation between underlying interest rates is dynamic and not constant over time. This necessitates that pricing models calibrate using dynamic correlations.

Nevertheless, correlation risk has been found to be a priced risk factor in other financial markets (Buraschi et al., 2010; Driessen et al., 2009), though the treatment of this risk is different across these markets. For example, in stock and bonds markets, a market-wide increase in correlations adversely affects investor welfare by limiting the diversification possible within and across markets, while a decrease in
correlation provides better portfolio diversification. Notably, low correlation does not persist, since no-arbitrage conditions force markets/products to co-vary on average, and correlations increase during the crisis periods.

In either case of higher, or lower, correlation, the time-varying correlation structure provides useful information for investors. Similar to other financial markets, the correlations between underlying interest rates (fixed and floating interest rates) provide critical inputs for managing, hedging and diversifying interest rate risks in swaps. Interestingly, unlike stock and bond markets, higher correlation is expected in swap markets since investor welfare does not decrease due to a higher correlation between the fixed and floating rates. Consequently, a high correlation indicates pricing efficiency in both the fixed and floating rates markets.

How does correlation risk affect the swap contracts? It is well known that in an interest rate swap contract, there are two counterparties: one paying the fixed rate and the other paying the floating rate. Markets expect that both these rates move together. In fact, before the emergence of swaps, the fixed rate and floating rate markets were operating separately. This attribute motivated market participants to move from one market to the other using their expectation about the shape of the yield curve (Handjinicolaou, 1991).

However, with the appearance of swaps, market players were able to consider both fixed and floating rate markets simultaneously. A fixed rate borrower not only needs to have a clear understanding (including pricing mechanism) of the fixed rate market but also has to consider effects or impacts in the floating-rate market. This process ensures that pricing is consistent and efficient in both the fixed rate and floating rate markets. With efficient pricing, a higher correlation is expected to limit arbitrage and is an indication of minimum pricing anomaly/uncertainty. Thus, market makers cannot demand an additional risk premium from hedgers. As a result, a highly significant time-varying correlation is expected to decrease the credit spread in swaps.

Although a higher correlation reduces the swap spread, it does not necessarily decrease the value of swaps. Instead, it brings about several benefits (Sultan, 2006). For example, an increased correlation between fixed and floating rates (i) reduces uncertainty among swap participants about the future movements of interest rates, (ii) reduces dealers’ hedging costs thereby allowing them to charge lower spread in subsequent contracts, (iii) improves the economic value of swap cash flows by decreasing mark-to-market risk of interest rate swaps and increases the effectiveness of interest rate swap usage, and (iv) improves the effectiveness of interest rate futures in hedging interest rate swaps.

In contrast, when the time-varying correlation between the fixed rate and the floating rate is significantly low (i.e., markets do not move together) and continues to drop over time, it poses some threat or uncertainty to pricing as well hedging costs (Sultan, 2006). In such an environment, dealers and market makers will demand higher spreads. Consequently, swap buyers dislike lower correlation since they will need to pay more for swaps. According to this view, correlation risk and swap spread are negatively related: the lower the correlation, the higher the spread. That is, swap spreads increase (decrease) due to low (high) correlation between the underlying interest rates.

When investigating the influence of correlation risk, one can look at the constant or time-changing structure of the correlation between fixed and floating interest rates. Since economic fundamentals play a vital role in the determination, or movement, of interest rates, it is impractical to rely on constant correlation. It is also rather plausible to utilise the time-varying correlation structure to dynamically update the information on the co-movement of two interest rates. Based on these explanations, this study formulates the third hypothesis as follows:

H3. Swap spreads are negatively (positively) associated with correlation risk at times of high (low) correlation between underlying interest rates.

3. Data

3.1. Data used for the three risk proxies

To explore whether business cycle risk, skewness risk and correlation risk are priced in swaps, one needs to first obtain a measure of these risks. Following Adrian and Rosenberg (2008), this study estimates the business cycle risk and market skewness risk from the stock market, which is considered to be the most active financial market.

The reasons to use stock market data are as follows: (i) the stock market is said to be more active than other financial markets and also representative of systematic skewness risk; (ii) Delianedis and Geske (2001) find that firm-specific financial factors including volatility of corporate value do not contribute to the determination of credit spreads on corporate bonds, and that individual credit spreads are heavily influenced by market risks measured in terms of returns and volatilities of equity market indexes; (iii) stock markets are highly correlated with business cycle risk (Schwert, 1989); (iv) it minimises the burden of estimating business cycle risk and skewness risk from each swap maturity; and finally (v) it reduces the estimation errors by producing a common measure that can be used for each maturity.

Adrian and Rosenberg (2008) show that it is possible to extract business cycle risk and skewness risk from the composite stock price index of a country. To estimate these two risk factors, this study uses TOPIX — a price index, which is available on DataStream. The time-varying correlation between the fixed and floating rate is estimated using Engle’s (2002) DCC approach. The fixed rate is the Treasury bond yield (Gensaki) corresponding to the relevant swap maturity and the floating rate is the interbank rate, which is the 6-month Tokyo Interbank Offer Rate (TIBOR). This data was collected from DataStream and cross-checked for consistency with Bloomberg. The full sample covers the daily data from April 1987 to December 2010. Note we deliberately end our sample prior to the financial shocks associated with the March 2011 earthquake and tsunami that devastated Tohoku and other parts of Japan.

