Determinants of Japanese Yen Interest Rate Swap Spreads: Evidence from a Smooth Transition Vector Autoregressive Model

Ying Huang
Carl R. Chen*
Maximo Camacho

This study investigates the determinants of variations in the yield spreads between Japanese yen interest rate swaps and Japan government bonds for a period from 1997 to 2005. A smooth transition vector autoregressive (STVAR) model and generalized impulse response functions are used to analyze the impact of various economic shocks on swap spreads. The volatility based on a GARCH (generalized autoregressive conditional heteroskedasticity) model of the government bond rate is identified as the transition variable that controls the smooth transition from a high volatility regime to a low volatility regime. The break

We thank two anonymous reviewers and the editor, Bob Webb, for helpful comments. The views in this paper are those of the authors and do not represent the views of the Bank of Spain or the Eurosystem.

*Correspondence author: Department of Economics and Finance, University of Dayton, 300 College Park, Dayton, Ohio 45469–2251; e-mail: chen@udayton.edu

Received April 2006; Accepted February 2007

■ Ying Huang is an Assistant Professor in the Department of Economics and Finance at Manhattan College in New York City, New York.
■ Carl R. Chen is the William J. Hohen Professor in the Department of Economics and Finance at the University of Dayton, Dayton, Ohio.
■ Maximo Camacho is a Fellow at the Bank of Spain and University of Murcia in Madrid, Spain.
point of the regime shift occurs around the end of the Japanese banking crisis. The impact of economic shocks on swap spreads varies across the maturity of swap spreads as well as regimes. Overall, swap spreads are more responsive to the economic shocks in the high volatility regime. Moreover, a volatility shock has profound effects on shorter maturity spreads, whereas the term structure shock plays an important role in impacting longer maturity spreads. Results of this study also show noticeable differences between the nonlinear and linear impulse response functions. © 2008 Wiley Periodicals, Inc. Jrl Fut Mark 28:82–107, 2008

INTRODUCTION

This study provides an empirical examination of the dynamic behavior of the Japanese yen interest rate swap spreads (hereafter swap spreads) and relevant risk factors within a smooth transition vector autoregressive (STVAR) framework. The nonlinear, state-dependent model better characterizes the Japanese swap market since the late 1990s, and it uncovers asymmetric and regime-shifting movements in swap spreads.

Among the major players, Japanese yen interest rate swap plays a pivotal role in the global interest rate derivatives market. It amounts to an average of 15% of the total outstanding interest rate derivatives worldwide. The expansion in the Japanese yen interest rate swap speaks for the importance of understanding the yen swap pricing mechanism. Surprisingly, few studies have undertaken the task of seeking an appropriate explanation of the Japanese swap market dynamics.

This research thus contributes to the literature in a number of aspects. First, the behavior of Japanese swap spreads is studied. Japanese swap spreads are second in importance to its U.S. counterpart, yet they are much ignored and understudied. Second, instead of using either a static single equation regression analysis or a linear vector autoregressive (VAR) model common in most swap studies, we employ a smooth transition vector autoregressive (STVAR) model to examine the asymmetric effects of economic shocks on Japanese swap spreads. The nonlinear STVAR model allows for a smooth transition from one regime of swap spreads to the other, controlled by an underlying economic determinant.

Third, the sample studied spans from 1997 to 2005, which not only offers the most updated dataset, but also encompasses the Japanese banking crisis

1They are the spreads between Japanese yen interest rate swaps and Japanese government bonds with comparable maturities.
2To the best of our knowledge, so far only two studies have examined Japanese yen interest rate swaps. One is written in Japanese, which we could barely understand, and the other is an unpublished working paper (Eom, Subrahmanyam, and Uno, 2000), which uses data of an earlier period (1990–1996). Their sample period is before the Japanese banking crisis and the subsequent extensive financial system reforms.
as well as a period of banking mergers and financial reforms. Thus, the study is well positioned to investigate the swap market’s behavior under different market conditions. Indeed, the STVAR methodology identifies the existence of two swap spread regimes, and the break point is around the end of the banking crisis. Using the latest data allows for the attainment of better-measured economic variables, which are lacking in earlier years of the Japanese financial market.

In this study, sequential tests are performed to determine the best model to employ. After that, within the nonlinear framework, the transition variable responsible for the shift of regimes is identified to be the volatility variable based on a GARCH (generalized autoregressive conditional heteroskedasticity) model of the government bond rate. The transition function suggests that the first regime is associated with periods of high volatility, whereas the second regime corresponds to periods of low volatility, with the transition around the end of the Japanese banking crisis. Furthermore, generalized impulse response functions find that swap spreads of all maturities are more responsive to the economic shocks in the high volatility regime when Japan was going through a banking crisis. Differences in responses are also observed between the shorter-end and the longer-end of the swap maturity. Specifically, 2-year swap spreads are more sensitive to the volatility shock than 5- or 10-year swap spreads, and more pronounced effects after a shock originating from the slope of the term structure are seen on longer maturity swap spreads in contrast to shorter maturity spreads. Finally, the implementation of an STVAR model over a linear VAR ensures sound results.

The rest of the article is organized as follows. In the next section, the issue of swap pricing is addressed and a literature review is provided along with a discussion of the determinants of swap spreads. Data sources and variable definitions are presented in the third section. In the fourth section, statistical methodologies are discussed and empirical results are reported in the fifth section. The conclusions are given in the final section.

SWAP PRICING, LITERATURE REVIEW, AND DETERMINANTS OF SWAP SPREADS

Swap Pricing

A plain vanilla interest rate swap is a contractual agreement for one party to pay a fixed rate (swap rate) in exchange for a stream of variable cash flows based upon a floating rate such as London Interbank Offered Rate (LIBOR) for a certain amount of notional principal. The interest rate that determines the fixed payment is the swap rate, and it is the interest rate that renders the value of a swap contract to be zero at the initiation of the contract. Let $F(t_0, t_1)$
denotes the implied forward rate from time $t_0$ to $t_i$ known at time 0 assuming $n$ swap settlements on dates $t_0$ to $t_i$. Furthermore, the price of a default-free pure discount bond can be written as $B(t_0, t_i)$, which represents the value of $\$1$ to be received at time $t_i$. Because floating-rate payments could be hedged using forward rate contracts, a hedged swap paying fixed rate, $S_{f_0}$, having zero net present value, requires that

$$\sum_{i=1}^{n} B(t_0, t_{i+1})[S_{f_0} - F(t_0, t_i)] = 0$$  \hspace{1cm} (1)$$

Rearranging Equation (1), the swap rate is obtained as:

$$S_{f_0} = \frac{\sum_{i=1}^{n} B(t_0, t_{i+1}) F(t_0, t_i)}{\sum_{i=1}^{n} B(t_0, t_{i+1})}$$  \hspace{1cm} (2)$$

Therefore, swap rate, $S_{f_0}$, can be regarded as a weighted average of the forward rate agreement paid-in-arrears rates during the life of the swap:

$$S_{f_0} = \omega_1 F(t_0, t_1) + \cdots + \omega_{n-1} F(t_0, t_{n-1})$$  \hspace{1cm} (3)$$

with the weight being

$$\omega = \frac{B(t_0, t_i)}{\sum_{i=1}^{n} B(t_0, t_{i+1})}$$  \hspace{1cm} (4)$$

Because swap spread is measured by the difference between the swap rate, $S_{f_0}$, and the government bond yield of equivalent maturity, arbitrage will ensure a zero swap spread in a complete financial market. That is, an arbitrage-free value of the swap spread should be zero, implying that the swap rate should be equal to the default-free par bond yield in the absence of market frictions. A non-zero swap spread is observed, however, when the financial markets are less than perfect, hence counterparty default risk exists. Because the swap spread changes over time, it is important to understand what drives the dynamics of swap spread.

**Literature Review**

In recent years, researchers have begun to study the behavior of swap spreads. Modeling interest rate swaps as a party who is short an option to receive (pay)

---

3It is paid-in-arrears, because the unknown forward interest rate will be known at time $t_1$ and the interest payments are exchanged at time $t_2$. 

---
fixed and long an option to pay (receive) floating cash flows, with the counterparty simultaneously owning the opposite pair of options. Sorensen and Bollier (1994) argue that the value of a swap depends on the value of the option to default. The value of the option to default, in turn, depends on a number of factors including the swap parties' default probabilities, the shape of the yield curve, and interest rate volatility. Swap spreads, therefore, are partially determined by the default risk, which may be associated with the interest rate volatility and the term structure of the interest rate.

Grinblatt (2001), however, advances that generic swaps are default-free, and he attributes the swap spread to the liquidity differences between government securities and Eurodollar borrowings. Specifically, he contends that swap spreads contain a convenience yield (liquidity premium) not available in the more liquid government securities. Increases in liquidity premium, therefore, imply that the market requires a higher premium to compensate for the reduced liquidity, which should result in a corresponding increase in the swap spread. Collin-Dufresne and Solnik (2001), and He (2000) echo the same argument because the net interest payment streams involved in the swap are much smaller than in a bond.

Empirical evidence to date is far from conclusive. Minton (1997) finds that bilateral counterparty default risk measured by corporate quality spread is not statistically related to the swap rate. However, unilateral default risk measured by aggregate default spread, exerts significant and positive impact on swap rate. Using VAR analyses, Huang and Neftci (2006) find that liquidity risk, not default risk, is the primary driver of U.S. interest rate swap spreads. Liu, Longstaff, and Mandell (2006) report that the risk of changes in the default probability is virtually not priced by the market. On the other hand, employing impulse response function and variance decomposition method, Duffie and Singleton (1997) conclude that both credit and liquidity risks have an impact on the U.S. swap zero spread, although the swap spread’s own innovation accounts for the majority of the spread’s variations. Other studies examining the impact of liquidity and default risk premiums on swap spreads include Brown, Harlow, and Smith (1994), Lang, Litzenberger, and Liu (1998), Sun, Sudaresan, and Wang (1993), and Fehle (2003). In addition to default and liquidity premiums, other economic determinants of swap spreads in prior studies consist of interest rate volatility and slope of the yield curve as they are alternative proxies of financial market risks (e.g., In, Brown, & Fang, 2003; Lekkos & Milas, 2001, 2004).