To ensure the robustness of our results, the usual measures of default risk and liquidity risk are used as control variables and are discussed below. Finally, the whole sample is divided into different sub-samples using the crisis events relevant to swap markets. The data source, measurement and hypotheses related to default risk and liquidity risk are discussed in Sections 3.2 and 3.3. The economic events that are used for sub-sample analysis are then described in Section 3.4.

3.2. Data for default and liquidity risks

The frequently used risk proxies in determining swap spreads are default risk and liquidity risk. Sections 3.2.1 and 3.2.2 discuss these two risk proxies and their measurement. Consistent with both the theoretical and empirical studies, this study also proposes a positive relationship between these two risks and swap spreads.

3.2.1. Default risk

Given that swap default spreads are unobservable, prior studies including those by Brown, Harlow, and Smith (1994), Duffie and Singleton (1997), Minton (1997), Lang et al. (1998) and Gupta and Subrahmanyam (2000) use different proxies and assume that the default risk in swaps can be accurately proxied with information from the corporate bond market. Following this literature, this study also proposes a positive association between the swap spread and the default premium in the corporate bond market. Following Ito (2007), we observe default risk as the yield difference between the 10-year corporate bond issued by Tokyo Electric Power Company and the 10-year Japanese Government Bond. This data was also collected from DataStream.
3.2.2. Liquidity risk

In line with prior literature including Duffie and Singleton (1997), Grinblatt (2001) and Liu et al. (2006), we argue that the swap spread and liquidity risk premium are positively related. Grinblatt (2001) shows that liquidity risk can be proxied by the spread difference between the floating rate (LIBOR) and fixed rate (Treasury bill) of the same maturities. This difference is interpreted as an increase in the liquidity advantage of government securities over floating rate loans. In this study we use the difference between 6-month TIBOR and 6-month Gensaki as a proxy for the liquidity risk premium. Data are obtained from Bloomberg and DataStream.

3.3. Relevant events and sub-samples

Since the analysis covers a wide range of economic experiences including the Long Term Capital Management (LTCM) episode in the late 1990s and the more recent Global Financial Crisis (GFC), this study takes into account those crises as they have affected the Japanese swap markets. Note the sample period ends in 2010 to avoid the financial shocks associated with the 2011 tsunami, which resulted into significant distortions in financial markets due to the monetary response by governments and corporations. Following Fang and Muljono (2003), the Asian Financial Crisis (AFC) is taken to reflect a currency crisis on the swap market. Moreover, the AFC was followed by the Russian Government bond default (RGBD) in August 1998 and the LTCM crisis in September 1998. Interestingly, Japan’s Long-Term Credit Bank (LTCB) and Nippon Credit Bank (NCB) also failed around the same time (in November 1998). As these events nearly simultaneously, a sub-sample is considered that covers the period from July 1997 to November 1998 that includes the AFC, LTCM, RGDB, LTCB and NCB crises. The second sub-sample that spans the period from January 1999 to June 2007 is taken as a normal period. The third sub-sample focuses on the GFC starting from July 2007 to November 2010. Altogether, three sub-samples are taken into account to reflect possible changes in the relationship between the risk proxies and swap spreads during periods of market calm and turbulence.

4. Methodology

In this paper the swap spread, \( s_s \), for 2, 3, 5, 7 and 10-year swaps, is defined simply as follows:

\[
ss_t = IRS_t - TB_t
\]  

where \( ss_t \) is the swap spread of each maturity, \( IRS_t \) is the swap mid (bid-ask average) rate as reported in DataStream and \( TB_t \) is the Treasury bond yield.

In key prior studies, such as Duffie and Singleton (1997) and Afonso and Strauch (2007), it is found that a substantial proportion of the variation in swap spreads is explained by their own shocks indicating that the swap spread is influenced by its market-specific activity. Duffie and Singleton (1997) argue that this market-specific shock accounts for 35 to 48%. That is, after accounting for other risk factors, a substantial fraction of the variation in swap spreads is left unexplained. Feldhüttner and Lando (2008) also use the ‘swap factor’ and default risk factor to decompose the swap spread.

Based on the discussion in Duffie and Singleton (1997) and Feldhüttner and Lando (2008), one needs to add the lagged swap spread as one of the independent variables. Moreover, studies of spread determinants typically include the lagged spreads as one of the regressors due to the persistent nature of the spreads. A similar approach is adopted by Afonso and Strauch (2007), Gerlach, Schulz, and Wolff (2010) and Arghyrou and Kontonikas (2012) to account for spread persistence. Following this discussion, the functional form with three new risk proxies can be written as:

\[
ss_t = a_0 + a_1 ss_{t-1} + a_2 bcyt + a_3 skewt + a_4 corr + e_t. \tag{2}
\]

Since prior studies, such as Liu et al. (2006) and Feldhüttner and Lando (2008) emphasise default risk and liquidity risk in their discussion of swap spreads, we include these additional two risk factors in Eq. (2). The revised form is then:

\[
ss_t = a_0 + a_1 ss_{t-1} + a_2 bcyt + a_3 skewt + a_4 corr + a_5 def + a_6 liq + e_t. \tag{3}
\]

Eq. (2) specifies the relationship between the swap spread and new risk proxies only, while Eq. (3) specifies the relationship between the swap spread and all risk proxies. Bcyt is the business cycle risk, skewt is the skewness risk, corr stands for the correlation risk, def indicates default risk and liq stands for the liquidity risk. bcyt and skewt are obtained from the factor spline GARCH (hereafter, FS-GARCH) model of Rangel and Engel (2012) on the stock index.