Although most of the studies focus on the U.S. swap rates and spreads, few examine interest rate swaps of other currencies. Suhonen (1998) considers the determinants of swap spreads in Finland and finds that spreads are positively related to the slope of the yield curve and interest rate volatility. Lekkos
and Milas (2001) study interest rate swaps using both U.S. and U.K. data. Lekkos and Milas (2004) model U.S. and U.K. swap spreads within an STVAR framework allowing for steep or flat yield curve slopes. Fang and Muljono (2003) investigate Australian dollar interest rate swaps and conclude that the spreads mostly represent a credit risk premium. In an unpublished working paper, Eom, Subrahmanyam, and Uno (2000) study the credit risk and the Japanese yen interest rate swap during the period of 1990–1996. They find that yen swap spreads behave very differently from the credit spreads on Japanese corporate bonds, and overall the yen swap market is sensitive to credit risk. Their study, however, only presents evidence on a period that is before the Japanese banking crisis and subsequent financial system reforms. Importantly, the majority of the swap rate studies rely upon ordinary least squares (OLS) and linear VAR analyses. Nonlinear models in recent years have been proven to outperform the linear ones, such as Lekkos and Milas (2004) and Milas, Lekkos, and Panagiotidis (2007), which find interpretation of the results more flexible and provide better predictive power on swap spreads.

DATA AND VARIABLES

Based upon the swap pricing model and the findings of extant literature, the relevant data is defined and presented in this section. Weekly data from August 8, 1997, through April 15, 2005 are collected from Datastream (Thomson Financial, Stamford, CT) and Bloomberg (Bloomberg L.P., New York, NY). Economic variables are defined as follows:

SS2—Two-year maturity swap spreads; computed as the differential between the swap rate and the Japan government bond (JGB) rate of 2-year maturity.

SS5—Five-year maturity swap spreads; computed as the differential between the swap rate and the Japan government bond rate of 5-year maturity.

SS10—Ten-year maturity swap spreads; computed as the differential between the swap rate and the Japan government bond rate of 10-year maturity.

SLOPE—Slope of the term structure; computed as the differential between the 2-year and the 10-year Japan government bond yields.

DEFAULT—Default risk premium; computed as the differential between BBB rated 5-year corporate bond yield and the Japan government bond yield of similar maturity.

VOLATILITY—Interest rate volatility fitted by a GARCH (1,1) model on 6-month Japan government bond rates.4

4An EGARCH model is discussed in In (2007).
LIQUIDITY—Liquidity premium; computed by subtracting 6-month Japan government bond rates from 6-month Japanese yen Tokyo Interbank Offered Rate (TIBOR).

JAPAN PREMIUM—the spread between TIBOR and LIBOR on Japanese yen.

Prior studies are followed in terms of measuring default risk. For example, Minton (1997) uses corporate quality spread (BAA−AAA) and aggregate default spread (BAA−T-Bond) to measure counterparty default risk. Duffie and Singleton (1997) use the spread between BAA- and AAA-rated commercial paper rates, and Huang and Neftci (2006) use the TED (T-bill/Eurodollar) spread to measure credit risk. In a similar fashion, yield data on Japanese government bonds (JGB), AAA-rated, and BBB-rated corporate bonds has been collected for this study. However, because AAA-rated bonds have a significant quantity of missing data, the spread between BBB-rated corporate bonds and JGB yields is employed to proxy the default premium.

The interest rate volatility generated by a GARCH model and the slope of the term structure of interest rates are also included in our empirical model because these two variables determine the value of the option to default in the Sorensen and Bollier’s (1994) model. Because increasing interest rate volatility is often associated with economic uncertainty, as such, it is expected to positively influence swap spreads. Theoretically, the impact of the slope of the term structure on swap spreads could be either positive or negative. For instance, according to Sorensen and Bollier (1994), when the yield curve is upward sloping, the fixed payer (floating receiver) is exposed to higher counterparty risk due to higher default risk exposure associated with the higher future floating payments. A lower fixed swap rate will compensate for this increased risk. Swap spreads are thus expected to be negatively related to the slope of the term structure. On the other hand, upward sloping yield curve normally coincides with strong economic growth, during which bond credit premium tends to become larger (Alworth, 1993). In this case, swap spreads are expected to be positively related to the slope of the term structure.

Following Grinblatt (2001), the liquidity premium is measured by subtracting 6-month JGB yield from a similar maturity TIBOR rate. Because increasing convenience yield implies that the market requires a higher premium to compensate for the decrease of liquidity in the TIBOR market, liquidity premium is also expected to be positively associated with swap spreads. The variable JAPAN PREMIUM, computed as the spread between 6-month TIBOR and LIBOR, is chosen to represent international financial markets’ assessment of risks unique to Japan. During the period of Japanese banking
crisis, Japanese banks borrowing U.S. dollars must pay a significant amount of premium.

Figure 1 provides plots of the above variables. Swap spreads are generally higher and more volatile before 2001, and the term structure of swap spreads is upward sloping with 10-year spreads the highest. There are also periods when 2-year spreads become negative. After 2001, however, swap spreads are lower, less volatile, and the term structure of swap spreads becomes inverted with 2-year and 5-year swap spreads higher than the 10-year spreads. The periods of higher and more volatile swap spreads coincide with the era that Japanese economy went through a recession and banking crisis. In late 1997, several reputable security firms including Sanyo Securities, Hokkaido Takushoku Bank, Yamaichi Securities, and Tokuyo City Bank, announced the closure of their business in a single month. Although the onset of the banking system trouble began in 1994 when credit cooperatives and housing finance companies (Jusen) encountered serious financial problems, the unprecedented collapse of major banks propagated the rumors and shook the confidence of the entire Japanese financial system. The credit ratings of banking firms rapidly degenerated during this period such that the term Japan Premium, a premium on lending to Japanese institutions, appeared in the international financial markets. In the plot of JAPAN PREMIUM, it is obvious that larger premiums predominately appear in the periods of the late 1990s. By late 2000, the new capital injection guided by the Financial Function Strengthening Law seemed to have restored confidence in Japanese banks, hence the decline in premiums. The magnitude of the premiums reduces to less than five basis points during the postbanking crisis period.5

Shown in the plot of VOLATILITY, volatilities are also much higher before 2001, but become minuscule after that. Interestingly, liquidity premiums also show similar patterns. Before 2001, liquidity premiums are generally higher and more volatile, but hovering around 10 basis points afterwards. Default premiums display those patterns alike, although not as dramatic as the other economic determinants of swap spreads. The only variable that does not exhibit a strong pattern is the slope of the JGB term structure. Most of the time, the slope moves within a range between 100 and 160 basis points, with two exceptions when it dips below 50 basis points.

Table I presents descriptive statistics of the economic variables employed in this study. Panel A shows the statistics for the whole sample. It can be seen that the term structure of swap spreads is upward sloping with SS10 the highest at 15.4 basis points, SS5 at 11.7 basis points, and SS2 the lowest at 8 basis points.

5For detailed discussions of the Japanese banking crisis, see Nakaso (2001), Miyajima and Yafeh (2003), and Krawczyk (2004).
FIGURE 1
Plots of swap spreads and economic determinants.
points. Considering the Japanese economic conditions, the ex post patterns of swap spreads and their economic determinants discussed above, the whole sample is further partitioned into two subperiods. Panel B shows the statistics for the subperiod between August 1997 and December 2000; Panel C presents the same statistics for the second subperiod between January 2001 and April 2005. Consistent with Figure 1, the default premium, the Japan premium, the liquidity premium, and volatility are larger and more volatile (higher standard deviations) in the first subperiod, reflecting the impact of the banking crisis. For swap spreads, both SS10 and SS5 are significantly higher in period 1. Average SS10 is 31 basis points in period 1, but is less than 3 basis points in period 2—a 10-fold difference. For the shorter-maturity swap spread (SS2), the mean spreads are nearly identical in the two subperiods. These preliminary statistics seem to suggest that longer-maturity swap spreads are more sensitive to changing economic conditions.

This preliminary sample partitioning for descriptive statistics in fact coincides with the test results of the regime shift reported in Section 5.
METHODOLOGY

The Baseline Model

Because the sampling period used in this study encompasses different economic regimes, a linear VAR may not be the appropriate model to use. In this section, the VAR extension of the STVAR model in Camacho (2004) is considered, which is also employed in Lekkos and Milas (2004), and Milas et al. (2007). The model permits a smooth transition of regimes based upon an empirically chosen economic factor. Let

\[ Y_t = A + B(L)Y_{t-1} + (C + D(L)Y_{t-1})F(Y_{i,t-d}) + u_t, \]  

(5)

where \( Y_t \) represents a time-series vector including swap spreads (SS2, SS5, or SS10), slope of the term structure (SLOPE), default premiums (DEFAULT), liquidity premiums (LIQUIDITY), Japan premiums (JAPAN PREMIUM), and interest rate volatilities (VOLATILITY). \( A \) and \( C \) are vectors of intercepts, \( B(L) \) and \( D(L) \) are polynomial matrices of \( p \)th order lag, \( d \) is the delay parameter, and \( u_t \) follows an independent and identically distributed Gaussian process with zero mean and variance \( \Omega \).

The key component of this STVAR system is the transition function \( F(\cdot) \), which controls the regime switching and is bounded between zero and one. When \( F(\cdot) \) is zero, Equation (5) becomes a linear VAR (VAR-a) with parameters \( A \) and \( B(L) \). On the contrary, when \( F(\cdot) \) is one, the model becomes a different linear VAR (VAR-b) with parameters \( A + C \) and \( B(L) + D(L) \). Hence, \( F(\cdot) \) may be interpreted as a filtering rule that locates the model between these two extreme regimes. Until these regimes can be interpreted economically, they will be referred to as first regime and second regime, respectively.