To maintain simplicity, the FS-GARCH model is not explained here. However, Appendix E explains how the business cycle and the skewness risks are obtained using the FS-GARCH model. corr is measured by the time-varying correlation between fixed and floating interest rates. To obtain dynamically correct estimates of the intensity of fixing and floating rate co-movements, the time-varying correlation is estimated employing the Dynamic Conditional Correlation (DCC) model of Engle (2002). Related to this, Rangel and Engel (2012) argue that with unconditional techniques such as rolling correlations or exponential smoothing, the sensitivity of the estimated correlations to volatility changes would restrict inferences about the true nature of the relationship between these variables, especially during periods of high volatility. Hence, the use of DCC is more appealing than competing models. DCC is widely used in the asset pricing literature and, for this reason its discussion is omitted from the main text but briefly discussed in Appendix B, which explains how the time-varying correlation between the Treasury bill and the LIBOR/TIBOR is estimated.

For specifications (2) and (3), the Generalized Method of Moment (GMM) is used for two reasons. The first is to reduce the estimation problem arising out of the serial correlation problem in the residuals particularly due to volatility aggregates of the spline measure as explained by Rangel and Engel (2012). The second is to avoid the endogeneity problem associated with simultaneous causality and possible correlation of errors with the regressors.

These problems occur when using the lagged dependent variable (lagged swap spread) as well as the spline-smoothing in FS-GARCH. These two problems may lead to inconsistency in OLS estimation and hence, a GMM approach is preferred. Furthermore, the GMM has superior ability to exploit stationarity restrictions (Durlauf, Johnson, and Temple (2005)). Therefore, Eqs. (2) and (3) are estimated by the GMM with robust Newey and West (1987) standard errors, and 2 to 4 lags of lagged dependent variable and explanatory variables are used as instruments. The heteroskedasticity and autocorrelation (HAC) covariance matrices are used as weighting options with Schwarz Bayesian Information Criteria (SBC) and automatic lag selection to avoid specification bias. Post-estimation diagnostics for the GMM estimations are also conducted.

5. Results and discussion

5.1. Preliminary statistics

This subsection reports the descriptive statistics and correlations among the variables. The descriptive statistics, which are shown in

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Footnote: This paper does not specifically address issues of contagion and integration within derivative and other financial markets. These are covered in a number of relevant studies including: Kim, Lucey, and Wu (2006); Cionetti (2014); Hausman and Johnston (2014); Zinna (2014); Castellacci and Choi (2015); Jotikasthira, Le, and Lundblad (2015); and Kessourgos and Dimitriou (2015).
Table 1, indicate that the Japanese swap market experienced a negative spread, a feature also found recently in the US swap markets. A negative spread occurs when swap rates are lower than the Japanese Government Bond (JGB) yields in all maturities. This phenomenon needs further explanation. Existing theory dictates that an increase in the number of fixed-rate payers would cause the quoted swap rate to increase. However, demand works in the exact opposite direction: an increase in demand for receiving fixed in swaps causes a decrease in the swap rate. Consequently, a negative swap spread – as observed in the Japanese market – is essentially an outcome of the increased demand from banks and corporations to receive fixed in swaps and pay floating. The supply of Treasuries also played a role in the 1990s, when the Bank of Japan (BoJ) financed the budget deficit by issuing JGBs. Consequently, an increase in the supply pushed the JGBs yield up thereby decreasing the swap rate relative to the Treasury yield.

In Table 1, business cycle risk (BCYC) and skewness risk (SKEW) are obtained from the TOPIX index using the FS-GARCH model (see Appendix A) of Rangel and Engel (2012). To reiterate, these two risks are proxied by the long-term and the short-term components of stock market volatility. The daily average long-term (BCYC) and short-term (SKEW) volatilities are 0.22% and 0.21%, respectively. The correlation risk measures between the underlying interest rates (correlations between the fixed-rate (JGBs) and the 6-month TIBOR rate) are the estimated DCC time-varying correlation coefficients, which vary from a minimum of 0.2602 (JGB2_TIB) to a maximum of 0.9897 (JGB2_TIB). The correlation coefficients between these underlying interest rates (JGBs, TIBOR) are smaller with the longer swap maturities compared to the shorter maturities. That is, the relationship between the fixed interest rate and floating interest rate is weaker for long-term swaps. The long-term 5-year, 7-year, and 10-year swaps, which are negatively correlated, are with the corresponding short-term 2-year and 3-year swaps. The correlation between the long-maturity JGBs and the TIBOR is lower than that between JGBs and TIBOR, which affects the correlation between the swap spread and other risks.

Table 2 reports the correlation structure among the swap spreads, as well as between the swap spread and the risk measures. The highest correlations are between the closest maturities. For example, the correlation between the 2-year spread and 3-year spread is higher (0.9470) than the correlation between the 2-year spread and 5-year spread (0.7245). These correlations are positive for all maturities with the exception of the 2-year and 10-year swaps, which are negatively correlated (−0.0899). That is, the most distant maturities hardly correlate with one another. These observations suggest that the information components of individual swap maturities differ and so it is important to incorporate these different swap maturities for a better understanding of market behaviour.

With regard to the correlation between swap spreads and the various risk measures, business cycle risk is positively correlated with the 2, 3 and 10-year swap spreads but negatively correlated with the 5 and 7-year swap spreads. All maturities except the 10-year swap spreads are positively correlated with skewness risk. The shorter maturity swap spreads (2-year and 3-year) are negatively correlated with their corresponding correlation risk measures, while longer maturities (5-, 7- and 10-year swaps) are positively correlated with their corresponding correlation risk measures. This is due to the time-varying nature of correlation (between JGBs and TIBOR), which affects the correlation between the swap spread and other risks.

To illustrate this point, the DCC time-varying correlations between JGBs of different maturities and the TIBOR are plotted. As can be seen from Figs. 1–5 (presented in Appendix C), the correlations between short-maturity (2 and 3-year) JGBs and the TIBOR are higher than the correlations between long-maturity (5, 7 and 10-year) JGBs and the TIBOR. Therefore, consistent with the discussion in Section 2.3, the low-correlation between the long-maturity JGBs and the TIBOR increases the swap spread, thereby causing a positive correlation between the swap spread and correlation risk. Theoretically, such a finding should hold in the final estimation stage in the next sub-section.

The default (DEF) risk is positively correlated with shorter maturities but negatively correlated with longer maturities. All maturities of swaps are positively correlated with liquidity (LIQ) risk and the correlation

### Table 1

<table>
<thead>
<tr>
<th>Swaps spread</th>
<th>BCYC</th>
<th>SKEW</th>
<th>Correlation risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.1284</td>
<td>0.2190</td>
<td>0.2125</td>
</tr>
<tr>
<td>Std. dev</td>
<td>0.1202</td>
<td>0.2190</td>
<td>0.2125</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.2210</td>
<td>0.2324</td>
<td>0.2125</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>2.6723</td>
<td>2.2821</td>
<td>0.2125</td>
</tr>
<tr>
<td>N</td>
<td>3639</td>
<td>3636</td>
<td>3363</td>
</tr>
</tbody>
</table>
| *Indicates that p-values for all p (Jaeck–Banerjee) statistics are significant at 1%.
coefficients are quite large compared to other risk measures. This is consistent with other findings by studies such as Grimbalt (2001) and Liu et al. (2006) that liquidity risk is a major determinant of the swap spread. The correlations among the risk measures are mixed because of the variation in the correlation risk measures. However, they are positive among the following risks: BCYC, SKEW, Default and Liquidity. Table 3 presents the unit root test results of the dependent variables (swap spreads with different maturities) and two independent variables, default risk and liquidity risk. The unit root null is rejected for all these variables. It should be noted that the unit root test is not required for the three risk proxies (business cycle risk, skewness risk and correlation risk) as this is already confirmed at the time of modelling those risks.

5.2. Regression results and discussion

The estimation results in this section are based on two models: model one (MI) involves the estimation results relating to three new risk factors, while model two (MiI) involves the estimation results relating to all five risk factors. The use of the lagged dependent variable requires application of a GMM estimation technique because of the endogeneity problem associated with simultaneous causality and possible correlation of errors with the regressors. We now discuss the estimation results relating to the research issue of whether the yen swap spreads contain risk premiums related to the three risks discussed earlier, once default and liquidity risk have been considered. The GMM estimation results on the Japanese swap market are presented in Table 4. In this table, MI shows results with three new risk measures only and MII shows results with all five risk proxies. It is evident from Table 4 that in all models, the lagged swap spread is found to be highly significant. Note that Afonso and Strauch (2007) also report similar empirical findings, with the size of the coefficient of the independent variables being small when the lagged dependant variable is included. For the 2-year swap, MI shows that business cycle risk is insignificant (H1 is not supported) but both skewness risk and correlation risk are significant and their coefficients are consistent with the hypotheses (H2 and H3 are supported). When the default risk and liquidity risk are included in MI, the coefficient of business cycle risk becomes both significant and negative implying a counter-cyclical effect. The counter-cyclical effect is also detected by Lekkos and Milas (2001), though in the longer maturity (US market) swap spread. Excluding business cycle risk, the coefficients of all other risk proxies are consistent with the hypotheses.

Regarding skewness risk, Nishioka and Baba’s (2004) argument is empirically supported for the Japanese swap market. Correlation risk is shown to have a negative influence on the swap spread, which is consistent with Sultan’s (2006) finding for the US swap market. This implies that when the correlation between the underlying interest rates is high, it reduces both the uncertainty in market interest rates and the market makers’ hedging costs. This allows market makers to charge a lower spread (i.e., swap spread is reduced) compared to a situation when the correlation risk is high. Both default risk and liquidity risk have positive influences on the 2-year swap spread as evidenced in other studies. For instance, Eom, Subrahmanyam, and Uno (2000) and Ito (2007) find that in the Japanese market, risk premia related to default risk are positive for various maturities.