To consider different forms of transition across these regimes, two transition functions have been developed in the literature. The first one is the logistic function, stated as:

\[ F(Y_{i,t-d}) = \frac{1 + \exp\left(-\gamma(Y_{i,t-d} - c)\right)}{\sigma}, \]  

(6)

where \( c \) is the threshold between two regimes, and \( \sigma \) is the standard deviation of \( Y_{i,t-d} \). The second one is the exponential transition function, which can be written as:

\[ F(Y_{i,t-d}) = 1 - \exp\left[-\gamma(Y_{i,t-d} - c)^2/\sigma^2\right]. \]  

(7)

When the transition function \( F(Y_{i,t-d}) \) is set to be logistic, it changes monotonically from the first regime to the second regime with transition value \( Y_{i,t-d} \). The transition function becomes a constant when \( \gamma \to 0 \), and the transition from 0 to 1 is instantaneous at \( Y_{i,t-d} = c \) when \( \gamma \to +\infty \). On the other hand,
under the exponential function, the system changes symmetrically relative to the threshold $c$ with $Y_{t,d}$, but the model turns linear if either $\gamma \to 0$ or $\gamma \to +\infty$. In both models, the smoothness parameter $\gamma$, which is restricted to be positive between zero and one, controls the speed of adjustment across regimes.

**Linearity Tests and the Transition Function**

We follow the specification suggested in Camacho (2004), which adapts the univariate proposal of Granger and Teräsvirta (1993) to a multiequation context, for the empirical examination of the behavior of Japanese Yen swap spreads.

The first step of the estimation is to specify a linear VAR model as the basis to obtain the nonlinear results. This is because even if the true model is nonlinear, the linear specification is a simpler framework to obtain preliminary results that may assist in obtaining the set of variables to include in the nonlinear specification. In a small-scale system, linear specification may also help us to decide the maximum lag length $p$. In a large-scale system, however, the selection of $p$ may be constrained to consider a tractable number of parameters to be estimated. Because our system contains six variables, we restrict our analysis to VAR models of order one. Estimations based upon higher order VARs have also been tried but they fail to converge in the nonlinear models.

Next, some linearity and model selection tests are conducted. The maximum likelihood method is employed for the estimation, in which $(2\times$ the log-likelihood under the alternative—the log-likelihood under the null) will follow asymptotically a $\chi^2$ distribution with degrees of freedom equal to the number of restrictions imposed under the null.\(^7\)

Assuming that $d$ is known, testing linearity is still nonstandard due to the presence of nuisance parameters. Following the suggestions of Luukkonen, Saikkonen, and Teräsvirta (1988), the problem may be overcome by suitable Taylor approximations of the transition function around $\gamma = 0$. Assuming $p = 1$, the problem of testing linearity is reduced to estimating the following auxiliary regression:

$$Y_t = g_1 G_0 Y_{t-1} + G_1 Y_{t-1} Y_{i,t-d} + G_2 Y_{t-1} Y^2_{i,t-d} + G_3 Y_{t-1} Y^3_{i,t-d} + \varepsilon_t$$  \(8\)

for each transition variable candidate $i = 1, 2, \ldots, 6$, and to test

$$H_0: G_1 = G_2 = G_3 = 0.$$

In empirical applications, $d$ is usually restricted to be less than or equal to $p$, therefore, just one lag is considered for each candidate of the transition variable.

\(^7\)See Camacho (2004) for technical details about maximum likelihood estimation.
Linearity tests are applied for each of these lagged variables. In case of multiple rejections of the null, we follow Teräsvirta (1994) such that the lagged variable with the highest rejection of linearity (i.e., the largest statistic or the lowest p-value) is chosen as the most suitable transition variable.

The results of the linearity tests appear in Table II. The null of linearity is essentially rejected in all variables with the exception of lagged swap spreads in the SS5 model. Hence, it confirms that a nonlinear model better fits our Japanese swap data. The following step is to choose the transition variable. To select just one transition variable that is responsible for the regime shift in the nonlinear model, the ratio of the linearity test statistic is also shown for each candidate over the statistic that corresponds to VOLATILITY, which has the largest statistic across all spread maturities. Accordingly, lagged volatility is adopted as the transition variable in the transition function.

After determining the delay parameter $d$ and the transition variable that governs the transition across regimes, the third step is to choose between a logistic and an exponential form of the transition function. The tests that are