The analysis of the 3-year swap shows that in MI, neither business cycle risk nor correlation risk is significant. Only skewness risk is found to be significant and consistent with the hypothesis (H2 is supported). In MI, due to the inclusion of default risk and liquidity risk, correlation risk turns out to be significant, while skewness risk becomes insignificant. Moreover, correlation risk confirms hypotheses 3, while default risk and liquidity risk are consistent with the other previous findings. Some similarities are also observed with the 5-year swap. Here, correlation risk is found to be significant in both MI and MII even after controlling for default and liquidity risk. The coefficient of business cycle risk also turns out to be significant and negative, and is similar to that of the 2-year swap. This also is consistent with a counter-cyclical effect.

For the 7-year swap, only business cycle risk is significant in MI indicating a counter-cyclical element similar to that present in stock and bond markets. This empirical finding is consistent with that of Lekkos and Milas (2001). In the US market, Lekkos and Milas (2001) find counter-cyclical behaviour for the longer maturity (7 and 10-year) swap spreads, while pro-cyclical behaviour is evident in the short-

### Table 2

Correlation between swap spread and its risk determinants.

<table>
<thead>
<tr>
<th>IRS2</th>
<th>IRS3</th>
<th>IRS5</th>
<th>IRS7</th>
<th>IRS10</th>
<th>BCYC</th>
<th>SKEW</th>
<th>JGB2_TIB</th>
<th>JGB3_TIB</th>
<th>JGB5_TIB</th>
<th>JGB7_TIB</th>
<th>JGB10_TIB</th>
<th>Default</th>
<th>Liquidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2928</td>
<td>0.1098</td>
<td>-0.0152</td>
<td>0.0227</td>
<td>0.0694</td>
<td>0.0299</td>
<td>0.0562</td>
<td>0.1414</td>
<td>0.0576</td>
<td>0.1092</td>
<td>0.1106</td>
<td>0.1106</td>
<td>-0.2282</td>
<td></td>
</tr>
<tr>
<td>0.7245</td>
<td>0.6225</td>
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<td>0.1939</td>
<td>0.1724</td>
<td>0.1443</td>
<td>0.0903</td>
<td>0.0694</td>
<td>0.1092</td>
<td>0.1107</td>
<td>0.1107</td>
<td>0.1107</td>
<td>-0.2282</td>
<td></td>
</tr>
<tr>
<td>0.9470</td>
<td>1.0000</td>
<td>0.9002</td>
<td>0.8790</td>
<td>0.8225</td>
<td>0.7972</td>
<td>0.5512</td>
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<td>0.9002</td>
<td>0.9002</td>
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<td>0.4206</td>
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<td>0.5259</td>
<td>0.7772</td>
<td>0.7772</td>
<td>0.7772</td>
<td>-0.2282</td>
<td></td>
</tr>
<tr>
<td>0.0406</td>
<td>0.6225</td>
<td>0.0902</td>
<td>0.0902</td>
<td>0.0902</td>
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<td>0.0902</td>
<td>-0.2282</td>
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</tbody>
</table>

### Table 3

Unit root test of the dependent and independent variables.

<table>
<thead>
<tr>
<th>IRS2</th>
<th>IRS3</th>
<th>IRS5</th>
<th>IRS7</th>
<th>IRS10</th>
<th>BCYC</th>
<th>SKEW</th>
<th>JGB2_TIB</th>
<th>JGB3_TIB</th>
<th>JGB5_TIB</th>
<th>JGB7_TIB</th>
<th>JGB10_TIB</th>
<th>Default</th>
<th>Liquidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2928</td>
<td>0.1098</td>
<td>-0.0152</td>
<td>0.0227</td>
<td>0.0694</td>
<td>0.0299</td>
<td>0.0562</td>
<td>0.1414</td>
<td>0.0576</td>
<td>0.1092</td>
<td>0.1106</td>
<td>0.1106</td>
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<td>0.7245</td>
<td>0.6225</td>
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<td>0.1939</td>
<td>0.1724</td>
<td>0.1443</td>
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<td>0.1092</td>
<td>0.1107</td>
<td>0.1107</td>
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<tr>
<td>0.9470</td>
<td>1.0000</td>
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<td>0.7972</td>
<td>0.5512</td>
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<td>0.9002</td>
<td>0.9002</td>
<td>0.9002</td>
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<tr>
<td>0.4206</td>
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<td>0.7772</td>
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<tr>
<td>0.0406</td>
<td>0.6225</td>
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<td>0.0902</td>
<td>0.0902</td>
<td>0.0902</td>
<td>-0.2282</td>
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</tr>
</tbody>
</table>

**Series** | **ADF test-statistics** | **Prob.** |
<table>
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<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
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<tr>
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</tr>
<tr>
<td>LIQUIDITY</td>
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<td>0.0756</td>
</tr>
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</table>
Table 4

Yen Swap spreads and business cycle risk, skewness risk and correlation risk: full sample.