### TABLE II
Linearity Tests and Identification of Transition Variable

<table>
<thead>
<tr>
<th>Transition variable candidates (in t-1)</th>
<th>SS</th>
<th>DEFAULT</th>
<th>JPPREM</th>
<th>LIQUIDITY</th>
<th>SLOPE</th>
<th>VOLATILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS2 model Test statistics (p-value)</td>
<td>136.58</td>
<td>161.36</td>
<td>206.48</td>
<td>345.18</td>
<td>357.71</td>
<td>385.11</td>
</tr>
<tr>
<td>Test statistics ratio</td>
<td>0.355</td>
<td>0.419</td>
<td>0.536</td>
<td>0.896</td>
<td>0.929</td>
<td>1.000</td>
</tr>
<tr>
<td>SS5 model Test statistics (p-value)</td>
<td>125.89</td>
<td>158.48</td>
<td>186.38</td>
<td>390.91</td>
<td>400.38</td>
<td>415.20</td>
</tr>
<tr>
<td>Test statistics ratio</td>
<td>0.303</td>
<td>0.382</td>
<td>0.449</td>
<td>0.941</td>
<td>0.964</td>
<td>1.000</td>
</tr>
<tr>
<td>SS10 model Test statistics (p-value)</td>
<td>147.91</td>
<td>155.88</td>
<td>159.86</td>
<td>468.13</td>
<td>480.09</td>
<td>498.02</td>
</tr>
<tr>
<td>Test statistics ratio</td>
<td>0.297</td>
<td>0.313</td>
<td>0.321</td>
<td>0.940</td>
<td>0.964</td>
<td>1.000</td>
</tr>
</tbody>
</table>

**Notes.** This table reports linearity test results and the identification of a transition variable that controls the regime shift. Test statistics along with the corresponding p-values for each swap maturity are reported. The ratios of the test statistic for each transition variable candidate over the test statistic for the lagged volatility are also shown. SS denotes swap spreads, DEFAULT is the default premium, JPPREM is the Japan premium, LIQUIDITY is the liquidity premium, SLOPE is the slope of the term structure of government bonds, and VOLATILITY is the interest rate volatility generated by a GARCH model.
sequentially applied to the auxiliary regression (i.e., $H_{01}$, $H_{02}$, and $H_{03}$, respectively) and subsequent decisions are illustrated in Table III. Using lagged volatility as the transition variable, the $p$-values of Test 1, Test 2, and Test 3 are all about 0.000. Therefore, the appropriate transition function is logistic.

**EMPIRICAL RESULTS**

**Regime Identification**

The logistic transition function model is now estimated using the maximum likelihood method.\textsuperscript{8} For the ease of presentation and to shed some light on the nonlinearities obtained in the model, Figure 2 plots the transition function against lagged volatility for all swap maturities. The estimates of the speed of transition ($\gamma$) between regimes and the threshold parameter ($c$) are also reported in the notes under each panel. The transition function suggests that the first regime (F close to one) is associated with periods of high volatility, whereas the second regime (F close to zero) is classified as the low volatility regime. The estimated threshold levels ($c$) are about 0.08, 0.10, and 0.12, which mark the halfway point between regimes, for SS2, SS5, and SS10 respectively. The estimated smoothness parameters ($\gamma$), which determine the velocity of transition between these two states, are close to 4 for all swap maturities with minor variations.

Figure 3 plots the values of the transition function (solid line, left-hand axis) and VOLATILITY (line with blocks, right-hand axis) for all swap maturities. It is clearly shown that high values of the transition function $F$ are associated with

\textsuperscript{8}Parameter estimates are not reported to save space. They are available from the authors upon request.
Panel A: SS2

Notes: The first regime ($F$ close to one) is interpreted as periods where volatility is high whereas the second regime ($F$ close to zero) can be seen as periods associated with relatively low volatility. The estimated transition function is $F(V_{t-1}) = \{1 + \exp(-3.92(V_{t-1} - 0.08)/\sigma)\}^{-1}$, where $V$ refers to volatility and $\sigma$ is its standard deviation.

Panel B: SS5

Notes: The first regime ($F$ close to one) is interpreted as periods where volatility is high whereas the second regime ($F$ close to zero) can be seen as periods associated with relatively low volatility. The estimated transition function is $F(V_{t-1}) = \{1 + \exp(-3.80(V_{t-1} - 0.10)/\sigma)\}^{-1}$, where $V$ refers to volatility and $\sigma$ is its standard deviation.

Panel C: SS10

Notes: The first regime ($F$ close to one) is interpreted as periods where volatility is high whereas the second regime ($F$ close to zero) can be seen as periods associated with relatively low volatility. The estimated transition function is $F(V_{t-1}) = \{1 + \exp(-4.01(V_{t-1} - 0.12)/\sigma)\}^{-1}$, where $V$ refers to volatility and $\sigma$ is its standard deviation.

FIGURE 2

Estimated transition function (vertical axis) against VOLATILITY (horizontal axis) at $t-1$. 
Notes: The transition function is the solid line (left-hand axis) and volatility is the line with blocks (right-hand axis). Values of the transition function close to one refer to the first regime and correspond to periods of high volatility. Note that the break point is at about the end of the banking crisis, a time period characterized with rapid reduction in volatility.

FIGURE 3
Transition function and VOLATILITY.
occurrence of high volatility from 1997 to 2000. From 2001 to 2005, however, the transition function falls dramatically to almost zero which corresponds to a long period of low volatility. It should be noted that the break point between regimes occurs near the end of the Japanese banking crisis.