This table reports the estimation results from the following two regression models (see Eqs. (2) and (3) for models MI and MII respectively):

\[ Y = \alpha + \beta_1 t + \beta_2 \text{trend} + \beta_3 \text{trend}^2 + \beta_4 \text{trend}^3 + \beta_5 \text{trend}^4 + \text{controls} + \epsilon \]

Where, \( \epsilon \) refers to swap spread. 2, 3, 5, and 10-year swap spreads are considered for Japan. Following Adrian and Rosenberg (2008), business cycle risk (BCY) and skewness risk (SKREW) are calculated from the daily market return data (log-difference of the Tokyo price index — TOPPIX from DataStream). However, unlike Adrian and Rosenberg (2008), this study uses the FS-GARCH model of Rangel and Engel (2012) to allow the asymmetry in the skewness risk component. Correlation risk (CORR) between Japanese Government Bond (JGB) yields and 6-Month Tokyo Interbank Offer Rate (TIBOR) is estimated using Engle’s (2002) DCC approach. Following Ito (2007), default risk (DEF) is calculated as the yield spread between the 10-year corporate bond issued by the Tokyo Electric Power Company and the 10-year JGB yield. These data are obtained from DataStream. Liquidity risk (LIQ) is observed as the difference between the 6-month TIBOR and 6-month JGB yield. The sample covers the daily data from November 21, 1995 to December 31, 2010. 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 spreads are taken as instruments. The R-squared statistics, which are on average 90% and above, are not reported.

<table>
<thead>
<tr>
<th>Predicted sign</th>
<th>MI</th>
<th>MI</th>
<th>MI</th>
<th>MI</th>
<th>MI</th>
<th>MI</th>
<th>MI</th>
<th>MI</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>(t-Stat)</td>
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<td>1.7140</td>
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<tr>
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<td>0.9704</td>
<td>0.9955</td>
<td>0.9923**</td>
<td>0.9918</td>
<td>0.9886</td>
<td>0.9015</td>
<td>0.9984</td>
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<td>3-year</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Intercept</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>(t-Stat)</td>
<td>-1.0799</td>
<td>-1.2160</td>
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<td>1.3940</td>
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<td>2.0731</td>
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<tr>
<td>BCYR</td>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>(t-Stat)</td>
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<td>0.8090</td>
<td>0.3224</td>
<td>0.2428</td>
<td>1.0113</td>
<td>1.8953</td>
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<tr>
<td>SKREW</td>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>(t-Stat)</td>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<tr>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
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<td>(t-Stat)</td>
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<td>0.5979</td>
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<tr>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>(t-Stat)</td>
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<td>-2.0143</td>
<td>-1.6947</td>
<td>-1.2133</td>
<td>-0.5909</td>
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<tr>
<td>LIQ</td>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>(t-Stat)</td>
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<td>-2.9541</td>
<td>0.4032</td>
<td>-1.4154</td>
<td>-1.1300</td>
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<tr>
<td>(p-Value)</td>
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<td>0.5180</td>
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<td>0.8618</td>
</tr>
</tbody>
</table>

* Denotes 10% significance levels.
** Denotes 5% significance levels.
*** Denotes 1% significance levels.

maturity (3-year) swap spread. Given market linkages, it is not surprising to obtain a similar result for the Japanese market. Note that neither skewness risk nor correlation risk is significant (H2 and H3 are not supported) for the 7-year swap. However, once default risk and liquidity risk are included in MI, all the key variables are found to be significant (confirmed hypotheses H1, H2 and H3). Business cycle risk now has a pro-cyclical effect, while the correlation risk turns positive and significant (conclusion levels).

For the longer maturity 10-year swap, the correlation risk is positive and significant in MI. Once default and liquidity risk is considered in MI, the significance of business risk improves.

Overall, for the Japanese market, the findings are consistent with Nishioka and Baba (2004) that skewness risk explains a substantial proportion of the credit spread in Japanese corporate markets. As for the default risk and liquidity risk, our results are consistent with Eom et al. (2000) and Ito (2007) in the Japanese market and with Liu et al. (2006) in the US market.

The positive coefficient of the correlation risk for longer maturities (7 and 10-year swaps) needs further explanation. Unsurprisingly, this result supports the hypothesis (H3) given that the time-varying correlations (see Figs. 1 to 5 in Appendix C) between fixed rates (JGBs) and floating rate (6-month TIBOR) are smaller in the case of longer swap maturities (7 and 10-year swaps) than those of shorter maturities (2, 3 and 5-year swaps).

As discussed in Section 2.3, the long-correlations between the fixed rate and the floating rate increase the swap spread. It is argued that a higher correlation reduces a dealer’s hedging costs, improves the effectiveness of interest rate futures for hedging interest rate swaps, and resolves uncertainty among market participants regarding future movements in the interest rates (Sultan, 2006). So, when underlying interest rates behave against this theoretical prediction, a dealer’s costs should increase, which would then be passed onto hedgers, resulting in a positive relationship between the swap spread and correlation risk. As for the default risk and liquidity risk, the coefficient of the default risk is positive and significant for 2 and 5-year swaps, while that of the liquidity risk is significant only for 2-year swap. The finding related to weaker statistical relationship between swap spread and default risk is consistent with that of Fehle (2003). Fehle (2003) argues that the positive relationship between swap spreads and LIBOR spreads is stronger in the case of shorter maturity of swap. This positive relationship, however, gets weaker as the swap maturity increases.

As an additional robustness check on these results for the full-sample, the next section shows whether the above findings hold in for a subsample analysis.

6. Subsample analysis

This section presents the empirical analysis of the various subsamples. As noted earlier, economic events and crises are expected to influence the relationship between the swap spread and its risk determinants (e.g., Eom, Subrahmanyam, & Uho, 2002; and Fang & Muljono, 2003). Therefore, as an important robustness check, the whole sample is divided into three different subsamples to ascertain the impact of crisis events. As discussed earlier, the first sub-sample is characterised as ‘crisis period — 1’, which includes the Asian Financial Crisis (AFC), Long-term Capital Management (LTCM), and the Russian government bond default crisis (RGBD), and the failure of Japanese Long-term Credit Bank (LTCB) and Nippon Credit Bank (NCB). Since all these events occurred consecutively, the sub-sample ‘crisis period — 1’ comprises all these events. Data for this subsample spans June 1997 to November
The empirical results are presented in the following sub-sections. It is worth noting that sub-sample analysis covers the empirical results of only 2- and 5-year swaps using Eq. (3).10

The second subsample is a ‘normal period’ spanning from January 1999 to June 2007. The third subsample, ‘crisis period —2’, refers to the global financial crisis (GFC) starting from July 2007 to December 2009. The empirical results are presented in the following sub-sections. It is worth noting that sub-sample analysis covers the empirical results of only 2- and 5-year swaps using Eq. (3).10

The sub-sample analysis of the Japanese markets is presented in Table 5. Overall these results are consistent with those of the full sample. For the 2-year swap the coefficient of business cycle risk remains negative and significant for crisis periods (sub-samples 1 and 3 in Table 5), but insignificant for the normal period. The counter-cyclical behaviour (negative coefficient) implies that the duration and strength of recessions are stronger in crisis periods than in normal periods. Hence, crisis periods would have dominated the coefficient of business cycle risk for the whole sample analysis in the previous section (see Table 4). Skewness risk is positive and significant for all sub-samples. This finding is consistent with the full sample analysis and implies that skewness risk matters for market interest rates, like swaps. As for correlation risk, it is negative and significant for ‘crisis period —1’ and the normal period, but insignificant for the ‘crisis period —2’. Default risk is positive and significant for the normal period, but insignificant for both crisis periods. Finally, liquidity risk is significant for all sub-samples. As noted in the previous section, these results are consistent with other findings that liquidity risk accounts for the largest part of the swap spread, while the default risk factor has a relatively small impact on the spread.

For the 5-year swap, business cycle risk remains negative and significant for all sub-samples, implying that even the longer maturity Japanese swap spread contains a counter-cyclical element. Similar to the 2-year swap, skewness risk is positive and significant for all sub-samples. This result is consistent with Nishiooka and Baba’s (2004) argument that the Japanese corporate market contains a skewness risk premium.

Correlation risk is also negative and significant for all sub-samples, suggesting that the determination of underlying interest rates (fixed and floating interest rates) for this maturity in Japanese markets is efficient. This finding also suggests that both the fixed and floating rates carry over time. In the case of default and liquidity risk, their coefficients are both positive and significant during ‘crisis period —1’ and the normal period, but insignificant for the GFC period. For both maturities, liquidity risk remains significant in all sub-samples with the exception of the 5-year swap during the GFC period. These results are in line with other findings that liquidity risk accounts for a substantial part of the swap spread13.

Overall, the sub-sample analysis confirms the earlier results for the full sample and demonstrates that business cycle risk, skewness risk and correlation risk remain significant after controlling for known default and liquidity risks. These findings indicate that swap users cannot ignore the significance of these risk measures in determining swap spreads.

7. Conclusion

In this paper, focus is directed towards understanding the pricing of yen denominated interest rate swaps. These swaps are of particular

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10 We also divided this sub-sample into different sub-samples to reflect the influences of the Y2K liquidity crisis, and US Treasury buy-back decision. However, the results are not different from the ones without these additional sub-samples.

11 For example, Litzenberger (1992); Duffie and Huang (1996); Minton (1997); Duffie and Singleton (1997); Gupta and Subrahmanyam (2000); Grinblatt (2001); Liu et al. (2006) and Feldhütter and Lando (2008).
academic and practitioner interest given the unique institutional characteristics of Japanese financial markets, which encourage investigation of additional pricing determinants. The yen swap market is also the third most important market after the US dollar and the euro. Swaps are typically used by the world’s major non-financial corporations for managing interest rate and macroeconomic risk. Their wide usage highlights the importance and need for better understanding pricing and application.

Our empirical analysis uses the structural model first introduced by Black and Scholes (1973) and Merton (1974) to explain default risk and those factors that drive credit spreads. Since the introduction of these models, a number of studies, including Collin-Dufresne, Goldstein and Martin (2001), have empirically examined the determinants and components of credit spreads and found numerous variables and proxies with liquidity risk being identified as the most important factor. However, correlation risk, business cycle risk and market skewness risk, which have been shown to be influential in other financial markets, have not been considered in the analysis of Japanese swap markets.