Generalized Impulse Response Analysis

In this subsection, the estimation procedure of the generalized impulse response function (GIRF) is explained, and associated empirical results for the STVAR models are reported. Because impulse responses identify the consequences of an increase in the $j$th variable innovation at date $t$ for the value of the $i$th variable at time $t + h$, the GIRF of the STVAR model traces the time path where the swap spread returns to equilibrium after an economic shock is injected into the system. The visual aids provided by the impulse response functions are particularly useful when the full impact of economic shocks on swap spreads takes long lags to materialize.

In the nonlinear context, however, these effects not only depend on the shocks that occur between $t$ and $t + h$, but also on the past shock history, $w_{t-1}$. Following Weise (1999), the generalized impulse response function of variable $i$ for an arbitrary shock to variable $j$ denoted by $\epsilon_j = \delta_j$ and history $w_{t-1}$ is defined as:

$$GIRF(h, \delta_j, w_{t-1}) = E(Y_{i,t+h}/\epsilon_j = \delta_j, w_{t-1}) - E(Y_{i,t+h}/w_{t-1}).$$ (9)

In the empirical application, $\delta_j$ is set to one standard deviation of variable $j$. In other words, the shock to each equation is equal to one standard deviation of the equation residual. Note that, in linear contexts, shocks between $t$ and $t + h$ are usually set to zero for convenience. As documented by Koop, Pesaran, and Potter (1996), this approach is not appropriate in the context of nonlinear models. To deal with the problem of shocks in intermediate time periods, the bootstrap procedure suggested by Weise (1999) is followed. First, we obtain 5,000 draws with replacements from the residuals of the nonlinear model, compute the GIRF for each of them, and then average the responses. In addition, GIRFs are history dependent. To account for this dependency, the GIRFs are computed

In linear models, impulse responses of variable $i$ to shocks in variable $j$ can be defined as the difference between realizations of $Y_{i,t+h}$ and a baseline “no shock” scenario:

$$IRF(h, \delta_j, w_{t-1}) = E(Y_{i,t+h}/\epsilon_j = \delta_j, e_{t+1} = 0, ..., e_{t+h} = 0, w_{t-1}) - E(Y_{i,t+h}/e_j = 0, ..., e_{t+h} = 0, w_{t-1})$$

where $\delta$ is set to one standard deviation of variable $j$. Note that all shocks in intermediate periods between $t$ and $t + h$ are set equal to zero. This is because the expectation of the path of $Y$ following a shock, conditional on the future shocks, is equal to the path of the variable when future shocks are set to their expected values. Therefore, future shocks can be set equal to zero for convenience.
conditional on two particular histories of $w_{t-1}$, namely, the periods that correspond to $F_t = 0.85$, a high volatility regime; and $F_t = 0.15$, a low volatility regime.\textsuperscript{10} As such, this allows us to compare the responses of shocks that hit the economy in two distinct regimes. Indeed, this is the advantage of nonlinear VAR models that incorporate the asymmetric effects of economic shocks on swap spreads across different regimes.

To contrast the difference between regimes, the impulse responses of SS2 to shocks imposed on various economic variables are presented in Figure 4 for

\textsuperscript{10}Imposing starting points of $F$ exactly equal to either 1 or 0 is not empirically plausible because we need enough observations in the right and left hand sides of the distribution.
the high and low volatility regimes. Several dissimilarities between regimes stand out. First, swap spreads are generally more responsive to economic shocks in the high volatility regime. For example, in the first regime a shock on default premium generates a positive impact on SS2, which peaks at approximately one basis point in week seven, and the impact gradually dies out in about 40 weeks. A similar shock in the second regime only provokes a response less than 0.4 bps from SS2. Although differing in magnitude, the positive impact of default shock on swap spreads is consistent with a priori expectations.

Similar observations can be found in swap spreads from a shock emanating from volatility. SS2 reacts stronger to a volatility shock in the first regime than in the second. The positive response of SS2 peaks out at 0.4 bps in about 5 weeks, leveling off in about 35 weeks in the high volatility regime. By contrast, in the low volatility regime, the response is merely less than half of the response in the first regime and rapidly disappears in about 5 weeks. The impulse response of SS2 to the term structure shock also displays an asymmetric pattern. A positive, though small response is observed in the first regime, which is in agreement with the findings reported in Alworth (1993) for the U.S. dollar swap spreads, and Suhonen (1998) for Finland data. The swap spread's response to the term structure shock, however, is virtually nil in the second regime. The responses of SS2 to liquidity premium and Japan premium also exhibit regime-dependent, asymmetric patterns, although not as dramatic as those that are invoked by shocks from default premium and volatility. The effects of swap spreads from the shock in Japan premium are by far the smallest among all.

In a similar fashion, the impulse responses of SS5 and SS10 to the economic shocks in different regimes are presented in Figures 5 and 6, respectively. Again, swap spreads appear to be more responsive to economic shocks when the high volatility regime dominates, and no significant responses are uncovered in the low volatility regime.