Using a wide range of swap maturities from Japan and employing GMM estimation techniques to ensure the robustness of our results, we demonstrate that business cycle risk, market skewness risk and correlation risk are important determinants of yen swap spreads after controlling for default and liquidity risk. As an important robustness check, controlling for default and liquidity risk. As an important robustness check, this appendix explains Engle’s (2002) DCC approach, which is used to calculate the correlation risk between the underlying interest rates (fixed rate and floating rate). To explain Engle’s (2002) DCC model, let $y_t = \{y_{t,1}, y_{t,2}\}$ be a $2 \times 1$ vector containing changes in the fixed rate (i.e., 6-month Gensaki rate) and the floating rate (i.e., 6-month TIBOR) series. The conditional distribution of these series can be modelled using Engle’s DCC approach as follows:

$$y_t = c_t \sim N(0, H_t) \quad \forall t = 1, \ldots, T \tag{B.1}$$

$$e_t = D_t \eta_t \tag{B.2}$$

where, $e_t = (e_{t,1}, e_{t,2}^2)'$, $\eta_t = (\eta_{t,1}, \eta_{t,2})'$ and $H_t$ is a conditional variance covariance matrix, which is explained below. $D_t = \text{diag} \left[ \sqrt{h_{1,t}}, \sqrt{h_{2,t}} \right]$ is a $2 \times 2$ diagonal matrix of time-varying standard deviations from univariate GARCH models and $\eta_t$ is the standardized shock. The elements in Eq. (B.2) follow the univariate GARCH (1,1) processes in the following manner:

$$h_{1,t} = c_{0,1} + c_{1,1} e_{t-1,1}^2 + c_{2,1} h_{1,t-1} \quad \forall t = 1, 2 \tag{B.3}$$

$$H_t = E + (e_t e_t' / F_{t-1}) = D_t R_t D_t' \tag{B.4}$$

$$R_t = Q_t^{-1} Q_t^{-1} \tag{B.5}$$

$$Q_t = (1 - \theta_1 - \theta_2) \bar{Q} + \theta_1 \eta_{t-1} \bar{Q} + \theta_2 Q_{t-1} \tag{B.6}$$

where $h_{1,t}$ is the conditional variance of interest rates $i = 1, 2$ (i.e., fixed rate and floating rate) $Q_t = \begin{bmatrix} \sqrt{q_{11}} & 0 \\ 0 & \sqrt{q_{22}} \end{bmatrix}$ is the diagonal component of the square root of the diagonal elements of $Q_t = \begin{bmatrix} q_{11} & q_{12} \\ q_{21} & q_{22} \end{bmatrix}$. The key element of interest in $R_t$ is $\rho_{12} = q_{12} / \sqrt{q_{11}\bar{Q} q_{22}}$, which represents the time varying conditional correlation between the two interest rates (fixed rate and floating rate). The conditional covariance is updated by Eq. (B.6). The scale parameters $\theta_1$ and $\theta_2$ represent the effects of previous standardized shock and conditional correlation persistence, respectively. Whether time-varying correlation exists between the underlying interest rates is examined through the significance of either of these scale parameters.
Appendix C. Time-varying correlations between JGB AND TIBOR

Fig. 1. Time-varying correlation between 2-year JGB and 6-month TIBOR. This figure shows the DCC time-varying correlation coefficient between the 2-year Japanese Government Bond rate (JGB) and the 6-month Tokyo Interbank Offer Rate (TIBOR), where the former is used as a fixed rate and the latter is used as a floating rate. The DCC model used to compute the time-varying correlation is explained in Appendix B. The sample covers the daily data from 21st November, 1995 to 31st December, 2010.

Fig. 2. Time-varying correlation between 3-year JGB and 6-month TIBOR. This figure shows the DCC time-varying correlation coefficient between the 3-year Japanese Government Bond rate (JGB) and the 6-month Tokyo Interbank Offer Rate (TIBOR), where the former is used as a fixed rate and the latter is used as a floating rate. The DCC model used to compute the time-varying correlation is explained in Appendix B. The sample covers the daily data from 21st November, 1995 to 31st December, 2010.

Fig. 3. Time-varying correlation between 5-year JGB and 6-month TIBOR. This figure shows the DCC time-varying correlation coefficient between the 5-year Japanese Government Bond rate (JGB) and the 6-month Tokyo Interbank Offer Rate (TIBOR), where the former is used as a fixed rate and the latter is used as a floating rate. The DCC model used to compute the time-varying correlation is explained in Appendix B. The sample covers the daily data from 21st November, 1995 to 31st December, 2010.
References


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Fig. 4. Time-varying Correlation between 7-year JGB and 6-month TIBOR. This figure shows the DCC time-varying correlation coefficient between the 7-year Japanese Government Bond rate (JGB) and the 6-month Tokyo Interbank Offer Rate (TIBOR), where the former is used as a fixed rate and the latter is used as a floating rate. The DCC model used to compute the time-varying correlation is explained in Appendix B. The sample covers the daily data from 21st November, 1995 to 31st December, 2010.

Fig. 5. Time-varying correlation between 10-year JGB and 6-month TIBOR. This figure shows the DCC time-varying correlation coefficient between the 10-year Japanese Government Bond rate (JGB) and the 6-month Tokyo Interbank Offer Rate (TIBOR), where the former is used as a fixed rate and the latter is used as a floating rate. The DCC model used to compute the time-varying correlation is explained in Appendix B. The sample covers the daily data from 21st November, 1995 to 31st December, 2010.