Our model also successfully captures differential responses in swap spreads across different maturities. The impulse response results for SS5 in the high volatility regime are used to illustrate these differences. First, the response of swap spreads to the default shock is more pronounced for the shorter-term swap (i.e., SS2). The peak response of SS2 to default shock is one bp, whereas it is approximately half of this magnitude for SS5. Similar effects are also revealed in the results for the volatility shock, where SS2 is more responsive to the volatility shock than SS5. Conversely, the response of SS5 to the term structure shock, the opposite is true. That is, the magnitude of the response of SS5 to the default shock is twice that of SS2. This is similar to the findings in other studies (e.g., Lekkos & Milas, 2004). This result stems from the fact that the exposure to the possibility of default (from the floating-rate
In terms of 10-year swap spreads, the difference in responses due to maturities is particularly manifest in shocks from default, liquidity, and term structure slope risks. Other than default shocks, responses of SS10 to shocks emanating from other variables more resemble those of SS5 than SS2. Distinct from shorter-maturity swap spreads, in the high volatility regime SS10 initially declines following a default shock, but the response reverts to be positive 7 weeks thereafter. This result seems to be somehow related to Eom et al.’s (2000) finding of a negative covariance between the default-free rate and the swap spread in Japan.

**FIGURE 5**
Generalized impulse responses of SS5 in two regimes.
Our result may be consistent with their finding if the correlation between BBB-bond yields and JGB yields is positive.11

Comparison of Nonlinear and Linear Impulse Response Functions

In this subsection, it is shown that results differ substantially between linear and nonlinear models. To save space, Figures 7 and 8 only exhibit the impulse responses of swap spreads to default shocks and spreads' own shocks. In Panel A

11We also run an OLS regression with all economic determinants and lagged SS10 (one lag) as the exogenous variables to ensure that our finding is not methodology-driven. The OLS results show a negative relation between default premium and swap spreads during this sample period.
Comparison of linear and nonlinear impulse responses of SS2 to default shock.
of Figure 7, the response of SS2 to default shock in the high volatility regime from the nonlinear model is presented for contrasting purpose. Panel B plots the response of SS2 to default shock in a linear model for the entire sample from 1997 to 2005 without considering the shift in regimes. The two panels reveal drastic differences in impulse responses. The significant impact of default shock on SS2 in the nonlinear model is completely absent in the linear model. Panel C indicates that the linear model also fails to capture the acute response of SS2 to default shock during the first regime.

In Figure 8, the responses of SS5 to its own shock based upon nonlinear and linear models are illustrated. In Panel A, the high volatility regime witnesses a rather short-lived, diminutive reaction of SS5 to its own shock in the nonlinear model. However, the linear model depicted in Panel B demonstrates that for the whole sample the long-lasting impact does not die out until 30 weeks later. Evident in Panel C, the linear impulse response of SS5 to its own shock under the first regime suggests that the effect persists over a long horizon. The STVAR results thus help us avoid any fallacious conclusions due to a linear model specification.

CONCLUSIONS

In this article, the nonlinear relationships of Japanese yen interest rate swap spreads and a number of risk factors within a smooth transition VAR framework are modeled. Weekly data for the 2-year, 5-year, and 10-year swap spreads and corresponding economic determinants of swap spreads, namely default premium, liquidity premium, the term structure slope, Japan premium, and interest rate volatility, are obtained from 1997 to 2005 for this purpose. This nonlinear model captures a time-varying component of swap spreads across different maturities. The nonlinear dynamics are corroborated by the fact that swap spreads of all maturities are very volatile and large in magnitude during the period of the Japanese banking crisis, but become much smaller and more stable during the post-banking crisis period. Most of the swap spread determinants exhibit signs of a regime shift as well.

Linearity tests reject the linear model in favor of a nonlinear VAR, and the model selection tests conclude that a logistic transition function better fits the data. Interest rate volatility is identified as the transition variable responsible for the shift of regimes. The estimated transition function suggests that the first regime is associated with periods of high volatility, whereas the second regime corresponds to periods of low volatility. Incidentally, this break point occurs near the end of the Japanese banking crisis.

Generalized impulse response functions help analyze the time paths of the impact of economic shocks on swap spreads of various maturities across
FIGURE 8
Comparison of linear and nonlinear impulse responses of SS5 to own shock.
regimes. Three major conclusions are in order. First, a regime effect is present during the period we study. Swap spreads of all maturities are more responsive to economic shocks in the high volatility regime when Japan was going through a banking crisis. It is found that the magnitude of the peak response of SS2 to default and volatility shocks in the high volatility regime is more than twice of that in the low volatility regime. The corresponding response of SS2 to a term structure shock can be hardly detected in the second regime. Second, a maturity effect is implied in the variability of swap spreads across regimes. Dissimilarities in responses are observed between the short-end of the swap maturity (SS2) and the longer-end (SS5 and SS10). It is evident from our estimation that SS2 is more responsive to the volatility shock than SS5 or SS10. Impulse responses of swap spreads to the term structure shock exhibit an opposite pattern, with longer maturity swaps more sensitive. This finding is consistent with the notion that the exposure to default risks for the fixed-rate payer increases during the later stage of the contract, hence higher embedded risks. Importantly, fallacious conclusions of a liner VAR are avoided under the STVAR framework.

BIBLIOGRAPHY


